WISGSK

A Computer Code for the Prediction of a Multistage Axial Compressor Performance With Water Ingestion

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LIST OF SYMBOLS

$C_p$ - Specific heat at constant pressure
$D_0$ - Initial droplet diameter
$D_{eq}$ - Equivalent pressure ratio
$i$ - Incidence angle
$k$ - Deviation constant
$N$ - Rotor speed
$N/\sqrt{\delta}$ - Rotor corrected speed
$PR$ - Stagnation pressure ratio
$P_{\text{01}}$ - Stagnation pressure at stage inlet
$P_{\text{02}}$ - Stagnation pressure at stage outlet
$P_{\text{02}}/P_{\text{01}}$ - Stagnation pressure ratio
$P_{\text{ref}}$ - Reference pressure
$TR$ - Stagnation temperature ratio
$T_{\text{01}}$ - Stagnation temperature at stage inlet
$T_{\text{02}}$ - Stagnation temperature at stage outlet
$T_{\text{02}}/T_{\text{01}}$ - Stagnation temperature ratio
$T_{\text{ref}}$ - Reference temperature
$U$ - Blade speed
$U_{\text{tip}}$ - Blade speed at tip
$V_z$ - Axial velocity
$V_{z1}$ - Axial velocity at stage inlet
$V_{z2}$ - Axial velocity at stage outlet
$W_1$ - Blade relative velocity at stage inlet
$W_2$ - Blade relative velocity at stage outlet
LIST OF SYMBOLS (continued)

\( X_W \) Water content (mass fraction)
\( X_{W,0} \) Initial water content
\( \beta_1 \) Relative flow angle at rotor inlet
\( \beta_2 \) Relative flow angle at rotor outlet
\( \gamma \) Ratio of specific heats
\( \zeta \) Adiabatic efficiency
\( \Delta T_0 \) Rise in stagnation temperature across a stage
\( \delta \) Deviation angle
\( \delta \) Corrected pressure (\( \delta = P/P_{\text{ref}} \))
\( \phi \) Deflection angle (\( \phi = \beta_1 - \beta_2 \))
\( \theta \) Corrected temperature (\( \theta = T/T_{\text{ref}} \))
\( \sigma \) Solidity
\( \phi \) Flow coefficient
\( \psi \) Pressure-rise coefficient

Subscript

0 Stagnation value
1 Stage inlet
2 Stage outlet
tip Blade tip
ax Axial direction

Superscript

* Pertaining to design point
SUMMARY

A computer code for predicting the performance of an axial-flow compressor with water ingestion has been developed at Purdue University under the NASA Grant NAG 3-62 and presented along with a test case that illustrates the use of the Code. The Code employs the same procedure and architecture as the NASA-STGSTK Code. The Code uses a meanline stage stacking method; stage and cumulative compressor performance is calculated utilizing representative triangles located at rotor inlet and outlet mean radii.

The aero-thermo-mechanical interactions arising during air-water droplet mixture flow are taken into account in terms of four processes: (i) changes in blade performance parameters (deviation and efficiency), (ii) centrifugal action due to flow rotation, (iii) heat and mass transfer processes between the gaseous and liquid phases and (iv) droplet instability and break-up. The latter three are introduced at the exit of each blade row. The aerodynamic performance of a stage is based on estimated rules for deviation and efficiency with air-water mixture flow. The nature of such rules is discussed in detail.

The Code provides options for the calculation of performance with (a) mixtures of gases such as air and water vapor and (b) air-water droplet mixtures with different water content.

The Code is useful in obtaining preliminary estimates of overall performance of compressors with water ingestion given the design point details corresponding to air flow and the nature of corrections for air-water mixture flow.
CHAPTER I

INTRODUCTION

Water ingestion into jet engines may arise due to various circumstantial reasons: high humidity in air resulting in condensation of water at the inlet, tire-generated spray entering the air stream during take-off and landing on rough runways with puddles of water, and flight through rain storms. It has been found that such water ingestion can lead to a loss of performance, engine mismatch, and loss of surge margin, and in some cases causes undesirable mechanical and aerelastic effects. Both steady state and transient performance are affected and the operational margins in the control system also become affected. With ingestion of large amounts of water, water may flow through the engine at low power settings and a flameout may arise at higher power settings. From the point of view of criticality of changes in the performance of different engine components, the compressor presents unique problems and is in many ways central to the performance of the engine (References 1 and 2).

The air-water mixture ingested into a compressor is characterized by the water content, the droplet size distribution and the vapor content. The mixture may enter the compressor nonuniformly in the circumferential and radial directions. In the case of rain water ingestion, the water content may range from 2.0 percent to 15.0 percent or more. The water droplet size variations in rain and mist are presented in Figure 1. Water vapor content in the atmosphere varies with the degree of saturation and the altitude. Figure 2 presents the variation of water vapor content corresponding to the saturation state as a function of altitude. Some typical values of vapor content corresponding to the
saturation state under different temperature and pressure conditions that are of interest in aircraft operation are given in Table 1.

At the end of each stage, and therefore also at the exit of a multistage compressor, the characteristics of the air-water mixture undergo modification: water, vapor and air become redistributed; the work done on the gaseous phase and efficiency become affected; and the stalling characteristics of stages undergo changes.

The performance of a compressor stage at a given speed and flow coefficient undergoes a change during water ingestion, compared to the performance with air flow, on account of a combination of processes associated with droplet-laden air flow:

(i) change in airfoil performance;
(ii) centrifugal action causing motion and accumulation of water and vapor towards the tip and hub sections, respectively; and
(iii) heat and mass transfer between the two phases.

These processes become further complicated due to:

(a) droplet impact and rebound at the blades and casing,
(b) droplet reingestion from blade surfaces into wakes,
(c) droplet break-up to remain under the critical size and
(d) droplet size distribution.

For a given compressor with specified

(i) blade and blade-loading,
(ii) aspect ratio and
(iii) interstage spacing

one can examine the changes in performance in terms of two major parameters:

(a) changes in aerodynamic performance and
(b) characteristic times available for centrifugal action and heat and mass transfer processes.

The changes in a given compressor depend upon the following:

(i) operating speed and throttle setting;
(ii) water and water vapor mass fractions in the air-water mixture
TABLE 1

SATURATION VALUES OF WATER VAPOR
UNDER TYPICAL CONDITIONS

<table>
<thead>
<tr>
<th>TEMPERATURE (°F)</th>
<th>PRESSURE (psi)</th>
<th>( w_s ) ( \frac{1b_{m}, \text{vapor}}{1b_{m}, \text{dry air}} )</th>
<th>( w_s^* ) ( \frac{1b_{m}, \text{vapor}}{1b_{m}, \text{mixture}} )</th>
</tr>
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<tr>
<td>59</td>
<td>14.696</td>
<td>0.011</td>
<td>0.011</td>
</tr>
<tr>
<td>86</td>
<td>14.696</td>
<td>0.027</td>
<td>0.026</td>
</tr>
<tr>
<td>104</td>
<td>14.696</td>
<td>0.049</td>
<td>0.047</td>
</tr>
<tr>
<td>125.4(^{(1)})</td>
<td>22.402(^{(4)})</td>
<td>0.060</td>
<td>0.057</td>
</tr>
<tr>
<td>155.8(^{(2)})</td>
<td>22.402(^{(4)})</td>
<td>0.148</td>
<td>0.129</td>
</tr>
<tr>
<td>176.1(^{(3)})</td>
<td>22.402(^{(4)})</td>
<td>0.275</td>
<td>0.216</td>
</tr>
<tr>
<td>65.1(^{(5)})</td>
<td>12.648(^{(6)})</td>
<td>0.025</td>
<td>0.024</td>
</tr>
<tr>
<td>212</td>
<td>15.698</td>
<td>9.124</td>
<td>0.901</td>
</tr>
<tr>
<td>212</td>
<td>15.494</td>
<td>11.459</td>
<td>0.920</td>
</tr>
<tr>
<td>212</td>
<td>15.365</td>
<td>13.661</td>
<td>0.932</td>
</tr>
</tbody>
</table>

Note: Condition corresponding to
(1) Mach number = 0.8 when T = 59°F
(2) Mach number = 0.8 when T = 86°F
(3) Mach number = 0.8 when T = 104°F
(4) Mach number = 0.8 when p = 14.696 psi
(5) Mach number = 0.8 when T = 5.5°F
(6) Mach number = 0.8 when p = 8.298 psi

15,000 ft. altitude
flow at entry; and

(iii) water droplet size distribution.

In order to determine the performance of an axial flow compressor based on the aforementioned physical model, a three-dimensional flow calculation procedure is eventually desirable. However there are at present considerable uncertainties in regard to the various two phase flow processes associated with droplet-laden gas flow in general and in axial-flow compressors in particular. It is therefore considered that a parametric mean-line (one-dimensional) model should be developed in the first instance for determining the overall performance of a compressor stage with water ingestion. Such a calculation scheme requires incorporation of a stage-stacking procedure for use in multi-stage machines.

The current report describes such a calculation procedure written in the form of a computer code named the NASA-WISGSK Code. It is similar to the NASA-STGSKT Code (Reference 3) written for the purposes of calculating the off-design performance of axial-flow compressors given the details of the design point.

1.1 Background

A model for the calculation of overall performance of a multi-stage axial-flow compressor was developed based upon a mean-line, stage-stacking procedure (Reference 4). The model incorporates all of the essential features of droplet-laden air flow:

(i) droplet motion during ingestion,
(ii) droplet-blade interactions,
(iii) blade performance changes,
(iv) centrifugal action,
(v) heat and mass transfer processes and
(vi) droplet break-up.

Two limiting cases have been considered:

(i) droplets generally following the air flow path and
(ii) droplets having equal probability of motion in all directions. Figure 3 illustrates the latter case which applies to large droplet sizes. The calculation procedure adopted with the model is

(a) to calculate a blade row (rotor or stator) performance for two phase flow and

(b) to "correct" the exit conditions for centrifugal action and heat and mass transfer based upon the (characteristic) times available for those processes, and for droplet size changes based on the concept of a critical diameter.

In order to calculate the transport and accumulation of water radially outwards, the flow is divided into ten streamtubes along the span and the calculations are carried out in the time domain over the available time (across the blade row). Water on the surface of blades is distinguished from that in the blade passages. The corrected conditions constitute the inlet conditions for the next blade row, and so on for various stages in a multistage machine. The calculation procedure, the associated computer code, namely the PURDU-WICSTK Code, and an illustrative case are presented in Reference 5.

The foregoing calculation procedure permits determination of the aerodynamic performance of a chosen section (such as the mean section), a compressor stage at given initial and operating conditions provided the details of the blade section are available. In other words, at design and at off-design conditions, the deviation of fluid flow over a blade section and the efficiency of the blade section are determined directly for given initial flow conditions.

The calculation procedure also permits such a direct determination of blade performance at other spanwise locations of a stage provided that, once again, details regarding the section under consideration are available. Such a calculation is again performed on a one-dimensional basis. It is, of course, necessary to account for the redistribution of water and water vapor due to centrifugal action across the span of the compressor. Thus, in most cases the hub sections may become depleted of water but repleted with water vapor, and there may arise
an appreciable accumulation of water in the tip sections. In the case of a compressor with many stages, there may also arise a change in the condition of the fluid mixture at the mean section of a stage.

The calculation procedure can be utilized for any specified inlet mixture of air, water and water vapor. When calculations have been performed for a compressor stage under a variety of conditions, one of the interesting results that can be obtained is a set of correlation rules for

(a) diffusion factor and
(b) efficiency for the particular type of blading in terms of flow coefficient and mass fraction of water content.

Such correlation rules may then be used to obtain off-design performance of the compressor utilizing a considerably simplified procedure such as for example the procedure of the NASA-STGSTK Code.

It will be recalled that the blade outlet conditions obtained on the basis of droplet-laden air flow over a blade section need to be "corrected" for (a) centrifugal action, (b) heat and mass transfer processes between the gaseous and the liquid phases and (c) droplet size adjustment according to the PURDU-WICSTK Code procedure. The corrected values then represent the final outlet conditions from a stage and thus the initial conditions into a following stage, if any.

The correlation rules for diffusion factor and efficiency are therefore of use only to obtain the initial aerodynamic performance of a blade section with two phase flow. The correlation rules will apply to the compressor for which they have been obtained utilizing the PURDU-WICSTK Code.

By performing such calculations on a number of compressors with different types of blading it is expected that distinct trends can be established in the correlation rules. It is then possible to utilize the generalized correlation rules for specific types of blading and thus to calculate the off-design performance of compressors.
The NASA-WISGSK Code, described in this Report, has been designed assuming that such correlation rules are available.

1.2 Illustrative Example

The utilization of the NASA-WISGSK Code is illustrated here utilizing the design details for a small 6-stage axial-flow Test Compressor consisting of the axial stages of a T-63 engine. Details regarding the Test Compressor are provided in Appendix 1.

It is of interest to point out that a series of tests has also been conducted on the Test Compressor with water ingestion, and the results of such tests have been reported in References 6 and 7.

1.3 Outline of the Report

Chapter II of the Report is devoted to a description of the overall program. The subroutines and external functions are listed in Chapter III. A listing of the input data and the output obtained in the code are given in Chapters IV and V respectively. In Chapter VI, an illustrative test case is presented along with a discussion on the utilization of the code.
CHAPTER II

OVERALL PROGRAM DESCRIPTION

The NASA-WISGSK Code is based on two earlier studies:

i) the development of the PURDU-WICSTK Code for the calculation of the performance of multi-stage compressors with water ingestion (Reference 5); and

ii) the NASA-STGSTK Code for the determination of the off-design performance of axial-flow compressors (Reference 3).

2.1 Description of the PURDU-WICSTK Code and the NASA-STGSTK Code

2.1.1 The PURDU-WICSTK Code

The one-dimensional flow equations for two phase flow in axial compressors have been derived in detail and presented in Reference 4. Those equations are suitable for the calculation of performance of any chosen section along the span of an axial compressor blade row. The PURDU-WICSTK Code is based on those equations. For given initial conditions at the entry to a stage, the outlet conditions can be calculated using those equations.

The PURDU-WICSTK program deals with a fluid that may consist of (a) a mixture of three different gases and (b) a mixture of two types of water droplets, distinguished by size. The mixture of gases may consist of air and water vapor along with another gas when necessary. The water droplets may be either "small" or "large" diameter droplets or a mixture of small and large droplets. Small droplets are defined as those that follow the gas flow path and hence, absorb work input into the compressor along with the gaseous phase. Large droplets are assumed to move largely independently of the gas phase, with equal probability of motion in all directions, and without absorbing work.
input but introducing drag losses. Currently one can only choose the sizes for small and large droplets in an arbitrary fashion; for example if small droplets are assumed to be of mean diameter equal to O(10 μm) large droplets may be assigned a mean size of about 1,000 μm in diameter. In a general two-phase mixture that is utilized as the working fluid in a compressor, the proportion of various constituents (namely, different gases and two types of droplets) may be chosen as desired in the initial conditions assumed for a calculation. Thus, to consider humid air carrying large droplets, the content of small droplets is set equal to zero while water vapor content is related to humidity.

The performance of a stage of a compressor is based in the PURDU-WICSTK Code on five physical models as follows:

(1) Model for the calculation of stage performance with respect to the gaseous phase and water droplets.
(2) Model for droplet motion across a blade row from a chosen upstream location to a designated downstream location.
(3) Model for centrifuging of water droplets.
(4) Model for heat and mass transfer processes between the two phases; and
(5) Model for droplet break-up and equilibration with respect to size.

The foregoing five models have been described in detail in Reference 5. The performance of a stage is calculated for given initial and operating conditions with respect to the gaseous phase and the water droplets. Regarding small droplets, any fraction of their total number may be taken into account depending upon assumptions relating to droplet impingement and rebound processes. Then, at the exit of a blade row, the three major processes, namely (1) centrifugal action on droplets, (2) heat and mass transfer processes between the two phases and (3) droplet size adjustment, are taken into account. When the stage performance parameters are "corrected" for the afore-mentioned three processes, one obtains the final outlet conditions from a stage. The
Outlet conditions from a stage are modified, to account for geometry of compressor, in order to obtain the initial conditions for the next stage, where such exists. Calculations are repeated for subsequent stages based on the well-known concept of stage-stacking. The Code can be used to predict the design point performance as well as off-design performance of a multi-stage compressor.

2.1.2 The NASA-STGSTK Code

The details regarding the NASA-STGSTK Code are given in Reference 3.

2.2 Correlations of Performance Parameters with Water Ingestion

The two principal performance parameters for axial-flow compressor blading are (i) the stage pressure-rise coefficient and (ii) the aerodynamic efficiency of a blade row. These may be expressed as functions of flow coefficient for air flow and air-water mixture flow through the compressor. The stage pressure-rise coefficient can be obtained from a knowledge of deflection of the working fluid over a rotor blade row or from a knowledge of blade metal angles and incidence and corresponding deviation angles.

The methods of obtaining correlations for (i) deviation of the working fluid over a blade, (ii) the stage pressure-rise coefficient and (iii) the aerodynamic efficiency of blade rows are described in the following.

2.2.1 Deviation Angle

A general rule for deviation may be written as follows (Reference 9).

\[ \delta - \delta^* = k (D_{eq} - D_{eq}^*) \]  

\[ (2.1) \]
where $\delta$ and $D_{eq}$ are the deviation angle and the equivalent diffusion ratio, respectively; $(\ )^*$ denotes values at the reference point; and $k$ is a (proportionality) constant. According to Lieblein (Reference 8), the equivalent diffusion ratio can be written as follows:

$$D_{eq} = \frac{\cos \beta_2}{\cos \beta_1} \cdot \frac{V_{Z_1}}{V_{Z_2}} \left[ 1.12 + 0.0117 (i-i^*)^{1.43} + 0.61 \frac{\cos^2 \beta_1}{\sigma} \left( \tan \beta_1 - \frac{V_{Z_2}}{V_{Z_1}} \tan \beta_2 \right) \right]$$

(2.2)

the equivalent diffusion ratio at the reference point can be obtained by setting $i=i^*$. Thus, Equation (2.1) can be rewritten as follows:

$$\delta - \delta^* = 1.12k \left[ (W_1/W_2) - (W_1/W_2)^* \right] + 0.0117 (i-i^*)^{1.43} k (W_1/W_2) + 0.61 k (\sin \varepsilon - \sin \varepsilon^*)/\sigma$$

(2.3)

Assuming that the second and third terms on the right-hand side can be incorporated into the first term, one can write the following equation.

$$\delta - \delta^* = K \left[ (W_2/W_1) - (W_2/W_1)^* \right]$$

(2.4)

where $K$ is referred to as the deviation constant. The deviation constant can be related to the amount of diffusion in a blade passage in the case of gas (single phase) flow through a compressor. In the case of droplet-laden gas flow, it is assumed that the deviation constant can still be related to the diffusion in a blade passage utilizing the water content in the mixture as a parameter. One can then obtain the deviation angle for given operating conditions and hence the corresponding blade outlet flow angle.
2.2.2 Correlations for Stage Pressure-Rise Coefficient

The stage pressure-rise coefficient for a compressor stage may be defined as follows.

\[ \psi = \frac{\eta C_p \Delta T_o}{U^2} \]

where
- \( \eta \) : stage adiabatic efficiency
- \( C_p \) : specific heat at constant pressure
- \( \Delta T_o \) : rise in stagnation temperature across a stage
- \( U \) : rotor whirl speed

The stage pressure-rise coefficient can be related to the stage flow coefficient utilizing water content.

2.2.3 Correlations for Efficiency

The adiabatic efficiency of the compression processes in a stage may be defined as follows:

\[ \eta = \frac{PR (\gamma-1) / \gamma - 1}{TR - 1} \]

where \( PR \) and \( TR \) are the stagnation pressure ratio and the stagnation temperature ratio across a stage, and \( \gamma \) is the ratio of specific heats. The stage adiabatic efficiency can be related to the stage flow coefficient utilizing water content as the parameter.

2.2.4 Procedure for Obtaining Correlations for Deviation Angle, Pressure-Rise Coefficient and Efficiency

It is common practice in compressor analysis to obtain correlations for the deviation angle, pressure-rise coefficient and efficiency for different classes of blading through cascade or compressor tests.
Such correlations with respect to flow coefficient are well-known in literature for air or other (single-phase) gaseous fluids. Similar correlations are not available for droplet-laden flows from experimental results.

One method of generating such correlations is by the use of the PURDU-WICSTK Code. The performance of a series of typical compressors can be calculated utilizing that code and from such performance calculations, the variation of the parameters of interest can be extracted for different classes of blading in those compressors while operating with two-phase fluids. The parametric variations may then be related to blading design and operational conditions. Thus, based on the performance results obtained on any compressor utilizing the PURDU-WICSTK program over appropriate ranges of initial and operating conditions, one can generate correlations for deviation angle, pressure-rise coefficient and efficiency in terms of the following.

(i) Values of deviation constant, K, as a function of the diffusion of the working fluid;
(ii) Values of pressure-rise coefficient as a function of the flow coefficient; and
(iii) Values of efficiency as a function of the flow coefficient.

The correlations are obtained for each class of blading or stage with water content at entry to that blading or stage as one parameter and the operating speed as the other parameter. Those correlations can then be utilized in the NASA-WISGSK Code for obtaining the performance of a similar compressor under desired operating conditions. When a series of such correlations have been generated for various classes of blading and for various operating conditions, several classes of axial-flow compressors can be analyzed on this basis in order to determine changes in performance with water ingestion.

In order to illustrate the nature of correlations that can be obtained utilizing the PURDU-WICSTK program and that are suitable for incorporating into the NASA-WISGSK program, a series of correlations
have been obtained for the 6-stage axial-flow Test Compressor, referred to in Section 1.2 of the report, utilizing the PURDU-WICSTK program.

Some examples of such correlations have been obtained under the following conditions.

Operating speed . . . 90 percent design speed.
Droplet size . . . 600 μm (referred to as large).
Water content as mass fraction of water in the mixture . . . 0.000, 0.025, 0.075, 0.125, and 0.150.

The correlations are presented in three parts, namely (i) for the deviation constant, (ii) for the pressure-rise coefficient and (iii) for the efficiency. In each case, the correlations have been given for different stages of the compressor. According to the basic design of the compressor, the type of blading employed in the different stages can be grouped as follows.

  a) blading in stage 1;
  b) blading in stage 2; and
  c) blading in stages 3, 4, 5 and 6.

From the point of view of blade loading, it appears that it is necessary to distinguish further between stage 3 and stages 4, 5 and 6.

The correlations for deviation constant have been presented in the following figures.

  Figure 4(a): Deviation constant vs [(W2/W1) - (W2/W2)*] (Stage 1)
  Figure 4(b): Deviation constant vs [(W2/W1) - (W2/W3)*] (Stage 2)
  Figure 4(c): Deviation constant vs [(W2/W1) - (W2/W1)*] (Stages 3, 4, 5, 6)
The correlations for pressure-rise coefficient corresponding to the afore-mentioned examples of correlations for the deviation constant have been presented in the following figures.

Figure 5(a): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 1)
Figure 5(b): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 2)
Figure 5(c): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 3)
Figure 5(d): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stages 4, 5, 6)

In these correlations, the stage pressure-rise coefficient and stage flow coefficient are normalized with respect to the design point values.

A set of examples of correlations for the adiabatic efficiency of different stages have been presented in the following figures. In all of the cases again only large droplets have been considered. The adiabatic efficiency is again normalized with respect to the design point value.

Figure 6(a): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 1)
Figure 6(b): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 2)
Figure 6(c): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 3)
Figure 6(d): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stages 4, 5, 6)

It is of interest to observe the following from the correlations presented.

(i) The correlations for both $K$ and $\eta$ show that there is some similarity in regard to their variation with water content in the entry mixture.

(ii) The variation of $K$ with respect to diffusion is rather severe for flow diffusion values in the vicinity of the design point, especially at the higher values of water content in the entry mixture. At large values of diffusion, the water content does not seem to have a significant effect.

It is of importance to note that the nature of variations of $K$ and $\eta$ may be different at other operating speeds. However, it is assumed
that such variations are small and that similar variations can be assumed over appropriate ranges of flow coefficients at other speeds. Nevertheless, the correlations presented should be considered as applicable only to the type of blading and blade-loading in the Test Compressor.

Other aspects of predictions of the Test Compressor performance utilizing the PURDU-WICSTK program can be found in References 6 and 7.

2.3 Modification of NASA-STGSTK Code to NASA-WISGSK Code for Use with Two-Phase Flow

The NASA-WISGSK Code for use with two-phase flow has been obtained by modifying the NASA-STGSTK Code in two respects.

(i) Introducing the stage characteristics for two-phase fluid flow in place of the stage characteristics utilized originally for air flow through the compressor; and
(ii) Incorporating various two-phase fluid associated processes at the stage exit in order to obtain the final state of the fluid at that location.

The principal stage characteristics are the efficiency and the pressure-rise coefficient. They are obtained at a reference operating speed, usually the design operating speed although another operating speed may be utilized.

The two-phase fluid flow effects of major interest are (i) the redistribution of water due to centrifugal action, (ii) the heat and mass transfer giving rise to a change in the temperature and mass fraction of the mixture constituents and (iii) the change in droplet size.

2.3.1. Efficiency Variation with Respect to Flow Coefficient

The reference curves for the variation of efficiency with respect to flow coefficient, obtained at the reference speed for various values
of water content in the entry mixture, for a particular compressor stage are adapted for use at other operating speeds in the NASA-WISGSK Code in two steps as follows.

(i) First, the reference curve for the case of air flow (and no water in the mixture) is shifted as illustrated in Figure 7 for use at the desired off-reference operating speed over the appropriate range of flow coefficient.

(ii) Next, the reference curve is modified for the presence of water following the correlations obtained for different water contents in the mixture at the reference speed. This part of the procedure is also illustrated in Figure 7.

2.3.2 Pressure-Rise Coefficient vs Flow Coefficient

In the NASA-STGSK Code, the pressure-rise coefficient is calculated in the subroutine CSPSI (Reference 3). In that subroutine, the pressure-rise coefficient is calculated based on the deflection of air flow over a rotor blade which in turn depends upon the blade outlet flow angle and hence the deviation angle. The blade deviation angle is estimated utilizing the following rule.

\[ \delta - \delta^* = K \left[ \left( \frac{W_2}{W_1} \right) - \left( \frac{W_2}{W_1}^* \right) \right] \]

with \( K = -10 \) for the case of air flow. In the case of operation with air-water mixture flow, the deviation constant, \( K \), is a function of water content and amount of diffusion.

Utilizing the appropriate values of \( K \), based, for example, upon the type of correlations presented in Figure 4, the pressure-rise coefficient can be obtained at the reference speed and at off-design speeds for various values of water content in the entry mixture as a function of flow coefficient.
2.3.3 Correction for Two-Phase Effects

The NASA-WISGSK Code incorporates the following new features in order to correct the blade outlet conditions that are obtained based upon stage characteristics for the following two-phase fluid flow effects:

(i) droplet size adjustment;
(ii) centrifugal force action; and
(iii) heat and mass transfer.

The details regarding modelling of these processes can be found in Reference 5.

2.4 The General Procedure for Utilization of the NASA-WISGSK Code

It is expected that for the compressor under consideration, the following stage characteristics are available for each stage of the compressor at a convenient reference speed over a range of mass flows.

(i) Adiabatic efficiency as a function of gas phase flow coefficient for various values of mass fraction of water in the mixture; and
(ii) Deviation factor as a function of diffusion of the working fluid for various values of mass fraction of water in the mixture.

Utilizing the latter, the pressure-rise coefficient characteristics for different stages can be obtained as a function of flow coefficient utilizing the mass fraction of water in the entry mixture as a parameter.

As stated earlier (Section 2.3.1) the efficiency curves may need to be shifted for use at off-reference operating speeds. The pressure-rise coefficient characteristics are treated as applicable at all values of operating speed, at least over a substantial range of speeds.
It can be visualized that the efficiency and the pressure-rise coefficient characteristics may be available at discrete values of mass fraction of water. Since the mass fraction of water changes along a compressor flow path in different ways along different streamlines, it is useful to devise rules for interpolating the stage characteristics for various values of mass fraction of water.

The water vapor in the mixture at entry to a compressor stage is taken into account in the form of mass fraction of vapor for the purposes of determining the thermodynamic properties as a part of the gas phase in the mixture.

The initial and operating conditions to be specified in utilizing the NASA-WISGSK Code are the following:

(i) the operating speed;
(ii) the mixture mass flow;
(iii) the mixture composition including the droplet size; and
(iv) the ambient conditions in the mixture entering the compressor.

The calculation procedure may then be divided into three parts as follows:

(i) calculation of performance of compressor at reference and off-reference speeds with air flow only;
(ii) calculation of performance of compressor at reference speed and different values of mass flows with various values of water content; and
(iii) calculation of performance of compressor at off-reference speeds with various values of mixture flows and mass fractions of water.

In each case, calculations may be performed along any streamtube selected in the compressor with specified (a) mass flow and mixture composition at entry, (b) area change and (c) work input at appropriate rotor locations. It may be recalled that the calculation procedure is based on a one-dimensional formulation.
2.4.1 Calculation with Air Flow

The performance calculation with air flow at the reference and the off-reference speeds is intended to establish (a) the extent to which the stage efficiency curve needs to be adjusted by shifting over the desired range of flow coefficient (utilizing the procedure described in Section 2.3.1) and (b) the ranges of flow coefficient that can be covered in the performance calculation at different operating speeds utilizing the available stage characteristics. When the compressor performance is available from another source at different operating speeds, one can compare such performance parameter values with those obtained utilizing the NASA-WISGSK Code. Utilizing a trial-and-error procedure, any small differences in performance at off-reference speeds can be adjusted through modifying the stage characteristics available at the reference speed for various off-reference speeds. However, such modifications need to be introduced with considerable judgement.

The calculation procedure for given (a) ambient conditions, (b) operating speed and (c) air mass flow may be summarized as follows.

(i) The flow coefficient is determined at the compressor inlet.

(ii) The stage efficiency can be obtained directly from the efficiency vs flow coefficient curve for the stage when the operating speed under consideration is the same as the reference speed. If the operating speed is different from the reference speed, the efficiency-flow coefficient curve has to be shifted appropriately (Section 2.3.1) and the efficiency then obtained for the value of flow coefficient specified.

(iii) The stage pressure-rise coefficient characteristic is utilized for obtaining the value of pressure-rise coefficient at the specified value of flow coefficient.
(iv) The stage pressure ratio and temperature ratio are calculated as follows:

\[ PR = 1.0 + \frac{U^2}{C_p T_0} \psi \]

\[ TR = 1.0 + (PR^{\gamma-1/\gamma} - 1.0) \eta \]

(v) The resulting stage outlet conditions become the inlet conditions for the next stage, if any. The procedure given under items (i) to (iv) is then repeated for each of the stages until the compressor outlet station is reached.

(vi) The performance of each stage of the compressor as well as the overall performance of the compressor can then be obtained from the predictions for the given operating conditions.

(vii) The entire procedure may be repeated at the desired operating speeds and mass flows.

2.4.2 Calculation with Air-Water Mixture Flow at Reference Speed

At the reference speed, the available stage characteristics (pertaining to efficiency and pressure-rise coefficient) are usable directly.

The procedure for calculation of performance at various values of mixture mass flow (or gas phase flow coefficient and liquid phase mass fraction) is identical to that described in Section 2.4.1 except for the following: (i) the efficiency and pressure-rise coefficient values should be chosen for the local value of water content in the entry mixture for each stage and (ii) the stage outlet conditions have to be corrected for two-phase flow effects.

The primary purpose of the calculation of performance at the reference speed is to establish the applicability of the available
stage characteristics for the ranges of water content that are likely to arise in different stages under different conditions. Since centrifugal action is only a function of the rotation in the flow field, by performing calculations at the reference operating speed, the effect of water content and the applicability of the available stage characteristics can be examined in the different stages of a compressor. If the general trend of performance changes is acceptable, the pressure-rise coefficient information can be utilized with some confidence at off-reference speeds.

2.4.3 Calculation with Air-Water Mixture Flow under General Conditions of Operation

At off-reference operating speeds, the efficiency-flow coefficient curves need to be shifted to become applicable over the relevant range of flow coefficient in each stage of a compressor.

The calculation procedure for obtaining the performance is then identical to that described in Section 2.4.1 except for the following: (i) the efficiency and pressure-rise coefficient values should be chosen for the local values of water content in the entry mixture for each stage, (ii) the efficiency curves should be moved as required to become applicable over the relevant range of flow coefficient at the operating speed specified and (iii) the correction of stage outlet conditions for two-phase flow effects.

The stage outlet conditions are corrected for the following effects associated with two-phase flow:

a) Droplet size adjustment;
b) Centrifugal force action; and
c) Heat and mass transfer.

The stage outlet conditions are then obtained in terms of mixture composition, gas phase properties and liquid phase properties, including the droplet size.
CHAPTER III

SUBROUTINES AND EXTERNAL FUNCTIONS

The following is the list of subroutines and external functions used in the NASA-WISGSK code. The subroutines and external functions consist of two parts as follows: Part I of the subroutines and external functions is the same as those in PURDU-WICSTK code (Reference 5) and Part II of the subroutines and external functions closely follows those in NASA-STGSK code (Reference 3). Only brief descriptions of these subprograms are given here. A more detailed description of each subprogram is presented in Appendix 3.

PART I

Subroutine WICSPC: calculation of stage performance based on the analytical/correlation method for large droplet.
Subroutine WICSPD: calculation of design point performance.
Subroutine WICSCC: calculation of the equivalent pressure ratio, equivalent temperature rise ratio, and stage adiabatic efficiency for a particular stage based on the inputed stage characteristic curves.
Subroutine WICGSL: calculation of single-phase (gas) flow loss.
Subroutine WICSDL: calculation of loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets.
Subroutine WICSTL: calculation of loss due to Stokesian drag of large droplets in the free stream of blade passage.
Subroutine WICFML: calculation of loss due to film formed on blade surface when large droplets are present either by themselves or along with small droplets.
Subroutine WICRSL: calculation of loss due to the rough surface when large droplets are present either by themselves or along with small droplets.

Subroutine WICVTL: calculation of components of velocity triangle and angles.

Subroutine WICCEN: calculation of swanwise displacement of droplets due to centrifugal action.

Subroutine WICDMS: calculation of amount of small droplets which are centrifuged.

Subroutine WICDML: calculation of amount of large droplets which are centrifuged.

Subroutine WICDRC: calculation of drag force on large droplet.

Subroutine WICMAC: calculation of Mach number.

Function WICASD: calculation of acoustic speed in two phase flow.

Subroutine WICBOA: calculation of blade outlet angle.

Subroutine WICEDD: calculation of equivalent diffusion at design point.

Function WICED: calculation of equivalent diffusion.

Function WICMTK: calculation of dimensionless momentum thickness.

Function WICLOS: calculation of total pressure loss coefficient.

Subroutine WICIRS: calculation of droplet impingement and rebound in rotor for small droplet.

Subroutine WICIRL: calculation of droplet impingement and rebound in rotor for large droplet.

Subroutine WICISS: calculation of droplet impingement and rebound in stator for small droplet.

Subroutine WICISL: calculation of droplet impingement and rebound in stator for large droplet.

Subroutine WICWAK: calculation of water reingestion into wake.

Subroutine WICHEC: calculation of heat transfer between gaseous phase and droplets.

Subroutine WICMAS: calculation of mass transfer between gaseous phase and droplets.

Function WICMTR: calculation of mass transfer rate.

Function WICPWB: calculation of vapor pressure.
**Function WICNEW:** calculation of new trial value in the interactive procedure.
**Function WICTAN:** calculation of the value of tangent function.
**Function WICBPT:** calculation of boiling point.
**Function WICSH:** calculation of specific humidity.
**Subroutine WICSIZ:** calculation of nominal droplet size.
**Subroutine WICPRP:** calculation of flow properties for gaseous phase.
**Function WICCPA:** calculation of specific heat at constant pressure for air.
**Function WICCPH:** calculation of specific heat at constant pressure for vapor.
**Function WICCPC:** calculation of specific heat at constant pressure for methane.

