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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

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.

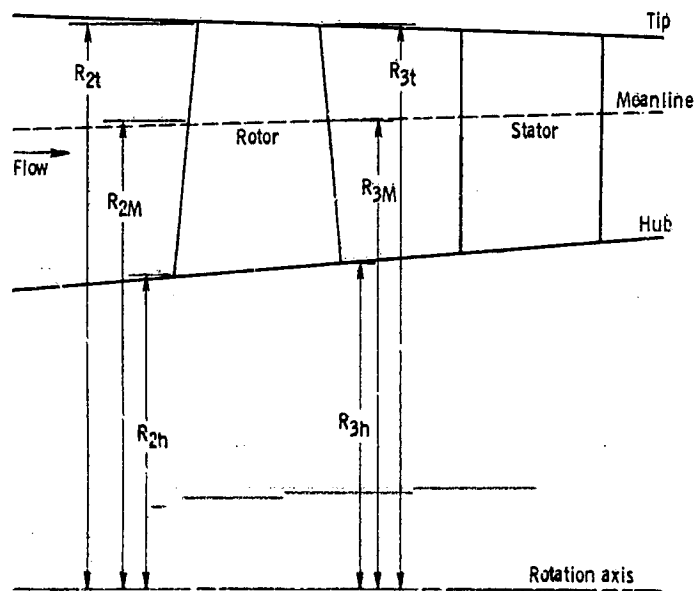


Figure 1. - Radii locations for a typical stage.

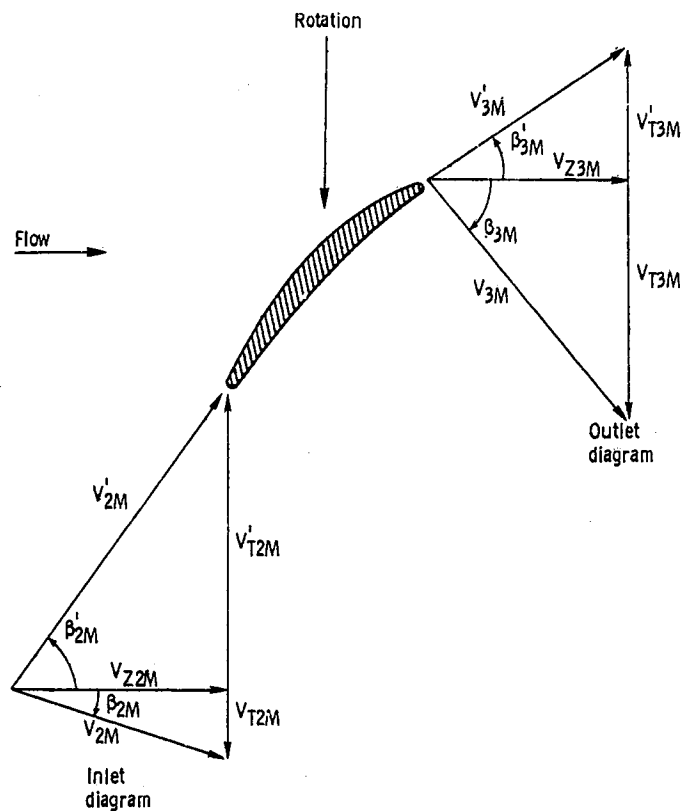


Figure 2. - Typical meanline inlet and outlet velocity diagrams for a rotor.

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

$$W = \rho AV_z \quad (1)$$

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 P_r 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

vary the representative meanline velocity diagrams and to predict changes in the associated stage performance parameters P_r 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

$$\phi = \frac{V_{Z2M}}{U_{2T}} \quad (2)$$

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

$$\eta_{ad} = \frac{P_r^{(\gamma-1)/\gamma} - 1}{T_r - 1} \quad (4)$$

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

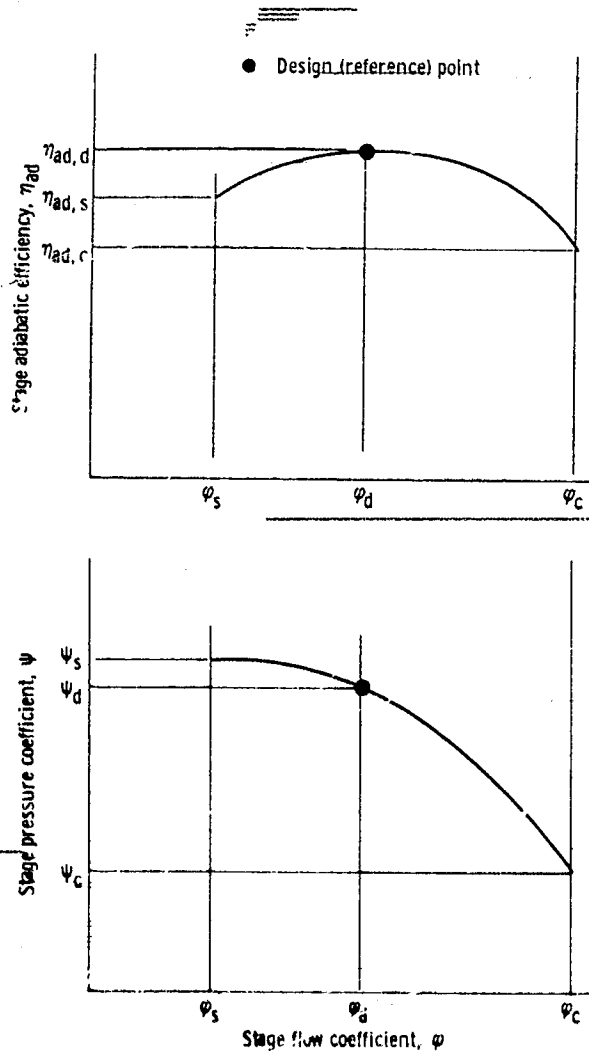


Figure 3. - Typical nondimensional stage characteristics.

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 η_{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.

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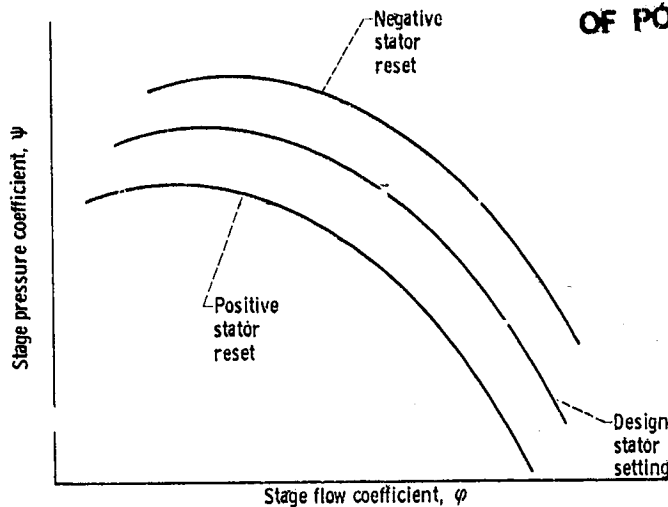


Figure 4. - Example of calculated changes of stage characteristic for a reset of upstream stator vanes.

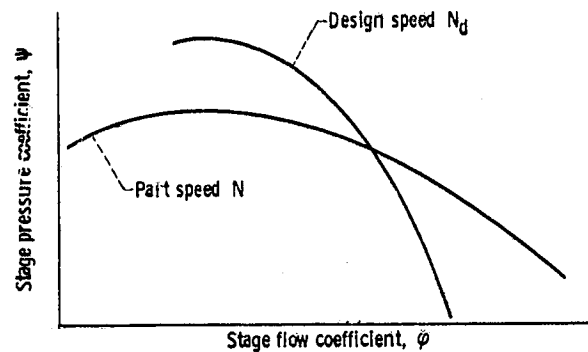


Figure 5. - Example of calculated change of stage characteristic for part-speed operating condition.

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 with 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

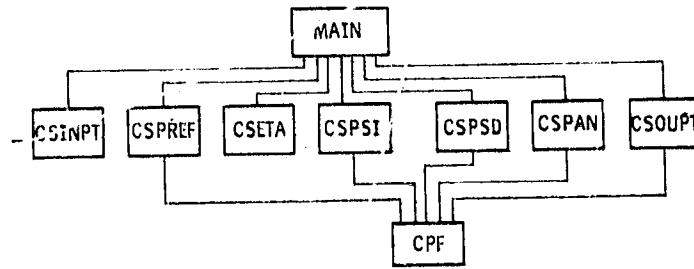


Figure 6. - Line representation of subroutine calls for stage-stacking program.

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 $n_{ad}(\varphi)$ 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

CSOUP - 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

STAGEN	SPEEDN	CHAPTS	TITLE		WTMOLE	DESRPM	DESFLO	
SPDPSI	SPDPHI	DRDEVG	PO	TO	UNITS			
	CPCO(1)		CPCO(2)		CPCO(3)			
	CPCO(4)		CPCO(5)		CPCO(6)			
RT2(1)	RT2(2)				RT2(NSTA)			
RH2(1)	RH2(2)				RH2(NSTA)			
RT3(1)	RT3(2)				RT3(NSTA)			
RH3(1)	RH3(2)				RH3(NSTA)			
BET2M(1,1)	BET2M(2,1)				BET2M(NSTA,1)			
CB2M(1)	CB2M(2)				CB2M(NSTA)			
CB2MR(1)	CB2MR(2)				CB2MR(NSTA)			
CB3MR(1)	CB3MR(2)				CB3MR(NSTA)			
RK2M(1)	RK2M(2)				RK2M(NSTA)			
RSOLM(1)	RSOLM(2)				RSOLM(NSTA)			
SK2M(1)	SK2M(2)				SK2M(NSTA)			
PR(1)	PR(2)				PR(NSTA)			
ETA1NP(1)	ETA1NP(2)				ETA1NP(NSTA)			
PCTSPD(1)	PCTSPD(2)				PCTSPD(NSPE)			
ETARAT(1)	ETARAT(2)				ETARAT(NSPE)			
BLEED(1,1)	BLEED(1,2)				BLEED(1,NSPE)	} One group for each stage, 1		
PHIDES(1,1)					PHIDES(1,1,NPTS)		} One group of three	
PSIDES(1,1)					PSIDES(1,1,NPTS)			} coefficients for each
ETADES(1,1)					ETADES(1,1,NPTS)	stage, 1		
SPEEDF	FLOWIN	DFLOW	FLOWF1				One card for each speed	

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/cm² (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.          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
1.        1.017    .8    .7    .5
.0        1.029    1.017    1.023
.0
.31       .35       .38       .42       .43       .44       .45       .46
.0
.40       .42       .44       .45       .46       .48       .51       .53
.0
1.        32.       .2       35.
.9        27.       .5       32.
.8        21.       .5       28.
.7        17.       .5       24.
.5        11.       .5       18.

