STGSTK

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.

![Diagram](image-url)
Stage-Stacking Method

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

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

\[ W = \rho A V_z \]  

(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 \( \beta_2 \), a meanline velocity diagram (fig. 2) can be obtained at the rotor inlet. And, by assuming that the stage overall pressure ratio and adiabatic efficiency apply at the rotor exit, a meanline velocity diagram can be obtained at the rotor exit. If rotor exit total pressure and temperature are then assumed to apply at the inlet of the next rotor, meanline velocity diagrams can be obtained at every rotor inlet and exit from the overall stage performance parameters of pressure ratio \( Pr \) and adiabatic efficiency \( \eta_{ad} \). 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 \( \eta_{ad} \) and \( \eta_{ad} \).

Stage characteristics. - The stage performance characteristics consist of three nondimensional quantities – adiabatic efficiency \( \eta_{ad} \), pressure coefficient \( \psi \), and flow coefficient \( \varphi \). They are calculated from

\[
\varphi = \frac{VZ2M}{U2T} \tag{2}
\]

\[
\psi = \frac{C_H \eta_{ad} (T_3 - T_2)}{U_3^2} \tag{3}
\]

\[
\eta_{ad} = \frac{p_r(\gamma-1)/\gamma - 1}{T r - 1} \tag{4}
\]

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

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\( \bullet \) Design (reference) point

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Figure 3. Typical nondimensional stage characteristics.
efficiency. At some low flow coefficient \( \varphi_s \) the stage will stall, and at some high flow coefficient \( \varphi_c \) 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 \( \eta_{ad} \) 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 \( \eta_{ad} \) 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 \( \varphi \).
2. From the stage characteristics \( \eta_{ad}(\varphi) \) and \( \psi(\varphi) \), obtain the stage overall adiabatic efficiency \( \eta_{ad} \) 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 \( \eta_{ad} \) 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 \( \gamma_{0} \) 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.
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 $\psi(\phi)$ 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 $\psi(\phi)$ adjustment for part speed. At the part-speed condition, as compared with design speed, the pressure coefficient $\psi$ drops by an amount $\Delta\psi$ and the range of the flow coefficient $\phi$ is expanded.

The second real flow adjustment option alters the stage characteristic $\eta_{ad}(\phi)$ for part-speed conditions. This adjustment option for $\eta_{ad}(\phi)$ at part speed consists of two parts: (1) the expansion of the range of the flow coefficient $\phi$, which is identical to the adjustment used for the stage characteristic $\psi(\phi)$ discussed in the previous paragraph, and (2) a change in the level of $\eta_{ad}$ 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 $\delta_{R}$ under any combination of three conditions: off-design flow coefficient $\phi$, rotative speed $N$, and blade setting angle $\gamma_{0}$. A change in the rotor deviation angle $\delta_{R}$ changes the rotor outlet relative flow angle $\beta_{3M}$. This in turn alters the rotor outlet representative meanline velocity diagram and changes the stage characteristic $\psi(\phi)$.

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

CSINPT - read and write the input data

CSPREF - calculate design (reference) parameters

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

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

CSPSD - perform option to alter pressure coefficient \( \psi \) at off-design speeds

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

CSOUPT - calculate and write the output data

CPF - calculate specific heat \( C_p \) and its ratio \( \gamma \)

Other optional calculations are located within the STGSTK code as follows. MAIN contains an option to alter the flow coefficient \( \psi \) at off-design speeds. CSPSI, CSPSD, and CSPAN contain an option to alter the rotor deviation angle \( \theta_R \) 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
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 |

Figure 7. - Input variable locations on cards for stage-stacking program.
DRDEVN, F10 alters rotor deviation angle for off-design speed when equal to 1.0
DRDEVP, F10 alters rotor deviation angle for off-design $\phi$ 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
ETA1NP, 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
ETAISP 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 $C_p$ polynomial coefficients.

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| 0.13391136E-09 | -0.78056154E-13 | 0.15042604E-16 |

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| 9.891  | 13.604 |
| 24.628 | 23.566 |
| 12.088 | 14.696 |
| .0     | .0     |
| .0     | .0     |
| .0     | .0     |
| 56.15  | 55.46  |
| 1.68   | 1.57   |
| 36.10  | 36.15  |
| 1.5906 | 1.5087 |
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| .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 CSOUPT writes the final output. The units of the output data are either all SI or all U.S. customary depending on the value of the input parameter UNITS. For SI output, UNITS equals 1.0; for U.S. customary output, UNITS equals 0.0.

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

- PHIREF: stage flow coefficient at design flow, speed, and blade setting angles
- PSIREF: stage pressure coefficient at design flow, speed, and blade setting angles
- DPHIA: change in flow coefficient PHIREF because of rotor- or stator-blade reset
- DPSIA: change in pressure coefficient PSIREF because of rotor- or stator-blade reset
- FLOCAL: calculated flow for a stage at design speed if blade reset is specified, kg/sec (lb/sec)
- BET2M: rotor inlet absolute flow angle at design speed and flow and specified blade reset, deg
- BET3MR: rotor outlet relative flow angle at design speed and flow and specified blade reset, deg
- RINCM: rotor incidence angle at design speed and flow and specified blade reset, deg
- RDFM: rotor diffusion factor at design speed and flow and specified blade reset, deg
- SINCM: stator incidence angle at design speed and flow and specified blade reset, deg
- DPSIS: change in pressure coefficient PSIREF because of off-design speed effects
- PHI: calculated stage flow coefficient for selected speeds with blade reset effects included
calculated stage pressure coefficient for selected speeds
with blade reset effects included

calculated stage adiabatic efficiency for selected speeds

stage temperature rise coefficient

stage pressure ratio

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 $Pr$ and adiabatic efficiency $\eta_{ad}$, (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 $\beta_2$ at the following rotor inlet, the corrected flow at the rotor
inlet will be reduced. Also, the stage pressure ratio $P_r$ will decrease, and this may cause the corrected flow at the stage exit to decrease. Corrected-flow reduction at the stage exit will depend on the amount of IGV reset, the design speed, and the stage performance.

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

Agreement between the calculated and measured IGV reset for a given flow reduction and tip speed is better at design speed than at 80 percent of design speed. However, for both speeds the trends of the calculated and measured data are very similar. This indicates that as the rotor speed goes up, IGV reset must be increased for a given flow reduction ratio $W/W_d$. This influence of rotor speed on the vane-reset flow reduction relationship was previously discussed in reference 9.
Figure 9. Comparison of calculated to experimental performance data for the 347-m/sec-design-speed single-stage compressor of reference 6 at various inlet guide vane setting angles.

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

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.
Rotor inlet tip reference design speed, \( U_{td} \), m/sec

Symbols denote experimental data
Curves denote calculations

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.

(a) Design speed.

(b) 80 Percent of design 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.