**PART II**

**Subroutine NASA:** subroutine which corresponds to MAIN program of NASA-STGSTK code.
**Subroutine CSINPT:** reads and writes the Part II of input data.
**Subroutine CSPREF:** calculates parameters at design speed and design flow conditions.
**Function CPFM:** calculates specific heat at constant pressure from static temperature using fifth degree polynomial.
**Subroutine CSETA:** calculates adiabatic efficiency versus flow coefficient.
**Subroutine CSPSI:** calculates pressure coefficients for inputed flow coefficients.
**Subroutine CSDEVS:** calculates stator deviation angle for small droplet calculation.
**Subroutine CDEVSL:** calculates stator deviation angle for large droplet calculation.
**Subroutine CSDEV:** calculates rotor deviation angle for small droplet calculation.
**Subroutine CSDEVL:** calculates rotor deviation angle for large droplet calculation.
Subroutine CSETA1: calculates adiabatic efficiency for small droplet calculation.
Subroutine CSETAL: calculates adiabatic efficiency for large droplet calculation.
Subroutine CSPSD: alters pressure coefficient for off design speeds.
Subroutine CSPAN: alters flow coefficient and pressure coefficient for blade reset.
Subroutine CSOUP: calculates and prints out stage performance for small droplet calculation.
Subroutine COUP: calculates and prints out stage performance for large droplet calculation.
Function DELK70: alters diffusion constant for 70% rotor speed.
Function DELK80: alters diffusion constant for 80% rotor speed.
Function DELK10: alters diffusion constant for 100% rotor speed.
Function DPHI: alters flow coefficient for different rotational speed.
CHAPTER IV

INPUT DATA

The following is a list of the input data as they are read in the NASA-WISGSK code. All input data that are needed to use the code are described herein. The input data consist of two parts as follows: Part I of the input data is the same as those in the PURDU-WICSTK code (Reference 5), and Part II of the input data follow very closely those in the NASA-STGSTK code (Reference 3).

PART I

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<th>Input Data</th>
<th>Comment</th>
<th>Format</th>
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<tr>
<td>1</td>
<td>NS</td>
<td>number of stage</td>
<td>I1</td>
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<tr>
<td>2</td>
<td>RRHUB(I)</td>
<td>hub radius at Ith stage rotor inlet. $I = 1 \sim NS$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unit: inch or cm</td>
<td>F 5.3</td>
</tr>
<tr>
<td>3</td>
<td>RC(I)</td>
<td>chord length of Ith stage rotor $I = 1 \sim NS$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unit: inch or cm</td>
<td>F 5.3</td>
</tr>
<tr>
<td>4</td>
<td>RBLADE(I)</td>
<td>number of blade for Ith stage rotor $I = 1 \sim NS$</td>
<td>F 5.2</td>
</tr>
<tr>
<td>5</td>
<td>STAGER(I)</td>
<td>staggerangle for Ith stage rotor $I = 1 \sim NS$</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Unit: degree</td>
<td>F 5.2</td>
</tr>
<tr>
<td>6</td>
<td>SRHUB(I)</td>
<td>hub radius at Ith stage stator inlet. $I = 1 \sim NS, I = NS + 1$ for IGV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unit: inch or cm</td>
<td>F 5.3</td>
</tr>
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<tr>
<td>7</td>
<td>SC(I)</td>
<td>chord length of Ith stage stator I = 1 ~ NS, I = NS + 1 for IGV Unit: inch or cm</td>
<td>F 5.3</td>
</tr>
<tr>
<td>8</td>
<td>SBLADE(I)</td>
<td>number of blade for Ith stage stator I = 1 ~ NS, I = NS + 1 for IGV</td>
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</tr>
<tr>
<td>9</td>
<td>SIGUMR(I)</td>
<td>solidity of Ith stage rotor I = 1 ~ NS</td>
<td>F 5.3</td>
</tr>
<tr>
<td>10</td>
<td>SIGUMS(I)</td>
<td>solidity of Ith stage stator I = 1 ~ NS, I = NS + 1 for IGV</td>
<td>F 5.3</td>
</tr>
<tr>
<td>11</td>
<td>BET2SS(I)</td>
<td>absolute flow angle at Ith stage stator outlet I = 1 ~ NS, I = NS + 1 for IGV</td>
<td>F 5.2</td>
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<tr>
<td>12</td>
<td>FNF</td>
<td>fraction of design corrected rotor speed for a particular speed</td>
<td>F 8.2</td>
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<td>13</td>
<td>XDIN</td>
<td>initial water content (mass fraction) of small droplet</td>
<td>F 5.3</td>
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<tr>
<td>13</td>
<td>ICENT</td>
<td>index for centrifugal calculation of small droplet ICENT = 1 when XDIN = 0.0 otherwise ICENT = 2</td>
<td>II</td>
</tr>
<tr>
<td>13</td>
<td>XDDIN</td>
<td>initial water content (mass fraction) of large droplet</td>
<td>F 5.3</td>
</tr>
<tr>
<td>13</td>
<td>IICNET</td>
<td>index for centrifugal calculation of large droplet IICENT = 1 when IUDIN = 0.0 otherwise IICENT = 2</td>
<td>II</td>
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<td>14</td>
<td>TOG</td>
<td>total temperature of gas phase at compressor inlet Unit: Rankine or Kelvin</td>
<td>F 7.2</td>
</tr>
<tr>
<td>14</td>
<td>TOW</td>
<td>temperature of droplet at compressor inlet Unit: Rankine or Kelvin</td>
<td>F 7.2</td>
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(continued)
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<tr>
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<td>PO</td>
<td>total pressure at compressor inlet&lt;br&gt;Unit: lbf/ft² or N/m²</td>
<td>F 7.2</td>
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<tr>
<td>15</td>
<td>DIN</td>
<td>initial diameter of small droplet&lt;br&gt;Unit: µm</td>
<td>F 6.1</td>
</tr>
<tr>
<td>15</td>
<td>DDIN</td>
<td>initial diameter of large droplet&lt;br&gt;Unit: µm</td>
<td>F 6.1</td>
</tr>
<tr>
<td>16</td>
<td>FND</td>
<td>rotor corrected speed at design point&lt;br&gt;Unit: RPM</td>
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<td>TOID</td>
<td>compressor inlet temperature at design point&lt;br&gt;Unit: Rankine or Kelvin</td>
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<td>POID</td>
<td>compressor inlet pressure at design point&lt;br&gt;Unit: lbf/ft² or N/m²</td>
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<td>17</td>
<td>XCH4</td>
<td>initial methane content (mass fraction)</td>
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<tr>
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<td>RHUMID</td>
<td>initial relative humidity&lt;br&gt;Unit: per cent</td>
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<td>FMWA</td>
<td>molecular weight of air</td>
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<tr>
<td>18</td>
<td>FMWV</td>
<td>molecular weight of steam</td>
<td>F 7.3</td>
</tr>
<tr>
<td>18</td>
<td>FMWC</td>
<td>molecular weight of methane</td>
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</tr>
<tr>
<td>19</td>
<td>PRER</td>
<td>percent of water droplet that rebound after impingement on blade surface</td>
<td>F 5.1</td>
</tr>
<tr>
<td>19</td>
<td>DLIMIT</td>
<td>maximum diameter for small droplet&lt;br&gt;Unit: µm</td>
<td>F 7.1</td>
</tr>
<tr>
<td>20</td>
<td>STAGES(I)</td>
<td>stagger angle for Ith stage stator&lt;br&gt;I = 1 ~ NS, I = NS + 1 for IGV&lt;br&gt;Unit: degree</td>
<td>F 5.2</td>
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<tr>
<td>Card No.</td>
<td>Input Data</td>
<td>Comment</td>
<td>Format</td>
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<tr>
<td>21</td>
<td>GAPR(I)</td>
<td>gap between Ith stage rotor and (I - 1)th stage stator. I = 1 ~ NS. Unit: inch or cm.</td>
<td>F 7.5</td>
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<td>22</td>
<td>GAPS(I)</td>
<td>gap between rotor blade and stator blade for Ith stage. I = 1 ~ NS. Unit: inch or cm.</td>
<td>F 7.5</td>
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<tr>
<td>23</td>
<td>RRTIP(I)</td>
<td>blade tip radius at Ith stage rotor inlet. I = 1 ~ NS. Unit: inch or cm.</td>
<td>F 6.3</td>
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<td>24</td>
<td>SRTIP(I)</td>
<td>blade tip radius at Ith stage stator inlet. I = 1 ~ NS. Unit: inch or cm.</td>
<td>F 6.3</td>
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<tr>
<td>25</td>
<td>IRAD</td>
<td>index for radius at which calculation is carried out. IRAD = 1: performance at tip. IRAD = 2: performance at mean. IRAD = 3: performance at hub.</td>
<td>I1</td>
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<td>26</td>
<td>RT(I)</td>
<td>rotor inlet radius at which tip performance calculation is carried out. I = 1 ~ NS. Unit: inch or cm.</td>
<td>F 5.3</td>
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<tr>
<td>27</td>
<td>RM(I)</td>
<td>rotor inlet radius at which mean line performance calculation is carried out. I = 1 ~ NS. Unit: inch or cm.</td>
<td>F 5.3</td>
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<tr>
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<td>RH(I)</td>
<td>rotor inlet radius at which hub performance calculation is carried out. I = 1 ~ NS. Unit: inch or cm.</td>
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<td>Card No.</td>
<td>Input Data</td>
<td>Comment</td>
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| 29      | ST(I)      | stator inlet radius at which tip performance calculation is carried out
          |            | I = 1 ~ NS
          |            | Unit: inch or cm | F 5.3  |
| 30      | SM(I)      | stator inlet radius at which mean line performance is carried out
          |            | I = 1 ~ NS
          |            | Unit: inch or cm | F 5.3  |
| 31      | SH(I)      | stator inlet radius at which hub performance calculation is carried out
          |            | I = 1 ~ NS
          |            | Unit: inch or cm | F 5.3  |
| 32      | BLOCK(I)   | blockage factor for Ith stage rotor
          |            | 0<BLOCK(I)<1 | F 5.3  |
| 33      | BLOCKS(I)  | blockage factor for Ith stage stator
          |            | 0<BLOCKS(I)<1 | F 5.3  |
| 34      | BET1MR(I)  | blade metal angle at Ith stage rotor inlet
          |            | Unit: degree | F 5.2  |
| 35      | BET2MR(I)  | blade metal angle at Ith stage rotor outlet
          |            | Unit: degree | F 5.2  |
| 36      | BET1MS(I)  | blade metal angle at Ith stage stator inlet
          |            | Unit: degree | F 5.2  |
| 37      | BET2MS(I)  | blade metal angle at Ith stage stator outlet
          |            | Unit: degree | F 5.2  |
| 38      | DSMASS     | mass flow rate at design point
<pre><code>      |            | Unit: lbm/s or kg/s | F 10.6 |
</code></pre>
<p>| 39      | PRI2D      | total pressure ratio for the Ith stage rotor at design point | F 5.3  |</p>
<table>
<thead>
<tr>
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<th>Input Data</th>
<th>Comment</th>
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<td>PRI3D</td>
<td>total pressure ratio for Ith stage</td>
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<td>ETARD(I)</td>
<td>adiabatic efficiency for Ith stage rotor</td>
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CHAPTER V

OUTPUT

The output generated utilizing the NASA-WISGSK code is described here. The output consists of five parts as follows:

1. output of the input data;
2. output of design point performance;
3. output of stage characteristic;
4. output of stage performance; and
5. output of overall performance.

These five parts are described in the following.

5.1 Output of Inputed Data

All of the data inputed can be printed out at the beginning of output.

5.2 Output of Design Point Performance

5.2.1 Compressor Inlet (Design Point Performance)

At the compressor inlet, the following properties can be printed out for the design point performance:

1. total temperature at compressor inlet: (R) or (K)
2. total pressure at compressor inlet: (lbf/ft$^2$) or (N/m$^2$)
3. static temperature at compressor inlet: (R) or (K)
4. static pressure at compressor inlet: (lbf/ft$^2$) or (N/m$^2$)
5. static density at compressor inlet: (lbm/ft$^3$) or (kg/m$^3$)
6. acoustic speed at compressor inlet: (ft/s) or (m/s)
7. axial velocity at compressor inlet: (ft/s) or (m/s)
(8) Mach number at compressor inlet
(9) stream tube area at compressor inlet: (ft²) or (m²)
(10) flow coefficient at compressor inlet

5.2.2 Stage Performance (Design Point Performance)

At the end of each stage, the following properties can be printed out for the design point performance:

1. total temperature: (R) or (K)
2. total pressure: (lbf/ft²) or (N/m²)
3. static temperature: (R) or (K)
4. static pressure: (lbf/ft²) or (N/m²)
5. static density: (lbm/ft³) or (kg/m³)
6. axial velocity: (ft/s) or (m/s)
7. absolute velocity: (ft/s) or (m/s)
8. relative velocity: (ft/s) or (m/s)
9. tangential component of absolute velocity: (ft/s) or (m/s)
10. tangential component of relative velocity: (ft/s) or (m/s)
11. rotor wheel speed: (ft/s) or (m/s)
12. absolute Mach number
13. relative Mach number
14. total temperature based on relative Mach number: (R) or (K)
15. total pressure based on relative Mach number: (lbf/ft²) or (N/m²)
16. absolute flow angle: (degree)
17. relative flow angle: (degree)
18. stream tube area: (ft²) or (m²)
19. radius at which calculation is carried out: (ft) or (m)
20. flow coefficient
21. stage total pressure ratio
22. stage adiabatic efficiency
23. rotor total pressure ratio
24. rotor adiabatic efficiency
25. stage total temperature ratio
5.2.3 **Overall Performance (Design Point Performance)**

After all of stage performance is printed out, the following properties can be printed out:

1. compressor inlet total temperature: (R) or (K)
2. compressor inlet total pressure: (lbf/ft²) or (N/m²)
3. corrected mass flow rate: (lbm/s) or (kg/s)
4. overall total pressure ratio
5. overall total temperature ratio
6. overall adiabatic efficiency
7. overall temperature rise: (F) or (C)
8. relative flow angle at rotor inlet: BET₁SR(I) (degree)
9. relative flow angle at rotor outlet: BET₂SR(I) (degree)
10. incidence for rotor: AINCᵢSR(I) (degree)
11. deviation for rotor: ADEVᵢSR (degree)
12. absolute flow angle for stator inlet: BET₁SS(I) (degree)
13. absolute flow angle for stator outlet: BET₂SS(I) (degree)
14. incidence for stator: AINCᵢSS(I) (degree)
15. deviation for stator: ADEVᵢSS (degree)
16. stage inlet temperature: TD(I) (R) or (K)
17. total pressure loss coefficient for stator: OMEGᵢS(I)
18. total pressure loss coefficient for rotor: OMEGᵢR(I)

5.3 **Output of Stage Characteristics**

The inputed and/or computed stage characteristic can be printed out. The flow coefficient, pressure coefficient and adiabatic efficiency for each stage are printed out. This part of output is the same as one in NASA-SGSTK code (Reference 3).

5.4 **Output of Stage Performance**

The performance of a stage is calculated for given initial and operating conditions with respect to the gaseous phase and the water droplets. At the exit of a blade row, the four major processes
associated with two phase flow, namely (a) droplet impingement process; (b) centrifugal action on droplets; (c) heat and mass transfer processes between the two phases; and (d) droplet size adjustment are taken into account. When the stage performance parameters are corrected for the afore-mentioned four processes, then one obtains the outlet conditions from a stage. The output of stage performance consist of two parts. First the following properties can be printed out before the afore-mentioned four processes are taken into account:

1. stage total pressure ratio
2. stage total temperature ratio
3. stage adiabatic efficiency
4. stage flow coefficient
5. axial velocity: (ft/sec) or (m/sec)
6. rotor speed: (ft/sec) or (m/sec)
7. total pressure: (lbf/ft$^2$) or (N/m$^2$)
8. static pressure: (lbf/ft$^2$) or (N/m$^2$)
9. total temperature of gas phase: (R) or (K)
10. static temperature of gas phase: (R) or (K)
11. static density of gas phase: (lbm/ft$^3$) or (kg/m$^3$)
12. static density of mixture: (lbm/ft$^3$) or (kg/m$^3$)
13. axial velocity: (ft/s) or (m/s)
14. absolute velocity: (ft/s) or (m/s)
15. relative velocity: (ft/s) or (m/s)
16. blade wheel speed: (ft/s) or (m/s)
17. tangential component of absolute velocity: (ft/s) or (m/s)
18. tangential component of relative velocity: (ft/s) or (m/s)
19. acoustic speed: (ft/sec) or (m/s)
20. absolute Mach number
21. relative Mach number
22. flow coefficient
23. stream tube area (ft$^2$) or (m$^2$)
24. absolute flow angle: (degree)
25. relative flow angle: (degree)
26. incidence: (degree)
27. deviation: (degree)
After the stage parameters are corrected for the afore-mentioned four processes, the following second part of output of stage performance can be printed out:

(1) stage total pressure ratio
(2) stage total temperature ratio
(3) stage adiabatic efficiency
(4) water vapor content: XV
(5) water content of small droplet: XW
(6) water content of large droplet: XWW
(7) total water content: XWT
(8) mass fraction of dry air: XAIR
(9) mass fraction of methane: XMETAN
(10) mass fraction of gaseous phase: XGAS
(11) mass flow rate of small droplet: WMASS (lbm/s) or (Kg/S)
(12) mass flow rate of large droplet: WWMASH (lbm/s) or (Kg/S)
(13) total mass flow rate of droplet: WTMASS (lbm/s) or (Kg/S)
(14) mass flow rate of dry air: AMASS (lbm/s) or (Kg/S)
(15) mass flow rate of methane: CHMASS (lbm/s) or (Kg/S)
(16) mass flow rate of water vapor: VMASS (lbm/s) or (Kg/S)
(17) mass flow rate of gaseous phase: GMASS (lbm/s) or (Kg/S)
(18) mass flow rate of mixture: TMASS (lbm/s) or (Kg/S)
(19) specific humidity: WS
(20) density of air: RHOA (lbm/ft³) or (Kg/m³)
(21) density of mixture: RHOM (lbm/ft³) or (Kg/m³)
(22) density of gaseous phase: RHOG (lbm/ft³) or (Kg/m³)
(23) temperature of gaseous phase: TG (R) or (K)
(24) temperature of small droplet: TW (R) or (K)
(25) temperature of large droplet: TWW (R) or (K)
(26) pressure: P (lbf/ft²) or (N/m²)
(27) boiling point: TB (R) or (K)
(28) dew point: TDEW (R) or (K)
5.5 Output of Overall Performance

At the end of compressor, the overall performance can be printed out. The properties to be printed out are as follows:

1. initial flow coefficient
2. corrected speed of compressor and fraction of design corrected speed
3. initial water content of small droplet
4. initial water content of large droplet
5. initial total water content
6. initial relative humidity
7. initial methane content
8. compressor inlet total temperature: (R) or (K)
9. compressor inlet total pressure: (lbf/ft²) or (N/m²)
10. corrected mass flow rate of mixture: (lbm/s) or (Kg/S)
11. corrected mass flow rate of gaseous phase: (lbm/s) or (Kg/S)
12. overall total pressure ratio
13. overall total temperature ratio
14. overall adiabatic efficiency
15. overall temperature rise of gaseous phase: (F) or (C)
CHAPTER VI

TEST CASE AND DISCUSSION

The performance calculation procedure is illustrated in the case of the Test-Compressor (referred to in Section 1.2) utilizing the correlations of performance parameters presented in Section 2.2 and the procedure for performance calculation presented in Sections 2.3 and 2.4.

The detailed printout of the input and output of the NASA-WISGSK Code is presented in Appendix 4 for the following two cases at a chosen value of inlet flow coefficient.

1) Test Case No. 1: Operation with air flow at 100 percent of the design speed at the meanline section of the compressor.

2) Test Case No. 2: Operation with air-water mixture containing large droplets (with a mass fraction of 0.040 of water) at 100 percent of design speed at the meanline section of the compressor.

Utilizing the same procedure, the performance of the Test Compressor has been determined at a number of operating conditions given in Table 2. The results of performance calculations have been presented in the following figures.

Figure 8(a): Overall stagnation pressure ratio as a function of gas phase corrected mass flow rate at tip section.

Figure 8(b): Overall stagnation temperature ratio as a function of gas phase corrected mass flow rate at tip section.
Figure 8(c): Overall adiabatic efficiency as a function of gas phase corrected mass flow rate at tip section.

Figure 9(a): Overall stagnation pressure ratio as a function of gas phase corrected mass flow rate at mean section.

Figure 9(b): Overall stagnation temperature ratio as a function of gas phase corrected mass flow rate at mean section.

Figure 9(c): Overall adiabatic efficiency as a function of gas phase corrected mass flow rate at mean section.

Figure 10(a): Overall stagnation pressure ratio as a function of gas phase corrected mass flow rate at hub section.

Figure 10(b): Overall stagnation temperature ratio as a function of gas phase corrected mass flow rate at hub section.

Figure 10(c): Overall adiabatic efficiency as a function of gas phase corrected mass flow rate at hub section.
6.1 Discussion

The NASA-WISGSK Code provides a means of calculating the overall performance of an axial-flow compressor with water ingestion at selected spanwise sections utilizing a one-dimensional calculation procedure. The principal inputs to the Code are the following at a particular spanwise section.

(i) The design point details of the compressor; and
(ii) The stage characteristics at a selected speed of operation with air flow and air-water mixture flow, the latter over the desired range of water mass fraction in the mixture.

The stage characteristics are then approximated at other values of operating speed and at other spanwise sections.

During the calculations of performance for the cases given in Table 2, the stage characteristics have been assumed for operation at 90 percent design speed and at the meanline section of the compressor. It can be seen from Figures 11(a) and 11(b) that the meanline predicted performance for the case of operation with air flow at 90 and 80 percent design speed values corresponds very nearly to the experimental data (Reference 6) obtained at that spanwise section and speed. At 100 percent design speed, it can be observed from the same figure that some difference arises between predictions and experimental data, although the general trend of performance is obtained qualitatively correctly.

By means of a trial and error procedure for adaptation of stage characteristics for each of the stages in the compressor, it is possible to obtain a prediction that is close to experimental data to any desired degree of agreement at any speed and at any section of the compressor. However, this involves considerable empiricism in the adaptation of stage characteristics for different operating conditions at different spanwise sections.
<table>
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<th>Range of Values</th>
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<td>1) Compressor speed</td>
<td>80, 90 and 100% design speed</td>
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<tr>
<td>2) Mass fraction of water in the mixture</td>
<td>0.000, 0.030, 0.040, 0.080 and 0.150</td>
</tr>
<tr>
<td>3) Mixture mass flow rates</td>
<td>At least five values at each speed</td>
</tr>
</tbody>
</table>
During water ingestion, the basic performance of a stage is again obtained in the NASA-WISGSK Code utilizing the stage characteristics estimated for one selected speed and one spanwise section at all other speeds and spanwise sections. Thus only the general trends in performance changes can be established.

A further limitation of the NASA-WISGSK Code procedure is that the ranges of mixture mass flow and water mass fraction over which predictions can be obtained become restricted to different extents at different speeds and at different spanwise sections. Thus, in the present case, the stage characteristics with water ingestion are estimated first at 90 percent design speed and at the tip section. They are then adapted for use at other speeds and spanwise sections. It is then found that depending upon the mass fraction of water at the entry section of the compressor the prediction of performance at the tip section for high water mass fraction values at a higher operating speed (say, 100 percent design speed) may only be carried out for a small range of mixture mass flows, considerably less than, for example, at the mean and hub sections of the compressor.

It may be pointed out that no general conclusions may be drawn at this stage of utilization of the Code regarding its applicability to various compressors of different design and operating conditions. At the same time, it is clear that (a) the trend of performance changes can be established utilizing the Code and (b) the limitations in applicability arise in regard to the ranges of (i) speed, (ii) mixture mass flow and (iii) water mass fraction.
Figure 1: Droplet Size Variations in Rain and Mist
Figure 2: Variation of Saturation Water Vapor Content in Ambient Air as a Function of Altitude
Reference Mean Droplet Velocity Vector in Sector (1)

$V_{g1}$: blade relative velocity at inlet

$V_{g2}$: blade relative velocity at outlet

$\beta_1$: blade relative flow angle at inlet

$\beta_2$: blade relative flow angle at outlet

Figure 3: Model for Large Droplet Motion
Figure 4(a): Deviation Constant vs Diffusion (Stage = 1)
$N / \sqrt{\theta} = 90\%$
Mean
Stage = 2
$D_0 = 600 \, \mu m$

$\delta - \delta^* = -K \left[ \frac{w_3}{w_2} - \left( \frac{w_3}{w_2} \right)^* \right]$
Figure 4(c): Deviation Constant vs Diffusion (Stage = 3-6)
Figure 5(a): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 1)

- $D_0 = 600 \, \mu m$
- $N\sqrt{\theta} = 90\%$
- Mean
- Stage = 1

Numbers indicate water content (%)

Pressure rise coefficient $\psi/\psi^*$ vs flow coefficient $\phi/\phi^*$
Figure 5(b): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 2)

- $D_0 = 600 \mu m$
- $N/\sqrt{\theta} = 90\%$
- Mean
- Stage = 2

Numbers indicate water content (%)
Figure 5(c): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 3)
Figure 5(d): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 4-6)

$D_0 = 600 \, \mu m$

$\sqrt{N/\theta} = 90\%$

MEAN

STAGE = 4, 5, 6

NUMBERS INDICATE WATER CONTENT (%)
Figure 6(a): Efficiency vs Flow Coefficient (Stage = 1)

- $D_0 = 600 \, \mu m$
- $N/\sqrt{\theta} = 90\%$
- MEAN
- STAGE = 1

Numbers indicate water content (%)

AD/ABATIC EFFICIENCY $\eta/\eta^*$ vs FLOW COEFFICIENT $\phi/\phi^*$
Figure 6(b): Efficiency vs Flow Coefficient (Stage = 2)
Figure 6(c): Efficiency vs Flow Coefficient (Stage = 3)

D₀ = 600 μm
N/√θ = 90%
MEAN
STAGE = 3

ADIASTIC EFFICIENCY

FLOW COEFFICIENT \( \phi/\phi^* \)

NUMBERS INDICATE WATER CONTENT (%)

Figure 6(c): Efficiency vs Flow Coefficient (Stage = 3)
Figure 6(d): Efficiency vs Flow Coefficient (Stage = 4-6)
Figure 7: Modification of Reference Efficiency Curve

1. Modification for Off-Reference Speed
2. Modification for Air-Water Mixture Flow
CORRECTED MASS FLOW RATE OF GAS PHASE

Figure 8(a): Predicted Overall Stagnation Pressure Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Tip Section
Figure 8(b): Predicted Overall Stagnation Temperature Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Tip Section
Figure 8(c): Predicted Overall Adiabatic Efficiency as a Function of Gas Phase Corrected Mass Flow at Tip Section
Figure 9(a): Predicted Overall Stagnation Pressure Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Mean Section
Figure 9(b): Predicted Overall Stagnation Temperature Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Mean Section
Figure 9(c): Predicted Overall Adiabatic Efficiency as a Function of Gas Phase Corrected Mass Flow Rate at Mean Section
Figure 10(a): Predicted Overall Stagnation Pressure Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Hub Section
CORRECTED MASS FLOW RATE OF GAS PHASE

Figure 10(b): Predicted Overall Stagnation Temperature Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Hub Section
Figure 10(c): Predicted Overall Adiabatic Efficiency as a Function of Gas Phase Corrected Mass Flow Rate at Hub Section
Figure 11(a): Overall Stagnation Pressure Ratio vs Gas Phase Corrected Mass Flow Rate ($N/\sqrt{\theta} = 80, 90, 100\%$, and Test Data)
Figure 11(b): Overall Stagnation Temperature Ratio vs Gas Phase Corrected Mass Flow Rate ($N/\sqrt{\delta} = 80, 90, 100\%$ and Test Data)
REFERENCES


APPENDIX 1

DETAILS OF COMPRESSOR USED FOR DEMONSTRATION OF CODE

The compressor utilized for demonstrating the application of the NASA-WISGSK Code is the so-called Test Compressor consisting of the six axial-flow stages of the ALLISON T63-A-5 engine compressor. The Test Compressor has been designed and built such that various stages of the compressor can be assembled and tested. Thus the first two, the intermediate two or the last two stages can be tested if desired, as well as the unit with all of the six stages. Only the 6-stage unit has been used in the current tests.

The first stage of the Test Compressor is preceded by an inlet guide vane row which imparts swirl to the inlet air. The relative Mach number of the incoming air at the rotor inlet is thereby reduced as far as permissible without causing inlet blockage. The axial component features unshrouded rotors, cantilever stators, and double circular arc blading in all stages. The values of T-63 compressor design velocity diagram are presented in Table A.1.1. Table A.1.3 and A.1.4 present the hardware geometry and aerodynamic design data for rotor and stator, respectively.

Figure A.1.1. to Figure A.1.6 show the stage performance characteristics of Test Compressor supplied by the manufacturer. In each of the figures, the equivalent pressure ratio, \( \psi \), equivalent temperature ratio, \( \tau \), and stage adiabatic efficiency, \( \eta \), are presented in terms of flow coefficient, \( \phi \). The definitions of these parameters are as follows:

\[ \phi = \frac{V_z}{U_{\text{tip}}} \]

\[ \psi = \left( \frac{U_{\text{tip}}}{T_{0_1}} \right) \left( \frac{T_{0_2}}{T_{0_1}} \right) \left( \frac{P_{0_2}}{P_{0_1}} \right) \frac{Y-1}{Y} -1 \right] + 1 \frac{Y}{Y-1} \]
(iii) equivalent temperature ratio:

\[ r = \left( \frac{U_{\text{tip}}}{T_{01}} \right)^2 \cdot \left( \frac{\Delta T_0}{U_{\text{tip}}} \right) \]

(iv) stage adiabatic efficiency:

\[ \eta = T_{01} \left( \frac{P_{02}}{P_{01}} \right)^{\frac{\gamma-1}{\gamma}} \cdot \frac{1}{\Delta T_0} \cdot \left( \frac{\gamma-1}{\gamma} \cdot \frac{T_{01}}{T_0} - 1 \right) \]

where \( \Delta T_0 \) is stage total temperature rise, \( P_0 \) total pressure, \( T_0 \) total temperatures, \( V_z \) axial velocity, \( U_{\text{tip}} \) blade tip wheel speed, \( \gamma \) specific heat ratio. The subscripts 1 and 2 mean inlet and outlet, respectively, and \( D \) design value.

Figure A.1.7 shows overall performance characteristics of Test Compressor supplied by the manufacturer. The performance parameters are the following:

(1) Corrected mass flow rate \[ = \frac{m \sqrt{\theta}}{\delta} \]

where \( m \) = mass flow rate

\( P_{01} \) = compressor inlet pressure

\( T_{01} \) = compressor inlet temperature

\( \theta = T_{01} / T_{\text{ref}} \)

\( \delta = P_{01} / P_{\text{ref}} \)

\( T_{\text{ref}} = 58.7^\circ F \) (15.2°C)

\( P_{\text{ref}} = 14.7 \) psig \((1.0132 \times 10^5 \text{N/m}^2)\)

(2) Corrected speed \[ = \frac{N}{\sqrt{\theta}} \]

where \( N \) = rotor speed (RPM)

(3) Overall total pressure ratio \[ = \frac{P_{02}}{P_{01}} \]

where \( P_{01} \) = compressor inlet total pressure

\( P_{02} \) = compressor outlet total pressure

(4) Overall adiabatic efficiency \[ = \eta = \frac{T_{01}}{\Delta T_0} \left( \frac{P_{02}}{P_{01}} \right)^{\frac{\gamma-1}{\gamma}} \cdot \left( \frac{\gamma-1}{\gamma} \cdot \frac{T_{01}}{T_0} - 1 \right) \]

where \( T_{01} \) = compressor inlet total temperature
\[ \Delta T_0 = \text{compressor total temperature rise} \]

\[ P_{02}/P_{01} = \text{overall total pressure ratio} \]

\[ \gamma = \text{ratio of specific heats} \]
TABLE A.1.1.
TEST COMpressor DESIGN VELOCITY DIAGRAM VALUES

<table>
<thead>
<tr>
<th>Stage</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
</tr>
<tr>
<td>U</td>
<td>963.5</td>
<td>963.5</td>
<td>963.5</td>
<td>963.5</td>
<td>963.5</td>
<td>963.5</td>
</tr>
<tr>
<td>$V_{z1}$</td>
<td>508.4</td>
<td>544.1</td>
<td>547.0</td>
<td>554.9</td>
<td>554.1</td>
<td>543.7</td>
</tr>
<tr>
<td>$V_{01}$</td>
<td>236.5</td>
<td>310.0</td>
<td>365.1</td>
<td>349.3</td>
<td>338.8</td>
<td>333.8</td>
</tr>
<tr>
<td>$\omega_{01}$</td>
<td>727.0</td>
<td>653.5</td>
<td>598.4</td>
<td>614.2</td>
<td>624.7</td>
<td>629.9 Rotor Inlet</td>
</tr>
<tr>
<td>$\alpha_{1}$</td>
<td>25.0</td>
<td>29.7</td>
<td>33.7</td>
<td>32.2</td>
<td>31.6</td>
<td>31.5</td>
</tr>
<tr>
<td>$\beta_{1}$</td>
<td>54.9</td>
<td>50.3</td>
<td>47.6</td>
<td>47.9</td>
<td>48.5</td>
<td>49.3</td>
</tr>
<tr>
<td>$M_{1abs}$</td>
<td>0.513</td>
<td>0.563</td>
<td>0.578</td>
<td>0.560</td>
<td>0.538</td>
<td>0.512</td>
</tr>
<tr>
<td>$M_{1rel}$</td>
<td>0.812</td>
<td>0.769</td>
<td>0.713</td>
<td>0.706</td>
<td>0.692</td>
<td>0.658</td>
</tr>
<tr>
<td>$V_{z2}$</td>
<td>507.0</td>
<td>554.9</td>
<td>551.0</td>
<td>554.5</td>
<td>548.9</td>
<td>544.6</td>
</tr>
<tr>
<td>$V_{02}$</td>
<td>405.2</td>
<td>501.3</td>
<td>598.8</td>
<td>614.6</td>
<td>625.1</td>
<td>630.3</td>
</tr>
<tr>
<td>$\omega_{02}$</td>
<td>558.3</td>
<td>462.2</td>
<td>364.7</td>
<td>348.9</td>
<td>338.4</td>
<td>333.2 Rotor Outlet</td>
</tr>
<tr>
<td>$\alpha_{2}$</td>
<td>38.6</td>
<td>42.1</td>
<td>47.4</td>
<td>47.9</td>
<td>48.7</td>
<td>49.2</td>
</tr>
<tr>
<td>$\beta_{2}$</td>
<td>47.8</td>
<td>39.8</td>
<td>33.6</td>
<td>32.2</td>
<td>31.7</td>
<td>31.5</td>
</tr>
<tr>
<td>$M_{2abs}$</td>
<td>0.588</td>
<td>0.665</td>
<td>0.706</td>
<td>0.698</td>
<td>0.680</td>
<td>0.660</td>
</tr>
<tr>
<td>$M_{2rel}$</td>
<td>0.683</td>
<td>0.643</td>
<td>0.574</td>
<td>0.552</td>
<td>0.528</td>
<td>0.506</td>
</tr>
</tbody>
</table>

Note: Symbols for Table A.1.1 are provided in Table A.1.2.
TABLE A.1.2
SYMBOLS FOR TEST COMPRESSOR DESIGN VELOCITY DIAGRAM VALUES

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Radius, inches</td>
</tr>
<tr>
<td>U</td>
<td>Rotor speed at R, ft/sec.</td>
</tr>
<tr>
<td>$V_z$</td>
<td>Air axial velocity, ft/sec.</td>
</tr>
<tr>
<td>$V_\theta$</td>
<td>Air absolute tangential velocity, ft/sec.</td>
</tr>
<tr>
<td>$W_\theta$</td>
<td>Air relative tangential velocity, ft/sec.</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Air absolute flow angle, degrees</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Air relative flow angle, degrees</td>
</tr>
<tr>
<td>M</td>
<td>Mach number</td>
</tr>
</tbody>
</table>

Subscript:
- 1: rotor inlet
- 2: rotor outlet
- abs: absolute
- rel: relative
### TABLE A.1.3
**TEST COMPRESSOR DESIGN DATA (ROTOR)**

<table>
<thead>
<tr>
<th>Stage</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>R</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
</tr>
<tr>
<td>Chamber Angle</td>
<td>θ</td>
<td>22.6</td>
<td>15.9</td>
<td>18.0</td>
<td>19.7</td>
<td>20.9</td>
</tr>
<tr>
<td>Stagger</td>
<td>γ</td>
<td>46.1</td>
<td>42.3</td>
<td>36.5</td>
<td>36.1</td>
<td>36.0</td>
</tr>
<tr>
<td>Incidence</td>
<td>i</td>
<td>0.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Deviation</td>
<td>δ</td>
<td>7.3</td>
<td>5.4</td>
<td>6.0</td>
<td>6.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Chord</td>
<td>c</td>
<td>0.605</td>
<td>0.554</td>
<td>0.534</td>
<td>0.510</td>
<td>0.483</td>
</tr>
<tr>
<td>Solidity</td>
<td>σ</td>
<td>0.713</td>
<td>0.815</td>
<td>0.787</td>
<td>0.941</td>
<td>0.997</td>
</tr>
<tr>
<td>Max. Thickness</td>
<td>t</td>
<td>0.036</td>
<td>0.039</td>
<td>0.037</td>
<td>0.036</td>
<td>0.034</td>
</tr>
<tr>
<td>Thickness-Chord Ratio</td>
<td>t/c</td>
<td>0.060</td>
<td>0.070</td>
<td>0.070</td>
<td>0.070</td>
<td>0.070</td>
</tr>
<tr>
<td>No. of Blades</td>
<td>n</td>
<td>16</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>28</td>
</tr>
</tbody>
</table>

Note: R, c, t in (inches) and θ, γ, δ, i in (degrees)

### TABLE A.1.4
**TEST COMPRESSOR DESIGN DATA (STRATOR)**

<table>
<thead>
<tr>
<th>Stage</th>
<th>IGV</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>R</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
<td>2.161</td>
</tr>
<tr>
<td>Camber Angle</td>
<td>θ</td>
<td>31.7</td>
<td>22.4</td>
<td>25.6</td>
<td>26.2</td>
<td>24.4</td>
<td>24.7</td>
</tr>
<tr>
<td>Stagger</td>
<td>γ</td>
<td>-15.9</td>
<td>31.3</td>
<td>36.3</td>
<td>36.6</td>
<td>36.8</td>
<td>37.4</td>
</tr>
<tr>
<td>Incidence</td>
<td>i</td>
<td>0.0</td>
<td>-2.0</td>
<td>-2.0</td>
<td>-2.0</td>
<td>-2.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>Deviation</td>
<td>δ</td>
<td>6.7</td>
<td>9.6</td>
<td>5.2</td>
<td>8.0</td>
<td>7.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Chord</td>
<td>c</td>
<td>1.395</td>
<td>0.442</td>
<td>0.412</td>
<td>0.412</td>
<td>0.412</td>
<td>0.412</td>
</tr>
<tr>
<td>Solidity</td>
<td>σ</td>
<td>0.719</td>
<td>0.456</td>
<td>0.789</td>
<td>0.850</td>
<td>0.972</td>
<td>1.093</td>
</tr>
<tr>
<td>Max. Thickness</td>
<td>t</td>
<td>0.170</td>
<td>0.040</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>Thickness-Chord Ratio</td>
<td>t/c</td>
<td>0.122</td>
<td>0.09</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>No. of Blades</td>
<td>n</td>
<td>7</td>
<td>14</td>
<td>26</td>
<td>28</td>
<td>32</td>
<td>36</td>
</tr>
</tbody>
</table>

Note: R, c, t in (inches) and θ, γ, δ, i in (degrees)
Figure A.1.1 Stage Characteristics of Test Compressor (1st Stage)
Figure A.1.2 Stage Characteristics of Test Compressor (2nd Stage)
Figure A.1.3 Stage Characteristics of Test Compressor (3rd Stage)
Figure A.1.4 Stage Characteristics of Test Compressor (4th Stage)
Figure A.1.5 Stage Characteristics of Test Compressor (5th Stage)
Figure A.1.6 Stage Characteristics of Test Compressor (6th Stage)
Figure A.1.7 Overall Performance of Test Compressor
APPENDIX 2

DETAILED DESCRIPTION OF SUBROUTINES
AND EXTERNAL FUNCTIONS

Each of the subroutines and external functions is presented as follows: (1) Description, (2) Input variables, (3) Output variables, and (4) Usage.