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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 CSOUP 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	<u>calculated stage pressure coefficient for selected speeds</u> 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 $\eta_{ad}(\phi)$ and $\psi(\phi)$ will be calculated from a reference design-point stage pressure P_r and adiabatic efficiency η_{ad} , (2) $\psi(\phi)$ 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

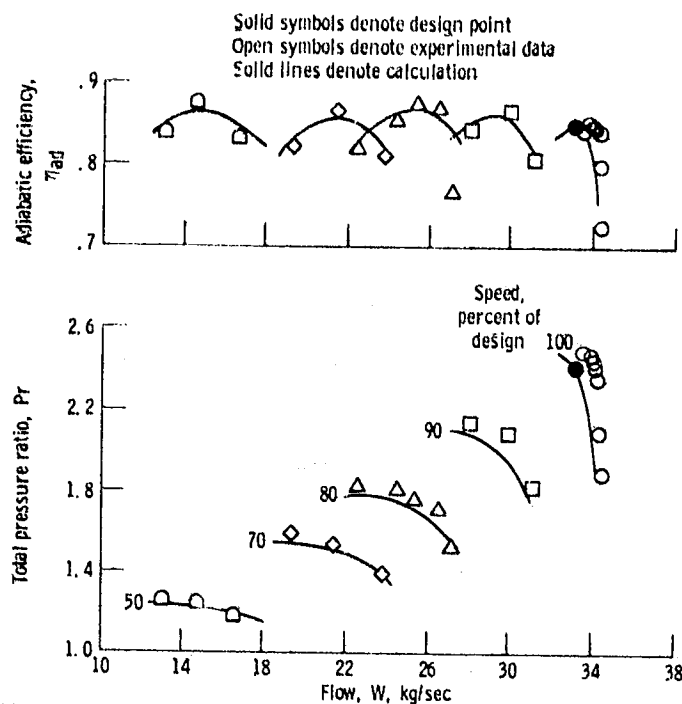


Figure 8. - Comparison of calculated performance by stage-stacking code to experimental data for NASA two-stage fan of reference 5.

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.

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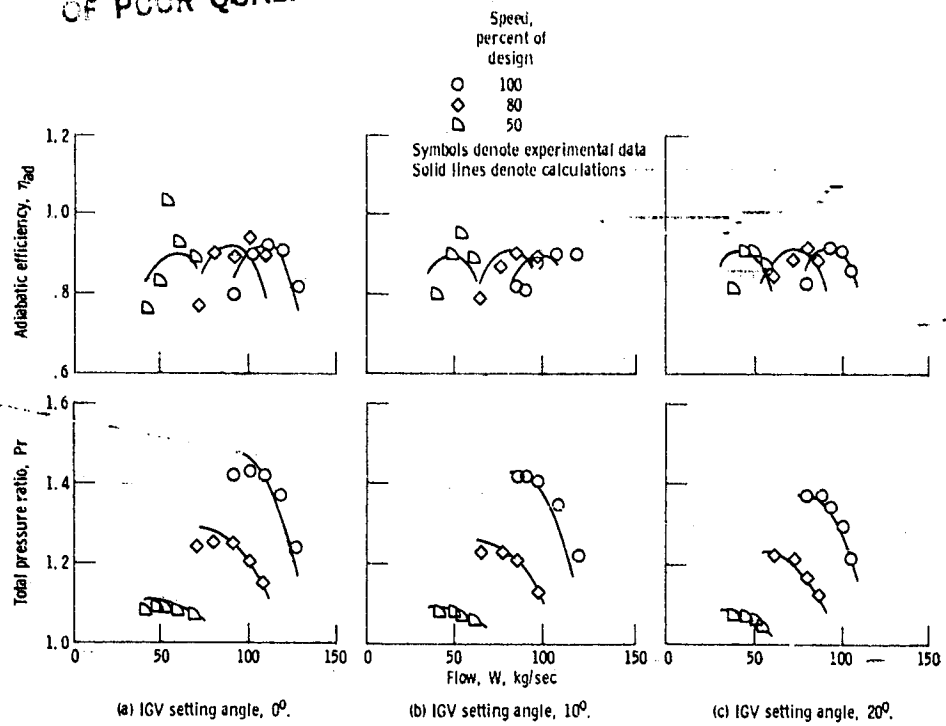


Figure 9. - Comparison of calculated to experimental performance data for the 347-m/sec-design-speed single-stage compressor of reference 6 at various inlet guide vane setting angles.

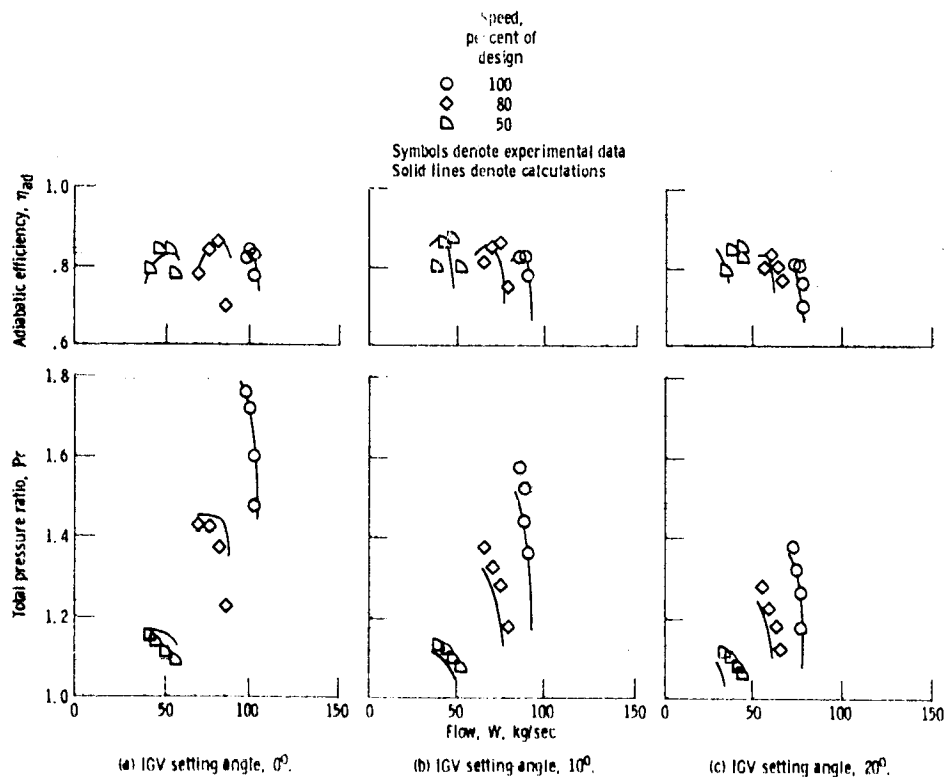


Figure 10. - Comparison of calculated to experimental performance data for the 457-m/sec-design-speed single-stage compressor of reference 7 at various inlet guide vane setting angles.

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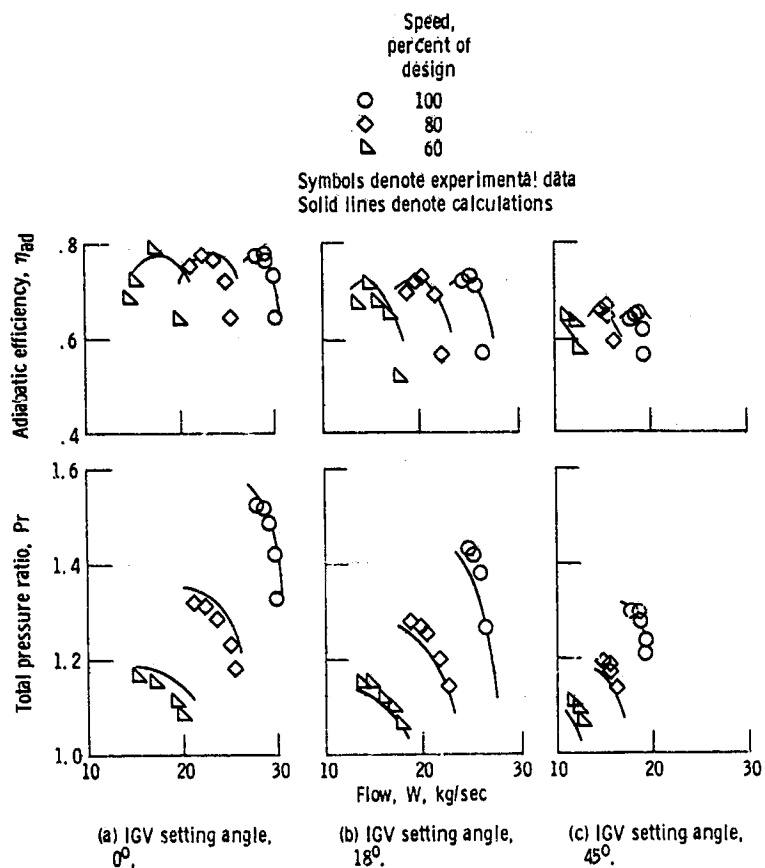


Figure 11. - Comparison of calculated to experimental performance data for the 427-m/sec-design-speed single-stage compressor of reference 8 at various inlet guide vane setting angles.

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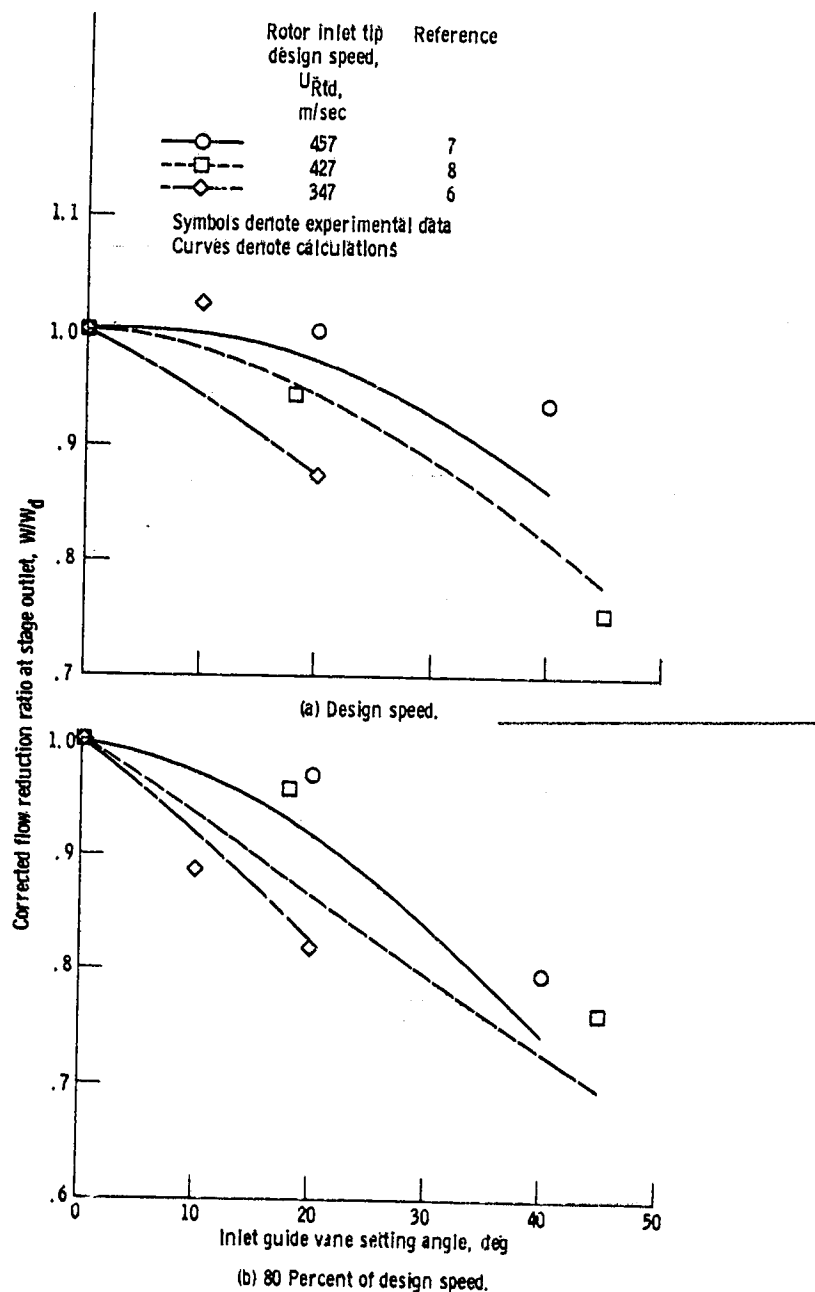


Figure 12. - Corrected flow reduction ratio at stage outlet, at peak efficiency, as a function of inlet guide vane setting angle for three single-stage compressors.