\( A \)  \hspace{1cm} \text{annulus area, m}^2

\( C_p \)  \hspace{1cm} \text{specific heat at constant pressure, J/kg K}

\( C_1, \ldots, C_6 \)  \hspace{1cm} \text{coefficients for } C_p \text{ polynomial, } JK^{-1}/kg \ldots JK^{-5}/kg

\( D_f \)  \hspace{1cm} \text{diffusion factor}

\( i \)  \hspace{1cm} \text{incidence angle, deg}

\( N \)  \hspace{1cm} \text{rotative speed, rpm}

\( P \)  \hspace{1cm} \text{total pressure, N/m}^2

\( Pr \)  \hspace{1cm} \text{pressure ratio}

\( R \)  \hspace{1cm} \text{gas constant, J/kg K}

\( T \)  \hspace{1cm} \text{total temperature, K}

\( Tr \)  \hspace{1cm} \text{temperature ratio}

\( t \)  \hspace{1cm} \text{static temperature, K}

\( U \)  \hspace{1cm} \text{wheel speed, m/sec}

\( V \)  \hspace{1cm} \text{velocity, m/sec}

\( W \)  \hspace{1cm} \text{flow, kg/sec}

\( \beta \)  \hspace{1cm} \text{flow angle, deg}

\( \gamma \)  \hspace{1cm} \text{ratio of specific heats}

\( \gamma_0 \)  \hspace{1cm} \text{blade setting angle}

\( \Delta\gamma_0 \)  \hspace{1cm} \text{blade reset}

\( \delta \)  \hspace{1cm} \text{deviation angle, deg}

\( \eta_{ad} \)  \hspace{1cm} \text{adiabatic efficiency}

\( \kappa \)  \hspace{1cm} \text{blade metal angle, deg}

\( \rho \)  \hspace{1cm} \text{static density, kg/m}^3
\( c \) \hspace{1cm} \text{blade solidity}

\( \varphi \) \hspace{1cm} \text{flow coefficient}

\( \psi \) \hspace{1cm} \text{pressure coefficient}

Subscripts:

\( c \) \hspace{1cm} \text{choke}

\( d \) \hspace{1cm} \text{design condition}

\( H \) \hspace{1cm} \text{highest value}

\( h \) \hspace{1cm} \text{hub}

\( i \) \hspace{1cm} \text{indicates } \varphi, N, \text{or } \sigma_0 \text{ subscript}

\( L \) \hspace{1cm} \text{lowest value}

\( M \) \hspace{1cm} \text{meanline}

\( N \) \hspace{1cm} \text{speed}

\( R \) \hspace{1cm} \text{rotor}

\( S \) \hspace{1cm} \text{stator}

\( s \) \hspace{1cm} \text{stall}

\( T \) \hspace{1cm} \text{tangential}

\( t \) \hspace{1cm} \text{tip}

\( Z \) \hspace{1cm} \text{axial}

\( \varphi \) \hspace{1cm} \text{flow coefficient}

2 \hspace{1cm} \text{rotor inlet}

3 \hspace{1cm} \text{rotor outlet}

Superscript:

( )' \hspace{1cm} \text{relative to rotor}
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

---

**Diagram:**

Start

MAIN Call CSINPT

CSINPT Read and write input data

MAIN Calculate meanline U, R, etc.

CSPREF Calculate design stage parameters

Are stage θ, d input at design speed?

No

Are stage θ input at design speed?

Yes

No

CSETA Calculate stage θ, d versus θ at design speed

CSPSI Calculate stage θ, d versus θ at design speed

Option to alter rotor deviation for off-design speed

CSPSD Update C₀, and θ for each stage

Should θ be altered for off-design speed?

Yes

CSPAN Calculate stage d and θ values with reset

Is there blade reset?

No

Yes

CPS Update C₀ and θ for each stage

Option to alter rotor deviation for off-design speed

MAIN Write design stage parameters and tables of stage characteristics at selected speeds

Option to alter stage θ values at off-design speeds

CSPUPT Calculate and write stage and compressor performance at selected speeds

CPS Update C₀ and θ for each stage

End
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

\[
R_{2M} = \left( \frac{R_{2T}^2 - A_2^2}{2\pi} \right)^{1/2} 
\]

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

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 \( \psi_d \), pressure coefficient \( \psi_p \), and adiabatic efficiency \( \eta_{ad,d} \) for each stage from the following general expressions:

\[
\psi = \frac{V_{Z2M}}{U_{ZT}} 
\]

\[
\psi = \frac{C_p \eta_{ad}(T_3 - T_2)}{U_3^2} 
\]

\[
\eta_{ad} = \frac{p_3(\gamma-1)/\gamma - 1}{\gamma r - 1} 
\]

The values of \( C_p \) and \( \gamma \) 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 \( \eta_{ad}(\psi) \) at design speed is not input, MAIN calls subroutine CSETA to obtain \( \eta_{ad}(\psi) \) for the stage at design speed. If the stage characteristic \( \psi(\psi) \) at design speed is not input, MAIN calls subroutine CSPSI to obtain \( \psi(\psi) \) 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 \( \psi(\psi) \) affected by the reset. Within MAIN there is an optional calculation that alters the flow coefficient \( \psi \) 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 \( \psi, \psi, \) and \( \eta_{ad} \) and specified flow angles, (2) changes in design values of stage \( \psi \) and \( \psi \) because of blade reset, and (3) tabulated stage characteristics of \( \psi(\psi) \)
and $\eta_{ad}(\phi)$ at specified speeds. These stage characteristics are used to calculate the compressor performance map.

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

Subroutine CSINPT

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

For input of design stage performance there is an option of either of the following inputs: (1) stage pressure ratio $Pr$ and adiabatic efficiency $\eta_{ad}$, or (2) stage characteristics, which consist of pressure coefficient versus flow coefficient $\psi(\phi)$ and adiabatic efficiency versus flow coefficient $\eta_{ad}(\phi)$. 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 $B_{2M}$, $W$, $N$, and $A_2$, calculate by iteration (with $C_p$ and $\gamma$ functions of $T_2$) the design values for $V_{Z2M}$ and $\phi$.
2. If design stage $Pr$ and $\eta_{ad}$ are input, calculate design $\psi$.
3. If stage characteristics $\psi(\phi)$ and $\eta_{ad}(\phi)$ at design speed are input, obtain $\psi$, $\eta_{ad}$, and $Pr$ by linear interpolation.
4. Calculate $B_{2M}$ 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

$$V_{T3M} = \frac{1}{U_{3M}} [C_p(T_3 - T_2) + \dot{U}_{2M}V_{T2M}]$$ (B6)
and \( C_p \) and \( \gamma \) functions of \( t_3 \).

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

\[
i_{MR} = \beta_{2M} - \kappa_{2MR} \tag{B7}
\]
\[
i_{MS} = \beta_{3M} - \kappa_{2MS} \tag{B8}
\]
\[
D_{fR} = 1 - \frac{V_{3M} + R_{2M}V_{T2M}}{V_{2M}} \frac{R_{3M}V_{T3M} - R_{2M}V_{T2M}}{(R_{3M} + R_{2M})c_{RM}V_{2M}} \tag{B9}
\]

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

Subroutine CPF

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

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

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

\[
\gamma = \frac{C_p}{C_p - R} \tag{B11}
\]

CPF also calculates various other functions of \( \gamma \) used by the calling subroutines for the flow calculations.

Subroutine CSETA

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

1. A curve is generated for \( n_{ad}(\phi) \) as depicted in figure 15. This curve consists of two parabolas. The first parabola extends from the minimum flow (stall) coefficient \( \phi_s \) to the design flow coefficient \( \phi_d \). The second parabola extends from the design flow coefficient \( \phi_d \) to the maximum flow (choke) coefficient \( \phi_c \).