SUBROUTINE WICSPD

(1) Description:
The subroutine WICSPD is used for the calculation of design point performance. The properties obtained in this subroutine become reference properties for calculation of off-design performance.

(2) Input Variables:
AMASS mass flow rate
ISTAGE stage at which performance calculation is carried out

(3) Output Variables:
none

(4) Usage:
CALL WICSPD (AMASS, ISTAGE)

SUBROUTINE WICCEN

(1) Description:
The subroutine WICCEN is used for the calculation of spanwise replacement of droplets due to centrifugal action.

Three forces act on a droplet moving through a fluid:
(1) the external force consisting of gravitational and
centrifugal forces; (2) the buoyancy force, which acts parallel to the external force, but in the opposite direction; and (3) the drag force, which appears whenever there is relative motion between the droplet and the fluid, and acts parallel to the direction of motion but in the opposite direction. In the present case, the direction of motion of a droplet relative to the fluid is not parallel to the direction of the external and buoyant forces, and therefore the drag force makes an angle with the other two forces. However, under the one-dimensional approximation, the lines of action of all forces acting on the droplet are co-linear and therefore the forces may be added in obtaining a balance of momentum, as follows:

\[
\frac{m}{g_c} \frac{du}{dt} = F_e - F_b - F_D
\]

where \( F_e \), \( F_b \) and \( F_D \) are the external, buoyance and drag forces respectively.

The external force can be expressed as the product of mass and acceleration, \( a_e \), of the droplet due to this force, and therefore

\[
F_e = \frac{m}{g_c} a_e.
\]

In the present case, because of the large rotor speeds, the centrifugal acceleration is far larger than the gravitational acceleration. Thus

\[
a_e = r \omega^2
\]

where \( r \) is the radius and \( \omega \), the angular velocity. The acceleration can also be written as follows:

\[
a_e = \frac{V_\theta^2}{r}
\]

where \( V_\theta \) is the circumferential velocity of the droplet. For droplets passing through a rotor blade passage, the
circumferential component of the relative velocity, $W_\theta$, should be used in place of $V_g$. When there is a large change in whirl velocity between the inlet and outlet of a blade row, a mean value of velocity may be more applicable.

The buoyancy force is, by Archimedes' Principle, the product of the mass of the fluid displaced by the droplet and the acceleration from the external force. The mass of fluid displaced is $(m/\rho_w)\rho_g$, where $\rho_w$ is the density of water and $\rho_g$ is the density of the surrounding fluid. The buoyancy force is then given

$$F_b = m\rho_g a_e/\rho_w g_c.$$ 

The drag force is expressed by the relation,

$$F_d = C_D \rho_g u^2 A_p,$$

where $C_D$ is the drag coefficient and $A_p$ is the projected area of the droplet measured in a plane perpendicular to the direction of motion of the droplet. The drag coefficient $C_D$ can be expressed in a general form as follows:

$$C_D = b_1/Re^n$$

where $Re$ is the Reynolds number based on relative velocity between gas and droplet. The constants $b_1$ and $n$ are as follows:

- $b_1 = 24.0$, $n = 1.0$ when $Re < 1.9$
- $b_1 = 18.5$, $n = 0.6$ when $1.9 < Re < 500$
- $b_1 = 0.44$, $n = 0.0$ when $500 < Re < 200,000$.

The equation of droplet motion then becomes the following:

$$\frac{du}{dt} = A/r - Bu^{2-n}$$

where

$$A = (W_\theta)_{\text{ave}}^2 \cdot (1 - \rho_g/\rho_w),$$
B = 3u^n b_1 \rho g 1-n/4 \rho_w D^{1+n}, and

D being the average droplet diameter. Over a small time
interval, the equation of motion can be written as follows:
\[ \Delta u = (A/r - Bu^{2-n}) \Delta t. \]

This equation can be used to determine the radial location of
a droplet in a stage as follows:
(i) Select the initial values for \( u_1 \) and \( r_1 \).
(ii) Calculate the Reynolds number to determine the values
of \( b_1 \) and \( n \).
(iii) Calculate \( A \) and \( B \).
(iv) Calculate the change of \( u \) during time interval \( \Delta t \).
(v) Calculate the new velocity \( u_2 \).
\[ u_2 = u_1 + \Delta u \]
(vi) Calculate the change in location of droplet in terms
of \( \Delta r \).
\[ \Delta r = (u_1 + u_2)/2.0 \cdot \Delta t \]
(vii) Calculate the new radial location.
\[ r_2 = r_1 + \Delta r \]
(viii) Repeat the calculation for new value of \( u_2 \) and \( r_2 \) and
progressively extend the calculation.

The time interval should be sufficiently small in order to
obtain reasonable accuracy. As stated in Section 2.1.3 in
Chapter II of Reference 4, the length between the leading
and trailing edges of a blade is divided into ten steps. The
time interval \( \Delta t \) is then given by the relation, namely
\[ \Delta t = \frac{\text{chord}}{V} \times \frac{1}{10} \]

where \( V \) is the velocity of mixture in the blade passage.

(2) Input Variables:
RZERO droplet spanwise location at rotor inlet
UZERO droplet spanwise velocity at rotor inlet
DD: droplet diameter
VZ: axial velocity
DELZZ: axial length of a stage
ALFAAV: average flow angle
FN: rotor blade rotational speed
IRS: index for rotor or stator
RHOGAS: density
RHUB: radius at hub
XG: mass fraction of gas phase
XA: mass fraction of dry air
XVV: mass fraction of vapor
XCH4: mass fraction of methane
RTIPIN: radius at blade tip

(3) Output Variables:
R2: droplet spanwise location blade outlet
U2: droplet spanwise velocity at blade outlet
ITIP: index for droplet spanwise location
VŽTIME: time in which flow pass through a stage

(4) Usage:
CALL WICCE (RZERO, VZERO, DD, VZ, DELZZ, ALFAAV, FN, IRS,
RHOGAS, RHUB, R2, U2, ITIP, VŽTIME, XG, XA, XVV,
XCH4, RTIPIN)

SUBROUTINE WICDMS

(1) Description:
The subroutine WICDMS is used for the calculation of amount of small droplets which is centrifuged.

(2) Input Variables:
IPRINT: index for printout
IRAD: index for spanwise location
AMASW1: mass flow rate of water at rotor inlet
AMASWT: mass flow rate of droplet
AMASW: mass flow rate of droplet
R1: droplet spanwise location rotor inlet
R2  droplet spanwise location at rotor outlet
STAREA  streamtube area
RSTAVE  radius of streamtube at its center
RTIP  radius at blade tip

(3) Output Variables:
DMIN  amount of water that is centrifuged and enters into a streamtube
DMOUT  amount of water that is centrifuged and leaves from a streamtube
AMASW2  mass fraction of water at rotor outlet after correction for centrifugal action
DELMAS  net amount of water that is centrifuged

(4) Usage:
CALL WICDMS (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1, R2, STAREA, RSTAVE, RTIP, DMIN, DMOUT, AMASW2, DELMAS)

SUBROUTINE WICDML

(1) Description:
The subroutine WICDML is used for the calculation of amount of large droplets which is centrifuged.

(2) Input Variables:
IPRINT  index for printout
IRAD  index for spanwise location
AMASW1  mass flow rate of water at rotor inlet
AMASWT  mass flow rate of droplet
AMASW  mass flow rate of droplet
R1  droplet spanwise location rotor inlet
R2  droplet spanwise location at rotor outlet
STAREA  streamtube area
RSTAVE  radius of streamtube at its center
RTIP  radius at blade tip
(3) Output Variables:

DMIN  amount of water that is centrifuged and enters into a streamtube

DMOUT  amount of water that is centrifuged and leaves from a streamtube

AMASW2  mass fraction of water at rotor outlet after correction for centrifugal action

DELMAS  net amount of water that is centrifuged

(4) Usage:

CALL WICDML (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1, R2, STAREA, RSTAVE, RTIP, DMIN, DMOUT, AMASW2, DELMAS)

SUBROUTINE WICMAC

(1) Description:

Subroutine WICMAC calculates the Mach number in the gas-water droplet mixture. First the acoustic speed in gaseous phase is determined by iteration as follows:

(i) Assume Mach number and calculate static temperature and density.

\[ T = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-1} T_0 \]

\[ \rho = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-1/\gamma} \rho_0 / RT_0 \]

(ii) Calculate acoustic speed in gaseous phase

\[ a_g = (\gamma R T_0 C_p)^{0.5} \]

(iii) Calculate the axial velocity

\[ V_z = \frac{m}{\rho A} \]

(iv) Calculate absolute velocity

\[ V_1 = V_z / \cos \alpha_1 \]

(v) Calculate Mach number

\[ M_1 = \frac{V_1}{a_g} \]
Compare the calculated Mach number with the assumed value in (i). Iterate steps (i) to (v) until the desired accuracy is obtained. After determining the acoustic speed in gaseous phase, Function WICASD is called to determine the acoustic speed in droplet-laden gas flow.

(2) Input Variables:
- ISTAGE stage number
- AMASSM mixture mass flow rate
- TOLG total temperature of gaseous phase
- PRES total pressure
- XWL total water content
- ALFA stator outlet angle of the previous stage
- RMIX gas content of gaseous phase
- CPMIX specific heat at constant pressure for gaseous phase

(3) Output Variables:
- M Mach number
- VZ axial velocity
- C acoustic speed in mixture

(4) Usage:
CALL WICMAC (ISATE, AMASSM, TOLG, PRES, M, VZ, C, XWL, ALFA, RMIX, CPMIX)

FUNCTION WICASD

(1) Description:
Function WICASD calculates the acoustic speed in droplet-laden gas flow. The following equation is used (Ref. 10).

\[ a = \left( (1 - \sigma_v) \rho_g + \sigma_v \rho_w \right)^{-1/2} \left( \frac{1 - \sigma_v}{\rho_g a_g} + \frac{\sigma_v}{\rho_w a_w} \right) \]

where
- \( a_g \) = acoustic speed in gaseous phase

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\( a_w = \text{acoustic speed in water} \)
\( \rho_g = \text{density of gaseous phase} \)
\( \rho_w = \text{density of water} \)
\( \sigma_v = \text{particulate liquid volume fraction} \)
\( x_w = \text{particulate liquid mass fraction} \)
\( \sigma_v = x_w \rho_g/(\rho_w - x_w(\rho_w - \rho_g)) \)

(2) Input Variables:
- XW total water content
- RHOG density of gas phase
- CG acoustic speed of gaseous phase

(3) Output Variable:
- WICASD acoustic speed in gas-water droplet mixture

(4) Usage:
- WICASD (XW, RHOG, CG)

SUBROUTINE WICIRS

(1) Description:
Subroutine WICIRS is called at outlet of rotor and performs the calculation of droplet impingement and rebound in rotor passage for small droplet.

(2) Input Variables:
- ISTAGE stage number
- RTIPIN blade tip radius
- XW1 mass fraction of small droplet
- XG mass fraction of gaseous phase
- RHOG1 density of gaseous phase
- BETA1 rotor inlet relative flow angle
- WI1 rotor inlet relative velocity

(3) Output Variables:
- WW1 amount of water that impacts stagnation region of blade
- WW2 amount of water that impacts aft of blade
- WW total amount of water that impacts blade
(4) Usage:
CALL WICIRS (ISTAGE, RTIPIN, XW1, XG, RHOG1, BETA1, W1, WW1, WW2, WW)

SUBROUTINE WICIRL
(1) Description:
Subroutine WICIRL is called at outlet of rotor and performs the calculation of droplet impingement and rebound in rotor passage for large droplet.

(2) Input Variables:
ISTAGE stage number
RTIPIN blade tip radius
XW1 mass fraction of large droplet
XG mass fraction of gaseous phase
RHOG1 density of gaseous phase
BETA1 rotor inlet relative flow angle
W1 rotor inlet relative velocity

(3) Output Variables:
WW1 amount of water that impacts upper surface of blade
WW2 amount of water that impacts lower surface of blade
WW amount of water that impacts blade surface

(4) Usage:
CALL WICIRL (ISTAGE, RTIPIN, XW1, XG, RHOG1, BETA1, W1, WW1, WW2, WW)

SUBROUTINE WICISS
(1) Description:
Subroutine WICISS is called outlet of stator and performs the calculation of droplet impingement and rebound in stator passage for small droplet.
(2) Input Variables:
ISTAGE  stage number
RTIPIM  blade tip radius
XW      mass fraction of small droplet
XG      mass fraction of gaseous phase
RHOG1   density of gaseous phase
ALFA2   stator inlet absolute flow angle
Wl      stator inlet absolute velocity

(3) Output Variables:
WWl     amount of water that impacts stagnation region of blade
WW2     amount of water that impacts off of blade
WW      total amount of water that impacts the blade

(4) Usage:
CALL WICISS (ISTAGE, TRIPIM, XW, XG, RHOG1, ALFA2, Wl, WWl, WW2, WW)

SUBROUTINE WICISL
(1) Description:
Subroutine WICISL is called at outlet of stator and performs the calculation of droplet impingement and rebound in stator passage for large droplet.

(2) Input Variables:
ISTAGE  stage number
RTIPIM  blade tip radius
XW      mass fraction of
XG      mass fraction of gaseous phase
RHOG1   density of gaseous phase
ALFA2   stator inlet absolute flow angle
Wl      stator inlet absolute velocity

(3) Output Variables:
WWl     amount of water that impacts upper surface of blade
WW2 amount of water that impacts lower surface of blade
WW total amount of water that impacts on blade surface

(4) Usage:
CALL WICISL (ISTAGE, RTIPIN, XW, XG, RHOG1, ALFA2, W1, WW1,
WW2, WW)

SUBROUTINE WICWAK

(1) Description:
Subroutine WICWAK is called at rotor outlet and stator outlet,
and calculates the droplet size of water that is re-entrained
at trailing edge of rotor and stator blades.

(i) Assume a value for a droplet diameter, d, that is
re-entrained into wake.
(ii) Calculate the stability number, SN.
SN = \( \frac{u_f^2}{\rho \sigma d g_c} \)
(iii) Calculate the critical Weber number
\( We = 12 \left( 1 + (SN)^{0.36} \right) \)
(iv) Calculate the largest stable droplet diameter
\( d_{max} = \frac{We \sigma g_c}{\rho_g V_c g} \)
(v) Compare the assumed droplet diameter with the calculated one. Iterate entire steps until the satisfactory agreement is obtained.

(2) Input Variables:
RHOG density of gaseous phase
V velocity of gaseous phase for small droplet or
relative velocity between droplet and gaseous phase for large droplet
(3) Output Variables:

DWAKE  droplet size that re-entrained at trailing edge
       in(ft^2)

DWAKEM droplet size that re-entrained at trailing edge
       in(\mu m)

(4) Usage:

CALL WICWAK (RHOG, V, DWAKE, DWAKEM)

SUBROUTINE WICHET

(1) Description:

Subroutine WICHET is called at end of stage to perform the
heat transfer calculation between water droplet and gaseous
phase. The heat transfer rate can be determined from the
following equation:

\[ \frac{dh}{dt} = h_A (T_g - T_w) \]

where \( h_A \) is the heat transfer coefficient, \( A \), the droplet
surface area, \( T_w \), the droplet surface temperature, and \( T_g \),
the temperature of the surrounding gas. The heat transfer
coefficient can be expressed as follows:

\[ h_A = \frac{k_a}{D_d} \cdot Nu \]

where \( k_a \) is the thermal conductivity of air, and \( Nu \), the
Nusselt Number. The Nusselt number can be expressed in terms
of the dimensionless groups as follows:

\[ Nu = 2.0 + 0.6 \cdot (Re)^{0.50} \cdot (Pr)^{0.33} \]

where \( Re \) is the Reynolds number based on the relative velocity
between the droplet and the surrounding air, and \( Pr \) is Prandtl
number.

After calculating the temperature rise of the water and gas
phase due to the work done by the rotor, the heat transfer
calculation is carried out as follows:
(i) Calculate the average droplet diameter, $D_d$.

(ii) Calculate the number of droplets, $N_d$.

$$N_d = \frac{m_w}{\rho_w \pi (D_d/2)^3} \cdot \frac{\Delta z}{z}$$

where $m_w$ is the mass flow rate of water phase, $\rho_w$, the density of water, $V_z$, the axial direction velocity, and $\Delta z$, the axial length of one stage.

(iii) Calculate the droplet surface area, $A$.

(iv) Calculate the Nusselt number, $Nu$.

(v) Calculate the heat transfer coefficient, $h_h$.

(vi) Calculate the stage outlet temperature for droplet and gas without heat transfer, that is

$$T_{g_2} = T_{g_1} + (\Delta T_{g wk})$$
$$T_{w_2} = T_{w_1} + (\Delta T_{w wk})$$

where $(\Delta T_{g wk})$ and $(\Delta T_{w wk})$ are the temperature rise of gas and water due to work done by rotor.

(vii) Calculate the amount of heat transferred from the gas to the droplet.

$$\Delta H = h_h A (T_{g_2} - T_{w_2})$$

(viii) Calculate the temperature rise of the droplet and the temperature drop of the surrounding gas.

$$(\Delta H_{g ht}) = \Delta H/m_c g_s$$

$$(\Delta H_{w ht}) = \Delta H/m_c w_w$$

where $C_w$ is the specific heat for water and $C_S$ is the humid heat for air-water mixture.

(ix) Calculate the stage outlet temperature for droplet and gas.

$$T_{g_2} = T_{g_1} + (\Delta T_{g wk}) - (\Delta T_{g ht})$$
$$T_{w_2} = T_{w_1} + (\Delta T_{w wk}) + (\Delta T_{w ht})$$
Using the temperature calculated in step (ix), repeat the steps (vii) to (ix) until a desired accuracy is obtained.

(2) **Input Variables:**
- $T_{G1}$: temperature of gaseous phase at stage inlet
- $T_{G3}$: temperature of gaseous phase at stage outlet
- $T_{W1}$: temperature of droplet at stage inlet
- $T_{W3}$: temperature of droplet at stage outlet
- $D_{AVEN2}$: droplet nominal diameter at stage inlet
- $D_{AVEN}$: droplet nominal diameter at stage outlet
- $D_{ELZI}$: length of stage
- $V_{Z}$: axial velocity
- $W_{MASS1}$: mass flow rate of water
- $V_{MASS1}$: mass flow rate of water vapor
- $A_{MASS}$: mass flow rate of dry air
- $C_{HAMASS}$: mass flow rate of methane
- $D_{PG}$: specific heat constant pressure to gaseous phase
- $C_{PW}$: specific heat of water
- $R_{E}$: Reynolds number based on relative velocity between droplet and gaseous phase

(3) **Output Variables:**
- $D_{ELIGH}$: temperature drop in gaseous phase due to heat transfer between water droplet and gaseous phase
- $D_{ELTWH}$: temperature rise in droplet due to heat transfer between water droplet and gaseous phase

(4) **Usage:**
```
CALL WICHET (T_{G1}, T_{G3}, T_{W3}, D_{AVEN2}, D_{AVEN}, D_{ELZI}, V_{Z}, W_{MASS1},
             V_{MASS1}, A_{MASS}, C_{HAMASS}, C_{PG}, C_{PW}, D_{ELIGH}, D_{ELTWH},
             R_{E})
```

**SUBROUTINE WICMAS**

(1) **Description:**
Subroutine WICMAS is called at end of stage to perform the mass transfer calculation between water droplet and gas phases.
The mass transfer rate can be calculated by the following equation:

\[
\frac{dm}{dt} = h_m A (C_{wb} - C_w)
\]

where \( h_m \) is the mass transfer coefficient, \( A \), the droplet surface area, \( C_{wb} \), the water vapor concentration at droplet surface, and \( C_w \), the water vapor concentration in fluid flow around droplet.

Since the density represents the mass concentration, and the vapor is almost a perfect gas, the mass transfer rate can be expressed in terms of vapor pressure as follows:

\[
\frac{dm}{dt} = h_m A (\rho_{wb} - \rho_w)
\]

or

\[
\frac{dm}{dt} = h_m A \left( \frac{P_{wb}}{T_{wb}} - \frac{P_w}{T_w} \right) \cdot \frac{1}{R_v}
\]

where \( R_v \) is the gas constant for water vapor, \( P_{wb} \), the vapor pressure at droplet surface, \( P_w \), the vapor pressure in fluid flowing around droplet, \( T_{wb} \), the vapor temperature at droplet surface, and \( T_w \), the vapor temperature in fluid flowing around droplet.

The surface area, \( A \), for the droplet cloud is given by the relation,

\[
A = \pi D_d^2 N_d
\]

where \( D_d \) is the average droplet diameter, and \( N_d \), the number of droplets.

The mass transfer coefficient, \( h_m \), is expressed as follows:

\[
h_m = \frac{D_v}{D_d} \cdot Sh
\]
A semi-empirical equation for the diffusion coefficient in gases is given by the following: (Reference 11)

\[ D_v = 435.7 \frac{T^{3/2}}{p(V_A^{1/3} + V_B^{1/3})^2} \left( \frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2} \]

where \( D_v \) is in square centimeters per second, \( T \) is in degree Kelvin, \( p \) is the total system pressure in newtons per square meter, and \( V_A \) and \( V_B \) are the molecular volumes of constituents A and B as calculated from the atomic volumes. \( M_A \) and \( M_B \) are given as follows:

\[ V_A = V_{\text{air}} = 29.9 \quad M_A = M_{\text{air}} = 28.9 \]
\[ V_B = V_{\text{water}} = 18.8 \quad M_B = M_{\text{water}} = 18.0 \]

When the relative velocity between a single droplet and the surrounding fluid approaches zero, the following relationship is used to determine the mass transfer rate:

\[ \text{Sh} = 2.0. \]

Mass transfer rates increase with increase in relative velocity between the droplet and the surrounding air due to the additional mass transfer caused by the convection in the boundary layer around the droplet. The mass transfer coefficient from a spherical droplet can be expressed in terms of dimensionless groups as follows:

\[ \text{Sh} = 2.0 + k \text{Re}^x \text{Sc}^y \]

where \( \text{Re} \) is the Reynolds number based on relative velocity, which expresses the ratio of inertial force to viscous force, and \( \text{Sc} \) is the Schmidt number, which expresses the ratio of kinetic viscosity to molecular diffusivity.

There is much discussion over the values of \( x, y, \) and \( k. \) The form most widely applied is the Ranz and Marshall equation which is

\[ \text{Sh} = 2.0 + 0.6 \text{Re}^{0.50} \text{Sc}^{0.33} \]
The procedure for determining the mass transfer rate is as follows:

(i) Calculate the Sherwood number, \( Sh \).

(ii) Calculate the diffusion coefficient, \( D_v \).

(iii) Calculate the average droplet size, \( D_d \).

(iv) Calculate the mass transfer coefficient, \( h_m \).

(v) Calculate the total number of droplets, \( N_d \).

(vi) Calculate the total surface area for all droplets.

(vii) Calculate the water vapor pressure at droplet surface, \( P_{wb} \), based on the droplet surface temperature, \( T_s \).

(viii) Assume the vapor pressure, \( P_w \), and set \( P_w = (P_w)_a \).

(ix) Calculate the mass transfer rate, \( \frac{dm}{dt} \).

(x) Calculate the new value of water mass flow rate.

\[ m_w = m_w - \frac{dm}{dt} \]

(xi) Calculate the new value of vapor mass flow rate.

\[ m_v = m_v + \frac{dm}{dt} \]

(xii) Calculate the specific humidity, \( W \).

\[ W = \frac{m_v}{m_a} \]

where \( m_a \) is the air mass flow rate.

(xiii) Calculate the vapor pressure.

(xiv) Compare the calculated value, \( (P_w)_c \), with the assumed value \( (P_w)_a \).

If \( (P_w)_c \) agrees reasonably well with the assumed value \( (P_w)_C \) proceed to step (xv). Otherwise, steps (viii) to (xiv) should be repeated.

(xv) Using the determined \( P_w \), the mass transfer rate is calculated. Also, the specific humidity can be determined by the following equation:

\[ W = 0.6219 \frac{P_w}{P - P_w} \]
Input Variables:

- HW1: specific humidity at stage inlet
- TW1: temperature of droplet at stage inlet
- TW2: temperature of droplet at stage outlet
- PP1: pressure of gaseous phase at stage inlet
- PP2: pressure of gaseous phase at stage outlet
- TG1: temperature of gaseous phase at stage inlet
- TG2: temperature of gaseous phase at stage outlet
- DZ: length of stage
- VZ: axial velocity
- DDAVE1: droplet nominal diameter at stage inlet
- DDAVE2: droplet nominal diameter at stage outlet
- AMASS: mass flow rate of air
- RE: Reynolds number based on relative velocity between droplet and gaseous phase
- VMASS1: mass flow rate of water vapor at stage inlet
- WMASS1: mass flow rate of water droplet at stage outlet

Output Variables:

- HW2: specific humidity at stage outlet
- VMASS2: mass flow rate of water vapor at stage outlet
- WMASS2: mass flow rate of water droplet at stage outlet
- DMDTAV: average mass transfer rate across stage

Usage:

CALL WICMAS (HW1, TW1, TW2, PP1, PP2, TG1, TG2, DZ, PWBl, PWB2, PW1, PW2, VZ, DDAVE1, DDAVE2, HW2, VMASS1, VMASS2, WMASS1, WMASS2, DMDTAV, AMASS, RE)

FUNCTION WICMTR

Description:

Function WICMTR is called in Subroutine WICMTR and calculates the mass transfer rate.

Input Variables:

- TTG: temperature of gaseous phase
TTW  temperature of water droplet
PPP  pressure of gaseous phase
DAVW droplet nominal diameter
VA  axial velocity
DZ  length of stage
MMASS mass flow rate of mixture
PW  vapor pressure
RE  Reynolds number based on relative velocity between droplet and gaseous phase

(3) Output Variable:
DMDT  mass transfer rate

(4) Usage:
WICMTR (TTG, TTW, PPP, DAVE, VZ, DZ, MMASS, PW, RE)

FUNCTION WICPWB
(1) Description:
Function WICPWB calculates the saturation pressure for water vapor as a function of temperature as follows:
\[ \log_{10} p_s = A - \frac{B}{T} \]
where units are (Kg/cm²) for \( p_s \) and (K) for \( T \). The values of constant \( A \) and \( B \) are given as follows:
\[ A = 5.97780, B = 2224.4 \text{ when } 20^\circ C < T < 100^\circ C \]
\[ A = 5.64850, B = 2101.1 \text{ when } 100^\circ C < T < 200^\circ C \]
\[ A = 5.45142, B = 2010.8 \text{ when } 200^\circ C < T < 350^\circ C \]

(2) Input Variable:
TWB  temperature of gaseous phase

(3) Output Variable:
WICPWB  saturation pressure for water vapor

(4) Usage:
WICPWB (TWB)
FUNCTION WICNEW
(1) Description:
Function WICNEW is used to estimate the new trial value in the iteration procedure.

(2) Input Variables:
X1 first trial value
Y1 calculated value corresponds to X1
X2 second trial value
Y2 calculated value corresponds to X2

(3) Output Variable:
WICNEW new trial value

(4) Usage:
WICNEW (X1, Y1, X2, Y2)

FUNCTION WICTAN
(1) Description:
Function WICTAN(X) is used to obtain the ratio of SINE(X) to COSINE(X), that is, TAN(X).

(2) Input Variable:
X angle

(3) Output Variable:
WICTAN value of TAN(X)

(4) Usage:
WICTAN(X)

FUNCTION WICBPT
(1) Description:
Function WICBPT calculates the temperature at boiling point.

(2) Input Variables:
TSTAG temperature
PSTAGE pressure
(3) Output Variable:
    WICBPT     temperature at boiling point

(4) Usage:
    WICBPT (TSTAG, PSTAG)

FUNCTION WICSH
(1) Description:
    Function WICSH calculates the specific humidity.

(2) Input Variables:
    TSTAGE     temperature
    PSTAG      pressure

(3) Output Variable:
    WICSH      specific humidity

(4) Usage:
    WICSH (TSTAG, PSTAG)

SUBROUTINE WICSI2
(1) Description
    Subroutine WICSI2 is called at outlet of rotor and stator to determine the nominal droplet sizes. It is assumed that two kinds of droplets exist at inlet of compressor; namely, small droplet and large droplet. However, at trailing edge of each blade, the new droplets are re-entrained into blade wake. The droplets which are larger than DLIMIT are treated as large droplets and droplets which are smaller than DLIMIT are treated as small droplets. Each droplet size weighted based on its mass fraction in determining the nominal droplet size. Therefore, at outlet of each blade row, Subroutine WICSI2 gives two nominal diameters; one for small droplet and one for large droplet. It may be noted that only two classes of droplets are recognized in the model.