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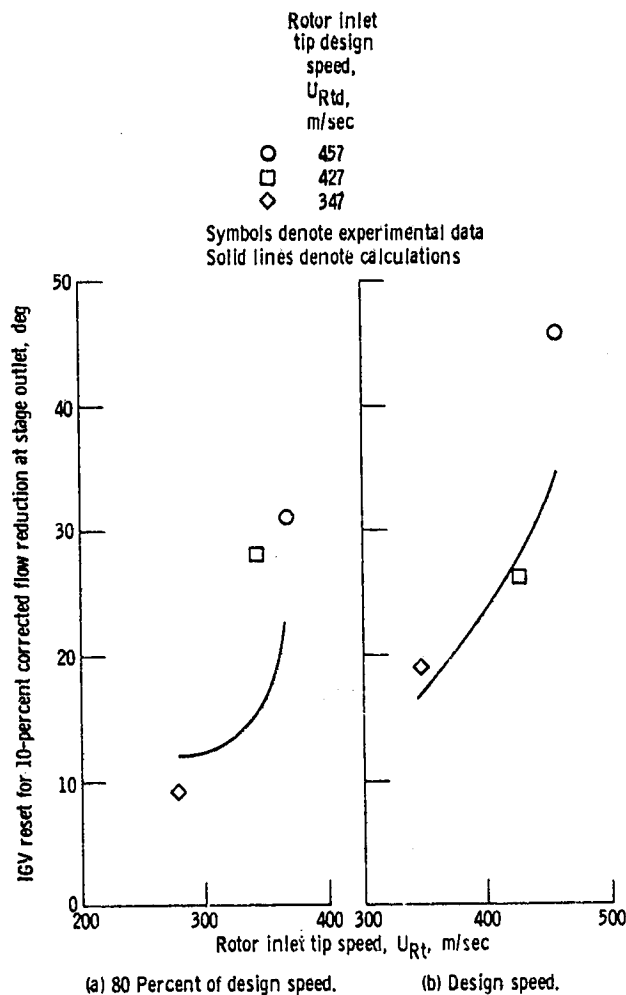


Figure 13. - Required inlet guide vane reset for a 10-percent corrected flow reduction at the stage outlet, at peak efficiency, as a function of rotor inlet tip speed.

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 , ... ,C ₆	coefficients for C _p polynomial, JK ⁻¹ /kg ... 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
Δγ 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:

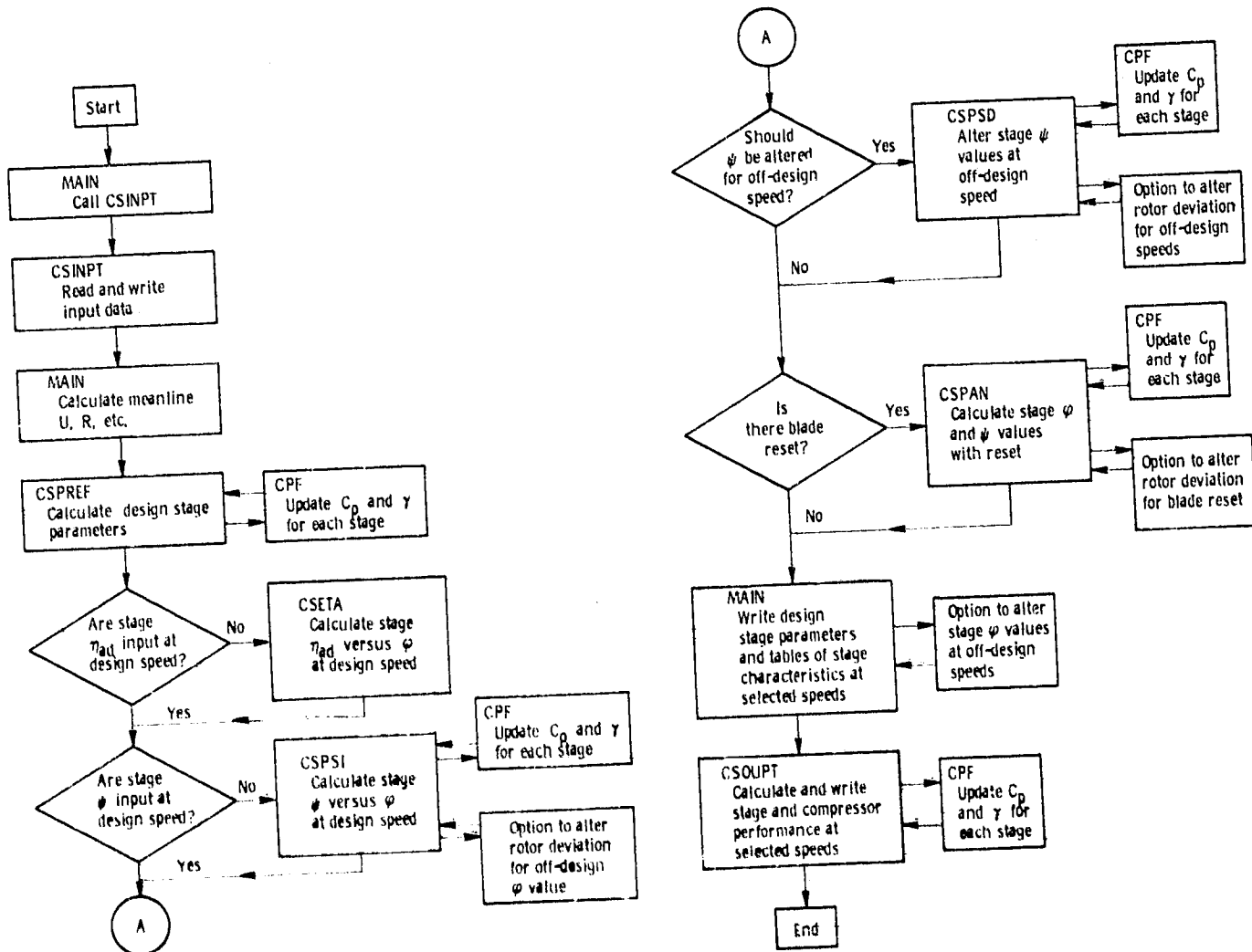
()' relative to rotor

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

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

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

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:

$$\varphi = \frac{V_{Z2M}}{U_{2T}} \quad (B3)$$

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

$$\eta_{ad} = \frac{p_r^{(\gamma-1)/\gamma} - 1}{T_r - 1} \quad (B5)$$

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

The final subroutine called by MAIN is CSOUP. Subroutine CSOUP reads the selected speeds and flows at which compressor performance is desired. At the selected speed and flow conditions CSOUP 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 P_r and adiabatic efficiency n_{ad} , or (2) stage characteristics, which consist of pressure coefficient versus flow coefficient $\psi(\varphi)$ and adiabatic efficiency versus flow coefficient $n_{ad}(\varphi)$. 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_{T2M} and φ .
- (2) If design stage P_r and n_{ad} are input, calculate design ψ .
- (3) If stage characteristics $\psi(\varphi)$ and $n_{ad}(\varphi)$ at design speed are input, obtain ψ , n_{ad} , and P_r 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

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

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

$$i_{MR} = \beta_{2M}' - \kappa_{2MR} \quad (B7)$$

$$i_{MS} = \beta_{3M}' - \kappa_{2MS} \quad (B8)$$

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

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 CSOUP. Subroutine CPF calculates C_p from a fifth-degree polynomial of t expressed by

$$C_p = C_1 + C_2t + C_3t^2 + C_4t^3 + C_5t^4 + C_6t^5 \quad (B10)$$

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

$$\gamma = \frac{C_p}{C_p - R} \quad (B11)$$

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) coefficient 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:

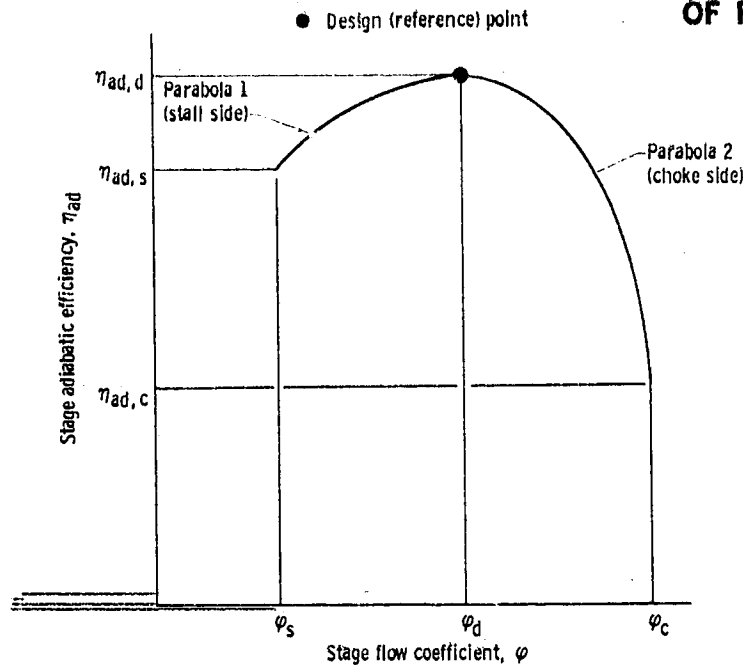


Figure 15. - Properties of curve fit for stage adiabatic efficiency as a function of stage flow coefficient generated by subroutine CSETA.

$$\frac{d\eta_{ad}}{d\phi} = 0 \quad \text{at } \phi = \phi_d$$

$$\eta_{ad} = \eta_{ad,d} \quad \text{at } \phi = \phi_d$$

$$\eta_{ad} = 0.9 \eta_{ad,d} \quad \text{at } \phi = \phi_s$$

$$\eta_{ad} = 0.8 \eta_{ad,d} \quad \text{at } \phi = \phi_c$$

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

(3) After the curve as described above is generated for stage $\eta_{ad}(\phi)$, 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 $\psi(\phi)$ 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_{3Md} , φ_d , and β_{3Md} .
- (2) For an input φ , calculate V_{Z2M} from

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

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

$$V_{T3M} = U_{3M} - V_{Z3M} \tan \beta_{3M} \quad (B13)$$

and $T_3 - T_2$ obtained from

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

the pressure coefficient corresponding to the input φ from

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

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_{3Md} , φ_d , and β_{3Md} .
- (2) For an input off-design rotative speed N , calculate V_{Z2M} from

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

and the flow corresponding to the input N from

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

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

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

and $T_3 - T_2$ obtained from

$$T_3 - T_2 = \frac{1}{c_p} \frac{N}{N_d} (U_{3M} V_{T3M} - U_{2M} V_{T2M}) \quad (B19)$$

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

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

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.