2. For each stage the generated curve for \( n_{ad}(\phi) \) has the properties:
Figure 15. - Properties of curve fit for stage adiabatic efficiency as a function of stage flow coefficient generated by subroutine CSETA.

\[
\begin{align*}
\frac{d\eta_{ad}}{d\phi} &= 0 \quad \text{at } \phi = \phi_d \\
\eta_{ad} &= \eta_{ad,d} \quad \text{at } \phi = \phi_d \\
\eta_{ad} &= 0.9 \eta_{ad,d} \quad \text{at } \phi = \phi_s \\
\eta_{ad} &= 0.8 \eta_{ad,d} \quad \text{at } \phi = \phi_c
\end{align*}
\]

The peak \( \eta_{ad} \) 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 \( \eta_{ad} \) value for every input \( \phi \) 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 \( \psi \) is 0.0). CSPSI obtains values of \( \psi \) for each stage at the various
input \( \varphi \) for the stage. The following calculation procedure is used within subroutine CSPSI:

1. Assume design values calculated in CSPREF for \( \beta_{2Md} \), \( \beta_{2Md} \), \( \varphi_d \), and \( \beta_{3Md} \).
2. For an input \( \varphi \), calculate \( V_{Z2M} \) from
   \[
   V_{Z2M} = V_{Z2Md} \left( \frac{\varphi}{\varphi_d} \right)
   \]  
   (B12)
   calculate the flow \( W \) corresponding to the input \( \varphi \) 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
   \[
   V_{T3M} = U_{3M} - V_{Z3M} \tan \beta_{3M}
   \]
   (B13)
   and \( T_3 - T_2 \) obtained from
   \[
   T_3 - T_2 = \frac{1}{C_p} \left( U_{3M} V_{T3M} - U_{2M} V_{T2M} \right)
   \]
   (B14)
   the pressure coefficient corresponding to the input \( \varphi \) from
   \[
   \psi = \frac{C_p \eta_{ad}(T_3 - T_2)}{U_{3T}^2}
   \]
   (B15)
   with the following conditions:
   1. \( W_3 = W_2 \)
   2. \( C_p \) and \( \varphi \) are functions of \( t_3 \) obtained from subroutine CPF
   3. \( \beta_{3M} = \beta_{3Md} + \Delta \beta_{3M} \), where \( \Delta \beta_{3M} \) is obtained from an option to alter rotor deviation angle for off-design \( \varphi \) values.
   These calculations within CSPSI are repeated for every input \( \varphi \) 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 \( \psi \) 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 \( \beta_{2Md} \), \( \beta_{2Md} \), \( \varphi_d \), and \( \beta_{3Md} \).
2. For an input off-design rotative speed \( N \), calculate \( V_{Z2M} \) from
and the flow corresponding to the input \( N \) from

\[
W_2 = \rho \bar{z} A_2 V_2 M
\]

(3) For this value of \( W_2 \) and the off-design rotative speed \( N \), with \( V_{13M} \) obtained from

\[
V_{13M} = U_{13M}(N_d) - V_{Z3M} \tan B_{3M}
\]

and \( T_3 - T_2 \) obtained from

\[
T_3 - T_2 = \frac{1}{C_p} \frac{N}{N_d} (U_{13M}V_{13M} - U_{2M}V_{2M})
\]

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

\[
\Delta \psi_N = \frac{C_p n_{ad, d}(T_3 - T_2)}{(U_{13M} N/N_d)^2} - \psi_d
\]

with the following conditions:

(1) \( W_3 = W_2 \)

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

(3) \( B_{3M} = B_{3M} + \Delta B_{3MN} \), where \( \Delta B_{3MN} \) is obtained from an option to alter the rotor deviation angle for off-design \( N \) values.

These calculations are repeated within CSF'SD for every input \( N \) value for each stage of the compressor. CSPSD changes the pressure coefficient \( \psi \) by an amount \( \Delta \psi_N \) for an off-design part speed \( N \). The overall effect of a typical stage characteristic \( \psi(\psi) \) 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 \( \psi_d \) and the pressure coefficient \( \psi_0 \). A new stage characteristic \( \psi(\psi) \) for the blade reset is calculated as follows:

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

\[
B_{2M} = B_{2Md} + \Delta B_{2M}
\]
Figure 16. Effects of program option to alter pressure coefficient for off-design part speed on a typical stage characteristic: \( \psi \) vs. \( \phi \).

\[
B_{2M} = B_{2M_0} + \Delta B_{2M}
\]

\[
B_{3M} = B_{3M_0} + \Delta B_{3M}
\]

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

\[
V_{Z2M} = \frac{U_{2M}}{\tan B_{2M} + \tan \beta_{2M}}
\]

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

\[
\Delta \psi_{\gamma_0} = \frac{V_{Z2M}}{U_{2M}} - \psi_{\gamma_0}
\]

and the flow from

\[
W_2 = p_e A_e V_{Z2M}
\]

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

\[
\Delta \psi_{\gamma} = \frac{C_p \eta_{ad, d}(T_3 - T_2)}{U_{3T}^2} - \psi_{\gamma_0}
\]

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with the following conditions:

1. \( W_3 = W_2 \)
2. \( C_p \) and \( \gamma \) are functions of \( t_3 \) and obtained from subroutine CPF.
3. \( \delta'_3 = \delta'_3 + \Delta \delta'_3 \gamma \), where \( \Delta \delta'_3 \gamma \) is obtained from an option to alter rotor deviation angle because of blade reset.

and where \( V_{T3M} \) is obtained from

\[
V_{T3M} = U_{3M} - V_{2M} \tan \delta'_3
\]

and \( T_3 - T_2 \) is obtained from

\[
T_3 - T_2 = \frac{1}{C_p} \left[ U_{3M}V_{T3M} - U_{2M}V_{T2M} \right]
\]

These calculations are repeated within CSPAN for each stage of the compressor. For an example of how CSPAN alters the stage characteristic \( \psi(\psi) \) 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, \( \Delta \beta_2 = \Delta \gamma_0 \) and \( \Delta \delta'_2 \) and \( \Delta \delta'_3 \) 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 \( \psi \) and the range of the flow coefficient \( \psi \) are both altered by the upstream stator reset \( \Delta \gamma_0 \).

Subroutine CSOUPT

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

1. Read input, which consists of speed fraction \( N/N_d \), lowest flow \( W_L \), flow increment \( \Delta W \), and highest flow \( W_H \). Calculations are performed for the input speed fraction \( N/N_d \) at flow increments \( \Delta W \) 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 \( \gamma \) are functions of \( t \) obtained from CPF.
3. Calculate the stage flow coefficient \( \psi = V_{2M}/U_{2T} \). Normally this calculated \( \psi \) will be within the range of \( \psi \) for this stage. Then, calculate by linear interpolation, from the stage characteristics for this stage, the stage pressure rise coefficient \( \psi \) and stage adiabatic efficiency. However, if the calculated \( \psi \) for this stage is not within the range of \( \psi \) for this stage, CSOUPT is coded to stop calculations for this flow \( W \) and to print a message with the calculated \( \psi \) 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 \( \gamma \) are functions of \( t \) obtained from CPF.
(6) Using the preceding calculated meanline velocity diagrams calculate (1) rotor and stator incidence angles and (2) rotor diffusion factor.

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

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

Option to Alter \( \psi \) Value for Off-Design Speeds

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

\[
\psi_N = \psi + \left(1 - \frac{N}{N_d}\right) \quad (B30)
\]

where

\[
\Delta \psi_N = \psi_N - \psi \quad (B31)
\]

and

![Figure 17. Effects of program option to alter flow coefficient for off-design part speed on a typical stage characteristic \( \psi(\varphi) \).](image)

Figure 17. Effects of program option to alter flow coefficient for off-design part speed on a typical stage characteristic \( \psi(\varphi) \).
\[ \varphi_N = \varphi \left( \frac{\varphi}{\varphi_d} \right)^{N_d/N} \]  

(B32)

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

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

(B33)

Equation (B33) is coded into MAIN to alter \( \varphi \) 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 \( \delta_R \) for off-design values of the flow coefficient \( \varphi \), rotative speed \( N \), and blade setting angle \( \gamma_0 \), 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 \( \Delta\delta_R \), \( \Delta\delta_RN \), 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 \( \beta_3M \) is related to the deviation angle \( \delta_R \) by

\[ \delta_R = \beta_3M - \kappa_3M \]  

(B34)

So for a fixed rotor exit blade metal angle \( \kappa_3M \)

---

Figure 18. - Angles associated with a typical rotor meanline blade element.
\[ \Delta \delta_R = \Delta \delta_{3M} \]  

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

\[ \Delta \delta_{3M_i} = -10 \left[ \frac{V'_{3M_i}}{V_{2M_i}} - \frac{V'_{3M_i}}{V_{2M_i}^d} \right] \]  

where the subscript \( i \) represents \( \psi, N, \) and \( \gamma_0 \) for subroutines CSPSI, CSPSD, and CSPAN, respectively. The design relative velocity ratio \( \left( \frac{V'_{3M}}{V'_{2M}} \right)_d \) 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 for the example program output listing given in this appendix.