(2) Input Variables:
    WMASSL     mass flow rate of large droplet
WMASSS  mass flow rate of small droplet
AMING1  amount of water which is to be re-entrained into
         wake, originally small droplet
AMING2  amount of water which is to be re-entrained into
         wake, originally large droplet and upper part
AMING3  amount of water which is to be re-entrained into
         wake, originally large droplet and lower part
DL      droplet nominal size for large droplet before
         impingement
DS      droplet nominal size for small droplet before
         impingement
D1      droplet size associated with AMING1
D2      droplet size associated with AMING2
D3      droplet size associated with AMING3
DLIMIT  largest droplet diameter which can be treated as
         small droplet

(3) Output Variables:
AMSLL  mass flow rate of small droplet after re-
        entrainment
AMLGE  mass flow rate of large droplet after re-
        entrainment
DSLL   droplet nominal size for small droplet
DLGE   droplet nominal size for large droplet

(4) Usage:
CALL WICSIZ (WMASSL, WMASSS, AMING1, AMING2, AMING3, DL, DS,
             D1, D2, D3, DLIMIT, AMSLL, AMLGE, DSLL, DLGE)

SUBROUTINE WICPRP

(1) Description
Subroutine WICPRP determines the flow properties such as gas
constant specific heat ratio, and specific heat at constant
pressure for the gaseous mixture. The working equations are
as follows:

\[ R_{\text{mix}} = x_a \cdot R_a + x_v \cdot R_v + x_c \cdot R_c \]
\[ c_{\text{pmix}} = x_a \cdot c_{\text{pa}} + x_v \cdot c_{\text{pv}} + x_c \cdot c_{\text{pc}} \]

\[ \gamma_{\text{mix}} = (1.0 - \frac{R_{\text{mix}}}{c_{\text{pmix}}})^{-1} \]

where

\( x_a \) = mass fraction of air in gaseous mixture
\( x_v \) = mass fraction of water vapor in gaseous mixture
\( x_c \) = mass fraction of methane in gaseous mixture
\( x_a + x_v + x_c = 1 \)
\( R_a \) = gas constant of air
\( R_v \) = gas constant of water vapor
\( R_c \) = gas constant of methane
\( R_{\text{mix}} \) = gas constant of mixture
\( c_{\text{pa}} \) = specific heat constant pressure for air
\( c_{\text{pv}} \) = specific heat constant pressure for water vapor
\( c_{\text{pc}} \) = specific heat at constant pressure for methane
\( c_{\text{pmix}} \) = specific heat at constant pressure for mixture
\( \gamma_{\text{mix}} \) = specific heat ratio for mixture

(2) Input Variables:

\( X\text{AIR} \) mass fraction of air in gaseous mixture
\( X\text{H2O} \) mass fraction of water vapor in gaseous mixture
\( X\text{CH4} \) mass fraction of methane in gaseous mixture
\( T \) temperature of gaseous mixture

(3) Output Variables:

\( R\text{MIX} \) gas constant of gaseous mixture
\( C\text{PMIX} \) specific heat constant pressure for gaseous mixture
\( \text{GAMMA} \) specific heat ratio of gaseous mixture
\( \text{G1} \) value for \( \text{GAMMA}/(\text{GAMMA} - 1.0) \)
\( \text{G2} \) value for \( ( \text{GAMMA} - 1.0)/2.0 \)
\( \text{G3} \) value for \( -1.0/(\text{GAMMA} - 1.0) \)

(4) Usage:

\text{CALL WICPRP (XAIR, XH2O, XCH4, T, RMIX, CPMIX, GAMMA, G1, G2, G3)}
**FUNCTION WICCPA**

(1) Description:
Function WICCPA calculates the specific heat at constant pressure for air as a function of temperature as follows: (Reference 11)

\[ c_p = (a + aT + cT^2 + dT^3 + eT^4)R \]

where units are (J/kg-K) for \( c_p \), (K) for \( T \), and (J/kg-K) for \( R \). The values of coefficients \( a \), \( b \), \( c \), \( d \), and \( e \) are as follows:

- \( a = 3.65359 \)
- \( b = -1.33736 \times 10^{-10} \)
- \( c = 3.29421 \times 10^{-6} \)
- \( d = -1.91142 \times 10^{-9} \)
- \( e = 0.275462 \times 10^{-12} \)

(2) Input Variable:
- \( T \) temperature

(3) Output Variable:
- WICCPH specific heat constant pressure

(4) Usage:
- WICCPH(T)

**FUNCTION WICCPH**

(1) Description:
Function WICCPH calculates the specific heat at constant pressure for water vapor as a function of temperature as follows: (Reference 11)

\[ c_p = (a + bT + cT^2 + dT^3 + eT^4)R \]

where units are (J/kg-K) for \( c_p \), (K) for \( T \), and (J/kg-K) for \( R \). The values of coefficients \( a \), \( b \), \( c \), \( d \), and \( e \) are as follows:

- \( a = 4.07013 \)
- \( b = -1.10845 \times 10^{-3} \)
\[ c = 4.15212 \times 10^{-6} \]
\[ d = -2.96374 \times 10^{-9} \]
\[ e = 0.807021 \times 10^{-12} \]

(2) Input Variable:
\[ T \quad \text{temperature} \]

(3) Output Variable:
\[ \text{WICCPC} \quad \text{specific heat at constant pressure} \]

(4) Usage:
\[ \text{WICCPC}(T) \]

FUNCTION WICCPC

(1) Description:
Function WICCPC calculates the specific heat at constant pressure for methane as a function of temperature as follows:
(Reference 12)
\[ c_p = (a + bT + cT^2 + dT^3 + eT^4)R \]
where units are \((\text{J/kg-k})\) for \(c_p\), \((\text{K})\) for \(T\), and \((\text{J/kg-K})\) for \(R\). The values of coefficients \(a\), \(b\), \(c\), \(d\), and \(e\) are as follows:
\[ a = 3.82619 \]
\[ b = -3.97946 \times 10^{-3} \]
\[ c = 24.5583 \times 10^{-6} \]
\[ d = -22.7329 \times 10^{-9} \]
\[ e = 6.92760 \times 10^{-12} \]

(2) Input Variable:
\[ T \quad \text{temperature} \]

(3) Output Variable:
\[ \text{WICCPC} \quad \text{specific heat constant pressure} \]

(4) Usage:
\[ \text{WICCPC}(T) \]
**SUBROUTINE NASA**

(1) **Description:**
The subroutine NASA corresponds to MAIN program of NASA-STGSTK program. NASA calls all of the major subroutines in NASA-STGSTK program. NASA first calculates the flow area at inlet and outlet of each stage. It next calls the subroutine CSPREF to calculate reference velocity diagrams at the specified radius for each stage. Then NASA calls CSETA to calculate efficiency if it is not inputed. The pressure coefficient is also calculated by calling CSPI. These computed characteristics for stage can be printed out in this subroutine.

(2) **Input Variables:**
All input variables are specified in Common blocks.

(3) **Output Variables:**
All output variables are specified in Common blocks.

(4) **Usage:**
CALL NASA

**SUBROUTINE CSINPT**

(1) **Description:**
The primary purpose of subroutine CSINPT is to read and write the input data which the program requires. For input of design stage performance, there is an option of either of the following input: (i) stage pressure ratio and adiabatic efficiency, or (ii) stage characteristics which consists of pressure coefficient versus flow coefficient and adiabatic efficiency versus flow coefficient. When either of the two above input options are used as input, the input parameters for the option not used are input as zero values. An example of input data is given in Chapter IV.

(2) **Input Variables:**
All input variables are specified in Common blocks.
(3) Output Variables:
All output variables are specified in Common blocks.

(4) Usage:
CALL CSINPT

SUBROUTINE CSPREF
(1) Description:
At design speed and flow, the subroutine CSPREF is coded to calculate: (i) velocity diagram at the specified radius for each stage inlet and outlet, and (ii) selected performance parameter for each stage. Basically CSPREF perform a one-dimensional compressible invicid flow calculation at each rotor inlet and outlet to obtain the velocity diagram for design input conditions.

(2) Input Variables:
All input variables are specified in Common blocks.

(3) Output Variables:
All output variables are specified in Common blocks.

(4) Usage:
CALL CSPREF

FUNCTION CPFM
(1) Description:
The subroutine CPFM is used to obtain values of the specific heat at constant pressure, $C_p$, and ratio of specific heats, $\gamma$, as a function of static temperature, $t$. CPFM calculates the value of the specific heat at constant pressure, $C_p$, from a fifth degree polynomial of static temperature, $t$, expressed by

$$C_p = \sum_{i=1}^{5} C_i t^i$$

where the polynomial coefficients, $C_i$, are input data read by CSINPT. The value of the ratio of specific heats, $\gamma$, is then
calculated from the following relations:
\[ \gamma = \frac{C_p}{C_p - R} \]
where \( R \) is gas constant.

(2) Input Variable:
TS static temperature for which the specific heat at constant pressure is determined

(3) Output Variable:
CPFM specific heat at constant pressure

(4) Usage:
CPRM(TS)

SUBROUTINE CSETA

(1) Description:
The subroutine CSETA is called by the subroutine NASA when values of stage adiabatic efficiency versus flow coefficient at design speed are not usable input (i.e. values of 0.0 for adiabatic efficiency are inputed). CSETA obtains values of adiabatic efficiency for each stage at the various input flow coefficient for the stage.

(2) Input Variables:
All input variables are specified in Common blocks.

(3) Output Variables:
All output variables are specified in Common blocks.

(4) Usage:
CALL CSETA

SUBROUTINE CSPSI

(1) Description:
The subroutine CSPSI is called by the subroutine NASA when values of stage pressure coefficient versus flow coefficient at design speed are not usable input (i.e. input values for stage pressure coefficient equal 0.0). The subroutine CSPSI
obtains values of stage pressure coefficient at the various input flow coefficient for the stage.

(2) Input Variables:
XWN water content
LORS index to specify calculation scheme
  LORS=1 for small droplet calculation
  LORS=2 for large droplet calculation

(3) Output Variables:
All output variables are specified in Common blocks.

(4) Usage:
CALL CSPSI(XWN, LORS)

SUBROUTINE CSDEVS
(1) Description:
The subroutine CSDEVS calculates the value of stator diffusion constant, K, for small droplet calculation. After determining the value of K, the deviation, δ, can be determined by the following:

δ = δ* + K \{(V_2/V_3) - (V_2/V_3)*\}

(2) Input Variables:
XW water content
V2M absolute velocity at stator inlet
V3M absolute velocity at stator outlet
V2V3S ratio of absolute velocity at stator inlet and absolute velocity at stator outlet at the design point
I stage

(3) Output Variable:
FK diffusion constant

(4) Usage:
CALL CSDEVS(XW, V2M, V3M, V2V3S, I, FK)
SUBROUTINE CDEVSL
(1) Description:
The subroutine CDEVSL calculates the value of stator diffusion constant, K, for large droplet calculation. After determining the value of K, the deviation, \( \delta \), can be determined by the following:
\[
\delta = \delta^* + K \ (V_2/V_3) - (V_2/V_3)^*
\]
(2) Input Variables:
- \( XW \) water content
- \( V2M \) absolute velocity at stator inlet
- \( V3M \) absolute velocity at stator outlet
- \( V2V3S \) ratio of absolute velocity at stator inlet and absolute velocity at stator outlet at the design point
- \( I \) stage
(3) Output Variable:
- \( FK \) diffusion constant
(4) Usage:
CALL CDEVSL(XW, V2M, V3M, V2V3S, I, FK)

SUBROUTINE CSDEV
(1) Description:
The subroutine CSDEV calculates the value of rotor diffusion angle, K, for small droplet calculation. After determining the value of K, the deviation, \( \delta \), can be determined by the following:
\[
\delta = \delta^* + K \ (W_2/W_3) - (W_2/W_3)^*
\]
(2) Input Variables:
- \( SPEEDF \) rotor speed
- \( XW \) water content
- \( V3MR \) relative velocity at rotor outlet
- \( V2MR \) relative velocity at rotor inlet
V3DV2 ratio of relative velocity at rotor inlet and relative velocity at rotor outlet at the design point

I stage

(3) Output Variable:
FK diffusion constant

(4) Usage:
CALL CSDEV(SPEEDF, XW, V3MR, V2MR, V3DV2, I, FK)

SUBROUTINE CSDEVL

(1) Description:
The subroutine CSDEVL calculates the value of rotor diffusion constant for large droplet calculation. After determining the value of K, the deviation, $\delta$, can be determined by the following:

$$\delta = \delta^* + K \left\{ \frac{W_2}{W_3} - \left( \frac{W_2}{W_3} \right)^* \right\}$$

(2) Input Variables:
SPEEDF rotor speed
XW water content
V3MR relative velocity at rotor outlet
V2MR relative velocity at rotor inlet
V3DV2 ratio of relative velocity at rotor inlet and relative velocity at rotor outlet and the design point
I stage

(3) Output Variable:
FK diffusion constant

(4) Usage:
CALL CSDEVL(SPEED, XW, V3MR, V2MR, V3DV2, I, FK)
FUNCTION DELK70

(1) Description:
The function DELK70 calculates the difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 70 per cent rotor speed.

(2) Input Variables:
  I  stage
  T1 \((W_2/W_3) - (W_2/W_3)\)

(3) Output Variable:
DELK70 difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 70 per cent rotor speed

(4) Usage:
DELK70(I, T1)

FUNCTION DELK80

(1) Description:
The function DELK80 calculates the difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 80 per cent rotor speed.

(2) Input Variables:
  I  stage
  T1 \((W_2/W_3) - (W_2/W_3)\)

(3) Output Variable:
DELK80 difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 80 per cent rotor speed

(4) Usage:
DELK80(I, T1)
FUNCTION DELK10
(1) Description:
The function DELK10 calculates the difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 100 per cent rotor speed.

(2) Input Variables:
   I     stage
   T1    \( (W_2/W_3) - (W_2/W_3)* \)

(3) Output Variable:
   DELK10  difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 100 per cent rotor speed

(4) Usage:
   DELK10(I, T1)

FUNCTION DPHI
(1) Description:
When the efficiency-flow coefficient curve is input at reference speed, the function DPHI alters the curve for off-reference speed.

(2) Input Variables:
   I     stage
   ISPD  rotor speed in per cent

(3) Output Variable:
   DPHI   amount of flow coefficient which is shifted for all-reference speed

(4) Usage:
   DPHI(I, ISPD)

SUBROUTINE CSETA1
(1) Description:
The subroutine CSETA1 corrects the stage efficiency for the presence of water in the small droplet calculation.
(2) **Input Variables:**

- I: stage
- J: index for speed
- K: index for point on a particular speed
- XW: water content
- PHID: flow coefficient at design point
- PHIR: flow coefficient
- ETAD: stage efficiency before correction for the presence of water

(3) **Output Variable:**

- ETAD: stage efficiency after correction for the presence of water

(4) **Usage:**

```
CALL CSETAL(I, J, K, XW, PHID, PHIR, ETAD)
```

**SUBROUTINE CSETAL**

(1) **Description:**

The subroutine CSETAL corrects the stage efficiency for the presence of water in the large droplet calculation.

(2) **Input Variables:**

- I: stage
- J: index for speed
- K: index for point on a particular speed
- XW: water content
- PHID: flow coefficient at design point
- PHIR: flow coefficient
- ETAD: stage efficiency before correction for the presence of water
- ETADD: stage efficiency at design point

(3) **Output Variable:**

- ETAD: stage efficiency after correction for the presence of water
(4) Usage:
CALL CSETAL(I, J, K, XW, PHID, PHIR, ETAD, ETADD)

SUBROUTINE CSPSD
(1) Description:
The subroutine CSPSD alters the pressure coefficient for off-design speeds. This subroutine is the same as one used in NASA-STGSTK program.

(2) Input Variables:
All input variables are specified in Common blocks.

(3) Output Variables:
All output variables are specified in Common blocks.

(4) Usage:
CALL CSPSD

SUBROUTINE CSPAN
(1) Description:
The subroutine CSPAN alters flow coefficient and pressure coefficient for blade reset. This subroutine is the same as one used in NASA-STGSTK program.

(2) Input Variables:
All input variables are specified in Common blocks.

(3) Output Variables:
All output variables are specified in Common blocks.

(4) Usage:
CALL CSPAN

SUBROUTINE CSOUPT
(1) Description:
The subroutine CSOUPT calculates the stage performance and prints them out in the small droplet calculation.
(2) Input Variables:
- FAIO: initial flow coefficient
- ISTAGE: stage
- FLOW1: mass flow rate
- ALFA1: absolute flow angle at rotor inlet
- BETA1: relative flow angle at rotor outlet

(3) Output Variables:
- BETA2: relative flow angle at rotor outlet
- VZ: axial velocity
- ALFA2: absolute flow angle at rotor outlet
- ALFA3: absolute flow angle at stator outlet
- DELTG: rise in stagnation temperature of gas phase
- DELTW: temperature rise of water
- WL: relative velocity at rotor inlet
- W2: relative velocity at rotor outlet
- V1: absolute velocity at stator inlet
- V2: absolute velocity at stator outlet

(4) Usage:
CALL CSOUPT(FAIO, ISTAGE, FLOW1, ALFA1, BETA1, BETA2, VZ, ALFA2, ALFA3, DELTG, DELTW, WL, W2, V1, V2)

SUBROUTINE CSOUPT2

(1) Description:
The subroutine CSOUPT2 calculates the stage performance and prints them out in the small droplet calculation.

(2) Input Variables:
- FAIO: initial flow coefficient
- ISTAGE: stage
- FLOW1: mass flow rate
- ALFA1: absolute flow angle at rotor inlet
- BETA1: relative flow angle at rotor outlet
Output Variables:

- BETA2: relative flow angle at rotor outlet
- VZ: axial velocity
- ALFA2: absolute flow angle at rotor outlet
- ALFA3: absolute flow angle at stator outlet
- DELTG: rise in stagnation temperature of gas phase
- DELTW: temperature rise of water
- W1: relative velocity at rotor inlet
- W2: relative velocity at rotor outlet
- V1: absolute velocity at stator inlet
- V2: absolute velocity at stator outlet

Usage:

CALL CSOUPT(FA10, ISTAGE, FLOW1, ALFA1, BETA1, BETA2, VZ, ALFA2, ALFA3, DELTG, DELTW, W1, W2, V1, V2)
APPENDIX 3

ILLUSTRATIVE TEST CASES FOR
THE NASA-WISGSK CODE

Two illustrative test cases for the calculation of the Test Compressor performance utilizing the NASA-WISGSK Code are presented as follows.

1) Test Case No. 1: Operation with air flow at 100 percent of design speed at the meanline section of the compressor.

2) Test Case No. 2: Operation with air-water mixture containing large droplets (with a mass fraction of 0.04 of water) at 100 percent of design speed at the meanline section of the compressor.
### Test Case No. 1

[test case input data]

**NS(number of stage) = 6**

**IPERFM = 1**

**Performance at Mean**

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<th>5</th>
<th>6</th>
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<td>.534</td>
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<td>.456</td>
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<td>.902</td>
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<td>.522</td>
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INPUT DATA

FNF (FRACTION OF DESIGN CORRECTED SPEED) = 1.000

XDIN (INITIAL WATER CONTENT OF SMALL DROPLET) = 0
XDILN (INITIAL WATER CONTENT OF LARGE DROPLET) = 0
RHUM (INITIAL RELATIVE HUMIDITY) = 0.00 PER CENT
XMCH (INITIAL METHANE CONTENT) = 0

TGG (COMPRESSOR INLET TOTAL TEMPERATURE OF GAS) = 518.70
TOW (COMPRESSOR INLET TEMPERATURE OF DROPLET) = 513.70
PO (COMPRESSOR INLET TOTAL PRESSURE) = 2116.80

DIN (INITIAL DROPLET DIAMETER OF SMALL DROPLET) = 20.0
DDIN (INITIAL DROPLET DIAMETER OF LARGE DROPLET) = 600.0

FND (DESIGN ROTATIONAL SPEED) = 51120.0

DSMASS (DESIGN MASS FLOW RATE) = 0.3755

COMPRESSOR INLET TOTAL TEMPERATURE (GAS PHASE) = 518.70 R
COMPRESSOR INLET TOTAL PRESSURE = 2116.60 LB/FT²

PRE (PERCENT OF WATER THAT REBOND AFTER IMPINGEMENT) = 50.0 PERCENT

ROTOR SPEED = 51120.0 RPM

CORRECTED ROTOR SPEED = 51120.0 RPM (100.0 PER CENT OF DESIGN CORRECTED SPEED)
*************** DESIGN POINT INFORMATION ***************

***** COMPRESSOR INLET *****

TOTAL TEMPERATURE AT COMPRESSOR INLET = 518.70000
TOTAL PRESSURE AT COMPRESSOR INLET = 2116.80
STATIC TEMPERATURE AT COMPRESSOR INLET = 456.28109
STATIC PRESSURE AT COMPRESSOR INLET = 1813.73
STATIC DENSITY AT COMPRESSOR INLET = .06850

ACOUSTIC SPEED AT COMPRESSOR INLET = 1092.25914
AXIAL VELOCITY AT COMPRESSOR INLET = 518.81873
MACH NUMBER AT COMPRESSOR INLET = .47500
STREAMTUBE AREA AT COMPRESSOR INLET = .01057
FLOW COEFFICIENT AT COMPRESSOR INLET = .53817
### Design Point Information

#### Stage = 1

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<td>Total Pressure</td>
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#### Stage Total Pressure Ratio at Design Point = 1.15200

#### Stage Adiabatic Efficiency at Design Point = .95333

#### Rotor Total Pressure Ratio at Design Point = 1.15400

#### Rotor Adiabatic Efficiency at Design Point = .95600

#### Rotor Total Temperature Ratio at Design Point = 1.04328
### DESIGN POINT INFORMATION

#### Stage = 2

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- Stage Total Pressure Ratio at Design Point = 1.15800
- Stage Adiabatic Efficiency at Design Point = .93231
- Rotor Total Pressure Ratio at Design Point = 1.16500
- Rotor Adiabatic Efficiency at Design Point = .96600
- Rotor Total Temperature Ratio at Design Point = 1.04618
### Design Point Information

**Stage: 3**

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Stage Total Pressure Ratio at Design Point: 1.21300
Stage Adiabatic Efficiency at Design Point: .93464
Rotor Total Pressure Ratio at Design Point: 1.22100
Rotor Adiabatic Efficiency at Design Point: .96800
Rotor Total Temperature Ratio at Design Point: 1.06062
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Stage Total Pressure Ratio at Design Point = 1.22800
Stage Adiabatic Efficiency at Design Point = 0.53002
Rotor Total Pressure Ratio at Design Point = 1.23700
Rotor Adiabatic Efficiency at Design Point = 0.96500
Rotor Total Temperature Ratio at Design Point = 1.06481
### DESIGN POINT INFORMATION

#### STAGE= 5

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Stage Total Pressure Ratio at Design Point: 1.22100
Stage Adiabatic Efficiency at Design Point: 0.97580
Rotor Total Pressure Ratio at Design Point: 1.23000
Rotor Adiabatic Efficiency at Design Point: 0.98200
Rotor Total Temperature Ratio at Design Point: 1.06311
### DESIGN POINT INFORMATION

#### STAGE = 6

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Stage Total Pressure Ratio at Design Point = 1.20800
Stage Adiabatic Efficiency at Design Point = .92365
Rotor Total Pressure Ratio at Design Point = 1.521500
Rotor Adiabatic Efficiency at Design Point = .95400
Rotor Total Temperature Ratio at Design Point = 1.05962
********** DESIGN POINT INFORMATION **********

********** OVERALL PERFORMANCE AT DESIGN POINT ******

COMPRESSOR INLET TOTAL TEMPERATURE = 518.70
COMPRESSOR INLET TOTAL PRESSURE = 2116.80
CORRECTED MASS FLOW RATE = 3.168
OVERALL TOTAL PRESSURE RATIO = 2.9334
OVERALL TOTAL TEMPERATURE RATIO = 1.3866
OVERALL ADIABATIC EFFICIENCY = .9223
OVERALL TEMPERATURE RISE = 201.559

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TOTAL PRESSURE

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STAGE TOTAL TEMPERATURE RATIO = 1.04756  
STAGE ADIABATIC EFFICIENCY = 0.94773  

**STAGE INLET**  
**BEFORE INTER-STAGE ADJUSTMENT**  
**AFTER INTER-STAGE ADJUSTMENT**  

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STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM = 2)

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STAGE ADIABATIC EFFICIENCY = 0.92822

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141
**INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 3 ) **

**STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)**

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STAGE ADIABATIC EFFICIENCY= .92441

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<tr>
<td>Deviation</td>
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**INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 4)**

**STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM=2)**

<table>
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<tr>
<th><strong>STAGE INLET (BEFORE INTER-STAGE ADJUSTMENT)</strong></th>
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<tbody>
<tr>
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<tr>
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<td>WWMASS= 0</td>
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<tr>
<td>WTMASS= 0</td>
<td>WTMASS= 0</td>
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<tr>
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<td>AMASS= .34491</td>
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<tr>
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**INITIAL FLOW COEFFICIENT** = 0.500  (STAGE = 5) **INITIAL FLOW COEFFICIENT** = 0.513

|----------------|-----------------|-------------------------|---------------------------|----------------------|------------------|------------------|-------------------|-------------|------------------------|-------------------------|----------------|-----------------------|-------------------|-----------------|-------------|-------------------|-------------------|-----------|------------|
INITIAL FLOW COEFFICIENT = .500 (ISTAGE = 5)

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM = 2)

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<td>Stage Adiabatic Efficiency</td>
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**Stage Inlet**

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<tr>
<td>XH</td>
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<tr>
<td>XM</td>
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<tr>
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<td>XGAS</td>
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<td>GMASS</td>
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<td>TDEW</td>
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**Stage Outlet**

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**INITIAL FLOW COEFFICIENT** = 0.500 (STAGE = 6)  

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<td>Axial Velocity</td>
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<table>
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**INITIAL FLOW COEFFICIENT** = 0.500 (ISTAGE = 6)

**STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM=2)**

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<th><strong>STAGE INLET</strong></th>
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<td>(t_{de})</td>
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********** OVERALL PERFORMANCE **********

INITIAL FLOW COEFFICIENT = 0.50
CORRECTED SPEED = 51120.0 1.000 FRACTION OF DESIGN CORRECTED SPEED

INITIAL WATER CONTENT (SMALL DROPLET) = 0
INITIAL WATER CONTENT (LARGE DROPLET) = 0
INITIAL WATER CONTENT (TOTAL) = 0
INITIAL RELATIVE HUMIDITY = 0.0 PER CENT
INITIAL METHANE CONTENT = 0

COMPRESSOR INLET TOTAL TEMPERATURE = 518.70
COMPRESSOR INLET TOTAL PRESSURE = 2116.80
CORRECTED MASS FLOW RATE OF MIXTURE = 0.345 (2.910)
CORRECTED MASS FLOW RATE OF GAS PHASE = 0.345 (2.910)
OVERALL TOTAL PRESSURE RATIO = 3.2482
OVERALL TOTAL TEMPERATURE RATIO = 1.4399
OVERALL ADIABATIC EFFICIENCY = 0.9046
OVERALL TEMPERATURE RISE OF GAS PHASE = 228.173
Test Case No. 2

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<td>STAGER(I)</td>
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<td>NTRM(I)</td>
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**INPUT DATA**

FNF (FRACTION OF DESIGN CORRECTED SPEED) = 1.000

XOIN (INITIAL WATER CONTENT OF SMALL DROPLET) = 0

XDDIN (INITIAL WATER CONTENT OF LARGE DROPLET) = 0.040

RHUMID (INITIAL RELATIVE HUMIDITY) = 0.00 PER CENT

XCH4 (INITIAL METHANE CONTENT) = 0

T0G (COMPRESSOR INLET TOTAL TEMPERATURE OF GAS) = 518.70

T0D (COMPRESSOR INLET TEMPERATURE OF DROPLET) = 513.70

P0 (COMPRESSOR INLET TOTAL PRESSURE) = 2116.80

DIN (INITIAL DROPLET DIAMETER OF SMALL DROPLET) = 20.0

DDIN (INITIAL DROPLET DIAMETER OF LARGE DROPLET) = 600.0

FND (DESIGN ROTATIONAL SPEED) = 51120.0

DSMASS (DESIGN MASS FLOW RATE) = 0.3755

COMPRESSOR INLET TOTAL TEMPERATURE (GAS PHASE) = 518.70 R

COMPRESSOR INLET TOTAL PRESSURE = 2116.80 LB/FT²

PREB (PERCENT OF WATER THAT REBOUND AFTER IMPINGEMENT) = 50.0 PERCENT

ROTOR SPEED = 51120.0 RPM

CORRECTED ROTOR SPEED = 51120.0 RPM (100.0 PER CENT OF DESIGN CORRECTED SPEED)
**DESIGN POINT INFORMATION**

**COMPRESSOR INLET**

- Total Temperature at Compressor Inlet: 518.70000
- Total Pressure at Compressor Inlet: 2116.80
- Static Temperature at Compressor Inlet: 496.29109
- Static Pressure at Compressor Inlet: 1813.73
- Static Density at Compressor Inlet: 0.06850
- Acoustic Speed at Compressor Inlet: 1092.25914
- Axial Velocity at Compressor Inlet: 518.81873
- Mach Number at Compressor Inlet: 0.47500
- Streamtube Area at Compressor Inlet: 0.01057
- Flow Coefficient at Compressor Inlet: 0.53817
### DESIGN POINT INFORMATION

#### STAGE = 1

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<th>TOTAL TEMP</th>
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Stage Total Pressure Ratio at Design Point = 1.15200
Stage Adiabatic Efficiency at Design Point = .95393
Rotor Total Pressure Ratio at Design Point = 1.15400
Rotor Adiabatic Efficiency at Design Point = .95600
Rotor Total Temperature Ratio at Design Point = 1.04328
### Stage 2 Information

#### Total Static

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#### Axial Absolute Relative TAN Comp TAN Comp Velocity Velocity Of Abs Vel Of Rel Vel

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#### Rotor Total Mach REL Mach REL Total REL Total Speed Number Number Temp Pressure

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#### ABS Flow REL Flow STREAMTUBE Flow Angle Angle Area Radius Coefficient

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#### Stage Total Pressure Ratio at Design Point= 1.15900

#### Stage Adiabatic Efficiency at Design Point= .93231

#### Rotor Total Pressure Ratio at Design Point= 1.15600

#### Rotor Adiabatic Efficiency at Design Point= .95600

#### Rotor Total Temperature Ratio at Design Point= 1.04618
### DESIGN POINT INFORMATION

#### STAGE = 3

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<th>RADIUS</th>
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STAGE TOTAL PRESSURE RATIO AT DESIGN POINT = 1.21300
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT = 0.93484
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT = 1.22100
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT = 0.96800
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT = 1.06062
### DESIGN POINT INFORMATION

#### TOTAL TEMPERATURE | TOTAL PRESSURE | STATIC TEMPERATURE | STATIC PRESSURE | STATIC DENSITY
---|---|---|---|---
ROTOR INLET | 600.462 | 3428.262 | 569.069 | 2839.938 | .094
ROTOR OUTLET | 639.381 | 4240.785 | 585.841 | 3118.959 | .100

#### AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL
---|---|---|---|---
ROTOR INLET | 580.04590 | 614.69778 | 809.54747 | 203.47020 | 564.72459
ROTOR OUTLET | 619.63965 | 603.61317 | 698.93304 | 511.70446 | 252.02926

#### ABS MACH | REL MACH | REL TOTAL | REL TOTAL | TEMP | PRESSURE
---|---|---|---|---|---
ROTOR INLET | 768.155 | .526 | .692 | 623.519 | 3912.431
ROTOR OUTLET | 763.734 | .670 | .584 | 622.951 | 8231.914

#### ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | FLOW RADIUS | FLOW COEFFICIENT
---|---|---|---|---
ROTOR INLET | 19.33000 | 44.23321 | .00692 | 1.72200 | .60169
ROTOR OUTLET | 35.55625 | 22.13332 | .00607 | 1.71200 | .64276

---

**STAGE TOTAL PRESSURE RATIO AT DESIGN POINT:** 1.22800

**STAGE ADIABATIC EFFICIENCY AT DESIGN POINT:** .93002

**ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT:** 1.23700

**ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT:** .95500

**ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT:** 1.06431
## Design Point Information

**Stage = 5**

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Stage Total Pressure Ratio At Design Point = 1.22100
Stage Adiabatic Efficiency At Design Point = .92530
Rotor Total Pressure Ratio At Design Point = 1.23000
Rotor Adiabatic Efficiency At Design Point = .93200
Rotor Total Temperature Ratio At Design Point = 1.08311
### Stage 6

#### Stage Total Pressure Ratio at Design Point = 1.20800

#### Stage Adiabatic Efficiency at Design Point = 0.92365

#### Rotor Adiabatic Efficiency at Design Point = 0.95400

#### Rotor Total Temperature Ratio at Design Point = 1.05962

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**TOTAL TEMP**

**PRESSURE**

**STATIC TEMP**

**PRESSURE**

**DENSITY**
**DESIGN POINT INFORMATION**

**OVERALL PERFORMANCE AT DESIGN POINT**

COMPRESSOR INLET TOTAL TEMPERATURE = 518.70

COMPRESSOR INLET TOTAL PRESSURE = 2116.80

CORRECTED MASS FLOW RATE = 3.168

OVERALL TOTAL PRESSURE RATIO = 2.9334

OVERALL TOTAL TEMPERATURE RATIO = 1.3666

OVERALL ADIABATIC EFFICIENCY = 92.23

OVERALL TEMPERATURE RISE = 201.559

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### INITIAL FLOW COEFFICIENT = 0.500 (STAGE = 1) ###

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INITIAL FLOW COEFFICIENT = .500 (ISTAGE = 1)

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFH = 3)

- **Stage Total Pressure Ratio**: 1.15672
- **Stage Total Temperature Ratio**: 1.04806
- **Stage Adiabatic Efficiency**: .88429

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<th><strong>Stage Outlet</strong> (After Inter-stage Adjustment)</th>
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<tr>
<td><strong>M</strong></td>
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**Values for Other Parameters**

- **UMRSS**: 0.00000
- **GHASS**: 0.34340
- **TMASS**: 0.35771
- **RHOA**: 0.07649
- **RHOM**: 0.07160
- **RHOG**: 0.06918
- **TG**: 518.70000
- **TH**: 513.70000
- **TW**: 513.70000
- **P**: 2116.80000
- **TB**: 671.40656
- **TDEW**: 271.99506

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**INITIAL FLOW COEFFICIENT= 0.500 (STAGE= 2 )**

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<table>
<thead>
<tr>
<th>Stage Flow Coefficient = 0.505</th>
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<td>Rotor Speed = 559.57</td>
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<tr>
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INITIAL FLOW COEFFICIENT = .500 (ISTAGE = 2) ***************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM = 3)

STAGE TOTAL PRESSURE RATIO = 1.17978
STAGE TOTAL TEMPERATURE RATIO = 1.05521
STAGE ADIABATIC EFFICIENCY = .87586

**STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**

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| Total Pressure                                | 2888.7433 | 3524.7140 | 3524.7140 |
| Static Pressure                               | 2456.9126  | 2718.3592 |           |
| Total Temperature (GAS)                       | 573.6432   | 611.4751  | 611.4751  |
| Static Temperature (GAS)                      | 550.3901   | 567.8526  |           |
| Static Density (GAS)                          | 0.0851     | 0.0897    |           |
| Axial Velocity                                | 501.0593   | 537.7831  |           |
| Absolute Velocity                             | 530.2182   | 724.9365  |           |
| Relative Velocity                             | 750.7661   | 590.6081  |           |
| Blade Speed                                   | 732.5053   | 730.2758  | 758.1948  |
| Tang. Comp. of Abs. Vel.                      | 173.4094   | 486.1298  |           |
| Tang. Comp. of Rel. Vel.                      | 559.0569   | 244.1460  |           |
| Acoustic Speed                                | 1149.1717  | 1167.3652 |           |
| Absolute Mach Number                          | 0.4514     | 0.6210    |           |
| Relative Mach Number                          | 0.6533     | 0.5059    |           |
| Flow Coefficient                              | 0.5229     | 0.5668    |           |
| Flow Area                                     | 0.0080     | 0.0071    |           |
| Absolute Flow Angle                           | 19.0800    | 42.1120   | 19.3300   |
| Relative Flow Angle                           | 48.1335    | 24.4174   |           |
| Incidence                                     | 6.5135     | -1.2480   |           |
| Deviation                                     |           | 11.2974   |           |
**INITIAL FLOW COEFFICIENT = 0.500 (ISTAGE = 3) **

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM=3)

STAGE TOTAL PRESSURE RATIO = 1.22015
STAGE TOTAL TEMPERATURE RATIO = 1.06595
STAGE ADIABATIC EFFICIENCY = 0.88573

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<th><strong>XAIR</strong></th>
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**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)

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<th><strong>RHOG</strong></th>
<th><strong>TG</strong></th>
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165
| **TOTAL PRESSURE** | 3524.7140 | 4370.7663 | 4370.7663 |
| **STATIC PRESSURE** | 3065.3014 | 3378.4066 |
| **TOTAL TEMPERATURE (GAS)** | 611.4751 | 654.1230 | 654.1230 |
| **STATIC TEMPERATURE (GAS)** | 587.6443 | 607.9245 |
| **STATIC DENSITY (GAS)** | 0.0978 | 0.1042 |
| **AXIAL VELOCITY** | 505.8407 | 540.1830 |
| **ABSOLUTE VELOCITY** | 556.0556 | 746.6544 |
| **RELATIVE VELOCITY** | 777.7231 | 594.4555 |
| **BLADE SPEED** | 766.1946 | 763.7337 | 793.0839 |
| **TANG. COMP. OF ABS. VEL.** | 177.4403 | 515.5351 |
| **TANG. COMP. OF REL. VEL.** | 520.7545 | 248.1936 |
| **ACOUSTIC SPEED** | 1187.1539 | 1207.4712 |
| **ABSOLUTE MACH NUMBER** | 0.4515 | 0.6184 |
| **RELATIVE MACH NUMBER** | 0.6551 | 0.4923 |
| **FLOW COEFFICIENT** | 0.5276 | 0.5703 |
| **FLOW AREA** | 0.0000 | 0.0001 |
| **ABSOLUTE FLOW ANGLE** | 19.3300 | 43.6636 | 20.1800 |
| **RELATIVE FLOW ANGLE** | 49.4278 | 24.6782 |
| **INCIDENCE** | 6.5778 | -1.3364 |
| **DEVIATION** | 10.9182 |
INITIAL FLOW COEFFICIENT = .500 (ISTAGE = 4)

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT (JPERFM = 3)

STAGE TOTAL PRESSURE RATIO = 1.24003
STAGE TOTAL TEMPERATURE RATIO = 1.06975
STAGE ADIABATIC EFFICIENCY = .90596

**STAGE INLET**  **STAGE OUTLET**  **STAGE OUTLET**

(AFTER INTER-STAGE ADJUSTMENT)

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| **TG** = 611.47514 | 654.12304 | 654.12303 |
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| **P** = 3524.71402 | 4370.76630 | 4370.76630 |
| **TB** = 697.25964 | 0           | 708.83369 |
| **TD** = 332.71852 | 335.32202 | 342.89517 |

167
**INITIAL FLOW COEFFICIENT= .500 (STAGE= 5)**

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**STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT**

*JPERFM=3*

| **STAGE TOTAL PRESSURE RATIO** | 1.23254 |
| **STAGE TOTAL TEMPERATURE RATIO** | 1.06806 |
| **STAGE ADIABATIC EFFICIENCY** | 0.89922 |

<table>
<thead>
<tr>
<th><strong>STAGE INLET</strong></th>
<th><strong>STAGE OUTLET</strong></th>
<th><strong>STAGE OUTLET</strong></th>
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<tbody>
<tr>
<td><em>(BEFORE INTER-STAGE ADJUSTMENT)</em></td>
<td><em>(AFTER INTER-STAGE ADJUSTMENT)</em></td>
<td><em>(AFTER INTER-STAGE ADJUSTMENT)</em></td>
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INITIAL FLOW COEFFICIENT= .500 (STAGE= 6 )

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### Initial Flow Coefficient

Stage performance after inter-stage adjustment (JPERFM=2)

- **Stage Total Pressure Ratio**: 1.22193
- **Stage Total Temperature Ratio**: 1.06404
- **Stage Adiabatic Efficiency**: 0.81223

#### Stage Inlet **Stage Outlet**  **Stage Outlet**

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</table>

### Additional Values

- **Density**: 1.04061
- **Enthalpy**: 723.33315
- **Entropy**: 6502.00001
- **Enthalpy Change**: 338.59428

---

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********** OVERALL PERFORMANCE **********

INITIAL FLOW COEFFICIENT = .50

CORRECTED SPEED=51120.0  1.000 FRACTION OF DESIGN CORRECTED SPEED

INITIAL WATER CONTENT (SMALL DROPLET) = .0
INITIAL WATER CONTENT (LARGE DROPLET) = .040
INITIAL WATER CONTENT (TOTAL) = .040
INITIAL RELATIVE HUMIDITY = .0 PERCENT
INITIAL METHANE CONTENT = 0

COMPRESSOR INLET TOTAL TEMPERATURE = 518.70

COMPRESSOR INLET TOTAL PRESSURE = 2116.80

CORRECTED MASS FLOW RATE OF MIXTURE = .358 (3.018)

CORRECTED MASS FLOW RATE OF GAS PHASE = .343 (2.897)

OVERALL TOTAL PRESSURE RATIO = 3.1056

OVERALL TOTAL TEMPERATURE RATIO = 1.4332

OVERALL ADIABATIC EFFICIENCY = .8750

OVERALL TEMPERATURE RISE OF GAS PHASE = 224.688
ABSTRACT:
PERFORMANCE OF AXIAL FLOW COMPRESSOR STAGE AND OVERALL PERFORMANCE FOR AIR-WATER MIXTURE FLOW WITH SMOKE-DROPLET LARGER DROPLET. THIS PROGRAM CODE IS WRITTEN ESPECIALLY FOR COMPRESSOR PERFORMANCE FOR THE GAS-WATER DROPLET MIXTURE FLOW. THIS PROGRAM CODE HAS BEEN PRODUCED FOR THE STUDY OF THE AXIAL FLOW ARE OBTAINED BY A STAGE-BY-STAGE CALCULATION. THIS FORTRAN COMPUTER CODE CAN PREDICT THE DESIGN AND OFF-DESIGN PERFORMANCE OF THIS AXIAL FLOW COMPRESSOR. STAGE AND OVERALL PERFORMANCE ARE OBTAINED BY A STAGE-BY-STAGE CALCULATION.