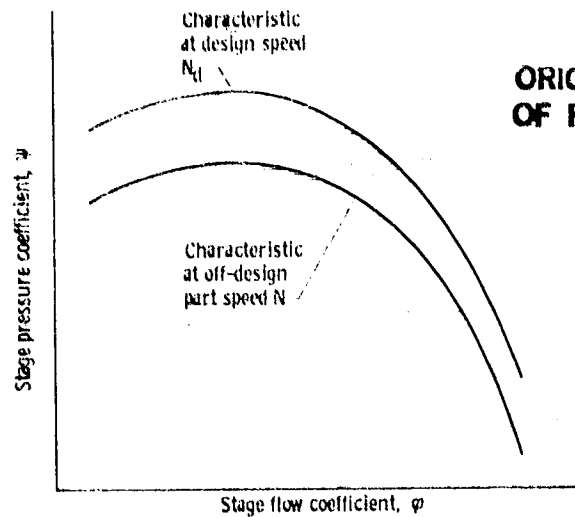
These calculations are repeated within CSPSD for every input N value for each stage of the compressor. CSPSD changes the pressure coefficient ψ by an amount $\Delta\psi_N$ for an off-design part speed N . The overall effect of a typical stage characteristic $\psi(\varphi)$ is depicted in figure 16.

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

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



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

$$\beta_{2M} = \beta_{2Md} + \Delta\beta_{2M} \quad (B22)$$

$$\beta_{3M} = \beta_{3Md} + \Delta\beta_{3M} \quad (B23)$$

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

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

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

$$\Delta\psi_{\gamma} = \frac{V_{Z2M}}{U_{2T}} - \psi_d \quad (B25)$$

and the flow from

$$W_2 = \rho_2 A_2 V_{Z2M} \quad (B26)$$

(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

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

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

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

and $T_3 - T_2$ is obtained from

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

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 CSOOPT

This subroutine calculates and writes individual stage and cumulative compressor performance parameters for various selected speeds and flow conditions. Output written by CSOOPT 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 CSOOPT 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 interpolation, 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, CSOOPT 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 CSOUP 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 $\psi(\phi)$. 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:

$$\phi_N = \phi + \left(1 - \frac{N}{N_d}\right) \quad (B30)$$

where

$$\Delta\phi_N = \phi_N - \phi \quad (B31)$$

and

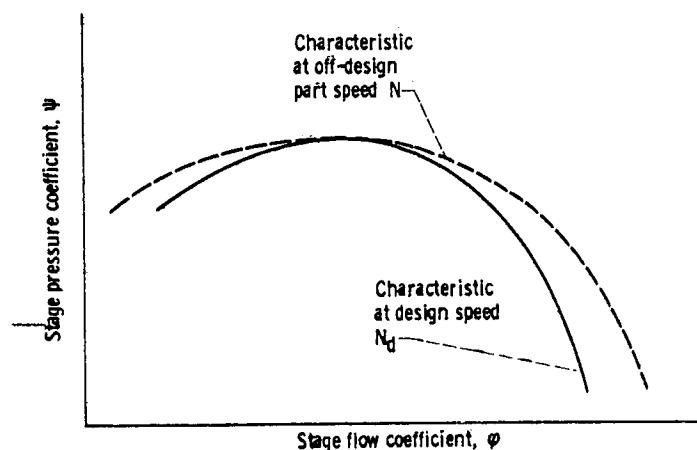


Figure 17. - Effects of program option to alter flow coefficient for off-design part speed on a typical stage characteristic $\psi(\phi)$.

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

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

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

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

$$\delta_R = \beta_{3M}' - \kappa_{3M} \quad (B34)$$

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

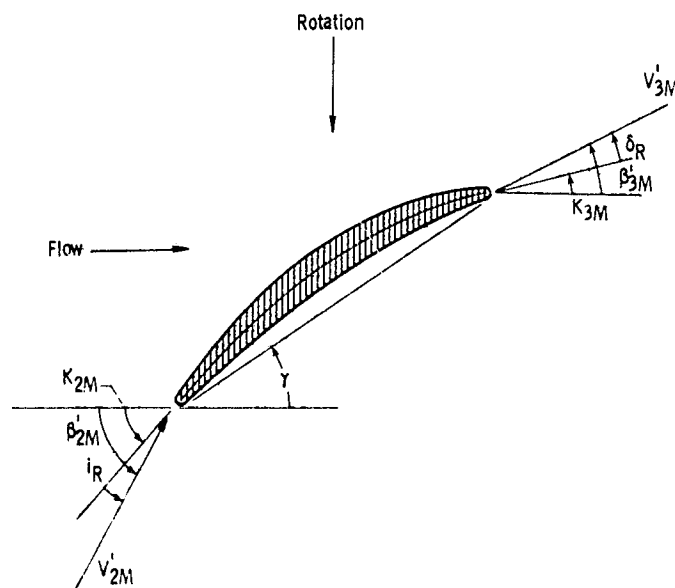


Figure 18. - Angles associated with a typical rotor meanline blade element.

$$\Delta\delta_R = \Delta\beta_{3M}^i \quad (B35)$$

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

$$\Delta\beta_{3M}^i = -10 \left[\left(\frac{V_{3M}^i}{V_{2M}^i} \right)_i - \left(\frac{V_{3M}^i}{V_{2M}^i} \right)_d \right] \quad (B36)$$

where the subscript i represents ϕ , N , and γ_0 for subroutines CSPSI, CSPSD, and CSPAN, respectively. The design relative velocity ratio

$\left(\frac{V_{3M}^i}{V_{2M}^i} \right)_d$ is calculated within subroutine CSPREF.

APPENDIX C

EXAMPLE PROGRAM OUTPUT LISTING

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 **

MASA TWO STAGE FAN, LOW RI 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	BE2M	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

STAGE	PR	ETAIMP
1	1.5906	0.8471
2	1.5087	0.8690

PCTSPD ETARAT

1.0000
0.9000
0.8000
0.7000
0.5000

BLEED(STAGE,PCT SPD) TABLE

PCT SPD	STAGE NUMBER											
	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

INPUT DESIGN CHARACTERISTICS FOR STAGE-- 1

PCT SPD	0.900 PCT SPD			0.800 PCT SPD		
	PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES
1.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

INPUT DESIGN CHARACTERISTICS FOR STAGE-- 1

PCT SPD	0.500 PCT SPD			0.000 PCT SPD		
	PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES
1.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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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		
0.0000	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
0.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.5100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.5300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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	0.0000	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

STAGE	PHIREF	PSIREF	ETAREF	DPHIA	DPSIA	FLOCAL	BET2M	BEI3MR	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

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	-0.0554	-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

PHI	1.000 PCT SPD			0.900 PCT SPD			0.800 PCT SPD		
	PSI	ETA	PHI	PSI	ETA	PHI	PSI	ETA	
0.3100	0.2802	0.7624	0.3007	0.2634	0.7759	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	0.8673	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	0.4614	0.2034	0.8367	0.4432	0.1896	0.8466	
0.4500	0.1881	0.7655	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

PHI	0.700 PCT SPD			0.500 PCT SPD			0.000 PCT SPD		
	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	0.2130	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

PHI	1.000 PCT SPD			0.900 PCT SPD			0.800 PCT SPD		
	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 0.8068
 0.4200 0.2828 0.8296 0.4158 0.2666 0.8435 0.4107 0.2523 0.8534
 0.4400 0.2828 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 0.4556 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

COMPUTED CHARACTERISTICS FOR STAGE NO. 2

PHI	0.700 PCT SPD			0.500 PCT SPD			0.000 PCT SPD		
	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	0.2494	0.8729	0.4195	0.2359	0.8781	0.0000	0.0000	0.0000	
0.4452	0.2364	0.8607	0.4389	0.2318	0.8858	0.0000	0.0000	0.0000	
0.4593	0.2299	0.8837	0.4584	0.2194	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	

** COMPUTED OUTPUT DATA **

PERCENT SPEED = 1.000 INLET FLOW = 32.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCH	R-DFM	S-INCH
1	0.4053	0.2541	0.3018	0.8418	1.6321	0.8418	1.6321	32.0000	5.74	0.5035	9.49
2	0.4286	0.2824	0.3355	0.8419	1.5326	0.8316	2.5013	32.0000	6.74	0.5127	9.36

PERCENT SPEED = 1.000 INLET FLOW = 32.200

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

0 2 0.4334 0.2822 0.3325 0.8488 1.5330 0.8357 2.4933 32.1999 6.48 0.5078 8.90

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

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

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

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	0.4768	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

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	0.4758	5.68

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PERCENT SPEED = 1.000 INLET FLOW = 33.600

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCH	R-DFM	S-INCH
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	0.8668	1.4990	0.8452	2.3740	33.3998	4.69	0.4595	4.49

PERCENT SPEED = 1.000 INLET FLOW = 33.600

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCH	R-DFM	S-INCH
1	0.4343	0.2306	0.2758	0.8361	1.5641	0.8361	1.5641	33.5998	4.06	0.4491	4.18
2	0.4772	0.2523	0.2940	0.8581	1.4749	0.8371	2.3070	33.5998	4.13	0.4384	2.59

PERCENT SPEED = 1.000 INLET FLOW = 33.800

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCH	R-DFM	S-INCH
1	0.4381	0.2237	0.2704	0.8271	1.5465	0.8271	1.5465	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

PERCENT SPEED = 1.000 INLET FLOW = 34.000

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

PERCENT SPEED = 1.000 INLET FLOW = 34.200

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

PERCENT SPEED = 1.000 INLET FLOW = 34.400

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

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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

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	0.2993	0.8438	1.4913	0.8439	1.4913	27.5000	7.82	0.4972	9.52
2	0.4260	0.2665	0.3104	0.8571	1.4050	0.8421	2.0952	27.4999	6.89	0.4650	5.91

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	0.8464	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

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	3.55

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	0.4203	1.59

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PERCENT SPEED = 0.900 INLET FLOW = 29.500
 STAGE PHI PSI PSI INLET FLOW = 29.500
 1 0.4045 0.2365 0.2762 0.8565 1.4559 0.8565 1.4559 29.9999 5.79 0.4655 5.68
 2 0.4747 0.2403 0.2746 0.8752 1.3654 0.8583 1.9879 29.9999 4.27 0.3969 -0.59

PERCENT SPEED = 0.900 INLET FLOW = 30.000
 STAGE PHI PSI PSI INLET FLOW = 30.000
 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