**Stage Stacking Program**

```
** NASA TWO STAGE FAN, LOW R1 AR, TP-1493 **

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<th>SPEEDS</th>
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<th>TO IN</th>
<th>MOL WT</th>
<th>DES RPM</th>
<th>DES FLOW</th>
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<th>CB2M</th>
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PCTSPD | ETARAT |
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The page is of poor quality.
### INPUT DESIGN CHARACTERISTICS FOR STAGE 2

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**INLET FLOW = 33.000**

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For Stage 2, Computed PHII 15, Computed choke 0.3470.

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**PERCENT SPEED = 0.800**  
**INLET FLOW = 29.000**

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**INLET FLOW = 25.000**

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**PERCENT SPEED = 0.800**  
**INLET FLOW = 25.500**

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**PERCENT SPEED = 0.800**  
**INLET FLOW = 26.000**

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**PERCENT SPEED = 0.800**  
**INLET FLOW = 27.000**

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For Stage 2, computed PHI is 0.5505 choke.

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For Stage 2, computed PHI is 0.3618 stall.

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Percent Speed = 0.700

Inlet Flow = 18.000

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Percent Speed = 0.700

Inlet Flow = 18.500

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Percent Speed = 0.700

Inlet Flow = 19.000

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Percent Speed = 0.700

Inlet Flow = 19.500

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**FOR STAGE 2, COMPUTED PHI IS 0.3461 STALL**

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### Percent Speed = 0.500

#### Inlet Flow = 15.000

<table>
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<tr>
<th>Stage</th>
<th>PHI</th>
<th>PSI</th>
<th>Tau</th>
<th>ETA</th>
<th>PR</th>
<th>C-ETA</th>
<th>C-PR</th>
<th>STG-Flow</th>
<th>R-INCm</th>
<th>R-DFM</th>
<th>S-INCm</th>
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<td>3.91</td>
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### Percent Speed = 0.500

#### Inlet Flow = 15.500

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<th>PR</th>
<th>C-ETA</th>
<th>C-PR</th>
<th>STG-Flow</th>
<th>R-INCm</th>
<th>R-DFM</th>
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### Percent Speed = 0.500

#### Inlet Flow = 16.000

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<th>Tau</th>
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<th>PR</th>
<th>C-ETA</th>
<th>C-PR</th>
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<th>R-DFM</th>
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### Percent Speed = 0.500

#### Inlet Flow = 16.500

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<th>PSI</th>
<th>Tau</th>
<th>ETA</th>
<th>PR</th>
<th>C-ETA</th>
<th>C-PR</th>
<th>STG-Flow</th>
<th>R-INCm</th>
<th>R-DFM</th>
<th>S-INCm</th>
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### Percent Speed = 0.500

#### Inlet Flow = 17.000

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<th>Stage</th>
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<th>PSI</th>
<th>Tau</th>
<th>ETA</th>
<th>PR</th>
<th>C-ETA</th>
<th>C-PR</th>
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<th>R-INCm</th>
<th>R-DFM</th>
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### Percent Speed = 0.500

#### Inlet Flow = 17.500

<table>
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<tr>
<th>Stage</th>
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<th>PSI</th>
<th>Tau</th>
<th>ETA</th>
<th>PR</th>
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<td>S-INCMM</td>
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<td>0.1205</td>
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PERCENT SPEED = 0.500
INLET FLOW = 18.000
STGSTK - A computer code for predicting multistage axial flow compressor performance using a meanline stage stacking method.

This main routine calls all major subroutines and writes

Intermediate output

Calculate fixed parameters

Write intermediate output
006800 XINCMM/((5X,15,5F10.4,4F10.2,F10.4,F10.2))
006900 DO 52 I=1,NSTAGE
007000 52 BET2M(I,1) = BET2M(I,1) / RAD
007100 BET3M(R,1) = BET3M(R,1) / RAD
007200 WRITE (6,2120)
007300 WRITE (6,2052) (NSTAGE(I),I=1,12), (PCTSPD(J), (DPSIS(I,J), I=1,12-J, J=1,NSPE)
007400 2052 FORMAT (20X,27H DPSIS(STAGE,PCTSPD)
007500 18H PCT SPD,12(15,SX)//(13FB.q))
007600 DO 52 I=1,NSTAGE
007700 DO 52 J=1,NSPE
007800 DO 60 K=1,NPTS
007900 PHI(I,J,K) = PHIDES(I,J,K) ÷ DPHIA(1)
008000 0008100 C *** OPTION TO ALTER FLOW COEFFICIENT FOR OFF DESIGN SPEEDS
008100 IF (SPDPHI.EQ.1.0) PHI(I,J,K) = PHI(I,J,K)W(I.O + ((PHI(I,J,K)/PHI-
008200 XREF(I))ww(I.O/POTSPD(J)) - I.O)WI.OWABS(I.O - PCTSPD(J)))
008300 PSI(I,J,K) = PSIDES(I,J,K) ÷ DPSIA(1) + DPSIS(I,J)
008400 ETA(I,J,K) = ETADES(I,J,K)*ETARAT(J) +
008500 0008600 60 CONTINUE
008700 DO 70 I=1,NSTAGE
008800 WRITE (6,2120).
008900 WRITE(6,2060) NSTAGE(1),(PCTSPD(J),J=1,6),((PHICI,J,K),PSI(I,J,K),
009000 IETA(I,J,K),J=1,6),K=I,NPT$)
009100 IF(NSPE.LT.4) GO TO 70
009200 WRITE (6,2120)
009300 WRITE(6,2060) NSTAGE(1),(PCTSPD(J),J=7,9),((PHI(I,J,K),PSI(I,J,K),
009400 IETA(I,J,K),J=7,9),K=I,NPTS)
009500 70 CONTINUE
009600 2060 FORMAT (20X,5H COMPUTED CHARACTERISTICS FOR STAGE NO.,13//3(SX,
009700 IFIO.5,10H PCT 5PD ,SX)//5(50H PHI PSI ETA))/(9FI-
009800 20._))
009900 CALL CSOUPT
010000 GO TO I0
010100 2120 FORMAT (1HO////)
010200 END
010300
001000 SUBROUTINE CSINPT
001100 COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RTS(i2),
001200 XPHIS(12,9,8), ETADES(12,9,8), PHI(12,9,8), ETA(12,9-
001300 X), DPHIA(12), DPHIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
001400 XBET2M(12,9), BLEED(12,9), TT(13), PR(12), TR(12), PRO(12),
001500 X, AREA3(12), RM2(12), RM3(12), UT2(12), UM2(12), UM3(12) -
001600 X, BET2MR(12,9), DPSIS(12,9), RSOLM(12), RK2M(12), CB2MR(12)-
001700 X, PHIFIX(12), DPHEF(12), CPREF(12), GSFREF(12), ETA1NP(12)
001800 X, FCLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3MR-
001900 X, DB3MRR(12,9), DB3MR(12,8)
002100 X, NSPE, NPTS, PD, TO, DESRPM, DESFLO, UNITS
002200 WRITE(6,2120)
002300 WRITE(6,2000) (TITLE(1),I=1,18)
002400 READ (5,1000,END=999) (TITLE(I),I=1,18)
002500 10 FORMAT (30H PHI PSI ETA )/(9F1-
002600 20.4))
002700 CALL CSOUPT
002800 GO TO 10
002900 2120 FORMAT (1HO////)
003000 END

52
ORIGINAL PAGE IS OF POOR QUALITY