REAL ND, NU, KA, MMNSS, MMASS
REAL MMASS
COMMON /PERDUE/ JPERFM, RHOC(3), RERUP, RERLOW, RESUP, RESLOW
COMMON /SKERR/ JERRF(3), JERRM(3), JERRL(3)
COMMON /PERDUE/ JPERFM, RHOC(3), RERUP, RERLOW, RESUP, RESLOW
COMMON /PHIS1/ PER1, PERI, PERI1, PER11, PERI2, PERI12
COMMON /SKERR/ JERRF(3), JERRM(3), JERRL(3)
COMMON /PERDUE/ JPERFM, RHOC(3), RERUP, RERLOW, RESUP, RESLOW
COMMON /PHIS1/ PER1, PERI, PERI1, PER11, PERI2, PERI12
COMMON /SKERR/ JERRF(3), JERRM(3), JERRL(3)
COMMON /PERDUE/ JPERFM, RHOC(3), RERUP, RERLOW, RESUP, RESLOW
COMMON /PHIS1/ PER1, PERI, PERI1, PER11, PERI2, PERI12
COMMON /SKERR/ JERRF(3), JERRM(3), JERRL(3)
COMMON /PERDUE/ JPERFM, RHOC(3), RERUP, RERLOW, RESUP, RESLOW

PROGRAM MAIN (INPUT, OUTPUT, TAPEC=INPUT, TAPEG=OUTPUT)

C This program code has been produced for the study of the axial flow
C compressor performance for the gas-water droplet mixture flow.
C The mixture consists of two types of droplet sizes and three
C kinds of gaseous phases. This program code is written especially
C for air-water vapor + methane + small droplet + large droplet.
C This program code can predict the design and off-design
C performance of axial flow compressor. Stage and overall performance
C are obtained by a stage-by-stage calculation.
C
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C MAIN PROGRAM NASA-WISGSK MQIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C MAIN
C INPUT DATA MAIN

C NUMBER OF STAGE
C RRHUB(I) ROTOR INLET RADIUS AT HUB FOR I-TH STAGE IN INCH
C RC(I) ROTOR CHORD FOR I-TH STAGE IN INCH
C RBLADE(I) NUMBER OF ROTOR BLADE FOR I-TH STAGE
C STAGER(I) ROTOR STAGER ANGLE FOR I-TH STAGE IN DEGREE.
C SRHUB(I) STATOR INLET RADIUS AT HUB FOR I-TH STAGE IN INCH
C SC(I) STATOR CHORD FOR I-TH STAGE IN INCH (I = NS+1, IGU)
C SBLADE(I) NUMBER OF STATOR BLADE FOR I-TH STAGE (I = NS+1, IGU)
C SIGUMR(I) SOLIDITY OF ROTOR FOR I-TH STAGE
C FNF FRACTION OF DESIGN CORRECTED ROTOR SPEED FOR A PARTICULAR
C XDIN INITIAL WATER CONTENT (MASS FRACTION) OF SMALL DROPLET
C XDIN INITIAL WATER CONTENT (MASS FRACTION) OF LARGE DROPLET
C ICENT INDEX FOR CENTRIFUGAL CALCULATION (ICENT = 1 WHEN XDIN = 0
C OTHERWISE ICENT = 2)
C IICENT SAME AS ICENT
C TG TOTAL TEMPERATURE AT COMPRESSOR INLET IN RANKIN
C TOW WATER DROPLET TEMPERATURE AT COMPRESSOR INLET IN RANKIN
C P0 TOTAL PRESSURE AT COMPRESSOR INLET IN LBS/FT**2
C DIN INITIAL WATER DROPLET DIAMETER IN MICRON (SMALL DROPLET)
C DDIN INITIAL WATER DROPLET DIAMETER IN MICRON (LARGE DROPLET)
C FND ROTOR ROTATIONAL SPEED AT DESIGN SPEED IN RPM
C TO1D DESIGN VALUE FOR COMPRESSOR INLET TOTAL TEMPERATURE
C IN RANKIN
C P1D DESIGN VALUE FOR COMPRESSOR INLET TOTAL PRESSURE
C IN LB/FT**2
C XCH4 INITIAL METHANE CONTENT (MASS FRACTION)
C RHUMID INITIAL RELATIVE HUMIDITY (PER CENT)
C FW AIR MOLECULAR WEIGHT OF AIR
C FWU MOLECULAR WEIGHT OF WATER VAPOR
C FWC MOLECULAR WEIGHT OF METHANE
C PREB PERCENT OF WATER THAT REBOUNDS AFTER IMPINGEMENT
C DLIMIT MAX. DIAMETER FOR SMALL DROPLET IN MICRON
C STAGES(I) STATUS STAGE ANGLE FOR I-TH STAGE IN DEGREE
C GAPR(I) GAP BETWEEN I TH STAGE ROTOR AND I-1 TH STAGE STATOR
C IN INCH
C GAPS(I) GAP BETWEEN I TH STAGE STATOR AND I-1 TH STAGE ROTOR
C IN INCH
C XBLED(I) AMOUNT OF BLEED AT I-TH STAGE OUTLET
C RRTIP(I) ROTOR INLET TIP RADIUS FOR I-TH STAGE IN INCH
C SRTIP(I) STATOR INLET TIP RADIUS FOR I-TH STAGE IN INCH
C IRAD INDEX FOR RADIUS AT WHICH CALCULATION IS CARRIED OUT
C IRAD=1: TIP
C IRAD=2: MEAN
C IRAD=3: HUB
C RT(I) RADIUS AT ROTOR INLET WHERE PERFORMANCE CALCULATION
C IS CARRIED OUT WHEN IRAD=1, INCH
C RM(I) RADIUS AT ROTOR INLET WHERE PERFORMANCE CALCULATION
C IS CARRIED OUT WHEN IRAD=2, INCH
C RH(I) RADIUS AT ROTOR INLET WHERE PERFORMANCE CALCULATION
C IS CARRIED OUT WHEN IRAD=3, INCH
C ST(I) RADIUS AT ROTOR OUTLET WHERE PERFORMANCE CALCULATION
C IS CARRIED OUT WHEN IRAD=1, INCH
C SM(I) RADIUS AT ROTOR OUTLET WHERE PERFORMANCE CALCULATION
C IS CARRIED OUT WHEN IRAD=2, INCH
C SH(I) RADIUS AT ROTOR OUTLET WHERE PERFORMANCE CALCULATION
C IS CARRIED OUT WHEN IRAD=3, INCH
C BLOCK(I) BLOCKAGE FACTOR FOR ROTOR
C BLOKS(I) BLOCKAGE FACTOR FOR STATOR
C BETMR(I) BLADE METAL ANGLE AT ROTOR INLET FOR I-TH STAGE IN DEG
C BET2MR(I) BLADE METAL ANGLE AT ROTOR OUTLET FOR I-TH STAGE IN DEG
C BETMS(I) BLADE METAL ANGLE AT STATOR INLET FOR I-TH STAGE IN DEG
C BET2MS(I) BLADE METAL ANGLE AT STATOR OUTLET FOR I-TH STAGE IN DEG
C DSNUPD RADIUS TOTAL PRESSURE RATIO FOR I-TH STAGE ROTOR
C PR12D(I) DESIGN TOTAL PRESSURE RATIO FOR I-TH STAGE
READ(5,1496) (SM(I),I=1,NS)

1496 FORMAT(GF5.3)  
READ(5,1497) (SH(I),I=1,NS)

1497 FORMAT(GF5.3)
READ(5,1498) (BLOCK(I),I=1,NS)  

1498 FORMAT(GF5.3)
READ(5,1499) (BLOCKS(I),I=1,NS)

1499 FORMAT(GF5.3)
READ(5,1500) (SH1(I),I=1,NS)

1500 FORMAT(GF5.3)
READ(5,1501) (SH2(I),I=1,NS)

1501 FORMAT(GF5.3)
READ(5,1502) (SH1S(I),I=1,NS)

1502 FORMAT(GF5.3)
READ(5,1503) (SH2S(I),I=1,NS)

1503 FORMAT(GF5.3)
READ(5,1504) (SH1S(I),I=1,NS)

1504 FORMAT(GF5.3)
READ(5,1505) (SH2S(I),I=1,NS)

1505 FORMAT(GF5.3)
READ(5,1506) (DSMASS)

1506 FORMAT(F10.6)
READ(5,1507) (PR12D(I),I=1,NS)

1507 FORMAT(GF5.3)
READ(5,1508) (PR13D(I),I=1,NS)

1508 FORMAT(GF5.3)
READ(5,1509) (ETARD(I),I=1,NS)

1509 FORMAT(GF5.3)
READ(5,1510) (SAREA(I),I=1,NS)

1510 FORMAT(GF10.7)
READ(5,1511) (SAREAS(I),I=1,NS)

1511 FORMAT(F10.7)
READ(5,1512) (SAREA(I),I=1,NS)

1512 FORMAT(F10.7)
READ(5,1513) (SAREAS(I),I=1,NS)

1513 FORMAT(GF5.2)
C ++++++++++++++++++++++++++++++++++++++++MAIN 211

C OTHER INPUT DATA

FNFN=FNF*100.0
IWIDTH=1.0
IPRINT=1
DO 1530 I=1,NS
  FMR1(I)=0.6
  FMA2(I)=0.6
CONTINUE
AK1=1.0
AK2=0.0
AK3=0.0
AAA1G=SGREA(I)
RU=1545.3
RH1=62.54
CP1=1.0
RH=RU/RH1
KCH=KU+MW
DLU=0.0
DELULU=10.0
DREJ=0.0
GC=32.174
AJ=778.16
PAI=3.1415926
DO 150 I=1,NS
  AAREAS(I)=PAI*((SRTIP(I)/12.0)**2-(SRHUB(I)/12.0)**2)*BLOCK(I)
  AAREAS(I)=PAI*(SRTIP(I)**2-SRTIP(I)**2)/144.0*BLOCKS(I)
  TILZ(I)=(RC(I)+SC(I))/12.0
CONTINUE
NS1=NS+1
AAREAS(NS1)=PAI*(SRTIP(NS1)**2-SRTIP(NS1)**2)/144.0*NLCS(NS1)
AAAR1=AAREA(I)
DO 152 I=1,NS
  AREA(I)=AAREA(I)
  AREAS(I)=SAREA(I)
 CONTINUE
ARCAG(N1)=SARCAG(N1)
FN=FNF*SQRT(TOG/518.7)

17C
UOU(I) = U0 + T0 * PI * FND/60.0
UTO(I) = RTO(I)/12.0 * 2.0 * PI * FND/60.0
UTO(I) = RTO(I)/12.0 * 2.0 * PI * FND/60.0
UO(I) = (UTO(I)/UTIPD(I))**2
UMEAN(I) = RM(I)/12.0 * 2.0 * PI * FND/60.0
UTO(I) = UO(I) * PI * FND/60.0
UTIP(I) = RT(I)/12.0 * 2.0 * PI * FND/60.0
UTIPG(I) = RRTIP(I)/12.0 * 2.0 * PI * FND/60.0
UHUB(I) = RH(I)/12.0 * 2.0 * PI * FND/60.0
UTIP2(I) = ST(I)/12.0 * 2.0 * PI * FND/60.0
UTIPD(I) = RT(I)/12.0 * 2.0 * PI * FND/60.0

DO 151 I = 1, NS

UMEAN2(I) = SM(I)/12.0 * 2.0 * PI * FND/60.0
UTIP(I) = RT(I)/12.0 * 2.0 * PI * FND/60.0
UTIPG(I) = RRTIP(I)/12.0 * 2.0 * PI * FND/60.0
UHUB(I) = RH(I)/12.0 * 2.0 * PI * FND/60.0
UTIP2(I) = ST(I)/12.0 * 2.0 * PI * FND/60.0
UTIPD(I) = RT(I)/12.0 * 2.0 * PI * FND/60.0

IF (IRAD.EQ.1) U(I) = UTIP(I)
IF (IRAD.EQ.2) U(I) = UMEAN(I)
IF (IRAD.EQ.3) U(I) = UHUB(I)
IF (IRAD.EQ.1) UU2(I) = UTIP2(I)
IF (IRAD.EQ.2) UU2(I) = UMEAN2(I)
IF (IRAD.EQ.3) UU2(I) = UHUB2(I)

IF (IRAD.EQ.1) RADI(I) = RT(I)
IF (IRAD.EQ.1) RADI2(I) = ST(I)
IF (IRAD.EQ.2) RADI(I) = RM(I)
IF (IRAD.EQ.2) RADI2(I) = SM(I)
IF (IRAD.EQ.3) RADI(I) = RH(I)
IF (IRAD.EQ.3) RADI2(I) = SH(I)

151 CONTINUE

C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C C PRINT OUT OF INPUT DATA C
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

WRITE(6,1610) NS
FORMAT(1H1,5X,.NUMBER OF STAGE=*, 12)
IF (IUNIT.EQ.1) WRITE(6,1601)
FORMAT(1H 9 1X, UNIT=ENGLISH UNIT+)
IF (IUNIT.EQ.2) WRITE(6,1602)
FORMAT(1H 9 1X, UNIT=METRIC UNIT+)
WRITE(6,1603) IPERFM
FORMAT(1H 9 1X, PERFORM AT TIP+
IF (IRAD.EQ.2) WRITE(6,1604)
FORMAT(1H 9 1X, PERFORMANCE AT MEAN+)
IF (IRAD.EQ.3) WRITE(6,1605)
FORMAT(1H 9 1X, PERFORMANCE AT HUB+)
WRITE(6,1606) (RKHUB(I), I=1, NS)
FORMAT(1H 9 1X, RKHUB(I), 2X, G(F5.3,1X))
WRITE(6,1607) (RBLADE(I), I=1, NS)
FORMAT(1H 9 1X, RBLADE(I), 2X, G(F5.3,1X))
WRITE(6,1608) (STAGER(I), I=1, NS)
FORMAT(1H 9 1X, STAGER(I), 2X, G(F5.3,1X))
WRITE(6,1609) (SRHUB(I), I=1, NS)
FORMAT(1H 9 1X, SRHUB(I), 2X, G(F5.3,1X))
WRITE(6,1610) (SIGURM(I), I=1, NS)
FORMAT(1H 9 1X, SIGURM(I), 2X, G(F5.3,1X))

150 CONTINUE
WRITE(6,1870) PO
1870 FORMAT(1HO,1X,#COMPRESSOR INLET TOTAL PRESSURE=#,F7.2,1X,#LB/FT**2)
WRITE(6,1880) PREB
1880 FORMAT(lHO,lX,~PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGEMENT)=#rFS)
WRITE(6,1900) FN
1900 FORMAT(lHO, 1X, *ROTOR SPEED=#, F7.1,1X, #RPM*)
WRITE(6,1910) CRPM,FNFN
1910 FORMAT(lHO,lX,#CORRECTED ROTOR SPEED= #,F7.1,1X,#RPM+,*C+,2X,F5.1,
162 PERCENT OF DESIGN CORRECTED SPEED)
TG(1)=T01D
P(1)=P01D
CALL WICSPD(DSMASS,ISTAGE)
SPEEDF=FNF
CALL CSINPT
XH(1)=0.0
CALL NASA
C Rotor Speed and Radius
DO 153 I=1,NS
UTIP(I)=RT(I)/12.0*2.0*PA1*FN/60.0
UTIPG(I)=RRTIP(I)/12.0*2.0*PA1*FN/60.0
UTIP2(I)=ST(I)/12.0*2.0*PA1*FN/60.0
UTIPD(I)=RT(I)/12.0*2.0*PA1*FND/60.0
UOU(I)=(UTIP(I)*UTIPD(I))*2
UMEAN(I)=RM(I)/12.0*2.0*PA1*FN/60.0
UMEAN2(I)=SM(I)/12.0*2.0*PA1*FN/60.0
UHUB(I)=RH(I)/12.0*2.0*PA1*FN/60.0
UHUB2(I)=SH(I)/12.0*2.0*PA1*FN/60.0
IF(IRAD.EQ.2) U(I)=UMEAN(I)
IF(IRAD.EQ.3) U(I)=UHUB(I)
IF(IRAD.EQ.1) UTIP(I)=UTIPG(I)
IF(IRAD.EQ.2) UTIP(I)=UTIP2(I)
IF(IRAD.EQ.3) UTIP(I)=UTIPD(I)
IF(IRAD.EQ.1) RAD12(I)=ST(I)
IF(IRAD.EQ.2) RAD12(I)=RM(I)
IF(IRAD.EQ.3) RAD12(I)=SM(I)
IF(IRAD.EQ.1) RAD11(I)=RT(I)
IF(IRAD.EQ.2) RAD11(I)=RH(I)
IF(IRAD.EQ.3) RAD11(I)=SH(I)
IF(IRAD.EQ.1) RAD0(I)=RT(I)
IF(IRAD.EQ.2) RAD0(I)=RHUB(I)
IF(IRAD.EQ.3) RAD0(I)=SHUB(I)
153 CONTINUE
C Mass Flow Rate
ISTAGE = 0
N=1
READ(5,200) FAI
200 FORMAT(F7.5)
IF(FAI.GT.1.0) GO TO 398
WRITE(6,197) FAI
197 FORMAT(1HO, 1X, #FAI=#,F7.5)
FAIO=FAI
V2=UTIPG(I)*FAI
TG(1)=QT01G
UZERO=0.0
UUZERO=0.0
KZERO=RHUB(1)
ARZERO=RHUB(1)
ITIP=0
IIIP=0
DAVE(N)=0.0
DDAVE(N)=0.0
TW(1)=OT01D
TW(1)=OT01D

IF(XDIN.GT.0.0) DAVE(N)=DIN
IF(XDDIN.GT.0.0) DDAVE(N)=DDIN
IF(XDDIN.GT.0.0) TW(1)=OT01D
IF(XDDIN.GT.0.0) TW(1)=OT01D

P(1)=DP01
TB(1) = WICEPT(TG(1), P(1))
W'S(1) = WICSH(TG(1), P(1))*RHUMID/100.0
Pw=WS(1)-~P(1)/(WS(1)+0.6213)
TDEW(1)=WiCBPT(TG(1),PW)

IF(XDIN.GT.0.0) DAUE(N)=DIN
IF(XDDIN.GT.0.0) DDAUE(N)=DDIN
IF(XDDIN.GT.0.0) TW(1)=OT01D

P(L)=OP01

TB(1) = WICEPT(TG(1), P(1))
W'S(1) = WICSH(TG(1), P(1))*RHUMID/100.0
Pw=WS(1)-~P(1)/(WS(1)+0.6213)
TDEW(1)=WiCBPT(TG(1),PW)

XW=(1-XW(1))+(1.0-WS(1))*1.0-XW(1)-XCH4

XG=XS+XW(1)+XU(1)

XU(1)=WS(1)/(1.0+WS(1)-XW(1)-XCH4~

XG=XS+XW(1)+XU(1)

XWTO=XWT(1)

XU(1)=WS(1)/(1.0+WS(1)-XW(1)-XCH4~

XG=XS+XW(1)+XU(1)

XM=XS

XCH4n=XCH4

ISTAGE=1

CALL WICPRP(XA,XU(1),XCH4,1,RMIX,CPMIX,GAMMA,CI,G2,G3)
CMAI=AMMA

RHOG(1)=P(1)/RMIX/TG(1)
RHOA(1)=P(1)/RA/TG(1)
ANASSM=1.0
AAP=APRRAI
AAP=APRRAI

CALL WICHAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,W,1,1,V2,1,BET2SS(NS1),

CMAI=AMMA

RHOG(1)=1.0*G2*K=2*G3*RHOG(1)
RHO(1)=1.0*(1.0-XW(1)*XW(1))/RHOG(1)+XW(1)/RHO
MMASS = AMMA(1)*FA1*UTPG(1)*AAM

MMASS=MMASS

WMASS=MMASS

MMASS=MMASS

IF(IPRINT.EQ.2) WRITE(6,5558) MMASSO,XDIN,WMASSO,MMASS

5558 FORMAT(1H0,2X,4(F10.5,2X))
P(3)=P(1)  MAIN  561
TB(3)=TB(1)  MAIN  562
WS(3)=WS(1)  MAIN  563
TDEW(3)=TDEW(1)  MAIN  564
XU(3)=XU(1)  MAIN  565
XH(3)=XH(1)  MAIN  566
VMASS(3)=VMASS(1)  MAIN  567
WMASS(3)=WMASS(1)  MAIN  568
WMASS(3)=WMASS(1)  MAIN  569
XG=XA+XU(3)+XCH4  MAIN  570
XW(3)=XU(1)  MAIN  571
MRW(3)=XRW(1)  MAIN  572
UMASS(3)=UMASS(1)  MAIN  573
WMASS(3)=WMASS(1)  MAIN  574
WWMASS(3)=WWMASS(1)  MAIN  575
UCENT=WMASS(1)  MAIN  576
WWCENT=WWMASS(1)  MAIN  577

C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

C C ICC IMPINGEMENT
CALL WICISS(RAD1(1),XW(1),XG,RHOG(1),UZ,WW1,WW2,WW)  MAIN  578
AMIPS=WW  MAIN  579
AMWAKS=AMIPS*(1.0-PREB)  MAIN  579
AMREBS=AMIPS*PREB  MAIN  580

C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

C ICC WAKE
N=2  MAIN  581
DAUE(2)=DAUE(1)  MAIN  582
MAUE(2)=MAUE(1)  MAIN  583
ALFA3=BET2SS(NS1)*(FAID/FAI)**(1.0/7.0)  MAIN  584
DWAKE=0.0  MAIN  585
IF(XDIN.GT.0.0.OR.XDDIN.GT.0.0) GO TO 628  MAIN  586
GO TO 629  MAIN  587

628 CALL WICWAK(RHOG(1),UZ,DWAKE,DWAKE)  MAIN  588
629 CONTINUE  MAIN  589

C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

C ICC OUTLET
WMASS(3)=WMASS(1)  MAIN  590
XH(3)=XH(1)  MAIN  591
PRATIO=1.0  MAIN  592
TRATIO=1.0  MAIN  593
EFF=1.0  MAIN  594
AMIMPR=0.0  MAIN  595
AMREBR=0.0  MAIN  596
AMWAKR=0.0  MAIN  597
DELTGH=0.0  MAIN  598
DELTGH=0.0  MAIN  599
DELTGH=0.0  MAIN  600
DELTGH=0.0  MAIN  601
DELT=0.0  MAIN  602
DELP=0.0  MAIN  603
DMDTAU=0.0  MAIN  604
XU(3)=XU(1)  MAIN  605
XH(3)=XH(1)  MAIN  606
XH(3)=XH(1)  MAIN  607
WMASS(3)=WMASS(1)  MAIN  608
WMASS(3)=WMASS(1)  MAIN  609
WMASS(3)=WMASS(1)  MAIN  610
WS(3)=WS(1)  MAIN  611
TDEW(3)=TDEW(1)  MAIN  612
RHOA(3)=RHOA(1)  MAIN  613
RHOH(3)=RHOH(1)  MAIN  614
RHO(3)=RHO(1)  MAIN  615
TG(3)=TG(1)  MAIN  616
TU(3)=TU(1)  MAIN  617
THW(3)=THW(1)  MAIN  618
P(3)=P(1)  MAIN  619
TB(3)=TB(1)  MAIN  620
XU(2)=0.0  MAIN  621
XH(2)=0.0  MAIN  622

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C IGU

IF (PRINT EO.2) WRITE (6, 300) INAGE
300 FORMAT (1HO, 5X, #ISTAGE=#, I1.2X, #IGU#)

IF (PRINT EO.2) WRITE (6, 310) PRATIO, TRATIO, EFF
310 FORMAT (IHO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 302) FAI, UZ, XA
302 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 303) MMASS, AMASS, ANIMPS, ANREBS, ANWAKS,
303 FORMAT (1HO, 5X, 8(F12.5,2X))

IF (PRINT EO.2) WRITE (6, 304) DELTGW, DELTGW, DELTGH, DELTH, DM9TAU,
304 FORMAT (1HO, 5X, 7(F12.5,2X))

IF (PRINT EO.2) WRITE (6, 305) XU(1), XU(2), XU(3)
305 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 306) XW(1), XW(2), XW(3)
306 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 307) WMASS(1), WMASS(2), WMASS(3)
307 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 308) UMASS(1), UMASS(2), UMASS(3)
308 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 309) US(1), US(2), US(3)
309 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 310) TB(1), TB(2), TB(3)
310 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 311) TDEW(1), TDEW(2), TDEW(3)
311 FORMAT (1HO, 5X, 3(F12.5,5X))

C ************************************************************
C ROVER INLET

C MAIN

XWW(2) = 0.0
WMASS(2) = 0.0
UMASS(2) = 0.0
W(2) = 0.0
RHOA(2) = 0.0
RHOMC(2) = 0.0
RHOG(2) = 0.0
TG(2) = 0.0
TW(2) = 0.0
TW(2) = 0.0
P(2) = 0.0
TB(2) = 0.0
TW(2) = 0.0
P(2) = 0.0

C INLET

IF (PRINT EO.2) WRITE (6, 300) INAGE
300 FORMAT (1HO, 5X, #ISTAGE=#, I1.2X, #IGU#)

IF (PRINT EO.2) WRITE (6, 310) PRATIO, TRATIO, EFF
310 FORMAT (IHO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 302) FAI, UZ, XA
302 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 303) MMASS, AMASS, ANIMPS, ANREBS, ANWAKS,
303 FORMAT (1HO, 5X, 8(F12.5,2X))

IF (PRINT EO.2) WRITE (6, 304) DELTGW, DELTGW, DELTGH, DELTH, DM9TAU,
304 FORMAT (1HO, 5X, 7(F12.5,2X))

IF (PRINT EO.2) WRITE (6, 305) XU(1), XU(2), XU(3)
305 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 306) XW(1), XW(2), XW(3)
306 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 307) WMASS(1), WMASS(2), WMASS(3)
307 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 308) UMASS(1), UMASS(2), UMASS(3)
308 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 309) US(1), US(2), US(3)
309 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 310) TB(1), TB(2), TB(3)
310 FORMAT (1HO, 5X, 3(F12.5,5X))

IF (PRINT EO.2) WRITE (6, 311) TDEW(1), TDEW(2), TDEW(3)
311 FORMAT (1HO, 5X, 3(F12.5,5X))

C ************************************************************
C ROVER INLET
P(l)=P(3)
TB(l)=TB(3)
WS(l)=WS(3)
TDEW(l)=TDEW(3)
XU(l)=XU(3)
XCH4=CH4ASS~NMASS
XR=AMASS~MMASS
XG=XA+XU(l)+XCH4
XAIR(l)=XA
XMETAN(1)=XCH4
XGAS(l)=XG
XW(l)=XW(3)
XWW(l)=XWW(3)
XWT(l)=XW(l)+XWW(l)
UMASS(l)=UMASS(3)
WMFSS(1)=WMASSSS(3)
WWMRSS(l)=WWMASS(3)
WTMRSS(l)=WMASS(l)+WUMASS(1)
MMRSS(l)=MMASS+CI-lMASS+UMRSS~l~+WTMASS(1)
GMASS(l)=TwASS(l)-WTMASS(1)
QLFRl=ALFA3
CALL WICPRP(A,XA~XU~1~~XCH4~TG~l~~RM~X~CPNIX~G~MN~~Gl~G2~G3~
GAMMAS=GAMMA

C STAGE PERFORMANCE CALCULATION

JPERFM=2
DAMY=0.0
IF(WTMASS(l).GT.1.0E-4) DAMY=WMASSSS(l)/WTMASS(1)
IF(DAMY.GT.0.20) JPERFM=3
IF(IPRINT.EQ.2) WRITE(6,8000) JPERFM
8000 FORMAT(1H0, 'STAGE PERFORMANCE CALCULATION (JPERFM==,I2,)*')
8001 CALL CSOUP1(FhIO, ISTAGE, MMAPSS, ALFA1, BETA1, BETA2, V2, ALFA2, ALFA3, XDELTG, DELTW, W1, W2, U1, U2)
8002 GO TO 1303
1301 CALL CSOUP'T(PA10, ISTAGE, MMAPSS, ALFA1, BETA1, BETA2, V2, ALFA2, ALFA3, XDELTG, DELTW, W1, W2, U1, U2)
1302 GO TO 1303
1303 CONTINUE

C ROTOR IMPINGEMENT

C ROTOR IMPINGEMENT (SMALL DROPLET)

8010 FORMAT(1H1,'ROTOR IMPINGEMENT SMALL DROPLET')
CALL WIIMP(S(ISTAGE, RADI), XU(1), XCH4, RHOC(l), BETA1, H1, H1,
$W1, W1, ANIMP=U)
ANIMP=ANIMP+0.0
IF(ANIMP.LT.0.0) ANIMP=0.0
IF(ANIMP.GT.WMASS(1)) ANIMP=WMASS(1)
ANIMP=ANIMP+100.0
ANIMP=ANIMP*60
ANIMP=ANIMP+100.0
ANIMP=WMASS(1)-ANIMP

183
C Rotor Impingement

IF(IREPRINT.EQ.2) WRITE(6,609) ANINPR,AMREBR,ANWAKR,AMNOIR,XWNOIR,XWREBR,XWWAKR
609 FORMAT(7(F12.5,1X))

C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++u
C ROTOR IMPINGEMENT(LARGE DROPLET)

IF(IREPRINT.EQ.2) WRITE(6,8020)
8020 FORMAT(7H,ROTOR IMPINGEMENT(LARGE DROPLET)+)

CALL WICIRL(*ISTAGE,RADI1(*ISTAGE),XWW1,WW1,RHOG1,BETA1,W1,WW1,WW)

BMIMPR=WW

IF(BMIMPR.LT.0.0) BMIMPR=0.0

BMREBR=BMIMPR*PREB/100.0

BMWAKR=BMIMPR*(1.0-PREB/100.0)

BMNOIR=WWMASS(1)-BMIMPR

XWWB=0.0

IF(WWNASS(1).GT.1.0E-6) XWWB=BMWAKR/WWMASS(1)

XWWNOR=BMNOIR/NNASS

XWWRER=BMREBR/MMASS

XWWWAR=BNWAKR/NMASS

IF(IREPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR,

6090 FORMAT(7H,7(F12.5,1X))

c ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

C ROTOR WAKE

IF(IREPRINT.EQ.2) WRITE(6,8030)
8030 FORMAT(7H,ROTOR WAKE+)