PERCENT SPEED = 0.900 INLET FLOW = 30.500
 STAGE PHI PSI PSI INLET FLOW = 30.500
 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

PERCENT SPEED = 0.900 INLET FLOW = 31.000
 STAGE PHI PSI PSI INLET FLOW = 31.000
 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

PERCENT SPEED = 0.900 INLET FLOW = 31.500
 STAGE PHI PSI PSI INLET FLOW = 31.500
 1 0.4408 0.2044 0.2439 0.8380 1.3866 0.8380 1.3866 31.4998 3.69 0.3740 -1.82
 0 FOR STAGE 2, COMPUTED PHI IS 0.5470 CHOKE

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
 0 FOR STAGE 2 , COMPUTED PHI IS 0.3762 STALL

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
 0 FOR STAGE 2 , COMPUTED PHI IS 0.3861 STALL

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 0.2470 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 0.8643 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

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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-INCH R-DFM S-INCH
 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-INCH R-DFM S-INCH
 1 0.3636 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-INCH R-DFM S-INCH
 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-INCH R-DFM S-INCH
 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-INCH R-DFM S-INCH
 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

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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	6.14	0.4054	1.75
2	0.5044	0.1894	0.2249	0.8424	1.2253	0.8508	1.6295	26.4998	2.73	0.2953	-9.06
0											

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
2	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
2	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											
2											
0											

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1 0.2863 0.2385 0.3034 0.7860 1.2635 0.7860 1.2635 17.5000 13.18 0.5238 14.24
0 FOR STAGE 2, COMPUTED PHI IS 0.3733 STALL

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 0.7968 1.2629 0.7969 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

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 0.8096 1.5393 18.4999 8.55 0.4202 3.28

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

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

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

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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	0.3756	-1.85

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	0.2762	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

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

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

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

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

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

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

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											

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

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	0.2701	0.2241	0.2768	0.8095	1.1208	0.8095	1.1208	12.0000	14.26	0.4781	11.92

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0 2 0.3788 0.2254 0.2680 0.8412 1.1064 0.8214 1.2401 12.0000 9.56 0.3660 1.21

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

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

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

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

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

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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

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

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

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

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	1.1816	16.9999	0.20	0.1838	-17.48

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	0.3886	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	1.1816	16.9999	0.20	0.1838	-17.48

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0	0.5000	0.1952	0.2259	0.8640	1.1847	0.8640	1.1847	17.4999	6.01	0.3198	-4.80
1	0.5747	0.1264	0.1612	0.7844	1.0592	0.8312	1.1700	17.4998	-0.71	0.1539	-19.79
2											

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

PERCENT SPEED = 0.500

INLET FLOW = 18.000

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APPENDIX D

PROGRAM SOURCE CODE LISTING

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0000100 C *** STGSTK - A COMPUTER CODE FOR PREDICTING MULTISTAGE AXIAL FLOW
0000200 C COMPRESSOR PERFORMANCE USING A MEANLINE STAGE STACKING METHOD.
0000220 C BY R. J. STEINKE, NASA LEWIS RESEARCH CENTER
0000400 C
0000500 C *** THIS MAIN ROUTINE CALLS ALL MAGOR SUBROUTINES AND WRITES
0000600 C INTERMEDIATE OUTPUT
0000700 COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0000800 XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0000900 XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9, -
0001000 X,8), DPHIA(12), DPSIA(12), DELTA(12), NSTAGE(12), PCTSPD(9), -
0001100 XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), -
0001200 XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12), -
0001300 X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0001400 X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0001500 X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12, -
0001600 X,9), PHIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12) -
0001700 X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR -
0001800 X(12,9), B2MB3R(12,9),
0001900 X, DB3MRN(12,9), DB3MRP(12,8)
0002000 COMMON /SCALAR/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA -
0002100 X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
0002200 X, CP, GAMMA, GMI, GF1, GF2, GF3, SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP
0002300 DIMENSION NSTG(12)
0002400 DATA NSTG/1,2,3,4,5,6,7,8,9,10,11,12/
0002500 RU=1545.44
0002600 PI=3.14159217
0002700 G= 32.1740
0002800 AJ=778.12
0002900 RAD=57.29578
0003000 DO 7 II=1,12
0003100 7 NSTAGE(II)= NSTG(II)
0003200 C
0003300 10 CALL CSINPT
0003400 C *** CALCULATE FIXED PARAMETERS
0003500 PD = PD*144.0
0003600 DO 20 I=1,NSTA
0003700 AREA2(I)= (RT2(I)+RH2(I))*(RT2(I)-RH2(I))*PI/144.0
0003800 AREA3(I)= (RT3(I)+RH3(I))*(RT3(I)-RH3(I))*PI/144.0
0003900 RM2(I)= SQRT(RT2(I)**2 - AREA2(I)*72.0/PI)
0004000 RM3(I)= SQRT(RT3(I)**2 - AREA3(I)*72.0/PI)
0004100 UM2(I)= RM2(I)*DESRPM*RPMRAD
0004200 UM3(I)= RM3(I)*DESRPM*RPMRAD
0004300 BET2M(I,1) = BET2M(I,1)/RAD
0004400 RK2M(I) = RK2M(I) + CB2MR(I)
0004500 SK2M(I) = SK2M(I) + CB2M(I+1)
0004600 CB2M(I) = CB2M(I)/RAD
0004700 CB2MR(I) = CB2MR(I)/RAD
0004800 CB3MR(I) = CB3MR(I)/RAD
0004900 20 CONTINUE
0005000 CALL CSPREF
0005100 IF (ETADES(1,1,1) .EQ. 0.0) CALL CSETA
0005200 IF (PSIDES(1,1,1) .EQ. 0.0) CALL CSPSI
0005300 IF (SPDPSI .EQ. 1.0) CALL CSPSD
0005400 CALL CSPAN
0005500 DO 51 I=1,NSTA
0005600 BET2M(I,1) = BET2M(I,1) * RAD
0005700 51 BET3MR(I,1) = BET3MR(I,1) * RAD
0005800 C *** WRITE INTERMEDIATE OUTPUT
0005900 WRITE (6,2120)
0006000 IF (UNITS .EQ. 1.0) FLOCAL(I,1) = FLOCAL(I,1)*0.453592
0006100 WRITE (6,2051) (NSTAGE(I),PHIREF(I),PSIREF(I),ETAREF(I),DPHIA(I), -
0006200 XDPSIA(I),FLOCAL(I,1),
0006300 X BET2M(I,1),BET3MR(I,1),RINCM(I),RDFM(I),SINCM(I), -
0006400 XI=1,NSTA)
0006500 IF (UNITS .EQ. 1.0) FLOCAL(I,1) = FLOCAL(I,1)/0.453592
0006600 2051 FORMAT (110H STAGE PHIREF PSIREF ETAREF DPHIA -
0006700 X DPSIA FLOCAL BET2M BET3MR RINCM RDFM,10H S-

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0006800      XINCM/(5X,15,5F10.4,4F10.2,F10.4,F10.2))
0006900      DO 52 I=1,NSTA
0007000      BET2M(I,1) = BET2M(I,1) / RAD
0007100      52 BET3MR(I,1) = BET3MR(I,1) / RAD
0007200      WRITE (6,2120)
0007300      WRITE (6,2052) (NSTAGE(I),I=1,12), (PCTSPD(J), (DPSIS(I,J), I=1,12-
0007400      1),J=1,NSPE)
0007500      2052 FORMAT (20X,27H DPSIS(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER/-
0007600      18H PCT SPD,12(I5,3X)//(13F8.4))
0007700      DO 60 I=1,NSTA
0007800      DO 60 J=1,NSPE
0007900      DO 60 K=1,NPTS
0008000      PHI(I,J,K) = PHIDES(I,1,K) + DPBIA(I)
0008100      C *** OPTION TO ALTER FLOW COEFFICIENT FOR OFF DESIGN SPEEDS
0008200      IF (SPDPHI.EQ.1.0) PHI(I,J,K) = PHI(I,J,K)*(1.0 + ((PHI(I,J,K)/PHI-
0008300      XREF(I))*((1.0/PCTSPD(J)) - 1.0)*1.0*ABS(1.0 - PCTSPD(J)))
0008400      PSI(I,J,K) = PSIDES(I,1,K) + DPSIA(I) + DPSIS(I,J)
0008500      ETA(I,J,K) = ETADES(I,1,K)*ETARAT(J) + DETA(I)
0008600      60 CONTINUE
0008700      DO 70 I=1,NSTA
0008800      WRITE (6,2120)
0008900      WRITE(6,2060) NSTAGE(I),(PCTSPD(J),J=1,3),((PHI(I,J,K),PSI(I,J,K),-
0009000      IETA(I,J,K),J=1,3),K=1,NPTS)
0009100      IF(NSPE.LT.4) GO TO 70
0009200      WRITE (6,2120)
0009300      WRITE(6,2060) NSTAGE(I),(PCTSPD(J),J=4,6),((PHI(I,J,K),PSI(I,J,K),-
0009400      IETA(I,J,K),J=4,6),K=1,NPTS)
0009500      IF(NSPE.LT.7) GO TO 70
0009600      WRITE (6,2120)
0009700      WRITE(6,2060) NSTAGE(I),(PCTSPD(J),J=7,9),((PHI(I,J,K),PSI(I,J,K),-
0009800      IETA(I,J,K),J=7,9),K=1,NPTS)
0009900      70 CONTINUE
0010000      2060 FORMAT (20X,39H COMPUTED CHARACTERISTICS FOR STAGE NO.,I3//3(5X, -
0010100      1F10.3,10H PCT SPD ,5X)//3(30H PHI      PSI      ETA      )(9F1-
0010200      20.4))
0010300      CALL CSOUP
0010400      GO TO 10
0010500      2120 FORMAT (1H0////)
0010600      END

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0000100      SUBROUTINE CSINPT
0000200      C *** SUBROUTINE CSINPT READS AND WRITES THE INPUT DATA
0000300      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0000400      XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0000500      XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
0000600      X,8), DPBIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9), -
0000700      XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), -
0000800      XTRO(12), ETAD(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
0000900      X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0001000      X,BET2MR(12,9),DPSIS(12,9),RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0001100      X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
0001200      X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12) -
0001300      X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
0001400      X(12,9), B2MB3R(12,9), -
0001500      X,DB3MRN(12,9), DB3MRP(12,8)
0001600      V3DV2R(12),DB3MRG(12)-
0001700      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
0001800      X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
0001900      X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPHI, SPDPHI, DRDEVG, DRDEVN, DRDEVP
0002000      10 READ(5,1000,END=999) (TITLE(I),I=1,18)
0002100      WRITE(6,2000) (TITLE(I),I=1,18)
0002200      1000 FORMAT (18A4)
0002300      2000 FORMAT (1H1////20X,30H ** STAGE STACKING PROGRAM ** ////20X, -
0002400      118A4////)
0002500      READ (5,1010) STAGEN, SPEEDN, CHAPTS, PO, TO, WTMOLE, DESRPM, DESFLO
0002600      WRITE(6,2010) STAGEN, SPEEDN, CHAPTS, PO, TO, WTMOLE, DESRPM, DESFLO
0002700      RG = RU/WTMOLE
0002800      DCP = RG/AJ
0002900      GJ = G*AJ
0003000      G2J = GJ*2.0
0003100      RPMRAD = PI/360.0