```
0003200  2010 FORMAT (80H Stages Speeds Points Po In To In Mo-
0003400 1le Wt Des Rpm Des Flow//(8F10.3)///)
0003500 WRITE (6,2011) Spdp3i, Spdpphi, Drdevn, Drdevp, units
0003600 2011 FORMAT (60H Spdp3i Spdpphi Drdevn Drdevp units
0003700 Xunits//(6F10.1)///)
0003800 READ (5,1020) (Cpc0(I),I=1,6)
0003900 WRITE (6,2020) (Cpc0(I),I=1,6)
000400 1020 FORMAT (3E20.8)
000410 2020 FORMAT (072H Cpc0(1) Cpc0(2) Cpc0(3) Cpc0(4) C-
000420 0 IPCO(5) IPCO(6)//(6E12.5)///)
000430 0 NSTA = STAGEN
000440 0 NSPE = SpeedN
000450 0 NPTS = ChaptS
000460 READ (5,1010) (Rt2(I),I=1,Nsta)
000470 READ (5,1010) (Rt3(I),I=1,Nsta)
000480 READ (5,1010) (Rt3(I),I=1,Nsta)
000490 READ (5,1010) (Rt3(I),I=1,Nsta)
000500 READ (5,1010) (Bet2m(I,1),I=1,Nsta)
000510 READ (5,1010) (Cb2m(I), I=1,Nsta)
000520 READ (5,1010) (Cb2mri(I), I=1,Nsta)
000530 READ (5,1010) (Cb3mri, I=1,Nsta)
000540 READ (5,1010) (Rk2m (I), I=1,Nsta)
000550 READ (5,1010) (Rsolm(I), I=1,Nsta)
000560 READ (5,1010) (Sk2m(I),I=1,Nsta)
000570 READ (5,1010) (Pr(I),I=1,Nsta)
000580 READ (5,1010) (Etainp(I),I=1,Nsta)
000590 READ (5,1010) (Xctb2m),I=1,Nsta)
000600 READ (5,1010) (Xctb2mr(I), CB3mri(I), Ra2mri, Rsolm, 10H -
000610 2030 FORMAT (110H Stage Rt2 Rh2, Rt3 Rh3 -
000620 X Bet2m CB2m CB2mr CB3mri RK2m Rsolm, 10H -
000630 X5K2m//(5X,I5,4F10.4,5F10.2, F10.4, F10.2))
000640 WRITE (6,2120)
000650 WRITE (6,2031) (Nstage(I), Pr(I), Etainp(I), I=1,NstA)
000660 2031 FORMAT (30H Stage Pr EtaInp/(5x,15,2F10.4))
000670 READ (5,1010) (Ptcspd(J),J=1,NSPE)
000680 2120 FORMAT (1Ho///)
000690 READ (5,1010) (Etarat(J), J=1,NSPE)
000700 WRITE (6,2120)
000710 WRITE (6,2121) (Pctspd(J), Etarat(J), J=1,NSPE)
000720 2121 FORMAT (20H PCTSPD ETARAT//(2F10.4))
000730 DO 21 1=1,Nsta
000740 READ (5,1010) (Bleed(I,J), J=1,NSPE)
000750 21 CONTINUE
000760 WRITE (6,2120)
000770 WRITE (6,2041) (Nstage(I),I=1,12), (Pctspd(J), (Bleed(I,J), I=1,12-
000780 1), J=1,NSPE)
000790 2041 FORMAT (10X, 27H BLEED(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER-/-
000800 16H PCT SPD, 12(I5,3X)//(13F8.3))
000810 DO 30 I=1,Nsta
000820 READ (5,1010) (Phides(I,1,K),K=1,Npts)
000830 READ (5,1010) (Psides(I,1,K),K=1,Npts)
000840 READ (5,1010) (Etaides(I,1,K),K=1,Npts)
000850 30 CONTINUE
000860 DO 50 I=1,Nsta
000870 WRITE (6,2120)
000880 WRITE (6,2050) Nstage(I), (Pctspd(J), J=1,3), (Phides(I,1,K),Etaides(I,1,J,K),J=1,3), K=1,Npts)
000890 IF (NSPE.LT.4) GO TO 50
000900 WRITE (6,2120)
000910 WRITE (6,2050) Nstage(I), (Pctspd(J), J=4,6), (Phides(I,1,K),Psides(I,1,J,K),J=4,6), K=1,Npts)
000920 IF (NSPE.LT.7) GO TO 50
000930 WRITE (6,2120)
000940 WRITE (6,2050) Nstage(I), (Pctspd(J), J=7,9), (Phides(I,1,J,K),Psides(I,1,J,K),J=7,9), K=1,Npts)
000950 50 CONTINUE
000960 2050 FORMAT (20X, 4H INPUT DESIGN CHARACTERISTICS FOR STAGE- IS///(5X,-
000970 1F10.3,10H PCT SPD .5X///(30H PHIDES PSIDES ETADES)//(9F10-
000980 20.4))
000990 010200 C XXX CHANGE METRIC INPUT INTO ENGLISH UNITS
001000 IF (UNITS.NE.1.0) GO TO 53
```
SUBROUTINE CSPREF
COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X) -
COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS -
X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDP, SPDPHI, DRDEVG, DRDEVN, DRDEV -
COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS -
SUBROUTINE CSPREF CALCULATES PARAMETERS AT DESIGN SPEED
AND FLOW CONDITIONS
SUBROUTINE CSPREF

COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

PARAMETERS AT DESIGN SPEED AND FLOW CONDITIONS

COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

\[ \text{PO} = \text{PO}/0.689476 \]
\[ \text{TO} = \text{TO}/9.0/5.0 \]
\[ \text{DESFLO} = \text{DESFLO}/0.453592 \]
\[ \text{DO} 51 \text{I}=1, \text{NSTA} \]
\[ \text{RT2(I)} = \text{RT2(I)}/2.54 \]
\[ \text{RH2(I)} = \text{RH2(I)}/2.54 \]
\[ \text{RT3(I)} = \text{RT3(I)}/2.54 \]
\[ \text{RH3(I)} = \text{RH3(I)}/2.54 \]
\[ \text{DO} 52 \text{J}=1, \text{NSPE} \]
\[ \text{BLEED(I,J)} = \text{BLEED(I,J)}/0.453592 \]
\[ \text{CONTINUE} \]
\[ \text{RETURN} \]
\[ \text{STOP} \]

SUBROUTINE CSPREF

COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

PARAMETERS AT DESIGN SPEED AND FLOW CONDITIONS

COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

\[ \text{PO} = \text{PO}/0.689476 \]
\[ \text{TO} = \text{TO}/9.0/5.0 \]
\[ \text{DESFLO} = \text{DESFLO}/0.453592 \]
\[ \text{DO} 51 \text{I}=1, \text{NSTA} \]
\[ \text{RT2(I)} = \text{RT2(I)}/2.54 \]
\[ \text{RH2(I)} = \text{RH2(I)}/2.54 \]
\[ \text{RT3(I)} = \text{RT3(I)}/2.54 \]
\[ \text{RH3(I)} = \text{RH3(I)}/2.54 \]
\[ \text{DO} 52 \text{J}=1, \text{NSPE} \]