N=N+1

ALFA=BETA2

DIWAKE=0.0

IF(DWAKR.GT.0.0) GO TO 630

630 CALL WICWAK(RHOG(1),W2,DWAKE,DWKEN)

D1=DIWAKE

IF(IN1.LT.0.0) N1=n-n

IF(D1.GT.DIN) D1=DIN

AMING1=ANWAKR

ALFA=BETA2

RDEL1=DELU2

DIWAKE=0.0

IF(BMWAKR.GT.0.0) GO TO 6310

GO TO 6311

6311 CALL WICWAK(RHOG(1),RDELV1,DWAKE,DWAKH)

D2=DIWAKE

IF(D2.LT.0.0) D2=0.0

IF(D2.GT.DIN) D2=DIN

RUP2=(90.0-BETA2)/180.0

AMING2=BMWAKR*RUP2

RDEL2=DELU2

DIWAKE=0.0

IF(BMWAKR.GT.0.0) GO TO 6312

GO TO 6313

6312 CALL WICWAK(RHOG(1),RDELV2,DWAKE,DWAKH)

D3=DIWAKE

IF(D3.LT.0.0) D3=0.0

IF(D3.GT.DIN) D3=DIN

RLOW2=(90.0+BETA2)/180.0

AMING3=BNWAKR*RLOW2

RDEL3=DELU3

DIWAKE=0.0

IF(BMWAKR.GT.0.0) GO TO 6313

GO TO 6314

6314 CALL WICWAK(RHOG(1),RDELV3,DWAKE,DWAKH)

D4=DIWAKE

IF(D4.LT.0.0) D4=0.0

IF(D4.GT.DIN) D4=DIN

RLOW2=(90.0+BETA2)/180.0

AMING4=BMWAKR*RLOW2

RDEL4=DELU4

DIWAKE=0.0

IF(BMWAKR.GT.0.0) GO TO 6314

GO TO 6315

6315 CALL WICWAK(RHOG(1),RDELV4,DWAKE,DWAKH)
```
WM ASS(2)=AM S L
IF(WM ASS(2).LT.0.0) WM ASS(2)=0.0
IF(WM ASS(2).LT.0.0) WM ASS(2)=0.0
WT M ASS(2)=WM ASS(2)+WM ASS(2)
UM ASS(2)=WM ASS(2)
M ASS(2)=T M ASS(2)-WT M ASS(2)
DAUE(N)=DLGE
DDAUE(N)=DLGE
W(2)=WM ASS(2)/AM ASS
IF(WM ASS(2).LT.0.0) WM ASS(2)=0.0
WWM ASS(2)=WM ASS(2)
WT M ASS(2)=WWM ASS(2)+WT M ASS(2)
UM ASS(E)=UM ASS(l)
M M ASS=AM ASS+CHM ASS+UM ASS(2)+WT M ASS(2)
T M ASS(2)=T M ASS
G M ASS(~)=T M ASS(~)-WT M ASS(~)
DAUE(N)=DLGE
DDAUE(N)=DLGE
XW(2)=W M ASS(2)/AM ASS
XWW(2)=WWM ASS(2)/AM ASS
XWT(2)=WT M ASS(2)/AM ASS
XU(2)=XU(l)
XCH4=CHM ASS+AM ASS
XG=XN+XU(2)+XCH4
XAIR(2)=XG
XMETfN(2)=XCH4
XGAS(2)=XG
WS(2)=UN ASS(2)/AM ASS
PW=WS(2)*P(2)/(WS(2)+0.6219)
TDEW(2)=WICB PT(TG(2),PW)
RHOA(2)=P(2)/RA/TG(2)
CALL WICPRP(XA,XU(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)
RHOG(2)=(1.0+G2*N*2)**G3*RHOG(2)
RHON(2)=1.0+(XWT(2))/RHOG(2)
RHOA(2)=(1.0+G2*N*2)**G3*RHOA(2)
IF(JPERFM.NE.3) BMASS=MN ASS
IF(JPERFM.EQ.3) BMASS=GMASS(2)
CALL WICMAC(ISTAGE,BMASS,TG(2),P(2),M,UZ,C,XWT(2),LF(2),RMIX,CPMIX,A A2)
ALFAAU=(BETA1+BETA2)/2.0
IRS=2
RHOGAS=RHOG(2)
Rhub=RRhub(ISTAGE)
CALL WICCN(RZERO,UZERO,DD,U2,DELZ,ALFAU,FR,IRS,RHOGAS,
1RHUB,RS2,U2,ITIP,VTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))
CALL WICMS(IPRINT,IRAD,WM ASS(1),AM ASS,ANASS,RZER0,R2,AAREA(ISTA)
G2),RADII(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AM ASS,DELMAS)
WCENT=DELMAS
```
C CENTRIFUGAL EFFECT IN ROTOR (LARGE DROPLET) MAIN 915
IF(INPRINT.EQ.2) WRITE(G,8050) MAIN 916
8050 FORMAT(1HO,# CENTRIFUGAL ACTION IN ROTOR (LARGE DROPLET) #) MAIN 917
DELMAS=0.0 MAIN 918
DELNW=0.0 MAIN 919
IF(IDAVEC(N-1).LT.1.0E-6) GO TO 9996 MAIN 920
UZERO=U2 MAIN 921
DELZ=RZC(ISTAGE)/12.0 MAIN 922
ALFAX=0.0 MAIN 923
IIRS=2 MAIN 924
RHOGAS=RHOG(2) MAIN 925
RHUB=RRHUB(ISTAGE) MAIN 926
CALL WICCEN(RRZERO, UUZERO, DD, UZ, DELZZ, ALFAQU,9,FN, IIRS, RHOGAS,1, RHUB, R2, U2, ITIP, UZTINE, XG, XA, XU, CH4, RRTIP, IITIP, UZTINE) MAIN 927
CALL WICDM1(IPRINT, IRAD, WWMASS,1, BM, SW, BMASW, RRZERO, R2, RRTIP, IITIP, 3, RADI1, ISTAGE, RRTIP(ISTAGE), RMASW, DMIN, DMOUT, MSW2, DELMAS, RZERO=R2 MAIN 928
UZERO=U2 MAIN 929
9996 DELMWW=DELMAS MAIN 930
WN=WMASS(2) MAIN 931
WWM=WWMASS(2) MAIN 932
WWMASS(2)=WMASS(2)+DELNW MAIN 933
WWMASS(2)=WWMASS(2)+DELMWW MAIN 934
WTMASS(2)=WTMASS(2)+DELMAS MAIN 935
MNASS=MNASS+DELMAS MAIN 936
M=AHASS/MMASS MAIN 937
XCH4=CHMASS/MMASS MAIN 938
XG=XA+XU(2)+XCH4 MAIN 939
DELUUM=RHOG(2)/RHOW*DELMAS MAIN 940
XW(2)=WMASS(2)/MMASS MAIN 941
XWW(2)=WWMASS(2)/MMASS MAIN 942
XU(2)=UMASS(2)/MNASS MAIN 943
X=AMASS/MMASS MAIN 944
CHMASS=CHMASS-DELUUM*(CHMASS/MMASS(2)) MAIN 945
AMASS=AMASS-DELUUM*(AMASS/MMASS(2)) MAIN 946
MMASS=MMASS+DELMAS MAIN 947
WTMASS(2)=WTMASS(2)+DELMAW MAIN 948
MMASS=MMASS+DELMAS MAIN 949
IF(INPRINT.EQ.2) WRITE(G,617) XW(2),XG, CHMASS/MMASS, WS(2)=UMASS(2)/MMASS MAIN 950
WCENT=WCENT+DELNW MAIN 951
WWCENT=WWCENT+DELMWW MAIN 952
IF(CWMASS(2).LT.1.0E-6) DDAU(N)=0.0 MAIN 953
IF(CWMASS(2).LT.1.0E-6) DDAU(N)=0.0 MAIN 954
C STATOR IMPINGEMENT C MAIN 955
C STATOR IMPINGEMENT (SMALL DROPLET) C MAIN 956
C STATOR IMPINGEMENT (SMALL DROPLET) C MAIN 957
C STATOR IMPINGEMENT (SMALL DROPLET) C MAIN 958
C STATOR IMPINGEMENT (SMALL DROPLET) C MAIN 959
IF(INPRINT.EQ.2) WRITE(G,8060) MAIN 960
8060 FORMAT(1HO,# STATOR IMPINGEMENT (SMALL DROPLET) #) MAIN 961
CALL WICISS(ISTAGE, RADI2(ISTAGE), XW(2), XG, RHOG(2), ALFA2, U2,2, XH4, XW, AMIMPS=WW MAIN 962
AMIMPS=WW MAIN 963
IF(AMIMPS.GT.WMASS(2)) AMIMPS=WMASS(2) MAIN 964
IF(AMIMPS.LT.0.0) AMIMPS=0.0 MAIN 965
AMREBS=AMIMPS*PREB/100.0 MAIN 966
AMWAKS=AMIMPS*(1.0-PREB/100.0) MAIN 967
IF(INPRINT.EQ.2) WRITE(G,617) XW(2), CH4, RHOAG(2), U2, WW, AMIMPS, AMREBS, AMWAKS, ANMIP$S, AMAINK=WW MAIN 968
617 FORMAT(IH,8(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C STATOR IMPINGEMENT (LARGE DROPLET)
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
8070 FORMAT(IH0:# STATOR IMPINGEMENT (LARGE DROPLET)*)
CALL WICISL (ISTAGE, RADI2(ISTAGE), XWW(2), XG, RHOG(2), ALFA2, U2, WH1
$1, W2, WH)
BMIPS=WW
IF(BMIPS.LT.0.0) BMIPS=0.0
IF(BMIPS.GT.WWMASS(2)) BMIPS=WWMASS(2)
BMREBS=BMIPS*PREB/100.0
BMWKS=BMIPS*(1.0-PREB/100.0)
IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2), XA, RHOG(2), UZ
WMIPS,BMREBS, BMWKS
6617 FORMAT(IH,8(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C STATOR WAKE
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
8080 FORMAT(IH0:# STATOR WAKE)*
N=N+1
ALFA=ALFA3
DWAKE=0.0
IF(CMWAKS.GT.0.0) GO TO 632
GO TO 633
632 CALL WICWAK (RHOG(2),U2,DWAKE,DWAKEM)
633 D1=DWAKEM
IF(D1.LT.0.0) D1=0.0
IF(D1.GT.DIN) D1=DIN
AMING1=AMWAKS
ALFA=ALFA3
SDELU1=DELU2
DWAKE=0.0
IF(CMWAKS.GT.0.0) GO TO 6330
GO TO 6331
6330 CALL WICWAK (RHOG(2), SDELU1, DWAKE, DWAKEM)
6331 D2=DWAKEM
IF(D2.LT.0.0) D2=0.0
IF(D2.GT.DIN) D2=DIN
SUP2=(95.0/ALFA3)/180.0
AMING2=BMWAKS*SUP2
SDELU2=DELU2
DWAKE=0.0
IF(CMWAKS.GT.0.0) GO TO 6332
GO TO 6333
6332 CALL WICWAK (RHOG(2), SDELU2, DWAKE, DWAKEM)
6333 D3=DWAKEM
IF(D3.LT.0.0) D3=0.0
IF(D3.GT.DIN) D3=DIN
SLOW2=(95.0+ALFA3)/180.0
AMING3=BMWAKS*SLOW2
WMASS=WMASS(2)-AMING3
WMASSL=WMASS(2)-BMWKS
IF(WMASS.LT.0.0) WMASS=0.0
IF(WMASS.LT.0.0) WMASS=0.0
CALL WICISL (WMASS, WMASS, AMING1, AMING2, AMING3, DDAVE(2), DAVE(2), D1, D3, D3, DLIMIT, AMSSL, AMGLE, DSLL, DLGE)
WMASS(3)=AMSSL
WMASS(3)=AMSS
IF(WMASS(3).LT.0.0) WMASS(3)=0.0
IF(WMASS(3).LT.0.0) WMASS(3)=0.0
WMASS(3)=WMASS(2)+WMASS(2)
WMASS(3)=WMASS(2)
MMASS=MMASS+CHMASS+UWMASS(3)+WMASS(3)
TMASS(3)=MMASS
CMASS(3)-TMASS(3)-WMASS(3)
DAVE(N)=DSL
DDAUE(N)=DLGE
XH(3)=WMASS(3)/MMASS
XTH(3)=WMASS(3)/MMASS
XU(3)=WMASS(3)/MMASS
XV(3)=WMASS(3)/MMASS
XG=XH
XW=WWMASS(3)/HMASS
XWT=WTHASS(3)/HMASS
XU=XU(2)
XUL=AMASS/HMASS
XCH4=CHMASS/MMASS
XG=XA+XU(3)+XCH4
XAIR=XA
XMETAN=XCH4
XGAS=XG
IF(WMASSO.LT.1.0E-6) GO TO 1051
IF(WWMASSO.LT.1.0E-6) GO TO 1051
IF(WTMASSO.GT.0.0) GO TO 1051
TG=TG(2)
TW=TW(2)
IF(IPRINT.EQ.2) WRITE(6,615) RHOA(2),UZ,FR,FL,
G,WMASS(3),UF,%S(3),XW(3),XU(3)
615 FORMAT(1H,10(FI2.5,LX))
IF(IPRINT.EQ.2) WRITE(6,620) Df, Df,
G,AUE(N),TG, TW
620 FORMAT(1H,3(FI2.5,LX))
IF(WMASS(2).GT.0.0.AND.WWMASS(2).GT.0.0) GO TO 951
IF(WMASS(2).GT.0.0) GO TO 951
IF(WWMASS(2).GT.0.0) GO TO 951
WS=WS(2)
TB=TB(2)
TDEW=TDEW(2)
DELTG2=0.0
DELTG3=0.0
DELTW2=0.0
TRATIO=TG(3)/TG(1)
DAUE(N)=0.0
RHOA(3)=P(3)/RVTG(3)
CQLL
CICPRP(XA,XU(3),XCH4,TG(3),RMIX1GAH,M1,G1,G2,G3)
RHOG1=0.0
IF(JPERFM.NE.3) BMASS=MHASS
IF(JPERFM.EQ.3) EMf%S=GMf&S(3)
CALL WiCMAC(ISTAGE,BMASS,TG,P,M,UZ,C,XWT,RF,AA3)
RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)
RHOM(3)=1.0-(1.0-XWT(3))**RHOA(3)
GO TO 950
951 CONTINUE
C ++CENTRIFUGAL EFFECT IN STATOR+
C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
GO TO 708
IF(IPRINT.EQ.2) WRITE(6,8030)
8030 FORMAT(H6,10(I6,5,1X))
IF(DAUE(N-1).LT.1.0E-6) GO TO 708
DD=DAUE(N-1)
DELZ=SC(ISTAGE)/12.0
ALFAU=(ALFA2+ALFA3)+2.0
IRS=1
RHOAS=RHOA(2)
RFS=RFSHUB(ISTAGE)
CALL WICCN(RZERO,LZERO,DD,VZ,DELZ,ALFAU,FR,IRS,RHOAS,
RHSUB,DSHUB,ISTAGE)
CALL WICEN(RZERO,LZERO,DD,VZ,DELZ,ALFAU,FR,IRS,RHOAS,
RHSUB,DSHUB,ISTAGE)
IF(WMbY%(3).LT.0.0) WMASS(3)=0.0
IF(WMASS(3).GT.TWMA.S) WMASS(3)=TWMAS
MHASS=MHASS+DELMAS
XWC3)=WMASS(B)/HMASS
XWW(3)=WWMASS(3)/HMASS
XU(3)=UMASS(3)/HMASS
XA=AHRSSMHASS
XCH4=CHMRSS/HMASS
XG=XA+XU(3)+XCH4
WS(B)=UMASS(3)/MMASS
RZERO=RE
UZERO=U2
708 CONTINUE
WTMI%S(~)=WHASS~~)+WUMASS(~)
708 CONTINUE
677 CONTINUE

C HEAT TRANSFER P
C HEAT-TRANSFER (SMALL DROPLET)

IF(IPRINT.EQ.2) WRITE(6,8:20)
FORHAT(lHO,# HEAT TRANSFERS)
DELTGH=O.0
DELTWH=O.0
IF(DAUE(N-2).GT.O.O.AND.DAVE(N).GT.O.O) GO TO 8121
GO TO 8122
RE=O.0
XUl=(XU(l)+XU(3))/2.0
XWl=(XW(l)+XW(3))/2.0
WMASSl=(WMASS(1)+WMASS(3))/2.0
CPGl=X~~WICCPA~TG~l~~-~XU~l~~WICCPH~TG~l~~+XCH4*WICCPC~TG~l~~
CPG3=Xn-~WICCPA(TG(l))+):U(3)-:rWiCCPH(TG(3))+XCH4"WICCPC(TG(3))
CPG=(CPGl+CPG3)/2.0
CALL WICHET(TG(l),TG(3),TWW(1),TWW(3),DD~UE(N-2),DD~UE(N)
$9 DELZ( ISTAGE), UZ, WM%Sl, UMASSl, AMASS, CHHASSt CPG, CPCJ, DELTGH
$9 DELTWH, RE)
8122 DELTG2=DELTGH
DELTW2=DELTWH

C HEAT TRANSFER ( LARGE DROPLET 1
DELTGtl=O. 0
DELTWH=O. 0
IF(DDAUE(N-2).GT.O.O.AND.DDAUE(N).GT.O.O) GO TO 8123
GO TO 8124
RE=O.O
IF(DDAUE(N-11.GT.O.O) RE=REfAJE
XUl=(XU(l)+XU(3))/2.0
XWl=(XWW(l)+XWW(3))/2.0
WMASSl=(WWMASS(l)+WWMASSo)/2.0
UCASSI=(UM~SS(l)+UMASS(3>)/2.0
CPGl=X~~WICCPA~TG~l~~-~XU~l~~WICCPH~TG~l~~+XCH4*WICCPC~TG~l~~
CPG3=Xn-~WICCPA(TG(l))+):U(3)-:rWiCCPH(TG(3))+XCH4"WICCPC(TG(3))
CPG=(CPGl+CPG3)/2.0
CALL WICHET(TG(l),TG(3),TWW(1),TWW(3),DD~UE(N-2),DD~UE(N)
$9 DELZ( ISTaGE), UZ, WM%Sl, UMASSl, AMASS, CHHASSt CPG, CPCJ, DELTGH
$9 DELTWH, RE)
IF(IWRITE.EQ.2) WRITE(6,25) RHOA(3),RHOM(3),RHOG(3),DMDTA1,DMD
$TA2,P2,TW(3),TG(3)
R2S FORMAT(IH,B12.5,I1X))
250 DELTG=DELTGI
DELTH=DELTH2
DEL=3-P(3)-P(1)
GAMMA=GAMMA
TB(3)=WICBPT(TG(3),P(3))

C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT(STAGE PERFORMANCE)
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
WRITE(6,400) FAIO, ISTAGE
400 FORHAT(1H1,1X,#**r*+*************** #,1X,#=#,1XV
$#)#,~~,#********************#)

PRATIO=P(3)/P(1)
TRATIO=TG(3)/TG(1)
GAMMAU=(GAMMA+GAMMA0)/2.0
G4=(GAMMAU-1.0)/GAMMA
ETAA(ISTAGE)=(PRATIO**G4-l.O)/(TRATIO-1.0)
WRITE(6,402) JPERFH
402 FORHAT(1HO,SX,#STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENTz,
B#(JPERFH=#, 11,#)#)
WRITE(6s401) PRATIO,TRATIOtETAACISTAGE)
401 FORMAT(lHO,SX,#STAGE TOTAL PRESSURE RATIO=#.Fl2.5,/, 36X.sSTAGE TOTAL TEMPERATURE RATIO=f,F12.5,/, 36X,STAGE ADIABATIC EFFICIENCY=#,Fl2.5)
WRITE(6,4025) XU(1), XU(1), XU(3)
4025 FORHAT(lH ,SX,#XU=#,3(Fl5.5,5X))
WRITE(6,406) XW(1), XW(1) , XW(3)
406 FORHAT(lH ,SX,#XW=#,3(Fl5.5,5X))
WRITE(6,4060) XWW(l),XWW(l),XWW(3)
4060 FORHAT(lH ,SX,#XWW=#,3(Fl5.5,5X))
WRITE(6,4061) XWT(l),XWT(l),XWT(3)
4061 FORHAT(lH ,SX,#XWT=#,3(Fl5.5,5X))
WRITE(6,4062) XAIR(l),XAIR(l),XAIR(3)
4062 FORHAT(lH ,SX,#XAIR=#,3(Fl5.5,5X))
WRITE(6,408) WMASS(l),RMASS(1),RMASS(3)
408 FORHAT(lH ,5X,#WMASS=#,3(Fl5.5,5X))
WRITE(6,407) WMASS(l),WMASS(1),WMASS(3)
407 FORHAT(lH ,5X,#WMASS=#,3(Fl5.5,5X))
WRITE(6,4070) WMAS(1),WMASS(l),WMASS(3)
4070 FORHAT(lH ,5X,#WMASS=#,3(Fl5.5,5X))
WRITE(6,4071) WMASS(l),WMASS(1),WMASS(3)
4071 FORHAT(lH ,5X,#WMASS=#,3(Fl5.5,5X))
WRITE(6,4072) WMAS(1),WMASS(l),WMASS(3)
4072 FORHAT(lH ,5X,#WMAS=#,3(Fl5.5,5X))
WRITE(6,4073) WMAS(1),WMASS(l),WMASS(3)
4073 FORHAT(lH ,5X,#WMAS=#,3(Fl5.5,5X))
WRITE(6,408) WMASS(l),WMASS(1),WMASS(3)
408 FORHAT(lH ,5X,#WMASS=#,3(Fl5.5,5X))
WRITE(6,4080) GMASS(l),GMASS(1),GMASS(3)
4080 FORHAT(lH ,5X,#GMASS=#,3(Fl5.5,5X))
WRITE(6,4081) TMASS(l),TMASS(1),TMASS(3)
4081 FORHAT(lH ,5X,#TMASS=#,3(Fl5.5,5X))
GO TO 450
IF(XDIN.GT.0.0) GO TO 460
GO TO 450
460 IF(TW(3).LT.TB(3)) GO TO 451
HU=115.3272-0.6840909*(TB(3)-460.0)
DAMY=CPG/HU*(TG(3)-TB(3))
XE=DAMY/(DAMY+1.0)
IF(XE.GT.XW(3)) GO TO 451
XEUAPO=XE
TW(3)=TB(3)
TG(3)=TB(3)
XW(3)=XW(3)-XEUAPO
XU(3)=XU(3)+XEUAPO
GO TO 452
451 XEUAPO=XU(3)
TH(3)=TB(3)
TH(3)=TB(3)
XH(3)=XH(3)-XEUAPO
XU(3)=XU(3)+XEUAPO
GMASS(3)=UMASS(3)+MMASS
IF(IPRINT.EQ.2) WRITE(6,453)
WMASS(3)=XW(3)*MMASS
GMASS(3)=UAMASS+AMASS
IF(IPRINT.EQ.2) WRITE(6,453)
WMASS(3)=XW(3)*MMASS
GAMASS(3)=UAMASS+AMASS
IF(IPRINT.EQ.2) WRITE(6,453)
454 FORMAT(1H0,10(F10.5,2X))
GMAS(3)=TMAS(3)-WTMAS(3)
XW(3)=WMAS(3)/MMASS
XWT(3)=WTMAS(3)/MMASS
XHA=AMASS/MMASS
XCH4=CHMASS/MMASS
XG=XA+XU(3)+XCH4
XAGAS(3)=XG
XAIR(3)=XA
XMETAN(3)=XCH4
455 CONTINUE
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C REPEAT
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
IF(ISTAGE.EQ.NS) GO TO 902
GO TO 900
902 OUALPR=P(3)/0POl
OUALTR=TG(3)/0TOlG
DELMT=(MMASS-TLMO)/TLMO
IF(WTMO.GT.O.0) DELMWT=(WTMASS(3)-WTMO)/WTMO
DELMG=(GMRSS(3)-GMO)/GMO
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C OUTPUT (OVERALL PERFORMANCE)
WRITE(6,421)
421 FORMAT(1H1,******** OVERALL PERFORMANCE *********)
WRITE(6,4220) FAIO
4220 FORMAT(1H0,1X,#INITIAL FLOW COEFFICIENT=#,F5.2)
WRITE(6,423) CRPM,FNF
423 FORMAT(1H0,1X,#CORRECTED SPEED=#,F7.1,5X,F5.3,1X,
$#FRACTION OF DESIGN CORRECTED SPEED#)
WRITE(6,424)XDIN,XDIN,XW,HRHUMID,XCH4IN
424 FORMAT(1H0,1X,#INITIAL WATER CONTENT(SMALL DROPLET)=#,F5.3,1/
$#INITIAL WATER CONTENT(LARGE DROPLET)=#,F5.3,1/
$#INITIAL WATER CONTENT(TOTAL)=#,F5.3,1/
$#INITIAL RELATIVE HUMIDITY=#,F5.1,1X,#PER CENT#/)
WRITE(6,425) XDIN,WTINO
WRITE(6,426) OUALPR
426 FORMAT(1H0,1X,#COMPRESSOR INLET TOTAL TEMPERATURE=#,F8.2)
WRITE(6,427) P0
427 FORMAT(1H0,1X,#COMPRESSOR INLET TOTAL PRESSURE=#,F8.2)
WRITE(6,428) CRPMA,CMAS
WRITE(6,429) CMAS,CMMASS
429 FORMAT(1H0,1X,#OVERALL TOTAL PRESSURE RATIO=#,F6.4)
WRITE(6,430) OUALTR
430 FORMAT(1H0,1X,#OVERALL TOTAL PRESSURE RATIO=#,F6.4)
SUBROUTINE WICSPC

COMMON /PERDUE/ JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESUP,RESLOW,
    PREB,RRTIP(B),SRTIP(8),~~~1,~~~2,AAA3,SAREG(6),SARES(7),
    RRHUB(6), RC(6), RBLADE(6), STAGER(6),
    SRHUB(7), SC(7), SBLADE(7), STAGES(7),
    SIGMR(6), BET1R(6), BET2R(6), AINC5R(6), ADEV5R(6),
    SIGMR(7), BET1S(7), BET2S(7), AINC7S(7), ADEV7S(7),
    UPIFG(6), UPIFG(6), UPIFG(6), ULO(6), UMEAN(6), UMEAN(6),
    UMEAN(6), UMEAN(6), UMEAN(6), IPRINT

IPA1=3.1415926
CALL WICPRP(XA,XU(1),XCH4,TG(1),RMIX,CMIX,CMIX,CMIX,G1,G2,G3)
RHOG(1)=P(1)/RMIX/TG(1)
BMASS=MMASS-WMAS-WWMAS
AAA2=AREAS(ISTAGE)
AAA3=AREA(ISTAGE+1)
CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,UZ,C,XWT(1),ALFA1,
    $RMIX,CPMX,AAA1)
ASPEED=C
ASPEED=ASPEED
RHOG(1)=(1.0+G2*ASPEED)**2**G3*RHO(1)
RHOG(1)=1.0/(1.0-AH(1))/RHOG(1)*XWT(1)/RHO(1)
U21=U2
UZ2=UZ
FAI2=UZ2/UTIPG(ISTAGE)
ALFAIR=ALFA1*PAI/180.0
V1=U2/COS(ALFA1)
VSI=V2*THM(ALFA1)
WS1=U(VISTAGE)-VSI
T=W1/U2
BETAIR=ATAN(T)
BETAIR=BETAIR*180.0/PAI
TT=U2*ASPEED+WS1*ASPEED
W1=ASPEED(T)
AMACH1=VI/ASPEED
AMACH1=U1/ASPEED
TS1=TG(1)/(1.0+G2*AMACH1**2)
P1=(TG(1)/TS1)**(-G1)*P(1)
PRINTL=(1.0+G2*AMACH1**2)**G1*PS1
2000  

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2001  
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2002  
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6090  
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6091  
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$ANG2, 8P, OMEG1, 8F, OMEG2, OMEG3, OMEH, OMEG4,

DELPU=OMEG3*0.5*RHOG(1)/GC*(W1**2)
IF(IPRINT.EQ.2) WRITE(6,6092) OMEG3, DELP3
6092 FORMAT(1H, 1X, #OMEG3=#, 2F10.5)
REAU1=REAE
BETA2R = BETA2 * PA1 / 180.0
200 UZAC=UZ
WS2 = UZ * TAN ( BETA2R )
US2 = UU2(I2STAGE) - WS2
TTT=US2/UZ
ALFA2R = ALFA2 * 180.0 / PAI
TTTT = UZ ** 2 + WS2 ** 2
W2 = SQRT ( TTTT )
TTTT = UZ ** 2 + US2 ** 2
U2 = SQRT ( TTTT )
DELH=DELH*U2(ISTAGE)*U2-U(ISTAGE)*U1)/GC/AJ

!WICIRS(I1), WICIRS(I3)
$WICSPC 133
$WICSPC 134
$WICSPC 135
$WICSPC 136
$WICSPC 137
$WICSPC 138
$WICSPC 139
$WICSPC 140
$WICSPC 141
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$WICSPC 196
$WICSPC 197
$WICSPC 198
$WICSPC 199
$WICSPC 200
$WICSPC 201
$WICSPC 202
UZ = UZ2
JJ = JJ + 1
IF (UZ LT 0.0 OR UZ GT ASPEED) GO TO 999
GO TO 200

201 XP = UZ
Y2 = UZ2
UZ = WICNEW(X1, Y1, X2, Y2)
IF (PRINT EQ. 2) WRITE(6, 203) JJ, UZ

203 FORMAT (1H, 1X, 11, 2X, X2, =, F10.5)
JJ = JJ + 1
IF (UZ LT 0.0 OR UZ GT ASPEED) GO TO 999
GO TO 200

202 IF (ABS((UZAS - UZ2) / UZAS) LT EPS) GO TO 300
X1 = X2
Y1 = Y2
X2 = UZAS
Y2 = UZ2
UZ = WICNEW(X1, Y1, X2, Y2)
IF (PRINT EQ. 2) WRITE(6, 204) JJ, UZ

204 FORMAT (1H, 1X, 11, 2X, X2, =, F10.5)
JJ = JJ + 1
IF (UZ LT 0.0 OR UZ GT ASPEED) GO TO 999
IF (JJ EQ. 20) GO TO 999
GO TO 200

300 UZ2CL = UZ
IF (JJJ EQ. 2) GO TO 2010
IF (JJJ GT. 2) GO TO 2020

2010 X2 = UZAS
Y2 = UZ2CL
UZ = WICNEW(X1, Y1, X2, Y2)
IF (PRINT EQ. 2) WRITE(6, 2030) JJJ, UZ

2030 FORMAT (1H, 1X, 12, X2, =, F10.5)
JJJ = JJJ + 1
GO TO 2000

2020 IF (ABS((UZAS - UZ2CL) / UZAS) LT EPS) GO TO 3000
X1 = X2
Y1 = Y2
X2 = UZAS
Y2 = UZ2CL
UZ = WICNEW(X1, Y1, X2, Y2)
IF (PRINT EQ. 2) WRITE(6, 2040) JJJ, UZ

2040 FORMAT (1H, 1X, 12, X2, =, F10.5)
JJJ = JJJ + 1
IF (JJJ EQ. 20) GO TO 3000
GO TO 2000

3000 UZ2 = UZ2CL
FAI2 = UZ2 / UFITP(IISTAGE)
P(2) = (1.0 + G2 * AMAC2**2) * G1 * PS2
JJJ = JJJ + 1

3001 UZAS = UZ
CALL WICSL(OMEGS(IISTAGE), SIGUMS(IISTAGE), BETISS(IISTAGE), BETISS
*(IISTAGE), AINCSS(IISTAGE), ADEUSS(IISTAGE), AMAC2, ALFA2, DEQS, DEQN,
$ITACS, SITAN, BETAN, OMEGAN, FMA2(IISTAGE), IDESIN, AK1, AK2, AK3, UZ2,
$UZAS, 0.0, RAD2(IISTAGE), RAD1(IISTAGE+1))

UMLARG = OMEGAN
ALFA3 = BETAN
ALFAPR = ALFA2*PAI/180.0
ALFAPR = ALFA3*PAI/180.0
ALFAPAR = (ALFA1R + ALFA2R) / 2.0
TANGT = WICTAN(ALFAIR) - WICTAN(ALFA2R)
CSAU = COS(ALFA2R)
CS1 = COS(ALFAIR)
CL = 2.0 + SIGUMS(IISTAGE) * TANGT * CSAU
COS = 0.018 * (CL**2)
OMEGSEN = COS*SIGUMS(IISTAGE)**CS1**2 / (CSAU**3)
H = SRTIP(IISTAGE) - SRHUB(IISTAGE)

197
SHR=SC(ISTAGE)/H&IGUMR(ISTAGE)
CDA=O.020*SHR
OMEGAN=CDA*SIGUMS(ISTAGE)+(CSl**2)/(CSAU**31
IF(IPRINT.EQ.2) WRITE(6,3002)
SOMEGSE. OMEGAN, OMEGB, CDS, CDA
3002 FORMAT(1H0,5F10.5)
OMES2=OMEGS2
OMEA2=OMEGAN
AINCIS=ALFA2-BET1MS(ISTAGE)
ADEUIS=BET2N-BET1MS(ISTAGE)
ALFA3=ALFA3=PAI/lBO.O
U3=UZ/COS(ALFA3R)
CALL WICRSL~SIGUMS~ISTAGE~rALFA2,ALFA3,SC(ISTAGE),D~U~CDR~OMEG~R~
OMEGAR=OMEGAR*2.0
DELP4=OMEGA4*0.5*RHOG(2)/GCr(U2**2)
IF(IPRINT.EQ.2) WRITE(6,3003) OMEGA4,DELP4
3003 FORMAT(1H0,#OMEGA4=#,2F10.5)
CALL WICISL~ISTAGE~SRTIPCISTAGE~~XWW~2~~XG,RHOG~2~~~LF~2~U2~WWl
BMIHPS=WW
IF(BMIHPS.GT.WWMAS) BMIHPS=WWMAS
BMREBS=BMIMPS*PREB/100.0
BMWAKS=BMIMPS*(1.0-PREB/100.0)
IF(IPRINT.EQ.2) WRITE(6,6616)
6616 FORMAT(1H0,#IMPINS#)
IF(IPRINT.EQ.2) WRITE(6.6617) XWW~2)~XA,RHOG(2)~UZ~WW~BMIMPSIBM
6617 FORMAT(lH0,BIFl2.5,1X))
RST1=RAD12(1STAGE)**2-~~~2*144.0/2.0/PR1
RST1=SQRT(RST1)
RST2=0.0*RF?DI~(ISTAGE)**~-RSTl**2
RST2=SQRT(RST2)
DELR=(RST2-RST1)/12.0
FMASSS=BMWAKSDELR
CALL WICFML~U2rU3~FMASSS,RHOG2,SC(ISTAGE),SIGUMS(ISTAGE),BET~l~BET~2,3ALFA2,ALFA3,BMASS,DELUU2,DELUL2,OMEGRU,OMEGRL~OMEGSU,OMEGSL, BDRAGRU,DRAGRL,DRr?GSU,DR~GSL,REAUE)
OMEGAG=OMEGSU+OMEGSL
DELP5=OMEGA5*0.5*RHOG(2)/GCn(U2**2)
IF(IPRINT.EQ.2) WRITE(6,6618) OMEGA5,DELP5
6618 FORMAT(lH0,#OMEGA5=#,2F10.5)
REAUE2=REAUE
REAUE=(REAUEl+REAUE2)*0.5
PR23=1.0-~OMEGA8+OMEGA4+OMEGA5+OMEGA6)x~1.0-PS2~P~2~~
PR13=(TG(2)/TG(l))*~Gl*PRREL*PR23
PR13I=(TG(2)/TG(l))**Gi
P(3)=PR13*P(1)
TC(3)=TC(2)
TS3=(TC(3)-U3**2)/(2.0*CPMIX*GC*AJ)
AC3=(GAMMA*RMIX~TS3*GC)**0.5
ASPEED=WICASD(XWT(l),RHOG(2),AG3)
ASPEED3=ASPEED
ANAC3=U3/ASPEED
PS3=(1.0+GC*ANAC3**2)**( G1)*P(3)
RHGC3=PS3/CP~IX/TS3
RHGC3=RHGC3
RHGC3-1.0-~X/RHOG3+CWT(1)/RHOG3
VZ=BNASS/RHOG3+AAS
VZ3CL=VZ
IF(JJ...EQ.2) GO TO 3010
IF(JJ...E Q.2) GO TO 3020
XXX1=VZ3AR
YYY=VZ3CL
JJJ=JJJ+1
GO TO 3001
3010 XXX2=UZ3AS
YYYY2=U23CL
V2=WICNEH(XXX1,YYY1,XXX2,YYYY2)
IF(IPRINT.EQ.2) WRITEC6,3030) JJJ11UZ
FORMAT(lH ,lX,I2.2X~#U233=f~F10.5~
JJJJ=JJJJ+l
GO TO 3001
3020 IF(ABS((U23AS-U23CL)/UZ3AS).LT.EPS1 GO TO 4000
XXX1=XXX2
YYYY1=YYYY2
XXX2=UZ3AS
YYYY2=U23CL
V2=WICNEH(XXX1,YYY1,XXX2,YYYY2)
IF(IPRINT.EQ.2) WRITE(6,3040) JJJJUZ
FORMAT(lH ,lX,I2.2X~#U233=#,F10.5~
JJJJ=JJJJ+l
IF(JJJJ.EQ.20) GO TO 4000
GO TO 3001
4000 UZ3=UZ3CL
FAI3=V23/UTIPG(ISTAGE+1)
TH(3)=TH(2)
THX(3)=THX(2)
OMEGX=OMEGA1+OMEGA2*OMEGA3*OMEGA7
OMEGS=OMEGA4+OMEGA5+OMEGA6
PUMG1=OMEGA1/UM6*1.0
POMG2=OMEGA2/OMEGX*100.0
POMG3=OMEGA3/OMEGX*100.0
PUMG4=OMEGA4/OMEGS*100.0
POMG5=OMEGA5/OMEGS*100.0
POMG6=OMEGA6/OMEGS*100.0
POMG7=OMEGA7/OMEGX*100.0
PRATIO=P(3)/P(1)
TRATIO=TLG(3)/TLG(1)
CALL WICPRF4(XA,XU(3),XCH4,TG(3),RMI6,CPMIX,GAMMA,G1,G2,G3)
G4=1.0/G1
ETAI(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)
WRITE(6,404) FAI1,ISTAGE
404 FORMAT4H1,1X,*************** *I X,1X$INITIAL FLOW COEFFICIENT=",1X,F5.3,1X*STAGE#121,IX,1X"$")$2X,"***************")
WRITE(6,401) PRATIO,TRATIO,ETAI(ISTAGE)
401 FORMAT4H1,1X,STAGE TOTAL PRESSURE RATIO=",F12.5,/
$6X,STAGE TOTAL TEMPERATURE RATIO=",F12.5,/
$6X,STAGE ADIABATIC EFFICIENCY=",F12.5)
WRITE(6,402) FAI1,V21,UTIPG(ISTAGE)
402 FORMAT4H1,5X,STAGE TOTAL PRESSURE RATIO=",F12.5,/
$6X,STAGE TOTAL PRESSURE RATIO(IDEAL)=",F12.5,/
$6X,LOSS FACTOR IN ROTOR=",F12.5,/
$6X,LOSS FACTOR IN STATER=",F12.5,/
WRITE(6,405) U21,U22,U23
405 FORMAT4H1,24X,*ROTOR INLET* *ROTOR OUTLET* *STATER OUTLET")
WRITE(6,405) P(1),P(2),P(3)
406 FORMAT4H1,1X,*TOTAL PRESSURE=",10X,3(F10.4,5X))
WRITE(6,407) PSI1,FS2,PS3
407 FORMAT4H1,1X,*STATIC PRESSURE=",9X,3(F10.4,5X))
WRITE(6,408) TG(1),TG(2),TG(3)
408 FORMAT4H1,1X,*TOTAL TEMPERATURE(GAS)=",3X,3(F10.4,5X))
WRITE(6,409) TS1,TS2,TS3
409 FORMAT4H1,1X,*STATIC TEMPERATURE(GAS)=","1X,3(F10.4,5X))
WRITE(6,410) RH0G1,RH0G2,RH0G3
410 FORMAT4H1,5X,*STATIC DENSITY(GAS)=",5X,3(F10.4,5X))
WRITE(6,411) RHOM1,RHOM2,RHOM3
411 FORMAT4H1,5X,*STATIC DENSITY(MIXTURE)=",5X,3(F10.4,5X))
WRITE(6,412) V21,U22,U23
412
SUBROUTINE WICMAC