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0003100 1010 FORMAT (6F10.0)
0003200 2010 FORMAT (80H STAGES SPEEDS POINTS PO IN TO IN MO-
0003300 1LE WT DES RPM DES FLOW//((8F10.3)////))
0003400 READ (5,1010) SPDPHI, SPDPHI, DRDEVG, DRDEVN, DRDEVP, UNITS
0003500 WRITE (6,2011) SPDPHI, SPDPHI, DRDEVG, DRDEVN, DRDEVP, UNITS
0003600 2011 FORMAT (60H SPDPHI SPDPHI DRDEVG DRDEVN DRDEVP -
0003700 XUNITS//((6F10.1)////))
0003800 READ (5,1020) (CPCO(I),I=1,6)
0003900 WRITE(6,2020) (CPCO(I),I=1,6)
0004000 1020 FORMAT (3E20.8)
0004100 2020 FORMAT (072H CPCO(1) CPCO(2) CPCO(3) CPCO(4) C-
0004200 IPCO(5) CPCO(6)//((6E12.5)////))
0004300 NSTA = STAGEN
0004400 NSPE= SPEEDN
0004500 NPTS = CHAPTS
0004600 READ (5,1010) (RT2(I),I=1,NSTA)
0004700 READ (5,1010) (RH2(I),I=1,NSTA)
0004800 READ (5,1010) (RT3(I),I=1,NSTA)
0004900 READ (5,1010) (RH3(I),I=1,NSTA)
0005000 READ (5,1010) (BET2M(I,1),I=1,NSTA)
0005100 READ (5,1010) (CB2M(I), I=1,NSTA)
0005200 READ (5,1010) (CB2MR(I), I=1,NSTA)
0005300 READ (5,1010) (CB3MR(I), I=1,NSTA)
0005400 READ (5,1010) (RK2M (I), I=1,NSTA)
0005500 READ (5,1010) (RSOLM(I), I=1,NSTA)
0005600 READ (5,1010) (SK2M(I),I=1,NSTA)
0005700 READ (5,1010) (PR(I),I=1,NSTA)
0005800 READ(5,1010) (ETAINP(I),I=1,NSTA)
0005900 WRITE(6,2030) (NSTAGE(I),RT2(I),RH2(I),RT3(I),RH3(I),BET2M(I,1),
0006000 XCB2M(I),CB2MR(I),CB3MR(I),RK2M(I),RSOLM(I),SK2M(I), I=1,NSTA)
0006100 2030 FORMAT (110H STAGE RT2 RH2 RT3 RH3 -
0006200 X BET2M CB2M CB2MR CB3MR RK2M RSOLM,10H -
0006300 XSK2M//((5X,I5,4F10.4,5F10.2,F10.4,F10.2))
0006400 WRITE (6,2120)
0006500 WRITE (6,2031) (NSTAGE(I), PR(I), ETAINP(I), I=1,NSTA)
0006600 2031 FORMAT (30H STAGE PR ETAINP//((5X,I5,2F10.4))
0006700 READ (5,1010) (PCTSPD(J),J=1,NSPE)
0006800 2120 FORMAT (1H0////)
0006900 READ (5,1010) (ETARAT(J),J=1,NSPE)
0007000 WRITE (6,2120)
0007100 WRITE (6,2121) (PCTSPD(J),ETARAT(J), J=1,NSPE)
0007200 2121 FORMAT (20H PCTSPD ETARAT//((2F10.4))
0007300 DO 21 I=1,NSTA
0007400 READ (5,1010) (BLEED(I,J),J=1,NSPE)
0007500 21 CONTINUE
0007600 WRITE (6,2120)
0007700 WRITE (6,2041) (NSTAGE(I),I=1,12), (PCTSPD(J), (BLEED(I,J), I=1,12-
0007800 1),J=1,NSPE)
0007900 2041 FORMAT (20X,27H BLEED(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER/-
0008000 18H PCT SPD,12(I5,3X)////(13F8.3))
0008100 DO 30 I=1,NSTA
0008200 READ (5,1010) (PHIDES(I,1,K),K=1,NPTS)
0008300 READ (5,1010) (PSIDES(I,1,K),K=1,NPTS)
0008400 READ (5,1010) (ETADES(I,1,K),K=1,NPTS)
0008500 30 CONTINUE
0008600 DO 50 I=1,NSTA
0008700 WRITE (6,2120)
0008800 WRITE(6,2050) NSTAGE(I), (PCTSPD(J),J=1,3), ((PHIDES(I,J,K),PSIDES(I-
0008900 1,J,K),ETADES(I,J,K),J=1,3),K=1,NPTS)
0009000 IF(NSPE.LT.4) GO TO 50
0009100 WRITE (6,2120)
0009200 WRITE(6,2050) NSTAGE(I), (PCTSPD(J),J=4,6), ((PHIDES(I,J,K),PSIDES(I-
0009300 1,J,K),ETADES(I,J,K),J=4,6),K=1,NPTS)
0009400 IF(NSPE.LT.7) GO TO 50
0009500 WRITE (6,2120)
0009600 WRITE(6,2050) NSTAGE(I), (PCTSPD(J),J=7,9), ((PHIDES(I,J,K),PSIDES(I-
0009700 1,J,K),ETADES(I,J,K),J=7,9),K=1,NPTS)
0009800 50 CONTINUE
0009900 2050 FORMAT (20X,41H INPUT DESIGN CHARACTERISTICS FOR STAGE--,I3//3(5X,-
0010000 1F10.3,10H PCT SPD ,5X)////3(30H PHIDES PSIDES ETADES)/(9F1-
0010100 20.4))
0010200 C *** CHANGE METRIC INPUT INTO ENGLISH UNITS
0010300 IF (UNITS.NE.1.0) GO TO 53

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0010400      PO = PO/0.689476
0010500      TO = TO*9.0/5.0
0010600      DESFLO = DESFLO/0.453592
0010700      DO 51 I=1,NSTA
0010800      RT2(I) = RT2(I)/2.54
0010900      RH2(I) = RH2(I)/2.54
0011000      RT3(I) = RT3(I)/2.54
0011100      RH3(I) = RH3(I)/2.54
0011200      DO 52 J = 1,NSPE
0011300      52 BLEED(I,J) = BLEED(I,J)/0.453592
0011400      51 CONTINUE
0011500      53 RETURN
0011600      999 STOP
0011700      END

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0013500      SUBROUTINE CSPREF
0013600 C *** SUBROUTINE CSPREF CALCULATES PARAMETERS AT DESIGN SPEED AND FLOW
0013700 C      CONDITIONS
0013800      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0013900      XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0014000      XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9, -
0014100      X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9), -
0014200      XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), -
0014300      XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
0014400      X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0014500      X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0014600      X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
0014700      X,9), PHIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12) -
0014800      X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR-
0014900      X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12)-
0015000      X, DB3MRN(12,9), DB3MRP(12,8)
0015100      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
0015200      X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
0015300      X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP
0015400      J= 1
0015500      I= 1
0015600      TT(I)= TO
0015700      PT(I)= PO
0015800      20 RHOT= PT(I)/(TT(I)*RG)
0015900      TS= TT(I)
0016000      RHOS= RHOT
0016100      UT2(I)= RT2(I)*DESRPM*RPMRAD
0016200      UT3(I)= RT3(I)*DESRPM*RPMRAD
0016300 C *** CALCULATIONS AT ROTOR INLET
0016400      30 VZ2M(I,J) = DESFLO/(RHOS*AREA2(I))
0016500      V= VZ2M(I,J)/COS(BET2M(I,J))
0016600      CP= CPF(TS)
0016700      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))*GF1
0016800      TS= TT(I)*(RHOS/RHOT)*GM1
0016900      WCAL= RHOS*AREA2(I)*VZ2M(I,J)
0017000      IF(ABS(WCAL - DESFLO) .GT. 0.01) GO TO 30
0017100      CPREF(I) = CP
0017200      GF1REF(I) = GF1
0017300      PHIREF(I)= VZ2M(I,J)/UT2(I)
0017400      DO 40 K=2,NPTS
0017500      IF(PHIREF(I)-PHIDES(I,J,K)) 50,60,40
0017600      40 CONTINUE
0017700      K= NPTS
0017800      50 PSIREF(I)= (PSIDES(I,J,K)-PSIDES(I,J,K-1))*(PHIREF(I)-PHIDES(I,J, -
0017900      1K-1))/(PHIDES(I,J,K)-PHIDES(I,J,K-1)) + PSIDES(I,J,K-1)
0018000      ETAREF(I)= (ETADES(I,J,K)-ETADES(I,J,K-1))*(PHIREF(I)-PHIDES(I,J, -
0018100      1K-1))/(PHIDES(I,J,K)-PHIDES(I,J,K-1)) + ETADES(I,J,K-1)
0018200      GO TO 70
0018300      60 PSIREF(I)= PSIDES(I,J,K)
0018400      ETAREF(I)= ETADES(I,J,K)
0018500      70 CONTINUE
0018600      IF (PSIREF(I).EQ.0.0) GO TO 71
0018700      PR(I)= (1.0 + PSIREF(I)*UT3(I)*UT3(I)/(GJ*CP*TT(I)))*GF2
0018800      71 CONTINUE
0018900      IF(ETAREF(I).EQ.0.0) ETAREF(I)= ETAINP(I)