\[ \text{BLEED(I,J)} = \text{BLEED(I,J)}/0.453592 \]
\[ \text{CONTINUE} \]
\[ \text{RETURN} \]
\[ \text{STOP} \]

SUBROUTINE CSPREF

COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

PARAMETERS AT DESIGN SPEED AND FLOW CONDITIONS

COMMON /VECTOR/ CPC0(6), TITLE(18), RT2(12), RH2(12), RT3(12), -
XRH3(12), PHiREF(12), PSIREF(12), ETARE(12), PHIDES(12,9,8), -
XPSIDES(12,9,8), ETADES(12,9,8), RK2M(12), CB2MR(12), CB3MR( -
X), XI(12), CB3MR(12), RTHCM(12), BET2HR(12,9), BLEED(12,9), -
X)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, G2J, RPMRAD, NSTA-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

\[ \text{PO} = \text{PO}/0.689476 \]
\[ \text{TO} = \text{TO}/9.0/5.0 \]
\[ \text{DESFLO} = \text{DESFLO}/0.453592 \]
\[ \text{DO} 51 \text{I}=1, \text{NSTA} \]
\[ \text{RT2(I)} = \text{RT2(I)}/2.54 \]
\[ \text{RH2(I)} = \text{RH2(I)}/2.54 \]
\[ \text{RT3(I)} = \text{RT3(I)}/2.54 \]
\[ \text{RH3(I)} = \text{RH3(I)}/2.54 \]
\[ \text{DO} 52 \text{J}=1, \text{NSPE} \]
\[ \text{BLEED(I,J)} = \text{BLEED(I,J)}/0.453592 \]
\[ \text{CONTINUE} \]
\[ \text{RETURN} \]
\[ \text{STOP} \]
FUNCTION CPF(TS)

CPF = CPCO(1) + (CPCO(2) + (CPCO(3) + (CPCO(4) + (CPCO(5) + CPCO(6))*TS)/TS)*TS

GAMMA = CPF/(CPF - DCP)

GMI = GAMMA - 1.0

GF1 = 1.0/GMI

GF2 = GAMMA/GMI

GF3 = 1.0/GF2

RHO5 = RHOT

CALCULATIONS AT ROTOR OUTLET

81 VZ3M(I,J) = DESFLO/(RHOSWAREA3(I))

V = SQRT(VZ3M(I,J)**2 + VT3M**2)

CP = CPF(TS)

RHOS = RHOST - V3MR/V2MR

CALCULATES SPECIFIC HEAT FROM STATIC

TEMPERATURE USING FIFTH DEGREE POLYNOMIAL

SUBROUTINE CPF(TS)
SUBROUTINE CSETA

SUBROUTINE CSETA GENERATES ADIABATIC EFFICIENCY VERSUS FLOW COEFFICIENT

COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
XPSIDES(12,9,8), ETADES(12,9,8), PHIDS(12,9,8), PSI(12,9,8), ETA(12,9-
X,8), PHIA1(12), DPHIA(12), DETA(12), NSTATE(12), NCTSPD(9),
XETAO(12), BET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12),
XETADO(12), ETA(12,9), BET3MR(12,9), V22M(12,9), V23M(12,9), AREA2(12),
XR(12,9), RM(12,9), RM3(12,9), UT3(12), U3M(12,9), NSTATE(12),
XET2M(12,9), ETA(12,9), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
X,9), PHIFIX(12), DPHIF(12), CPREF(12), GFIREF(12), ETA(12,9),
XETARAT(9), ETA(12,9), XML(12,9), ETA(12,9), ETA2M(12,9), DB3M(12,9),
XETARAT(9), ETA(12,9), ERM3R(12,9,9), DB3MR(12,9), DB3MRG(12,9),
XETARAT(9), ETA(12,9), ERM3R(12,9,9), DB3MRG(12,9),
THRESH(12,9,9), DB3MRP(12,8)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTATE-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

XCPF, GAMMA, GMI, GF1, GF2, GF3, SPDP1, SPDPHI, DRDEVG, DRDEVN, DRDEV

J = I

DO 10 I=1,NSTA

PSMPRS = (PHIDES(I,J,K) - PHIREF(I))**2

PCMPRS = (PHIDES(I,J,K) - PHIREF(I))**2

AS = -0.1*ETAREF(I)/PSMPRS

AC = -0.2*ETAREF(I)/PCMPRS

BC = -0.5*PHIDES(I,K)

CS = ETAREF(I) + AS*PHIDES(I,K)

CC = ETAREF(I) + AC*PHIDES(I,K)

DO 20 K=1,NPTS

IF(PHIDES(I,J,K) - PHIREF(I)) Ii,12,13

ASW = (PHIDES(I,J,K) - PHIREF(I))**2

PSMPRS = (PHIDES(I,J,K) - PHIREF(I))**2

DO 20 K=1,NPTS

IF(PHIDES(I,J,K) - PHIREF(I)) Ii,12,13

ETADESI,J,K) = (AS*PHIDES(I,J,K) + BS)*PHIDES(I,J,K) + CS

10 ETADESI,J,K) = ETAREF(I)

GO TO 20

12 ETADESI,J,K) = ETAREF(I)

GO TO 20

13 ETADESI,J,K) = AC*PHIDES(I,J,K) + BC)*PHIDES(I,J,K) + CC

20 CONTINUE

10 CONTINUE

RETURN

END

SUBROUTINE CSPSI

SUBROUTINE CSPSI CALCULATES PRESSURE COEFFICIENTS FOR INPUT FLOW COEFFICIENT

COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
XPSIDES(12,9,8), ETADES(12,9,8), PHIDS(12,9,8), PSI(12,9,8), ETA(12,9-
X,8), PHIA1(12), DPHIA(12), DETA(12), NSTATE(12), NCTSPD(9),
XETAO(12), BET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12),
XETADO(12), ETA(12,9), BET3MR(12,9), V22M(12,9), V23M(12,9), AREA2(12),
XR(12,9), RM(12,9), RM3(12,9), UT3(12), U3M(12,9), NSTATE(12),
XET2M(12,9), ETA(12,9), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
X,9), PHIFIX(12), DPHIF(12), CPREF(12), GFIREF(12), ETA(12,9),
XETARAT(9), ETA(12,9), XML(12,9), ETA(12,9), ETA2M(12,9), DB3M(12,9),
XETARAT(9), ETA(12,9), ERM3R(12,9,9), DB3MR(12,9), DB3MRG(12,9),
XETARAT(9), ETA(12,9), ERM3R(12,9,9), DB3MRG(12,9),
THRESH(12,9,9), DB3MRP(12,8)

COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTATE-
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS

XCPF, GAMMA, GMI, GF1, GF2, GF3, SPDP1, SPDPHI, DRDEVG, DRDEVN, DRDEV

J = I

DO 10 I=1,NSTA

PSMPRS = (PHIDES(I,J) - PHIREF(I))**2

PCMPRS = (PHIDES(I,J) - PHIREF(I))**2

AS = -0.1*ETAREF(I)/PSMPRS

AC = -0.2*ETAREF(I)/PCMPRS

BC = -0.5*PHIDES(I,K)

CS = ETAREF(I) + AS*PHIDES(I,K)

CC = ETAREF(I) + AC*PHIDES(I,K)

DO 20 K=1,NPTS