FORMAT(1H, 1X, *AXIAL VELOCITY*, 10X, 3(F10.4, 5X))
WRITE(6, 413) U1, U2, U3

FORMAT(1H, 1X, *ABSOLUTE VELOCITY*, 7X, 3(F10.4, 5X))
WRITE(6, 414) W1, W2

FORMAT(1H, 1X, *RELATIVE VELOCITY*, 7X, 2(F10.4, 5X))
WRITE(6, 415) UI, U(2), U(3), U(4)

FORMAT(1H, 1X, *BLADE SPEED*, 13X, 3(F10.4, 5X))
WRITE(6, 416) VS1, VS2

FORMAT(1H, 1X, *TANG. COMP. OF ABS. VEL.*, 2(F10.4, 5X))
WRITE(6, 417) W51, W52

FORMAT(1H, 1X, *TANG. COMP. OF REL. VEL.*, 2(F10.4, 5X))
WRITE(6, 418) ASPED1, ASPED2, ASPED3

FORMAT(1H, 1X, *ACOUSTIC SPEED*, 9, 1OX, 3(F10.4, 5X))
WRITE(6, 419) FAI1, FAI2, FAI3

FORMAT(1H, 1X, *RELATIVE FLOW ANGLE*, 5X, 3(F10.4, 5X))
WRITE(6, 420) ALFA1, ALFA2, ALFA3

FORMAT(1H, 1X, *FLOW AREA*, 15X, 3(F10.4, 5X))
WRITE(6, 421) AREA(6), AREA(7), UPRINT

REAL MA1, MA2, MC1, MC2, MANEW, MCNEW
COMMON /PERDFM, JPERFM, RHOS(3), REUP, RELW, RESUP, RELW

P(3), TG(3), XA, XU(3), XCH4, XH(3), XW(3), XW(3), TH(3), TH(3)
Omega(7), KMEQ(6), CAPP(6), CAPP(6)
PH(7), SG(7), SBLADE(7), STAGES(7)
SIGUS(6), SIGUS(6), SIGUS(6), SIGUS(6), SIGUS(6)
UP(6), UP(6), UP(6), UHUB(6), UHUB(6), UHUB(6)
AREA(6), AREA(7), AREA(7), UHUB(6), UHUB(6), UHUB(6), UHUB(6)
ICEN, ICEN, FMR(6), FMA(6), IRA, FRA
MR, NS, NS1, RT(6), RH(6), RH(6), ST(6), SH(6), SH(6)

GAMMA=1.0/(1.0-RHOS/PXMX/778.0)
G2=(GAMMA-1.0)/2.0
G3=1.0/(GAMMA-1.0)

WRITE(6, 422) A(1), A(2), A(3), A(4), A(5)
WRITE(6, 423) ALFA1, ALFA2, ALFA3

RETURN
END
MC1=UZ/C/COS(ALFAR)
MA2=0.6
RHOGS=(1.0+G2*MA2**2)**G3*RHOG1
RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOG1)
TS=TO1G/(1.0+G2*MA2**2)
A=SORT(GAMMA+RMIX*TS+32.174)
C=VICASD(XW1,RHOGS,A)
IF(JPERFM.NE.3) UZ=AMASSM/RHOMS/AREA1
IF(JPERFM.EQ.3) UZ=AMASSM/RHOGS/AREA1
IF(AMASSM.LT.0.001) UZ=UTIPG(ISTAGE)*FAI
MCN=UZ/C/COS(ALFAR)

300 MANEW=VICNEW(MA1,MC1,MA2,MC2)
RHOGS=(1.0+G2*MANEW**2)**G3*RHOG1
RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOG1)
TS=TO1G/(1.0+G2*MANEW**2)
A=SORT(GAMMA+RMIX*TS+32.174)
C=VICASD(XW1,RHOGS,A)
IF(JPERFM.NE.3) UZ=AMASSM/RHOMS/AREA1
IF(JPERFM.EQ.3) UZ=AMASSM/RHOGS/AREA1
IF(AMASSM.LT.0.001) UZ=UTIPG(ISTAGE)*FAI
MCN=UZ/C/COS(ALFAR)
ERROR=ABS(MANEW-MANEW)
ERROR=ERROR/MANEW
EPS=1.0E-6
IF(ERROR.LT.EPS) GO TO 200

403 FORMAT(1HO,*MZ DOES NOT CONVERGE AT STAGE=*,I1)
GO TO 998
200 M=MANEW
IF(AMASSM.LT.0.001) ISTR=0
RETURN
END

CFUNCTION WICASD
C
FUNCTION WICASD(XW,RHOG,CG)
RHOW=62.2567
CW=4956.04
SIGUMA=(XW*RHOG)/(RHOW-XW*(RHOW-RHOG))
A1=(1.0-SIGUMA)*RHOG+SIGUMA*RHOW
A2=(1.0-SIGUMA)/(RHOG+CG*CG)
A3=SIGUMA/(RHOW*CW*CW)
A4=A1*(A2+A3)
WICASD=1.0/SORT(A4)
RETURN
END

CFUNCTION WICBOA
C
SUBROUTINE WICBOA

CFUNCTION WICMAC
C
WICMAC
S-DEQS
ADEUI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
IF(AMACH1.LT.X) ADEUI=ADEVIS+6.40*DELDEQ*AK1
BET2C=BET2S-ADEVIS-ADEUI
Y1=BET2C
N=1
12 IF(N.GT.1) GO TO 10
BET2=E8T2S*1.1
X2=BET2A
DEQ=WICED(AK3,U1,UR1,R1,R2,BET1,X2,ANIGMA,AINCIS,AINCI)
DELDEQ=WICED(AK3,U1,UR1,R1,R2,BET1,X2,ANIGMA,AINCIS,AINCI)
ADEUI=WICED(AK3,UR1,R1,R2,BET1,X2,ANIGMA,AINCIS,AINCI)
IF(AMACH1.LT.X) ADEUI=WICED(AK3,UR1,R1,R2,BET1,X2,ANIGMA,AINCIS,AINCI)
BET2C=WICED(AK3,UR1,R1,R2,BET1,X2,ANIGMA,AINCIS,AINCI)
Y2=BET2C
DELBET=ABS((X2-Y2)/X2)
EPS=1.0E-6
IF(DELBET.LE.EPS) GO TO 11
BET2A=WICED(X1,Y1,X2,Y2)
X1=X2
Y1=Y2
N=N+1
IF(N.GT.50) GO TO 13
GO TO 12
11 BET2N=X2
GO TO 15
13 WRITE(6,201)
FORMAT(1HO,=DO NOT CONVERGE=)
RETURN
END

C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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PA1 = 3.1415926
R1 = 1.0
B2 = COS ( B2R )
LWC = XW1 / XG * RHOG1
DS1 = (30.0 - BETA1 + STAGER ( N )) * PAI / 180.0
B2R = (30.0 - BETA1 + STAGER ( N )) * PI / 180.0
B2 = COS ( B2R )
H = (60.0 + H) / 144.0
A1 = DS1 + R / RBLADE ( N ) / 144.0
A2 = DS2 + R / RBLADE ( N ) / 144.0
WW1 = LWC * W1 * B1 / A1
WW2 = LWC * W1 * B2 / A2
WW = WW1 + WW2
RETURN
END
A = DS1 = H * BLADE(N) / 144.0  
WW1 = LWC * V1 * B1 * A1  
WW2 = LWC * V2 * B2 * A2  
WW = WW1 + WW2  
RETURN  
END

C

C SUBROUTINE WICISS

C

SUBROUTINE WICISS (ISTAGE, R, XW1, XG, RHOGAS, ALFA2, VI, W1, W2, WW)

REAL LWC

COMMON /PERDUE/ JPERFM, RHOG(3), RERUP, RERLOW, RESUP, RESLOW, XPREB, RRTIP(8), SRTIP(8), AAA1, AAA2, AAA3, SAREA(6), SAREAS(?), P(3), TG(3), XA, XU(3), XCH4, XH(3), XWW(3), TW(3), TH(3), THW(3)

OMEGS(?), OMEGR(6), GAPR(6), CAPS(6)

X, RRHUB(6), RC(6), RBLADE(6), STAGER(6)

X, GRIUD(?), GC(?), SBLADE(?) , STAGE3(?)

X, SIGMR(6), BETISR(6), BETISR(6), AINCSR(6), ADEUSR(6)

X, SIGMS(?), BETISS(?), BETISS(?) , AINCSS(?) , ADEUS(?)

X, UTIPG(6), UTIP(6), UTPD(6), UU(6), UHUB(6), U6, FAI

X, A6, AREAS(?) , U6W(6), UTIP(6), UHUB(6), UHUB2(6), IPRINT

X, ICENT, IICENT, FMR1(6), FMA2(6), IRAD, FAID

X, NS, NS1, RT(6), RM(6), RH(6), ST(6), SH(6), SH(6)

X, DSMASS, AAREA(7), AAREAS(7), PR12D(6), PR13D(6), ETARD(6)

X, DR(6), DS(6), DEOR(6), DEOS(6), BLOCK(6), BLOCKS(?)

X, BETIMR(6), BETMR(6), BETIM(7), BETMS(7), RAD1(6), RAD2(6)

LWC = XW1 / XG * RHOGAS

AI = DS1 * H * SBLADE(ISTAGE) / 144.0  
A2 = DS2 * H * SBLADE(ISTAGE) / 144.0  
WW1 = LWC * VI * B1 = AI  
WW2 = LWC * VI * B2 * A2  
WW = WW1 + WW2  
RETURN  
END

C

C COMMON /PERDUE/ JPERFM, RHOG(3), RERUP, RERLOW, RESUP, RESLOW, XPREB, RRTIP(8), SRTIP(8), AAA1, AAA2, AAA3, SAREA(6), SAREAS(?), P(3), TG(3), XA, XU(3), XCH4, XH(3), XWW(3), TW(3), TH(3)

OMEGS(?), OMEGR(6), GAPR(6), CAPS(6)

X, RRHUB(6), RC(6), RBLADE(6), STAGER(6)

X, GRIUD(?), GC(?), SBLADE(?) , STAGE3(?)

X, SIGMR(6), BETISR(6), BETISR(6), AINCSR(6), ADEUSR(6)

X, SIGMS(?), BETISS(?), BETISS(?) , AINCSS(?) , ADEUS(?)

X, UTIPG(6), UTIP(6), UTPD(6), UU(6), UHUB(6), U6, FAI

X, A6, AREAS(?) , U6W(6), UTIP(6), UHUB(6), UHUB2(6), IPRINT

LWC = XW1 / XG * RHOGAS

V1 = 3.1425926

B1 = 1.0

B2R = (90.0 - ALFA2 + STAGES(ISTAGE)) * PAI / 180.0

B2 = COS(B2R)

ALFA2R = ALFA2 * PAI / 180.0

DS2 = 2.0 * PAI / SBLADE(ISTAGE) - COS(ALFA2R) / COS(B2R)

IF (DS2.GT.SC(ISTAGE)) DS2 = SC(ISTAGE)

H = (A1 + A2) / 2.0

AI = DS1 * H * SBLADE(ISTAGE) / 144.0

A2 = DS2 * H * SBLADE(ISTAGE) / 144.0

WW1 = LWC * VI * B1 = AI  
WW2 = LWC * VI * B2 * A2  
WW = WW1 + WW2  
RETURN  
END
$X, BET1MR(6), BET2MR(6), BET1MS(7), BET2MS(7), RADI(6), RADI2(6) WICISL 24$

$PAI=3.1415926 WICISL 25$

$LWC = XW1 / XG * RHOGl WICISL 26$

$LFA=(90.0-ALFA2)/2.O*PI180.0 WICISL 27$

$BETA=(90.O+ALFA2)/2.O*PI180.0 WICISL 28$

$Bl=SIN(ALFA) WICISL 29$

$B2=SINCBETA) WICISL 30$

$Ul=Ul*COS(ALFA) WICISL 31$

$U2=Wl*COS(BETA) WICISL 32$

$S=2.0*PAI*SRTIP(ISTAGE~~SBLADE(ISTAGE)~2.O WICISL 33$

$GSI=ALFA2+(90.0-ALFA21H2.0 WICISL 34$

$GSI=PI180.0 WICISL 35$

$STAG=STAGES(ISTAGE)*PAI/180.0 WICISL 36$

$Y2=GAPS~ISTAGE~~2.0*~WICTAN(ST~GR~-WICTAN~GSI)~~+S WICISL 37$

$DAHY1=(90.0-GSI)*PI/180.0 WICISL 38$

$Yl=Y2*SIN(DAMYl) WICISL 39$

$DAHY2=(GSI-STAGES(ISTAGE)>+PI/18D.O WICISL 40$

$DSl=Yl/SIN(DAMY2) WICISL 41$

$IF(DSi.GT.SC(ISTAGE)) DSl=SC(ISTAGE) WICISL 42$

$DAMY3=(90.-(90.0+ALFA2)/2.0)*PI180.0 WICISL 43$

$GSI=ALFA2*PI/180.0 WICISL 44$

$STAGR=STAGES(ISTAGE)*PI180.0 WICISL 45$

$Y2=GAPS~ISTAGE~~2.0*~WICTAN(ST~GR~-WICTAN~GSI)~~+S WICISL 46$

$DAHY1=(90.0-GSI)*PI/180.0 WICISL 47$

$Yl=Y2*SIN(DAMYl) WICISL 48$

$DAHY2=(GSI-STAGES(ISTAGE)>+PI/18D.O WICISL 49$

$DS2=DAHY6/DAMY7 WICISL 50$

$IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE) WICISL 51$

$H=(ARA2*144.0)/(2.0*PI1*R) WICISL 52$

$Al=DSl*H*SBLADE(ISTAGE)/144.0 WICISL 53$

$A2=DS2*H*SBLADE(ISTAGE)/144.0 WICISL 54$

$W1=U1*Bl*Al WICISL 55$

$W2=U2*B2*A2 WICISL 56$

$W=WWl+WW2 WICISL 57$

$RETURN WICISL 58$

$END WICISL 59$

$SUBROUTINE WICWAKE WICISL 60$

$UISCOF=1.20E-3 WICISL 61$

$SIGUHA = 4.6534E-3 WICISL 62$

$GC = 32.174 WICISL 63$

$WE=21.0 WICISL 64$

$DWAKE1 = ( WE * SIGUMA * GC ) / RHOG / U ** 2 WICISL 65$

$SN=UISCOF**2/(RHOG*SIGUHA*DWAKE1*GC) WICISL 66$

$WELIMT=12.0*(1.0+SN**0.36) WICISL 67$

$DI=WELIMT*SIGUMA*GC/(RHOG*U**2) WICISL 68$

$WE=22.0 WICISL 69$

$DWAKE2=(WE*SIGUMA*GC)/RHOG/U**2 WICISL 70$

$SN=UISCOF**2/(RHOG*SIGUHA*DWAKE2*GC) WICISL 71$

$WELIMT=12.0*(1.0+SN**0.36) WICISL 72$

$DI=WELIMT*SIGUMA*GC/(RHOG*U**2) WICISL 73$

$WE=23.0 WICISL 74$

$DWAKE=WELIMT*SIGUMA*GC/(RHOG*U**21 WICISL 75$

$DWAKEM = DWAKE / 3.2802 * 1.0E6 WICISL 76$

$RETURN WICISL 77$

$END WICISL 78$

$SUBROUTINE WICHET(TGl,TG3,TWl,TW3,DAUEN2,DAUEN2,DrVJEN, BDELZI, UZ, WMASSl, UHASSl, AMASS, CHMASS, CPG, CPU, DELTGH, DELTWH, RE) WICISL 79$

$DIMENSION DELHET(51) WICISL 80$

$END WICISL 81
REAL ND, KA, NU, MMASS, NU

DELTHG=0.0
DELTHM=0.0
IF(WMASS1.LT.1.0E-6) GO TO 11
DAVEAV=(DAVEN2+DAVEN)*2.0*1.0E-6*3.2802
IF(WAVEAV.LT.1.0E-6) GO TO 11
RHOW = 62.54

PR = 0.7
NU=2.0+0.6*SQRT(RE)*PR**0.33
MCONV = KA/DAVEAV*NU

J=1

DEL=( (TG1-TW1)+(TG3-TW3)/2.0

GMASS1=UMASS1+AMASS+CHMASS
DELTHG=DELTHM/(GMASS1*CPG)
DELTHM=DELTHH/(GMASS1*CPH)

TG3=3-DELTHG
TW3=TW3+DELTHM

DELHET(J)=DELHH
J=J+1

IF(J.EQ.2) GO TO 10
ERROR=ABS(DELHET(J-1)-DELHET(J-2))

EPS=0.0001

IF(ERROR.GT.EPS) GO TO 10

RETURN

END

SUBROUTINE WICHAS

 SUBROUTINE WICMAS(HW1, TH1, TH2, PP1, PP2, TG1, TG2, DZ, 

 PWAS1, PWAS2, PW1, PW2, UZ, DDAVE1, DDAVE2, HW2, UMASS1, 

 1 VMASSE, VMASN, VMASSE, DMDTAU, AMASS,RE)

 PW1 = WICPB1*(TH1)*144.0
 PW2 = WICPB2( TW2 )*144.0

 PW1 = ( HW1 * PP1 ) / ( HW1 + 0.6219 )

 DMDT1 = WICMTR( TG1, TW1, PP1 , DDAVE1, UZ, DZ, WMASS1, 

 PWAS1, RE)

 PW2AS1 = PW1

 DMDT2 = WICMTR( TG2, TW2, PP2, DDAVE2, UZ, DZ, WMASS1, 

 PWAS2, RE)

 DMDTA1 = ( DMDT1 + DMDT2 ) / 2.0

 VMASSE = VMASSE + DMDTA1
 VMASSE = VMASSE - DMDTA1

 HW2=VMASSE-AMASS

 PW2CL1 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )

 PW2AS2 = PW1 + 1.05

 DMDT2 = WICMTR( TG2, TW2, PP2, DDAVE2, UZ, DZ, WMASS2, 

 PW2AS2, RE)

 DMDTA2 = ( DMDT1 + DMDT2 ) / 2.0

 VMASSE = VMASSE + DMDTA2
 VMASSE = VMASSE - DMDTA2

 HW2=VMASSE-AMASS

 PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )

 PW2ASN = WICNEW( PW2AS1, PW2CL1, PW2AS2, PW2CL2 )

 PWAS1 = PW2AS1

 PW1CL1 = PW2CL1

 PWAS2 = PW2ASN

 DMDT2 = WICMTR( TG2, TW2, PP2, DDAVE2, UZ, DZ, WMASS2, PW

 12AS2, RE)

 DMDTA2 = ( DMDT1 + DMDT2 ) / 2.0

 VMASSE = VMASSE + DMDTA2
 VMASSE = VMASSE - DMDTA2

 HW2=VMASSE-AMASS
HW2 = UHASS2 / AMASS
PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )
ERROR = ABS ( PW2AS2 - PW2CL2 )
EPS = 0.01
IF ( ERROR . GT . EPS ) GO TO 2
PW2 = PW2AS2
RETURN
END

FUNCTION WICHTR(TTG,TTW,PPP,DAVE,UZ,DZ,MMASS,PW,RE)
REAL KG, ND, MMASS
IF(DAUE.LT.1.0E-6) WICHTR=0.0
IF(DAUE.LT.1.0E-6) GO TO 10
DD=DAVE*1.0E-6*3.2802
T = ( TTG + TTW ) / 2.0
PA1 = 3.1415926
RHOW = 62.2567
RR = DD / 2.0
TT = T * 5.0 / 9.0
PP = PPP * 47.890259
DU=4.24028E-3*(TT**1.5)/PP
SCT=0.50
SH=2.0+0.60*SQRT(RE)*SCT**0.33
KG = DU / DD * SH
HU=1115.3279-0.6840909*(TTW-460.01
PWBB=PW+29.0/18.0*0.45/HUrPPP*(TTG-TTW)
R = 85.78
ND = MMASS / ( RHOW * 4.0 / 3.0 * PA1 * RR ** 3 )
WICHTR = KG * 4.0 * PA1 * RR ** 2 * ( PWBB / TTW - PW / TTG ) / R
1 * ND * DZ / UZ
10 RETURN
END

FUNCTION WICPWB(TWB)
TSTAG=TWB
TSTAGC=(TSTAG-492.0)/1.8
IF(TSTAGC.LT.100.0) GO TD 40
IF(TSTAGC.GE.100.O.AND.TSTAGC.LT.2OO.O~ GO TO 41
A=5.45142
B=2010.8
GO TO 42
A=5.9778
B=2224.4
GO TO 43
41 A=5.6485
B=2101.1
GO TO 44
42 AA=A-B*(TSTAGC+273.0)
PS=10.0*AA
PS=PS/4.88247E-4
WICPWB=PS/144.0
RETURN
END

FUNCTION WICNEW(X1,Y1,X2,Y2)
T=ABS((X2-X1)/X1)
IF(T.LT.1.0E-6) WICNEW=(Y1+Y2)/2.0
IF(T.LT.1.0E-6) GO TO 100
A=(Y2-Y1)/(X2-X1)
B=Y1-A*X1
WICNEW=B/(1.0-A)
100 RETURN
END

FUNCTION WICBPT(TSTAG,PSTAG)
TSTAGC=(TSTAG-492.0)/1.8
IF(TSTAGC.LT.100.0) GO TO 20
IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 21
A=5.45142
B=2010.8
GO TO 22
20 A=5.9778
B=2224.4
GO TO 22
21 A=5.6485
B=2101.1
GO TO 22
22 PS=PSTAG*4.88247E-4
TBOILK=B/(A-ALOG10(PS))
WICBPT=TBOILK*1.8
RETURN
END

FUNCTION WICSH(TSTAG,PSTAG)
TSTAGC=(TSTAG-492.0)/1.8
IF(TSTAGC.LT.100.0) GO TO 40
IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 41
A=5.45142
B=2010.8
GO TO 42
40 A=5.9778
B=2224.4
GO TO 42
41 A=5.6485
B=2101.1
GO TO 42
42 AA=A-B/(TSTAGC+273.0)
PS=10.0*AA
PS=PS/4.88247E-4
WICSH=0.6216647*PS/(PSTAG-PS)
RETURN
END

SUBROUTINE WICCEN
SUBROUTINE WiCCEN(RZERO, UZERO, DD, UZ, DELZZ, ALFAAU, FN, IRS, RHOGAS, IRHUB, R2, U2, ITIP, UZTIME, XG, XA, XXU, XCH4, RTIPIN)

C IRS=1: STATOR
C IRS=2: ROTOR

REAL N

PAI=3.1415926
ALFARR=ALFAAU/PAI/180.0

IF(DD.LT.1.OE-6) GO TO 12

D=DD*1.OE-6*

RHOD=62.37

XXAA=XA/XG

XXUU=XXU/XG

XXCC=XCH4/XG

VISCO=(XXAA*0.05715+XXUU*0.03293+XXCC*0.035)/3600.0

ENDTIM=DELZZ/UZ

JJ=10

DELTIM=ENDTIM/FLOAT(JJ)

R1=RZERO

U=UZERO

TIME=O.0

JJJ=1

RE=D*U/VISCO

B1=0.44

N=0.0

IF(RE.LT.1.9) B1=24.0

IF(RE.LT.1.9) N=1.0

IF(RE.GT.1.9.AND.RE.LT.5.0) B1=18.5

IF(RE.GT.1.9.AND.RE.LT.5.0) N=0.6

B=((VISCO=0.0)+B1*(RHOGAS*(1.0-N)+5.0))/(0.0+RHOD+PAI)

C=(D/0.0(N))

UW1=R1/12.0*2.0*PAI*FN/60.0

UW2=UZ=WiCTfiN(nLFRAR)

IF(ALFRAU.LT.1.0) UW=UW1

IF(ALFAAU.GT.1.0) UW=UW1/2.0

A=UW=U(1.0-RHOA/RHOD)

DETU=(A*R1=12.0-C=U1**((2.0-N)**DELTIM

UZ=U1+DELU

WAVE=U1+DELU/2.0

DELR=WAVE+DELTIM=12.0

R2=R1+DELR

TIME=TIME+DELTIM

IPRINT=1

IF(IPRINT.EQ.2)

BWRITE(6,101) R1, UW, A, U1, DELU, U2, WAVE, DELR, R2, TIME

101 FORMAT(1H ,7(F11.4,2X),E10.4,2X,FlO.4,2X,ElO.4~

Ul=U2

R1=R2

TIME=TIME+DELTIM

IF(TIME.GT.ENDTIM) GO TO 12

IF(JJJ.EQ.JJ) GO TO 12

GO TO 11

12 RETURN

END
SUBROUTINE UICDML(IPRINT, IRAD, AMASWL, AMASWT, R1, R2, STAREA, RTIP, DHIN, DMOUT, DMCENT, AHASW, AHASW2, DELMAS)

RHASWL: MASS FLOW RATE OF WATER IN A STRAY STRAY TUBE IN INTEREST
AMASWT: TOTAL MASS FLOW RATE OF WATER WHICH IS SUBJECT TO CENTRIFUGAL FORCE
AMASWL: TOTAL MASS FLOW RATE OF WATER WHICH ENTER THE COMPRESSOR

IRAD = 1: TIP
IRAD = 2: MEAN
IRAD = 3: HUB
PAI = 3.1415926

R1 = STAREA
A2 = PAI*(R2**2 - R1**2)/144.0
A2 = A2/0.5

DMCENT = A2/STAREA

120 IF(DMCENT.LT.0.0) DMCENT = 0.0
IF(DMCENT.GT.AMASWT) DMCENT = AMASWT
IF(R1.GT.RSTL) GO TO 110

R1.LT.RSTL
DHIN = DMCENT

GO TO 100

CONTINUE

R1.GT.RSTL
DHIN = 0.0
DMOUT = DMCENT

IF(IRAD.EQ.1) DHOUT = 0.0
IF(IRAD.EQ.3) DMIN = 0.0

AMASWL = AMASWL + DHIN - DMOUT

IF(AMASWL.LT.0.0) AMASWL = 0.0
IF(AMASWL.GT.AMASWT) AMASWL = AMASWT

DELMAS = AMASWL - AMASWL

IF(IPRINT.EQ.2) WRITE(6, 200) AMASWL, AMASWL, DMIN, DMOUT, DMCENT, $AMASWL, AMASWL, DELMAS

200 FORMAT(1H0, 8(F10.5, 3X))

RETURN

END
SUBROUTINE WICDRG

REAL N1, N2
GC=32.174
IPRINT=1
VISCOG=1.2,0E-6
PAT=3.1415927
IF(D.GT.0.0) GO TO 300
CD2=0.0
DELU2=0.0
DRAG1=0.0
RE=0.0
GO TO 301
300 RE1=(RHGAS1*D*DELU1)/VISCOG
RE=RE1
B11=0.44
N1=0.0
IF(RE.LT.1.9) B11=24.0
IF(RE.LT.1.9) N1=1.0
IF(RE.GT.1.9.AND.RE.LT.500.0) B11=18.5
IF(RE.GT.1.9.AND.RE.LT.500.0) N1=0.6
CD1=B11/(RE1**N1)
DRAG1=0.5*RHGAS1*(DELU1**2)*PAT*D**2)*CD1
B/GC
DAMY=DRAG1*GC/(CD1*0.5*RHG2*(PAT*D**2)**CD1)

IF(IPRINT.EQ.2) WRITE(6,200) D,DELU1,RHGAS1,RHGAS2,RE1,B11,N1
$CD1,DRAG1,DAMY
200 FORMAT(1HO,1O(Fl0.5,2X))
DELU2=SQRT(DAMY)
RE2=RHGAS2*D*DELU2/VISCOG
B1=0.44
N=0.0
IF(REG.LE.1.9) B1=24.0
IF(RE.GT.1.9) N=1.0
IF(RE.GT.1.9.AND.RE.LT.500.0) B1=18.5
IF(RE.GT.1.9.AND.RE.LT.500.0) N=0.6
CD2=B1/(RE2**N)
IF(IPRINT.EQ.2) WRITE(6,101) RE1,B11,N1,CD1,DELU1,RE2,B1,N,CD2,
*DELU2
101 FORMAT(1HO,2X,1O(F10.5,2X))
RE=(RE1+RE2)/2.0
IPRINT=
301 RETURN
END

SUBROUTINE WICSIZ

TMASS1=WHASSL+WMASSS+AMING1+AMINGl+AMING2+AMING3
AML=0.0
AHS=0.0
IF(DL.GT.DLIMIT) AHL=AHL+WHASSL
IF(DL.LT.DLIMIT) AMS=AHS+WMASSL
IF(DS.GT.DLIMIT) AML=AML+UMASSS
IF(DS.LT.DLIMIT) AMS=AMS+WMASSS
IF(D1.GT.DLIMIT) AML=AML+AHING1
IF(D1.LT.DLIMIT) AMS=AMS+AMING1
IF(D2.GT.DLIMIT) AHL=AML+AHING2
IF(D2.LT.DLIMIT) AMS=AMS+AMING2

RETURN
END
IF(D3.GT.DLIMIT) AML=AML+AMING3
IF(D3.LT.DLIMIT) AMS=AMS+AMING3
TMASS2=AML+AMS
ERROR=ABS(TMASS1-TMASS2)
IF(ERROR.LT.1.OE-6) GO TO 100
IF(TMASS2.LT.1.OE-6) GO TO 100
TT=TMASS1/TMASS2
IF(TT.LT.1.O) AML=AML/TT
IF(TT.LT.1.O) AMS=AMSTT
IF(TT.GT.1.O) AML=AML*TT
IF(TT.GT.1.O) AMS=FIMS*TT
100 AMLGE=AML
AMSLL=AMS
ADL=O.O
ADS=O.O
IF(DL.GT.DLIMIT.AND.AML.GT.O.0)
IF(DL.LT.DLIMIT.AND.AMS.GT.O.0)
IF(DS.GT.DLIMIT.AND.AML.GT.O.0)
IF(DS.LT.DLIMIT.AND.AMS.GT.O.0)
IF(D1.GT.DLIMIT.AND.AML.GT.O.0)
IF(D1.LT.DLIMIT.AND.AMS.GT.O.0)
IF(D2.GT.DLIMIT.AND.AML.GT.O.0)
IF(D2.LT.DLIMIT.AND.AMS.GT.O.0)
IF(D3.GT.DLIMIT.AND.AML.GT.O.0)
IF(D3.LT.DLIMIT.AND.AMS.GT.O.0)
DLGE=ADL
ADL=ADL+DL*(WMASSL/AML)
ADS=ADS+DL*(WMASSL/AMS)
ADL=ADL+DS*(WMCVL3SSAML1
ADS=ADS+DS*(WMCVL3SSAMS)
ADL=ADL+D1*(AMING1/AML)
ADS=ADS+D1*(AMING1/QMS)
ADL=ADL+D2*(AMING2/AML)
ADS=ADS+D2*(AMING2/AMS)
ADL=ADL+D3*(AMING3/AML)
ADS=ADS+D3*(AMING3/AMS)
RETURN
END
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SUBROUTINE WICPRP E
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SUBROUTINE WICPRP(XAIR,XH20,XCH4,T,RMIX,CPMIX,GAMMA,G1,G2,G3)
CT INR
C CPMIX IN BTU/LBM-R
C RMIX IN LBFT/LBM-R
RAIR=1545.3/28.964
RH20=1545.3/18.016
RCH4=1545.3/16.043
XXAIR=XAIR/(XAIR+XH2O+XCH4)
XXH20=XH20/(XAIR+XH2O+XCH4)
XXCH4=XCH4/(XAIR+XH2O+XCH4)
RMIX=XXAIR*RAIR+XXH20*RH20+XXCH4*RCH4
CPMIX=XXAIR*WICCPA(T)+XXH20*WICCPH(T)+XXCH4*WICCPC(T)
GAMMA=1.0/(1.0-RMIX/CPMIX/778.0)
G1=GAMMA/(GAMMA-1.0)
G2=(GAMMA-1.0)/2.0
G3=-1.0/(GAMMA-1.0)
RETURN
END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
SUBROUTINE WICCPA E
C CPAIR IN BTU/LBM-R
C T IN R
C FUNCTION WICCPA E
C c
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FUNCTION WICCPA(T)
CT INR
C CPAIR IN BTU/LBM-R
C T IN R
C CPAIR IN BTU/LBM-R
TK=5.0/9.0*T
A=3.65359
B=-1.33736E-3
C=3.29421E-6
D=-1.91142E-9
E=0.275462E-12
R = 8314.3 / 28.964
CP = (A + B * TK + C * TK**2 + D * TK**3 + E * TK**4) * R
WICCPA = CP * 2.3885E-4
RETURN
END