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0019000      TR(I)= 1.0 + (PR(I)**GF3-1.0)/ETAREF(I)
0019100      TT(I+1)= TT(I)*TR(I)
0019200      IF (PSIREF(I).EQ.0.0) PSIREF(I) = GJ*CP*(TT(I+1)-TT(I))*ETAREF(I) -
0019300      X/UT3(I)**2
0019400      PT(I+1)= PT(I)*PR(I)
0019500      TRO(I)= TT(I+1)/TO
0019600      PRO(I)= PT(I+1)/PO
0019700      I= I+1
0019800      IF(I .LE. NSTA) GO TO 20
0019900      DO 80 I=1,NSTA
0020000      VT2M= VZ2M(I,J)*TAN(BET2M(I,J))
0020100      VT2MR= UM2(I) - VT2M
0020200      BET2MR(I,J)= ATAN2(VT2MR,VZ2M(I,J))
0020300      TS= TT(I+1)
0020400      RHOT= PT(I+1)/(TT(I+1)*RG)
0020500      RHOS= RHOT
0020600 C *** CALCULATIONS AT ROTOR OUTLET
0020700   81 VZ3M(I,J)= DESFLO/(RHOS*AREA3(I))
0020800      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UM2(I)*VT2M)/UM3(I)
0020900      V= SQRT(VZ3M(I,J)**2 + VT3M**2)
0021000      CP= CPF(TS)
0021100      RHOS = RHOT*(1.0-V*V/(G2J*CP*TT(I+1)))*GF1
0021200      TS = TT(I+1)*(RHOS/RHOT)**GM1
0021300      WCAL= RHOS*AREA3(I)*VZ3M(I,J)
0021400      IF(ABS(WCAL-DESFLO) .GT. 0.01) GO TO 81
0021500      BET3M(I,J) = ATAN2(VT3M,VZ3M(I,J))
0021600      SINCM(I) = BET3M(I,J)*RAD - SK2M(I)
0021700      VT3MR= UM3(I) - VT3M
0021800      BET3MR(I,J)= ATAN2(VT3MR,VZ3M(I,J))
0021900      RINCM(I)= BET2MR(I,J)*RAD - RK2M(I)
0022000      V2MR= VZ2M(I,J)/COS(BET2MR(I,J))
0022100      V3MR= VZ3M(I,J)/COS(BET3MR(I,J))
0022200      V3DV2R(I) = V3MR/V2MR
0022300      RDFM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +
0022400      XRM2(I))/RSOLM(I)/V2MR
0022500      DB2M(I,J) = BET2M(I,J)
0022600      DB2MR(I,J) = BET2MR(I,J)
0022700      DB3M(I,J) = BET3M(I,J)
0022800      DB3MR(I,J) = BET3MR(I,J)
0022900      B2MB3R(I,J) = BET2MR(I,J) - BET3MR(I,J)
0023000   80 CONTINUE
0023100  100 RETURN
0023200      END
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0023300      FUNCTION CPF(TS)
0023400 C *** SUBROUTINE CPF(TS) CALCULATES SPECIFIC HEAT FROM STATIC
0023500 C TEMPERATURE USING FIFTH DEGREE POLYNOMIAL
0023600      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0023700      XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0023800      XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9, -
0023900      X,8), DPHIA(12), DPSIA(12), DELTA(12), NSTAGE(12), PCTSPD(9), -
0024000      XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), -
0024100      XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
0024200      X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0024300      X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0024400      X,12), C3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12)-
0024500      X,9), PIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12) -
0024600      X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR-
0024700      X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12)-
0024800      X, DB3MRN(12,9), DB3MRP(12,8)
0024900      COMMON /SCALER/ RO, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
0025000      X, NSPE, NPTS, PU, TO, DESRPM, DESFLO, UNITS -
0025100      X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPHI, SPDPHI, DRDEVG, DRDEVN, DRDEVP
0025200      CPF = CPCO(1)+(CPCO(2)+(CPCO(3)+(CPCO(4)+(CPCO(5)+ CPCO(6)*TS)*TS)-
0025300      X *TS)*TS)*TS
0025400      GAMMA = CPF/(CPF - DCP)
0025500      GM1 = GAMMA - 1.0
0025600      GF1 = 1.0/GM1
0025700      GF2 = GAMMA/GM1
0025800      GF3 = 1.0/GF2
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0025900
0026000

RETURN
END

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0010700 SUBROUTINE CSETA
0010800 C *** SUBROUTINE CSETA GENERATES ADIABATIC EFFICIENCY VERSUS FLOW
0010900 C COEFFICIENT
0011000 COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0011100 XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0011200 XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9, -
0011300 X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9), -
0011400 XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), -
0011500 XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12) -
0011600 X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0011700 X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0011800 X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12 -
0011900 X,9), PHIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12) -
0012000 X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR -
0012100 X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12) -
0012200 X, DB3MRN(12,9), DB3MRP(12,8)
0012300 COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA -
0012400 X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS -
0012500 X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP -
0012600 J = 1
0012700 C *** TWO PARABOLAS ARE USED FROM STALL AND CHOKE TO DESIGN CONDITIONS
0012800 DO 10 I=1,NSTA
0012900 PSMPRS= (PHIDES(I,J,1) - PHIREF(I))*2
0013000 PCMPRS = (PHIDES(I,J,NPTS) - PHIREF(I))*2
0013100 AS= -0.1*ETAREF(I)/PSMPRS
0013200 AC= -0.2 * ETAREF(I)/PCMPRS
0013300 BS= -2.0*PHIREF(I)*AS
0013400 BC= -2.0*PHIREF(I)*AC
0013500 CS= ETAREF(I) + AS*PHIREF(I)*2
0013600 CC= ETAREF(I) + AC*PHIREF(I)*2
0013700 DO 20 K=1,NPTS
0013800 IF(PHIDES(I,J,K) - PHIREF(I)) 11,12,13
0013900 11 ETADES(I,J,K) = (AS*PHIDES(I,J,K) + BS)*PHIDES(I,J,K) + CS
0014000 GO TO 20
0014100 12 ETADES(I,J,K)= ETAREF(I)
0014200 GO TO 20
0014300 13 ETADES(I,J,K) = (AC*PHIDES(I,J,K) + BC)*PHIDES(I,J,K) + CC
0014400 20 CONTINUE
0014500 10 CONTINUE
0014600 RETURN
0014700 END

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0011800 SUBROUTINE CSPSI
0011900 C *** SUBROUTINE CSPSI CALCULATES PRESSURE COEFFICIENTS FOR INPUT FLOW
0012000 C COEFFICIENTS
0012100 COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0012200 XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0012300 XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9, -
0012400 X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9), -
0012500 XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), -
0012600 XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12) -
0012700 X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0012800 X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0012900 X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12 -
0013000 X,9), PHIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12) -
0013100 X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR -
0013200 X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12) -
0013300 X, DB3MRN(12,9), DB3MRP(12,8)
0013400 COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA -
0013500 X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS -
0013600 X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP -
0013700 J=1
0013800 DO 100 K=1,NPTS
0013900 I=1

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0014000      TT(I) = TO
0014100      PT(I) = PO
0014200      10 VZ3M(I,J) = VZ2M(I,J)*PHIDES(I,J,K)/PHIREF(I)
0014300      V2MR = VZ3M(I,J)/COS(DB2MR(I,1))
0014400      BET3MR(I,J) = DB3MR(I,1)
0014500      VT2M = VZ3M(I,J)*TAN(DB2M(I,1))
0014600      V2S = VT2M**2 + VZ3M(I,J)**2
0014700      RHOT = PT(I)/(TT(I)*RG)
0014800      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))*GFIREF(I)
0014900      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
0015000      TS = TT(I)
0015100      ID = 0
0015200      11 VT3M = UM3(I) - VZ3M(I,J)*TAN(BET3MR(I,J))
0015300      CP = CPF(TS)
0015400      DT = (UM3(I)*VT3M - UM2(I)*VT2M)/(GJ*CP)
0015500      TRA = (DT + TT(I))/TT(I)
0015600      PTA3 = PT(I)*(1.0 + ETADES(I,J,K)*(TRA - 1.0))*GF2
0015700      TTA3 = DT + TT(I)
0015800      RHOT = PTA3/(TTA3*RG)
0015900      V3S = VT3M**2 + VZ3M(I,J)**2
0016000      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3))*GF1
0016100      TS = TTA3*(RHOS/RHOT)*GM1
0016200      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
0016300      IF (TRA.GE.1.U) GO TO 12
0016400      DT = 0.0
0016500      GO TO 13
0016600      12 ID = ID + 1
0016700      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
0016800      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
0016900 C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN FLOW
0017000 C COEFFICIENT
0017100      IF (DRDEVP.EQ.1.0)
0017200      XDB3MRP(I,K) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
0017300      BET3MR(I,J) = DB3MR(I,1) + DB3MRP(I,K)
0017400      IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 11
0017500      13 PSIDES(I,J,K) = GJ*CP*DT*ETADES(I,J,K)/UT3(I)**2
0017600      DV3DV2 = V3DV2R(I)
0017700      FV3DV2 = V3MR/V2MR
0017800      I = I + 1
0017900      IF (I.LE.NSTA) GO TO 10
0018000      100 CONTINUE
0018100      RETURN
0018200      END

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0018300      SUBROUTINE CSPSD
0018400 C *** SUBROUTINE CSPSD ALTERS PRESSURE RISE COEFFICIENTS FOR OFF DESIGN
0018500 C SPEEDS
0018600      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
0018700      XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), -
0018800      XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9, -
0018900      X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9), -
0019000      XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), IR(12), PRO(12), -
0019100      XTRO(12), ETA0(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12) -
0019200      X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0019300      X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR( -
0019400      X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12 -
0019500      X,9), PHIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12) -
0019600      X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR -
0019700      X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12) -
0019800      X, DB3MRN(12,9), DB3MRP(12,8)
0019900      COMMON /SCALAR/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA -
0020000      X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
0020100      X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP
0020200      DO 100 J=1,NSPE
0020300      I = 1
0020400      TT(I) = TO
0020500      PT(I) = PO
0020600      10 VZ3M(I,J) = VZ2M(I,1)*PCTSPD(J)
0020700      V2MR = VZ3M(I,J)/COS(DB2MR(I,1))
0020800      BET3MR(I,J) = DB3MR(I,1)

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0020900      ID = 0
0021000      VT2M= VZ2M(I,1)*PCTSPD(J)* TAN(DB2M(I,1))
0021100      V2S = VT2M**2 + VZ3M(I,J)**2
0021200      RHOT = PT(I)/(TT(I)*RG)
0021300      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))*GF1REF(I)
0021400      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
0021500      TS = TT(I)
0021600 11 VT3M = UM3(I)*PCTSPD(J) - VZ3M(I,J)*TAN(BET3MR(I,J))
0021700      CP = CPF(TS)
0021800      DT = (UM3(I)*VT3M - UM2(I)*VT.M)/(GJ*CP)*PCTSPD(J)
0021900      TRA = (DT + TT(I))/TT(I)
0022000      PTA3 = PT(I)*(1.0 + ETAREF(I)*(TRA - 1.0))*GF2
0022100      TTA3 = DT + TT(I)
0022200      RHOT = PTA3/(TTA3*RG)
0022300      V3S = VT3M**2 + VZ3M(I,J)**2
0022400      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3))*GF1
0022500      TS = TTA3*(RHOS/RHOT)**GMI
0022600      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
0022700      IF (I.NE.1) GO TO 12
0022800      DVZ3M = VZ3M(I,J)
0022900 12 CONTINUE
0023000      ID = ID + 1
0023100      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
0023200      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
0023300 C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN SPEEDS
0023400      IF (DRDEVN.EQ.1.0)
0023500      XDB3MRN(I,J) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
0023600      BET3MR(I,J) = DB3MR(I,1) + DB3MRN(I,J)
0023700      IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 11
0023800      DPSIS(I,J) = GJ*CP*DT*ETAREF(I)/(UT3(I)*PCTSPD(J))**2 - PSIREF(I)
0023900      DPSIS(I,J) = DPSIS(I,J) - DPSIS(I,1)
0024000      I = I + 1
0024100      IF (I.LE.NSTA) GO TO 10
0024200 100 CONTINUE
0024300      RETURN
0024400      END