IF(PHIDES(I,J,K) - PHIREF(I)) Ii,12,13

ASW = (PHIDES(I,J,K) - PHIREF(I))**2

PSMPRS = (PHIDES(I,J,K) - PHIREF(I))**2

DO 20 K=1,NPTS

IF(PHIDES(I,J,K) - PHIREF(I)) Ii,12,13

ETADESI,J,K) = (AS*PHIDES(I,J,K) + BS)*PHIDES(I,J,K) + CS

10 ETADESI,J,K) = ETAREF(I)

GO TO 20

12 ETADESI,J,K) = ETAREF(I)

GO TO 20

13 ETADESI,J,K) = AC*PHIDES(I,J,K) + BC)*PHIDES(I,J,K) + CC

20 CONTINUE

10 CONTINUE

RETURN

END
0014000 TT(I) = TO
0014100 PT(I) = PO
0014200 10 VZ3M(I,J) = VZ3MI,J)*PHIDES(I,J,K)/PHIREF(I)
0014300 VZ2M = VZ3M(I,J)*COS(DB2MR(I,J))
0014400 BET3MI,J) = DB3MR(I,J)
0014500 VT2M = VZ3M(I,J)*TAN(DB2MR(I,J))
0014600 V2S = VT2M**2 + VZ3M(I,J)**2
0014700 RHOT = PT(I)/TT(I)/RG
0014800 RHOS = RHOT*DB2M(I,J)
0014900 CESFLC = RHOS*AREA2(I)*VZ3M(I,J)
0015000 TS = TT(I)
0015100 ID = 0
0015200 11 VZ3M = UM3(I,J) - VZ3M(I,J)*TAN(BET3MR(I,J))
0015300 CP = CP(TS)
0015400 DT = (UM3(I,J) - UM2(I,J))/GJ*CP
0015500 PTA3 = PT(I) + ETADES(I,J,K)*TRA - 1.0)*G2J
0015600 TTA3 = (PTA3 + TT(I))/TT(I)
0015700 ID = ID + 1
0015800 VZ3HR = VZ3H(I,J)/COS(BET3MR(I,J))
0015900 C = OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN FLOW
0016000 IF (DRDEVP.EQ.1.0)
0016100 XDB3MRP(I,K) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
0016200 BET3MR(I,J) = DB3MR(I,J) + DB3MRP(I,K)
0016300 IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 13
0016400 13 PSIDES(I,J,K) = GJ*CP*DI*KETADES(I,J,K)/UT3(I)**2
0016500 DV3DV2 = V3DV2R(I)
0016600 FV3DV2 = V3MR/V2MR
0016700 I = I + 1
0016800 IF (I.LE.NSTA) GO TO 10
0016900 CONTINUE
0017000 RETURN
0017100 END

0018300 COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
0018400 XRH3(12), PHIREF(12), P51REF(12), ETAREF(12), PHIDES(12,9,8),
0018500 XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), ETA(12,9,
0018600 X, DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
0018700 XET2M(12,9). BLEED(12,9), TI(13), PR(13), IR(12)
0018800 XTR(12), ETA0(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(I)
0018900 X, AREA(12), RM3(12), RM2(12), UT2(12), UT3(12), UM2(12), UM3(12)
0019000 X, BET3MR(12,9), DPSIA(12,9), RSOLM(12), RKCM(12), CB2M(12), CB3M(12,
0019100 X, RSOL(12), RDKM(12), SK2M(12), SINCM(12), BET3MR(12-
0019200 X, 9), PHFIX(12), DPHIF(12), CPREF(12), GFIREF(I), ETADES(12,9)
0019300 X, FLOCAL(12,9), ETAARAT(9), DB2M(12,9), DB3M(12,9), DB3MR(12-
0019400 X, DB3MR(12,9), DB3MR(12,8)
0019500 COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
0019600 X, NPS, NTS, PT0. TS, DESRPM, DESFLO, UNITS
0019700 X, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSTI, SPDPHII, DRDEVG, DRDEVN, DRDEV,
0019800 DN 100 J = 1.NSPE
0019900 10 VZ3M(I,J) = VZ3M(I,J)*PCTSPD(J)
0020000 V2MR = VZ3M(I,J)/COS(DB2MR(I,J))
0020100 AFTMR(I,J) = DB3MR(I,J)
ID = 0
V2M = VZ2M(I,1)*PC1PSD(J)*TAN(DB2M(I,1))
VZ2 = VZ2M*2 + VZ3M(I,J)*2
RHOT = PT(I)/(TT(I)*RG)
RHOS = RHOT*(1.0 - VZ2/G2J*CPREF(I)*TT(I))**GF1REF(I)
DESLC = RHOS*AREAE2(I)*VZ3M(I,J)
TS = TT(I)
11 V3M = UMS3(I)*PC1PSD(J) - VZ3M(I,J)*TAN(BET3MR(I,J))
CP = CPFTS
DT = (UM3(I)*VT3M - UM2(I)*VT.M)/(GJ*CP)*PC1PSD(J)
TRA = (DT + TT(I))/TT(I)
PTA5 = PT(I)/(UT2(1)*PC1PSD(J)) + ETAREF(I)*TR - 1.0)**GF2
TTA3 = DT + TT(I)
RHO5 = RIIOTW(I,0 - V3S/(G2J*CPWTTA3))**GF1
W3S = VT3DW_2 + VZ3M(I,J)W_2
RHOS = RIIOTW(I,0 - V3S/(G2J*CPWTTA3))**GF1
TS = TT(I)
IX
VT3M = UD13(I)*PC1PSD(J) - VZ3M(I,J)W(TAN(BET3MR(I,J))
CP : CPF(T5)
DT = (UH3(I)_VT3M - UM2(i)_VT3_)/(GJ*CP)WPC1PSD(J)
TRA = (DT + TT(1))/TT(I)
PTA5 = PT(I)/(I.0 + ETAREF(I)W(TRA - 1.0))**GF2
TTA3 = DT + TT(1)
RHO5 = PTA3/(TTA3_RG)
V3S = VT3HW_2 + VZ3M(I,J)W_2
RHOS = RIIOTW(I,0 - V3S/(G2J*CPWTTA3))**GF1
TS = TT(I)
IF (I.NE.I) GO TO 12
DVZ3M = VZ3M(I,J)
12 CONTINUE
ID = ID + 1
VZ3M(I,J) = DESFLC/RHOS*AREA3(I)
V3DIR = VZ3M(I,J)/COS(BET3HR(I,J))
IF (DRDEVN.EQ.1.0)
XDB31'IRN(I,J) -(IO.O0/RAD)*(V3HR/V2MR - V3DV2R(I))
BET3NR(I,J) = DB3MR(I,I) + DB3rIRN(I,J)
IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 11
DPSIS(I,J) = GJ*CP*ETAREF(I)/UT3(I)*PC1PSD(J)**GF2 - PSIREF(I)
DPSIS(I,J) = DPSIS(I,J) - DPSIS(I,I)
IF (I.LE.NSTA) GO TO 10
100 CONTINUE
RETURN
END

SUBROUTINE CSAN
BLADE RESET
COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
XRH3(12), PHIRF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
XI3D(12,9,8), ETADES(12,9,8), PHIC(12,9,8), PSI(12,9,8), ETA(12,9,8),
X8, DPFIH(12), DPSIA(12), DETAI(12), NSTAGE(12), PCTSPD(9),
X8ET2M(12,9), BLEED(12,9), TII(13), PT(13), PR(12), TRC(12), PRO(12),
XTRD(12), ETAQ(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12),
X, AREA3(12), RM3(12), UT2(12), UT3(12), UM2(12), UMS(12),
X, BET2MR(12,9), DPSIS(12,9), RPS(12,9), RSK2M(12), CB3MR(12),
X83M(12), CB3HR(12), RINCM(12), RDFM(12), SK2M(12), SINC(12), BET3M(12),
X81000 X8, PHIFIX(12), DPFIH(12), CPREF(12), GFIN1(12), ETAINF(12),
X81000, X, FLOCAL(12,9), ETAAT(9), DB2M(12,9), DB2MR(12,9), DB3MR-
X81000, X812, 83M18(12,9), V3DVR12(12), DB3MRG(12),
X81000, X, DB3MNC12,9), DB3MNC18, DB3MR12,9),
X81640 COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RFMRAD, NSTA-
X81650 X, NSPE, NPS, PD, TO, DESRFM, DESFLD, UNITS
X81660 X8, CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSI, SPDPSI1, DRDEVG, DRDEVW, DRDEVP
X81700 J = 1
X81680 I = 1
X81690 TT(I) = TO
X81700 PT(I) = 0
X81710 90 TS = TT(I)
X81720 DPHA(I) = 0.0
X81730 DPSIA(I) = 0.0
X81740 DETAI(I) = 0.0
X81750 IF(CB2M(I) + CB2MR(I) + CB3MR(I)).EQ.0.00) GO TO 93
X81760 BET2M(I,J) = DB2M(I,J) + CB2M(I)
X81770 BET2MR(I,J) = DB2MR(I,J) + CB2MR(I)
X81780 BET3MR(I,J) = DB3MR(I,J) + CB3MR(I)
X81790 VZ2M(I,J) = UM2(I,J)*TAN(BET2M(I,J)) + TAN(BET2M(I,J))
X81800 VZ3M(I,J) = VZ2M(I,J)*COS(BET2M(I,J))
58
C ** CHANGE IN FLOW COEFFICIENT FOR RESET
  DPHA(I) = VZ2M(I,J)/UT2(I) - PHIREF(I)

C ** CHANGE IN ROTOR DEVIATION ANGLE FOR BLADE RESET
  IF (DRDEVG.EQ.1.0)
    XDB3MRG(I) = -(IO.00/RAD) * V3MR/V2HR - VEDV2R(I)
  BET3MR(I,J) = DB3HR(I,J) + C3MR(I) + DB3MRG(1)

C ** CHANGE IN PRESSURE RISE COEFFICIENT FOR RESET
  DPSIA(I) = GJ * CP * DT/(UT3(I) * UT3(I)) - PSIREF(I)

C ** PERFORMANCE PARAMETERS
  COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),
  X3D(12), PHID(12), PSIFR(12), ETADES(12,9,8), PHIDES(12,9,8), ETA(12,9),
  X(8), DPHA(12), DPSIA(12), ETA(12), NSTAGE(12), PCTSPD(9),
  X(8), DB3MR(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
  XR0(12), ETA0(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12),
  X(12,9), RM3(12), UT3(12), UM2(12), UM3(12),
  X(12,9), DB3MR(12,9), DB3MRG(12,9), DB3MRG(I)
  X(12,9), DB3MRG(12,9), DB3MR(12,9),

C ** COMPUTED OUTPUT DATA
  FORMAT 19H "COMPUTED OUTPUT DATA ("/19H "STAGE"
  DO 82 I = 1, NSTA
    WRITE(6,20) I, VS, ETA, PR, R - DF, S - INCH/
  END
IF (SPEEDF.EQ.PCT$PD(J)) JS=J
CONTINUE

**CALCULATE THE OUTPUT**

I=1

TT(I)= TO
PT(I)= PO

WTFLOW = FLOWIN

RHO$ = PT(I)/TT(I)*RG

TS= TT(I)
RHO$= RHT

WTFLOW = WTFLOW - FLOWIN*BLEED(I,JS)

U$ = UT(I)*SPEEDF

UMM2 = UM2(I)*SPEEDF

UMM3 = UM3(I)*SPEEDF

VZ = WTFLOW/*RHS*AREA2(I))

V= VZ/COS(BET2M(I,I))

CP = CPF$TS)

RHOS = RHT*(1.0-VZ/(G2J*CP*TT(I)))*XGF$1

IF ((VZV).GT.(G2J*CP*TT(I))) GO TO 113

TS= TT(I)*(RHS/RHT)*XGM

U$ = AB5(WCAL-WTFLOW)*0.0.01) GO TO 100

PHIC = VZ/U2

IF (PHIC*1XNE.0.0) PHIC = PHIC + DPHIF(T)

IF(PHIC.LT.PHI(I,JS,1)) GO TO 110

IF(PHIC.GT.PHI(I,JS,NPTS)) GO TO 120

DO 130 K=2,NPTS

IF(PHIC-PHI(I,JS,K)) 1_0,150,130

K= NPTS

160 PSIC=(PSI(I,JS,K)-PSI(I,JS,K-1))/PHIC-PHI(I,JS,K-1)

ETAC=(ETA(I,JS,K)-ETA(I,JS,K-1))/PHIC-PHI(I,JS,K-1)

GO TO 160

150 PSIC= PSI(I,JS,K)

ETAC= ETA(I,JS,K)

160.CONTINUE

PR(I)= (1.0 + PSIC*UM3*U3/ (G3J*CP*TT(I)))*XGF$2

TAU = PSIC/ETAC

TR(I)= 1.0 + (PR(I)*XGF3-1.0)/ETAC

TT(I+I)= TT(I)*XTR(I)

PT(I+I)= PT(I)*XPR(I)

TRD(I)= TT(I+I)/TQ

FRO(I)= PT(I+I)/PO

IF(I,EQ.1) GF3 = GF$3

GF30 = (GF3 + GF35)/2.0

EIA0(I)= (PRO(I)*XGF30 - 1.0)/(TRO(I) - 1.0)

VTZ2M = VZ + TAC(BET2M(I,I))

VRT2MR = UMM2 - VTZ2M

BET2MR(I,JS)= ATAN2(VT2MR.VZ)

RINGC(M(I)= BET2MR(I,JS) X RAD - RK2M(I)

V2M3 = VZ/COS(BET2MR(I,JS))

HO$ = PT(I+1)/(TT(I+1)*XGM)

TS= TT(I+1)

RHO$= RHT

VTZ3M(I,JS)= WTFLOW/*RHS*AREA3(I))

V$ = VTZ3M(I,JS)*XGF + UMM3 *XVT2M/XUMM3

V2M3 = VXZ3M(I,JS)*X2 + V73M*X2

CP = CPF$TS)

RHOS = RHT*(1.0-VZ/(G2J*CP*TT(I)))*XGF$1

IF((VZ).GT.(G2J*CP*TT(I+1))) GO TO 113

TS= TT(I+1) X(RHS/RHT)*XGM

WCAL = RHO$*AREA3(I)*VZ3M(I,JS)

IF(A5(WCAL-WTFLOW)*G.0.01) GO TO 161

BET3M(I,JS)= ATAN2(VT3M.VZ3M(I,JS))

SINC(M(I)= BET3M(I,JS) X RAD - SKCM(I)

V$ = VT3M = UMM3 - VT3M

BET3MR(I,JS)= ATAN2(VT3MR.VZ3M(I,JS))

V$ = VXZ3M(I,JS) + CGS(BET3MR(I,JS))

RM3(I)= 1.0 - V3MR/XVMR + (RM3(I)/V3M) - RM2(I)*XVT2M/XRM3(I) + -
WRITE (6,2090) I,PHIC,PSIC,TAU,ETAC,PR(I),ETAO(I),PRO(I),WTFLOW
X,RINCM(I),RDFM(I),SINCM(I)
IF (UNITS.EQ.1.0) WTFLOW = WTFLOW/0.453592
2090 FORMAT (5X,I5,8F10.4,F10.2,F10.4,F10.2)
I = I+1
IF(I.LE.NSTA) GO TO 91
GO TO 111
110 WRITE(6,2100) I,PHIC
GO TO 111
120 WRITE(6,2110) I,PHIC
GO TO 113
2100 FORMAT (10X FOR STAGE,I3,18H, COMPUTED PHI IS,F8.4,06H STALL)
2110 FORMAT (10X FOR STAGE,I3,18H, COMPUTED PHI IS,F8.4,06H CHOKE)
111 FLOWIN = FLOWIN + DFLOW
IF (FLOWIN.LE.FLOWFI) GO TO 81
113 IF (JS.LT.NSPE) GO TO 80
DO 112 I=1,NSTA
DO 112 J=1,NSPE
112 DPSIS(I,J) = 0.0
RETURN
1010 FORMAT (8F10.0)
END

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REFERENCES