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0014800      SUBROUTINE CSPAN
0014900 C *** SUBROUTINE CSPAN ALTERS FLOW AND PRESSURE RISE COEFFICIENTS FOR
0015000 C BLADE RESET
0015100      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
0015200      XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
0015300      XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9,
0015400      X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
0015500      XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
0015600      XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
0015700      X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0015800      X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR(
0015900      X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
0016000      X,9), PHIFIX(12), DFHIF(12), CPREF(12), GF1REF(12), ETAINP(12)
0016100      X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9) DB3MR-
0016200      X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12)-
0016300      X, DB3MRN(12,9), DB3MRP(12,8)
0016400      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
0016500      X, NSPE, NPIS, PO, TO, DESRPM, DESFLD, UNITS
0016600      X, CP, GAMMA, GMI, GF1, GF2, GF3, SPDPHI, SPDPHI, DRDEVG, DRDEVP, DRDEVP
0016700      J=1
0016800      I=1
0016900      TT(I)= TO
0017000      PT(I)= PO
0017100 90 TS= TT(I)
0017200      DPHIA(I) = 0.0
0017300      DPSIA(I) = 0.0
0017400      DETA(I) = 0.0
0017500      IF((CB2M(I) + CB2MR(I) + CB3MR(I)).EQ.0.00) GO TO 93
0017600      BET2M(I,J)= DB2M(I,J) + CB2M(I)
0017700      BET2MR(I,J)= DB2MR(I,J) + CB2MR(I)
0017800      BET3MR(I,J)= DB3MR(I,J) + CB3MR(I)
0017900      VZ2M(I,J)= UM2(I)/(TAN(BET2M(I,J))+ TAN(BET2MR(I,J)))
0018000      V2MR = VZ2M(I,J)/COS(BET2MR(I,J))

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0018100 C *** CHANGE IN FLOW COEFFICIENT FOR RESET
0018200 DPHIA(I)= VZ2M(I,J)/UT2(I) - PHIREF(I)
0018300 VZ3M(I,J)= VZ2M(I,J)
0018400 VT2M= VZ2M(I,J)*TAN(BET2M(I,J))
0018500 V2S = VT2M**2 + VZ3M(I,J)**2
0018600 RHOT = PT(I)/(TT(I)*RG)
0018700 RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))*GF1REF(I)
0018800 DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
0018900 FLOCAL(I,J) = DESFLC
0019000 92 VT3M= UM3(I) - VZ3M(I,J) *TAN(BET3MR(I,J))
0019100 CP = CPF(TS)
0019200 DT= (UM3(I) * VT3M - UM2(I)*VT2M)/(GJ*CP)
0019300 TRA = (DT + TT(I))/TT(I)
0019400 PTA3 = PT(I)*(1.0 + ETAREF(I)*(TRA -1.0))*GF2
0019500 TTA3 = DT + TT(I)
0019600 RHOT= PTA3 / (TTA3 *RG)
0019700 V3S = VT3M**2 + VZ3M(I,J)**2
0019800 RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3 ))**GF1
0019900 TS = TTA3 *(RHOS/RHOT)**GM1
0020000 WCAL = RHOS*AREA3(I)*VZ3M(I,J)
0020100 VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
0020200 V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
0020300 C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR BLADE RESET
0020400 IF (DRDEVG.EQ.1.0)
0020500 XDB3MRG(I) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
0020600 BET3MR(I,J) = DB3MR(I,J) + CB3MR(I) + DB3MRG(I)
0020700 IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 92
0020800 C *** CHANGE IN PRESSURE RISE COEFFICIENT FOR RESET
0020900 DPSIA(I) = GJ*CP*DT/(UT3(I)*UT3(I))*ETAREF(I) - PSIREF(I)
0021000 93 I = I+1
0021100 IF (I.LE.NSTA) GO TO 90
0021200 100 RETURN
0021300 END

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0000100 SUBROUTINE CSOUP
0000200 C *** SUBROUTINE CSOUP CALCULATES AND WRITES STAGE AND COMPRESSOR
0000300 C PERFORMANCE PARAMETERS
0000400 COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
0000500 XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
0000600 XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9,
0000700 X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
0000800 XBET2M(12,9), BLEED(12,9), TT(13), PR(12), TR(12), PRO(12),
0000900 XTRO(12), ETAD(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
0001000 X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
0001100 X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2M(12), CB2MR(
0001200 X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12)-
0001300 X,9), PHIFIX(12), DPHIF(12), CPREF(12), GF1REF(12), ETAINP(12)
0001400 X, FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DB3MR-
0001500 X(12,9), B2MB3R(12,9), V3DV2R(12), DB3MRG(12)-
0001600 X, DB3MRN(12,9), DB3MRP(12,8)
0001700 COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
0001800 X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
0001900 X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPHI, SPDPHI, DRDEVG, DRDEVN, DRDEVP
0002000 WRITE(6,2070)
0002100 2070 FORMAT (1H1////20X,27H ** COMPUTED OUTPUT DATA **////)
0002200 C *** READ SPEED AND FLOWS
0002300 80 READ (5,1010) SPEEDF, FLOWIN,DFLOW, FLOWFI
0002400 IF (UNITS.NE.1.0) GO TO 81
0002500 FLOWIN = FLOWIN/0.453592
0002600 DFLOW = DFLOW/0.453592
0002700 FLOWFI = FLOWFI/0.453592
0002800 81 CONTINUE
0002900 IF (UNITS.EQ.1.0) FLOWIN = FLOWIN*0.453592
0003000 WRITE(6,2080) SPEEDF, FLOWIN
0003100 IF (UNITS.EQ.1.0) FLOWIN = FLOWIN/0.453592
0003200 2080 FORMAT (1H0////
0003300 1 17H PERCENT SPEED = ,F8.3,10X,15H INLET FLOW = ,F8.3//080-
0003400 1H STAGE PHI PSI TAU ETA PR
0003500 2C-ETA C-PR,40H STG-FLOW R-INCM R-DFM S-INCM/)
0003600 DO 82 J=1,NSPE

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0003700      IF (SPEEDF.EQ.PCTSPD(J)) JS=J
0003800      82 CONTINUE
0003900 C *** CALCULATE THE OUTPUT
0004000      I=1
0004100      TT(I)= T0
0004200      PT(I)= P0
0004300      WFLOW = FLOWIN
0004400      91 RHOT= PT(I)/(TT(I)*RG)
0004500      TS= TT(I)
0004600      RHOS= RHOT
0004700 C
0004800      WFLOW = WFLOW - FLOWIN*BLEED(I,JS)
0004900      U2 = UT2(I)*SPEEDF
0005000      U3 = UT3(I)*SPEEDF
0005100      UMM2 = UM2(I)*SPEEDF
0005200      UMM3 = UM3(I)*SPEEDF
0005300      100 VZ = WFLOW/(RHOS*AREA2(I))
0005400      V= VZ/COS(BET2M(I,1))
0005500      CP= CPF(TS)
0005600      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))*GF1
0005700      IF ((V*V).GT.(G2J*CP*TT(I))) GO TO 113
0005800      TS= TT(I)*(RHOS/RHOT)*GM1
0005900      WCAL = RHOS*VZ*AREA2(I)
0006000      IF (ABS(WCAL-WFLOW).GT.0.01) GO TO 100
0006100      PHIC = VZ/U2
0006200      IF (PHIFIX(I).NE.0.0) PHIC = PHIC + DPHIF(I)
0006300      IF (PHIC.LT.PHI(I,JS,1)) GO TO 110
0006400      IF (PHIC.GT.PHI(I,JS,NPTS)) GO TO 120
0006500      DO 130 K=2,NPTS
0006600      IF (PHIC-PHI(I,JS,K)) 140,150,130
0006700      130 CONTINUE
0006800      K= NPTS
0006900      140 PSIC=(PSI(I,JS,K)-PSI(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
0007000      1      (PHI(I,JS,K)-PHI(I,JS,K-1)) + PSI(I,JS,K-1)
0007100      ETAC=(ETA(I,JS,K)-ETA(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
0007200      1      (PHI(I,JS,K)-PHI(I,JS,K-1)) + ETA(I,JS,K-1)
0007300      GO TO 160
0007400      150 PSIC= PSI(I,JS,K)
0007500      ETAC= ETA(I,JS,K)
0007600      160 CONTINUE
0007700      PR(I) = (1.0 + PSIC*U3*U3/      (GJ*CP*TT(I)))*GF2
0007800      TAU = PSIC/ETAC
0007900      TR(I)= 1.0 + (PR(I))*GF3-1.0)/ETAC
0008000      TT(I+1)= TT(I)*TR(I)
0008100      PT(I+1)= PT(I) *PR(I)
0008200      TR0(I)= TT(I+1)/T0
0008300      PRO(I)= PT(I+1)/P0
0008400      IF (I.EQ.1) GF3S = GF3
0008500      GF30= (GF3 + GF3S)/2.0
0008600      ETA0(I)= (PRO(I))*GF30 - 1.0)/(TR0(I) - 1.0)
0008700      VT2M = VZ * TAN(BET2M(I,1))
0008800      VT2MR = UMM2 - VT2M
0008900      BET2MR(I,JS)= ATAN2(VT2MR,VZ)
0009000      RINCM(I)= BET2MR(I,JS) * RAD - RK2M(I)
0009100      V2MR= VZ/COS(BET2MR(I,JS))
0009200      RHOT= PT(I+1)/(TT(I+1)*RG)
0009300      TS= TT(I+1)
0009400      RHOS= RHOT
0009500      161 VZ3M(I,JS)=WFLOW/(RHOS*AREA3(I))
0009600      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UMM2 *VT2M)/UMM3
0009700      VS= VZ3M(I,JS)**2 + VT3M**2
0009800      CP= CPF(TS)
0009900      RHOS= RHOT*(1.0-VS/(G2J*CP*TT(I+1)))*GF1
0010000      IF ((VS).GT.(G2J*CP*TT(I+1))) GO TO 113
0010100      TS= TT(I+1) * (RHOS/RHOT)*GM1
0010200      WCAL= RHOS*AREA3(I)*VZ3M(I,JS)
0010300      IF (ABS(WCAL-WFLOW).GT.0.01) GO TO 161
0010400      BET3M(I,JS) = ATAN2(VT3M,VZ3M(I,JS))
0010500      SINCM(I) = BET3M(I,JS)*RAD - SK2M(I)
0010600      VT3MR = UMM3 - VT3M
0010700      BET3MR(I,JS)= ATAN2(VT3MR,VZ3M(I,JS))
0010800      V3MR = VZ3M(I,JS)/COS(BET3MR(I,JS))
0010900      RDM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +

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0011000      XRM2(I))/RSOLM(I)/V2MR
0011100      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW*0.453592
0011200 C *** WRITE THE OUTPUT
0011300      WRITE (6,2090) I,PHIC,PSIC,TAU,ETAC,PR(I),ETAO(I),PRO(I),WTFLOW
0011400      X,RINCM(I),RDFM(I),SINCM(I)
0011500      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW/0.453592
0011600 2090 FORMAT (5X,I5,8F10.4,F10.2,F10.4,F10.2)
0011700      I= I+1
0011800      IF(I.LE.NSTA) GO TO 91
0011900      GO TO 111
0012000 110 WRITE(6,2100) I,PHIC
0012100      GO TO 111
0012200 120 WRITE(6,2110)I,PHIC
0012300      GO TO 113
0012400 2100 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H STALL)
0012500 2110 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H CHOKE)
0012600 111 FLOWIN = FLOWIN + DFLOW
0012700      IF (FLOWIN.LE.FLOWFI) GO TO 81
0012800 113 IF (J$.LT.NSPE) GO TO 80
0012900      DO 112 I=1,NSTA
0013000      DO 112 J=1,NSPE
0013100 112 DPSIS(I,J) = 0.0
0013200      RETURN
0013300 1010 FORMAT (8F10.0)
0013400      END

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