FUNCTION WICCPH
CTINR
CPH20 IN BTU/LBM-R
TK = 5.0 / 9.0 * T
A = 4.07013
B = -1.10845E-3
C = 4.15212E-6
D = -2.96374E-9
E = 0.807021E-12
R = 8314.3 / 18.016
CP = (A + B * TK + C * TK**2 + D * TK**3 + E * TK**4) * R
WICCPH = CP * 2.3885E-4
RETURN
END

FUNCTION WICCPC
CTINR
CPCH4 IN BTU/LBM-R
TK = 5.0 / 9.0 * T
A = 3.82619
B = -3.97946E-3
C = 24.5583E-6
D = -22.7329E-9
E = 6.96270E-12
R = 8314.3 / 16.043
CP = (A + B * TK + C * TK**2 + D * TK**3 + E * TK**4) * R
WICCPC = CP * 2.3885E-4
RETURN
END

SUBROUTINE WICGSL
OMEGAS, SIGUMA, BET1S, BET1S, BET2S, INCIS, ADEUIS, AMACH1, 1BET1, DEQS, DEQN, SITACS, SITACH, BET2N, OMEGAN, X, IDESIN, AK1, AK2, AK3
2, V1, V2, UR1, R1, R2)
CALL WICEDD(AK3, U1, V2, UR1, R1, R2, BET1, X1, SIGUM, INCIS, INCI, SDEQS, SITACS)
AICI = BET1 = BET1S + AINCI
BET2A = BETAS
X1 = BET2A
DELDEQ = WICED(AK3, V1, V2, UR1, R1, R2, BET1, X1, SIGUM, AINCI, AINCI)
ADEUI = ADEUS + 6.40 - 9.45 * AMACH1 + 9.45 * X * DELDEQ * AK1
IF (AMACH1.LT.X) ADEUI = ADEUS + 6.40 * DELDEQ * AK1
BET2C = BET2S - ADEUI
Y1 = BET2C
IF (N.GT.1) GO TO 10
12 BET2A = BET2S + 1.11
10 X2 = BET2A
DEQN = WICED(AK3, V1, V2, UR1, R1, R2, BET1, X2, SIGUM, AINCI, AINCI)
RETURN
END

WICCPH
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DELDEQ=DEQN-DEQS
ADEUI=ADEVIS+6.40+9.45*X*DELDEQ*K
IF(AMACH1.LT.X) ADEUI=ADEUIS+6.40*DELDEQ*K
BET2C=BET2S+ADEUI
Y2=BET2C
DELBET=ABS((X2-Y2)/X2)
EPS=1.0E-6
IF(DELBET.LE.EPS) GO TO 11
BET2A=WICNEW(X1,Y1,X2,Y2)
X1=X2
Y1=Y2
N=N+1
IF(N.GT.50) GO TO 13
GO TO 12
BET2N=X2
GO TO 14
WRITE(6,201)
FORMAT(1H0,2D0)
DO NOT CONVERGE
GO TO 15
SITACN=WICMTK(SITACS,AMACH1,DELDEQ,DELPS)
OMEGAN=WICLOS(BET1,BET2N,SIGUMA,SITACN)
SSS=SITACN-SITACS
RETURN
END

SUBROUTINE WICSDL
SUBROUTINE WICSDL(CHORD,SIGUMA,BETA1,BETA2,UG,RHOG,
                 UMASS, AREA, UZ, IPRINT, ONEGAP)
PAI=3.1415926
RHOGO=RHOG
RHOPO=UMASS/AREA/UZ
RR=RHOPO/RHOGO
UISCOG=0.128E-4
C=CHORD/12.0
RE=UG*C*RHOGO/UISCOG
DELC=0.37/RR**0.2/(1.0+1.442*RR**0.8
DELP=0.1402*DELC
BETA1R=BET1*PAI/180.0
BET2R=BET2*PAI/180.0
OMEGAP=DELP**2.0*SIGUMA/COS~BETA2R~*COS~BET~I~*COS~BET~2R~**2
RETURN
END

SUBROUTINE WICSTL
SUBROUTINE WICSTL( ISTAGE, IROTOR,DAUt W1, W2, DELU,U2, U3, WMASS, UZ, N
                 8, BETAl, BETA2, ALFA2, ALFA3, MMASS, DELUU2, DELUL2,
                 OMEGRU, OMEGRL, OMEGS, OMEGL, DRAl, DRAl2, DRAl3,
                 8, IROTOR=1 ROTOR
                 8, IROTOR=2 STATOR
                 REAL M, MMASS
                 COMMON /PERDE/ JPERFM, RHOG(3), RERUP, RERLOW, RESUP, RESLOW
                 X, PREB, RRTIP(8), SRTP(8), A1A1, A1A2, A1A3, SAREA(8), SAREAS(7)
                 X, P(3), TG(3), XA, XV(3), XCHA, XV(3), WM(3), WM(3), TW(3), TH(3)
                 X, OMEG (7), OMEGR(6), GAPR(6), GAP(6)
                 X, RRHUB(6), RC(6), RBLADE(6), STAGER(6)
                 X, SUBL(7), SUBL(7), SUBL(7), STAGES(7)
                 X, SIGUR(6), BETIS(6), BETISR(6), AICS(6), ADEV(6)
                 X, SIGUR(7), BETIS(7), BETIS(7), AICS(7), ADEV(7)
                 X, UTP(6), UTP(6), UTP(6), UMEAN(6), UHUB(6), U(6), FAI
                 X, AREA(6), AREAH(7), AREA(8), UTP(6), UMEAN(6), UHUB(6), UPRINT
                 X, ICENT, ICENT, FMA(6), FMA(6), IRAD, FAI
                 X, NS, NS1, RT(6), RK(6), RH(6), ST(6), SM(6), SH(6)
**C DROPLET DRAG IN ROTOR**

$$DD = DAU * 1.0E-6 * 3.28$$

$$UG1 = W1$$

$$UPl = UGl - DELU$$

$$fIi = WMASS * RC(ISTRGE)**12.0/UZ$$

$$A2 = RWHE*4.0/3.0*PAI*(DD/2.0)**3$$

$$TN = 0.0$$

IF(WMASS.GT.0.0) GO TO 2000

$$UA;E = (Wl + W2/2.0$$

$$GML1 = (90.0 + BETA1)/180.0$$

$$DELUL1 = UGl - UPl*COS(GML1)$$

IF(N.GT.2) DELUL1 = DELUL2

$$TNL = TN*(180.0+BETA1+BETA2)/360.0$$

IF(IPRINT.EQ.2) WRITE(6,2010)

$$DMERUP = RERUP*DAU/2.0$$

$$DMERLOW = RERLOW*DAU/2.0$$

IF(IPRINT.EQ.2) WRITE(6,2002)

GO TO 200

**C DROPLET DRAG IN STATOR**

$$DD = DAU*1.0E-6*3.28$$

$$UG1 = W1$$

$$UPl = UGl - DELU$$

$$fIi = WMASS*SC(ISTAGE)**12.0/UZ$$

$$A2 = RWHE*4.0/3.0*PAI*(DD/2.0)**3$$

$$TN = 0.0$$

IF(WMASS.GT.0.0) GO TO 2000

GO TO 2001

**100**

$$RAU1 = RHO1*DAU/2.0$$

$$RAU2 = RHO2*DAU/2.0$$

$$RAE = RERUP*RUP1+RUP2)*0.5+RERLOW*(RLOU1+RLOU2)*0.5$$

IF(IPRINT.EQ.2) WRITE(6,2010) RUP1, RUP2, RLOU1, RLOU2

GO TO 2001

**4000**

**4001**

**2002**

**2010**

GO TO 200

216
IF(WMASS.GT.0.0) GO TO 5002
GO TO 5003

5002 TN=A1/A2
5003 VAVE=(U3+U2)/2.0
DELU1=DELU2
TNU=TN*(180.0-ALFA2-ALFA3)/360.0
IF(IPRINT.EQ.2) WRITE(6,2005)
FORMAT(1HO,DROPLET DRAG IN STATOR (UPPER PART))
CALL WICDRC(DD,DELU1,PHOG(2),PHOG(2),CD2,DELU2,DRAG1,RE)
DELUL2=DELU2
CDSL=CDSL
RESUP=RE
DRAGSU=DRAG1*TNU
IF(IPRINT.EQ.2) WRITE(6,2006)
FORMAT(1HO,DROPLET DRAG IN STATOR (LOWER PART))
CALL WICDRC(DD,DELU1,PHOG(2),PHOG(2),CD2,DELU2,DRAG1,RE)
DELUL2=DELU2
CDSL=CDSL
RESLOW=RE
DRAGSL=DRAG1*TNU
S1=S1
OMEGA1=OMEG1*0.5*(CDL1+CDL2)*RE
CDSLL=CDSL*DELUL2**2*UNIT/4.0*DD**2*TNL/U2**2/SC(ISTAGE)
IF(IPRINT.EQ.2) WRITE(6,2007)
FORMAT(1HO,DROPLET DRAG IN STATOR (SUMMARY))
IF(IPRINT.EQ.2) WRITE(6,721) DELUU1,DELUU1,DELUL1,DELUL2,CDSU,CDSL,CDSL,DELPSL,DRAGSU,DRAGSL
721 FORMAT(1HO,Z)
SUP1=(90.0-ALFA2)/180.0
SLOW1=(90.0+ALFA2)/180.0
SUP2=(90.0-ALFA3)/180.0
SLOW2=(90.0+ALFA3)/180.0
SUPL=(D**2*PHOG1*S1+D**2*PHOG2*OMEGA1)*S1:S2
END
C SUBROUTINE WICRSL

C

C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

C SUBROUTINE WICRSL(SIGMA, BETA1, BETA2, CHORD, DL, CDR, OMEGA)

C PAI = 3.1415926

C IF (DL.LT.1.0E-6) CDR = 0.0

C IF (DL.LT.1.0E-6) OMEGA = 0.0

C IF (DL.LT.1.0E-6) GO TO 10

C BETA1R = BETA1 * PAI / 180.0

C BETA2R = BETA2 * PAI / 180.0

C BETA3R = 0.5 * (BETA1 + BETA2)

C CS1 = COS(BETA1R)**2

C CS2 = COS(BETA3R)**3

C C = CHORD * 2.54 = 0.01 * 1.0E6

C A = C / DL

C IF (A.LT.100.0) A = 100.0

C CDR = 1.89 + 1.62 * ALOG10(A)

C CDR = 1.0 / CDR**2

C OMEGA = CDR * SIGMA / CS1 / CS2

10 RETURN

END

C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

C SUBROUTINE WICUT

C

C

C SUBROUTINE WICUT(ISTAGE, ASPEED, ALFA1, UZ, U1, U2, V1, V2, ALFA2, W1, W2, WICUT)

C 1ALFA3, U3, AK1, AK3) WICUT

C COMMON /PERDUE/ JPERFM, RHOG(3), RERUP, RERLOW, RESUP, RESLOW

C X, PREB, RRTIP(8), SRTIP(8), XA, AA3, V1, V2, W1, W2, W3, WICUT

C X, PAI = 3.1415927

C ALFA1R = ALFA1 * PAI / 180.0

C U1 = UZ / COS(ALFA1R)

C US1 = UZ * TAN(ALFA1R)

C US1 = U(ISTAGE) - US1

C T = US1 / UZ

C BETAlR = ATAN(T)

C BETAl = BETAlR * 180.0 / PAI

C BETAl = BETAlR * 180.0 / PAI

C T = UZ **2 + W1 **2

C W1 = SQRT(T)

C AMACH1 = W1 / ASPEED

C CALL WICBOA (OMEGA(ISTAGE), SIGMUR (ISTAGE), BETISR (ISTAGE),

C 1, BETISR (ISTAGE), AMACH1, BETAls, BETAlR, BETAlS, BETAlR, BETAlS, BETAI, BETAlR, BETAI

C 1, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI

C PAI = 3.141592?

C ALFA1R = ALFA1 * PAI / 180.0

C U1 = UZ / COS(ALFA1R)

C US1 = UZ * TAN(ALFA1R)

C US1 = U(ISTAGE) - US1

C T = US1 / UZ

C BETAI = BETAI * 180.0 / PAI

C TT = UZ **2 + W1 **2

C W1 = SQRT(T)

C AMACH1 = W1 / ASPEED

C CALL WICBOA (OMEGA(ISTAGE), SIGMUR (ISTAGE), BET1S (ISTAGE),

C 1, BET1S (ISTAGE), AMACH1, BETAls, BETAlR, BETAlS, BETAlR, BETAlS, BETAI, BETAlR, BETAI

C 1, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI, BETAI

C 218
W2 = SORT ( TTTT )
TTTT = UZ ** 2 + US2 ** 2
V2 = SORT ( TTTT )
AMACH2 = U2 / ASPEED
CALL WICBOA (OMEGS(ISTAGE), SIGUMS(ISTAGE), BETISS(ISTAGE),
  IBESS (ISTAGE), AINCSS (ISTAGE), ADESSS (ISTAGE),
  IAHACH2, ALFA2, DEGS, DEGN, SITACS, SITACN, BET2N, FMA2(ISTAGE),
  IAK1, AK2, UZ, U2, 0.0, RAD2(ISTAGE), RAD1(ISTAGE+1))
ALFAS = BET2N
ALFAS=ALFAS*PAI/180.0
VS=UZ/COS(ALFASR)
RETURN
END

C++++++++++++++++++++++++++++++++++$+++++++++++$++++++~+++++++++++++++++++-----------------

SUBROUTINE WICSPD (AMASS, ISTAGE)

REAL M, M1, M2, M1REL, M2REL
COMMON /PERDUE/ JPERFM, RHOG(3), RERUP, RERLOW, RESUP, RESLOW
X, PREB, RRTIP(B), RRTP(B), AA1, AA2, AA3, SAREA(B), SAREAS(7)
X, P(3), IG(3), XA, XU3(X), XCH4, XW3(X), XHT(3), TW(3), THW(3)
X, OMEGS(7), OMEGR(6), GAPR(6), GAPS(6)
X, RRHUB(B), RC(B), RBLADE(B), STAGER(B)
X, SRRUB(B), SC(B), SBLADE(B), STAGES(7)
X, SIGUMS(B), BETISS(B), BET2SS(B), AINCSS(B), ADESSS(B)
X, SIGUMS(7), BETISS(7), BET2SS(7), AINCSS(7), ADESSS(7)
X, UTIPG(B), UTIP(6), UTPD(B), UDU(B), UMEAN(6), UHUB(6), UG, FAI
X, AREA(6), AREAS(7), UU2(6), UTP2(6), UMEAN2(B), UHUB2(6), IPRINT
X, ICENT, IICENT, FMR1(6), FMA2(B), IRED, IFAI
X, NS, NS1, RT(B), RM(B), RH(B), ST(B), SH(B), SHG(B), SHG(6)
X, DISMASS, AAREAS(7), AAREAS(7), FRI2D(B), FRI3D(B), ETARD(6)
X, DR(B), DS(6), DECR(B), DEOS(6), BLOCK(6), BLOCKS(7)
X, BETIMR(6), BET2MR(6), BETIMS(7), BET2MS(7), RADI(6), RAD2(6)
DIMENSION TD(8)
AJ=778.26
IUNIT=1
CFT=1.01/1.8
CFP=47.880258
CFD=16.018463
CF=0.3048
CFA=0.00290304
CFL=2.54
CFM=0.45359237
PAI=3.1415926
GC=32.174
TREF=518.70
PREF=14.7*144.0
AAAR1T=(RRTIP(1)**2-RRHUB(1)**2)/144.0*BLOCK(1)
CMASS=AMASS*SQRT(TG(1)/TREF)/(P(1)/PREF)**AAAR1T/SAREA(1)
C TGU INLET
ISTAGE=NS1
CALL WICPRP(1.0, 0.0, 0.0, TG1), RMIX, CMIX, GAMMA, G1, G2, G3
CALL WICMAC(ISTAGE, AMASS, TG1, P(1), M, UZ, C, 0.0, 0.0, RMIX, CMIX, ARE
$AS(NS1))
VZIN=UZ
AIN=C
MIN=M
TOIN=TG1
POIN=P(1)
PSIN=P(1)/(1.0+G2*M**2)**G1
TSIN=TSIN/(1.0+G2*M**2)
RHOCIN=PSIN/RMIX/TSIN
FAIN=VZIN/UTIPG(1)
FAID=FAIM
GAMIN=GAMMA
TOIN=TG1
POIN=P(1)

219
C IGU INLET PRINTOUT

IF (IUNIT.EQ.2) THEN
  TOIN=TOIN*CFT
  POIN=POIN*CFP
  TSIN=TSIN*CFT
  PSIN=PSIN*CFP
  RHOGIN=RHOGIN*CFD
  AIN=AIN*CFU
  UZIN=UZIN*CFU
  AREAS(NS1)=AREAS(NS1)/CFA
ENDIF

WRITE(6,1000)
1000 FORMAT(1H1,************* DESIGN POINT INFORMATION *************
$1s+f)

WRITE(6,1010)
1010 FORMAT(1HO,lX,f***** COMPRESSOR INLET *****)
WRITE(6,1020) TOIN, POIN, TSIN, PSIN, RHOGIN
1020 FORMAT(1HO,lX,$TOTAL TEMPERATURE AT COMPRESSOR INLET=f,FlO.S,
$62X$TOTAL PRESSURE AT COMPRESSOR INLET=#.F10.2./(1
$2X$STATIC TEMPERATURE AT COMPRESSOR INLET=#.F10.2,
$2X$STATIC PRESSURE AT COMPRESSOR INLET=#.F10.5)
WRITE(6,1030) AIN, UZIN, AREAS(NS1), FAII
1030 FORMAT(1HO,lX,$ACOUSTIC SPEED AT COMPRESSOR INLET=#.F10.5,
$2X$F9XIAL VELOCITY AT COMPRESSOR INLET=#.F10.5,
$2X$MACH NUMBER AT COMPRESSOR INLET=#.F10.5,
$2X$STREAMTUBE AREA AT COMPRESSOR INLET=#.F10.5,
$2X$FLOW COEFFICIENT AT COMPRESSOR INLET=#.F10.5)

IF (IUNIT.EQ.2) THEN
  TOIN=TOIN*CFT
  POIN=POIN/CFP
  TSIN=TSIN*CFT
  PSIN=PSIN/CFP
  RHOGIN=RHOGiN/CFD
  AIN=AIN/CFU
  UZIN=UZIN/CFU
  AREAS(NS1)=AREAS(NS1)/CFA
ENDIF

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
$CPMIX, AREA(IS))
CPMIX1=CPMIX
GAMMA1=GAMMA
VZ1=VZ

C ROTOR INLET

ISTAGE=1

100 I=ISTAGE-1
IF (I.EQ.0) I=NS1
ALFAl=ALFA(IS)
ADEVSS(IS)=ALFA1-BET2MS(IS)
CALL WICMAC(ISTAGE, AMASS, TG(IS), P(IS), VZ, C, 0.0, ALFA1, RMIX,
IF(ISTAGE.GE.2) DEQS(ISTAGE-1)=COS(ALFA1R)/COS(ALFA2R)*$
$(1.12+0.61*COS(ALFA2R)**2)/SIGUMS(ISTAGE-1)*$(WICTAN(ALFA1R)-$
$WICTAN(ALFA2R))

$WICTAN(ALFA2R))

IF(ISTAGE.GT.NS) GO TO 101

C ROTOR OUTLET

IF(ISTR.GE.2) P(1)=P12D(ISTAGE)*PC1

TR12=1.0/PR12D(ISTAGE)**1.0/G1

TG(2)=TR12*TG(1)

CALL WICPR(1.0,0.0,0.0,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)

GAMMA2=GAMMA

CPMIX2=CPMIX

GAMMAU=(GAMMA1+GAMMA2)/2.0

CPMIXU=(CPMIX1+CPMIX2)/2.0

G2AU=(GAMMAU-1.0)/2.0

IF(ISTR.GE.2) P(12)=(TG(2)/TG(1))**G2AU

DELT=TG(2)-TG(1)

US2=(U(ISTAGE)*US1+DELT*CPMIXU+GC+AJ)/UU2(ISTAGE)

JJ=1

UZ2AS=US2AJZ2

ALFA2R=ATAN(US2UZ2)

ALFA2=ALFA2R*180.0/PI

BETlSS(ISTAGE)=ALFA2

AINCSS(ISTAGE)=ALFA2-BETlSS(ISTAGE)

WS2=UU2(ISTAGE)-US2

WS2UZ2=WS2AJZ2

BETA2R=ATAN(WS2UZ2)

BETA2=BETA2R*180.0/PI

BET2SR(ISTAGE)=BETA2

ADEUSR(ISTAGE)=BETA2-BET2MR(ISTAGE)

U2=UZ2AS/COS(ALFA2R)

W2=UZ2ASCOSIBETA2R)

TS2=TG(2)-U2**2/(2.0*CPMIX2*GC*QJ)

A2=SQRT(GAMMA2*RMIX*TS2*GC)

M2=U2/A2

PS2=P(1.0+G2*M2**2)**G1

RHOGS2=PS2/RMIX/TS2

M2REL=W2/A2

TREL2=(1.0+G2*M2REL**2)*TS2

PREL2=(1.0+M2REL**2)*G1*PS2

V22CL=MASS/RHOGS2/AREAS(ISTAGE)

EPS=1.0E-6

IF(JJ.EQ.2) GO TO 201

IF(JJ.GT.2) GO TO 202

JJ=JJ+1

GO TO 200

201 X2=UZ2AS

Y2=UZ22CL

UZ2AS=WICNEW(X1,Y1,X2,Y2)

JJ=JJ+1

GO TO 200

202 IF(ABS(U22AS-U22CL)/U22AS).LT.EPS) GO TO 300

X1=U22AS

Y1=UZ22CL

X2=U22AS

Y2=U22CL

UZ2AS=WICNEW(X1,Y1,X2,Y2)

JJ=JJ+1

GO TO 200

300 U22=U22CL

FAIOUT=U22/UTPC(ISTAGE)

DR(ISTAGE)=1.0-U22/WR1+ABS(U21-U22)/2.0/SIGUMR(ISTAGE)/W1

DEOR(ISTAGE)=SIGUMR(ISTAGE)-SIGUMR(BETA2R)**2/SIGUMR(ISTAGE)*$
$WICTAN(BETA2R)-WICTAN(BETA2R))

PLOSSR=PR12D(ISTAGE)/(TG(2)/TG(1))**G1AU

128 WICSPD

129 WICSPD

130 WICSPD

131 WICSPD

132 WICSPD

133 WICSPD

134 WICSPD

135 WICSPD

136 WICSPD

137 WICSPD

138 WICSPD

139 WICSPD

140 WICSPD

141 WICSPD

142 WICSPD

143 WICSPD

144 WICSPD

145 WICSPD

146 WICSPD

147 WICSPD

148 WICSPD

149 WICSPD

150 WICSPD

151 WICSPD

152 WICSPD

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184 WICSPD

185 WICSPD

186 WICSPD

187 WICSPD

188 WICSPD

189 WICSPD

190 WICSPD

191 WICSPD

192 WICSPD

193 WICSPD

194 WICSPD

195 WICSPD

196 WICSPD

197 WICSPD
B = (U(1)T(1)A(1)) + a^2 - l.0

IF (PRREL = PLOSS) PRREL = 1.0

OMERI(ISTAGE) = (PRREL - PLOSS) / (1.0 - PREL)

PLOSS = P(13) / P(12)

OMEGS = P(13) - PLOSS

ETAS = (P(13) - 1.0) / (T(12) - 1.0)

P(3) = P(13) * P(1)

T(3) = T(2)

C PRINTOUT OF STAGE PERFORMANCE

IF (IUNIT = 2) THEN

TG(1) = TG(1) * CFT

TG(2) = TG(2) * CFT

P(1) = P(1) * CFP

P(2) = P(2) * CFP

TSL = TSL * CFT

TS2 = TS2 * CFT

PSL = PSL * CFP

PS2 = PS2 * CFP

RHOSL = RHOSL * CFD

RHOS2 = RHOS2 * CFD

UZ1 = UZ1 * CFU

UZ2 = UZ2 * CFU

U1 = U1 * CFU

U2 = U2 * CFU

W1 = W1 * CFU

W2 = W2 * CFU

WS1 = WS1 * CFU

WS2 = WS2 * CFU

U(ISTAGE) = U(ISTAGE) * CFU

UU2(ISTAGE) = UU2(ISTAGE) * CFU

TREL1 = TREL1 * CFT

PREL1 = PREL1 * CFP

PREL2 = PREL2 * CFP

AREA(ISTAGE) = AREA(ISTAGE) * CFA

RAD1(ISTAGE) = RAD1(ISTAGE) * CFL

RAD2(ISTAGE) = RAD2(ISTAGE) * CFL

ENDIF

WRITE (6, 1000)

WRITE (6, 1100) ISTAGE

1100 FORMAT (1H0, "**** STAGE=", I2, " ****")

WRITE (6, 1101)

1101 FORMAT (1H0, 1X, "TOTAL", 6X, "STATIC", 7X, "RELATIVE", 7X, "TAN", 6X, "DENSITY")

WRITE (6, 1110) TG(1), P(1), TS1, PS1, RHOS1

1110 FORMAT (1H0, 1X, "TOTAL", 7X, "STATIC", 7X, "RELATIVE", 7X, "TAN", 7X, "DENSITY")

WRITE (6, 1111) TG(1), P(1), TS2, PS2, RHOS2

1111 FORMAT (1H0, 1X, "TAN", 6X, "RELATIVE", 6X, "DENSITY")

WRITE (6, 1120) TG(2), P(2), TS2, PS2, RHOS2

1120 FORMAT (1H0, 1X, "TOTAL", 5(X, F10.3))

WRITE (6, 1130) TG(2), P(2), TS2, PS2, RHOS2

1130 FORMAT (1H0, 1X, "TAN", 5(F10.3))

WRITE (6, 1140) TG(2), P(2), TS2, PS2, RHOS2

1140 FORMAT (1H0, 1X, "TOTAL", 5(F10.3))

WRITE (6, 1150) TG(2), P(2), TS2, PS2, RHOS2

1150 FORMAT (1H0, 1X, "TAN", 5(F10.3))
WRITE(6,1160) UU2(ISTAGE),M2,M2REL,TREL2,PREL2

1160 FORMAT(1H ,1X,#ROTOR OUTLET#,5(F10.3,3X))

WRITE(6,1161) WICSPD

1161 FORMAT(1HO,14X,#!ABS FLOW#,5X,#REL FLOW#,4X,#STREAMTUBE#,18X, #COEFFICIENT#)

WRITE(6,1170) BET2SS(I-1),BETlSS(ISTAGE),AREA(ISTAGE), WICSPD

1170 FORMAT(1HO,1X,#ROTOR INLET#,1X.SIF1O.S,3X))

WRITE(6.1180) BETlSS(ISTAGE),BET2SS(ISTAGE),AREAS(ISTAGE), WICSPD

1180 FORMAT(1HO ,1X,#STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=#,FlO.S, WICSPD

C REPEAT

TG(1)=TG(3) WICSPD
P(1)=P(3) WICSPD
IF(IUNIT.EQ.2) THEN WICSPD
TG(l)=TG(l)/CFT WICSPD
P(l)=P(l)/CFP WICSPD
ENDIF WICSPD

C OVERALL PERFORMANCE AT DESIGN POINT

101 OUALPR=P(3)/POIN WICSPD
OUALTR=TG(3)/TOIN WICSPD
GAMMAU=(GAMMAU+GAMMA)/2.0 WICSPD
GAMMAU=GAMMAU/(GAMMAU-1.0) WICSPD
OUALDR=(OUALPR**(l.0/GAMMAU)-1.0)/(OUALTR-1.0) WICSPD
OUALTR=TG(3)-TOIN WICSPD

C PRINTOUT OF OVERALL PERFORMANCE AT DESIGN POINT

IF(IUNIT.EQ.2) THEN WICSPD
TOIN=TOIN*CFT WICSPD
POIN=POIN*CFP WICSPD
WICSPD
CMASS=CMASS*CFM WICSPD

OUALDT=OUALDT*CFT
DO 422 I=1,NS
TD(I)=TD(I)*CFT
CONTINUE
ENDIF
WRITE(6,1000)
WRITE(6,421)
$**** OVERALL PERFORMANCE AT DESIGN POINT ****
WRITE(6,425) TIN
FORMAT(1HO,f~~***~**** OUERALL PERFORMRNCE fJT DESIGN POINT i*++
WRITE(6,425) TOIN
FORMAT(1HO,lX,#COMPRESSOR INLET TOTAL TEMPERATURE=Z,F8.2)
WRITE(6,426) POIN
FORMAT(lHO,lX,#COMPRESSOR INLET TOTAL PRESSURE=#,F10.2)
WRITE(6,427) CMAS
WRITE(6,429) OUALPR
WRITE(6,429) OUALPR
WRITE(6,427) CMAS
WRITE(6,1621)
FORMAT(lH0,14X,#l#r5X,~2#,5X,#3#,5X,#4#,5X,#5~,5X~#6#,4X~~IGU~
WRITE(6,1710) (BET1SR(I),I=l,NS)
FORMAT(lH ,lX,ZBET1SR(I)f.2X,6(F5.2.1X)
WRITE(6,1720) (BET2SR(I),I=l,NS)
FORMAT(lH ,lX,#BET2SR(I)#~2X,G(F5.2.1X)
WRITE(6,1730) (AINCSR(I),I=l,NS)
FORMAT(lH ,lX,~AINCSR(I)#,2X,G(F5.2,1X)
WRITE(6,1740) (ADEUSR(I),I=l,NS)
FORMAT(lH ,lX,~ADEUSR(I)~~2X,6(F5.2,1X)
WRITE(6,1760) (BET1SS(I),I=l,NS)
FORMAT(lH ,lX,~BET1SS(I)~,2X,6(F5.2,lX)~
WRITE(6,1770) (BET2SS(I),I=l,NS)
FORMAT(lH ,lX,$BET2SS(I)f,2X,7(F5.2,lX)
WRITE(6,1780) (AINCSS(I),I=l,NS)
FORMAT(lH ,lX,$AINCSS(I)#,2X,G(F5.2,lX)
WRITE(6,1790) (ADEUSS(I),I=l,NS)
FORMAT(lH ,lX,$ADEUSS(I)+,2X,G(FS.2,lX)
WRITE(6,1793) (OMEGS(I),I=l,NS)
FORMAT(lH ,lX,sfOMEGS(I)#,3X,G(F5.3,lX)
WRITE(6,1794) (OMEGR(I), I=l,NS)
FORMAT(lH ~lX~zOMEGR(I)#,3X,G(F5.3,lX)
IF(IUNIT.EQ.2) THEN
TOIN=TOIN/CFT
POIN=POIN/CFP
CMASS=CMASS/CFM
OUALDT=OUALDT/CFT
DO 423 I=l,NS
TD(I)=TD(I)*CFT
CONTINUE
ENDIF
RETURN
END
C+++++++++++++++++++++++++++++~++++++~++++++++++++++++~+++++++++++++++++
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
cc
*** STGSTK - A COMPUTER CODE FOR PREDICTING MULTISTAGE AXIAL FLOW cc
E
COMPRESSOR PERFORMANCE USING A MEANLINE STAGE STACKING METHOD.
DOCUMENTATION NASA TP-XXXX, XXXe 1980, BY R. J. STEINKE E
C C
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C *** CALCULATE FIXED PARAMETERS

PO = PO*144.0
DO 20 I=1,NSTA
AREA(I)= (RT2(I)+RH2(I))* (RT2(I)-RH2(I))*PI/144.0
AREA3(I)=(RT3(I)+RH3(I))*(RT3(I)-RH3(I))*PI/144.0
IF(IRAD.EQ.1) RMI(I)=RT2(I)
IF(IRAD.EQ.1) RMI(I)=RT3(I)
IF(IRAD.EQ.2) RMI(I)=RM1(I)
IF(IRAD.EQ.2) RM2(I)=SM1(I)
IF(IRAD.EQ.3) RM2(I)=RH2(I)
IF(IRAD.EQ.3) RM3(I)=RH3(I)
AREA2(I)=SAREA(I)
AREA3(I)=SAREA3(I)
UM2(I)=RMI(I)*DES RPM* RPMRAD
UM3(I)=RMI(I)*DES RPM* RPMRAD
BETM(I,1) = BETM(I,1)/RAD
RK2M(I) = RK2M(I) + CB2MR(I)
SK2M(I) = SK2M(I) + CB2MR(I)
CB2M(I)= CB2M(I)/RAD
CB2MR(I)= CB2MR(I)/RAD
CB3MR(I)= CB3MR(I)/RAD

20 CONTINUE

CALL CSPREF
IF(ETADES(I,1,1).EQ.0.0) CALL CSETA
CALL CPSISI(0.00,1)
DO 100 I=1,NSTA
DO 100 K=1,NPTS
PSIDES(I,1,K)=PSIDES(I,1,K)
100 CONTINUE

CALL CPSISI(0.025,1)
DO 101 I=1,NSTA
DO 101 K=1,NPTS
PSIDES(I,1,K)=PSIDES(I,1,K)
101 CONTINUE
CONTINUE
CALL CSPSI(0.075,1)
DO 102 I=1,NSTA
DO 102 K=1,NPTS
PSID3(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.125,1)
DO 103 I=1,NSTA
DO 103 K=1,NPTS
PSID4(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.150,1)
DO 104 I=1,NSTA
DO 104 K=1,NPTS
PSID5(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.00,2)
DO 200 I=1,NSTA
DO 200 K=1,NPTS
PSID1(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.025,2)
DO 201 I=1,NSTA
DO 201 K=1,NPTS
PSID2(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.075,2)
DO 202 I=1,NSTA
DO 202 K=1,NPTS
PSID3(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.125,2)
DO 203 I=1,NSTA
DO 203 K=1,NPTS
PSID4(I,K)=PSIDES(I,K)
CONTINUE
CALL CSPSI(0.150,2)
DO 204 I=1,NSTA
DO 204 K=1,NPTS
PSID5(I,K)=PSIDES(I,K)
CONTINUE
DO 800 I=1,12
DO 800 J=1,NSPE
DPSIS(I,J)=0.0
CONTINUE
IF (SPDPSI.EQ.1.0) CALL CSPSD
CALL CSPAN
DO 51 I=1,NSTA
BET2M(I)=BET2M(I)*RADIUS
51 BET3MR(I)=BET3MR(I)*RADIUS
C *** WRITE INTERMEDIATE OUTPUT
WRITE (6,2120)
IF(UNIT.EQ.1) THEN
DO 300 I=1,NSTA
FLOCAL(I)=FLOCAL(I)*0.453592
300 CONTINUE
ENDIF
WRITE (6,2051) (NSTAGE(I),PHIREF(I),PSIREF(I),ETAREF(I),CPREF(I),
XCHAREF(I),FLOCAL(I),
XI,I,NSTA)
IF(UNIT,EQ.1) THEN
DO 310 I=1,NSTA
FLOCAL(I)=FLOCAL(I)*0.453592
310 CONTINUE
ENDIF
2051 FORMAT (110H STAGE PHIREF PSIREF ETAREF CPREF
X GMREF FLOCAL BET2M BET3MR RINCM RDMF,10H S
X RINCM/(5X,15,5F10.4,4F10.2,F10.4,F10.2))
WRITE(6,2171)
3474 FORMAT(IH,STAGE, UZ2M, UZ3M) NASA 153
DO 177 I=1,NSTA NASA 154
WRITE(6,3473) I, UZ2M(I,1), UZ3M(I,1) NASA 155
3473 FORMAT(4X,I2,F14.2,F11.2) NASA 156
177 CONTINUE NASA 157
DO 52 I=1,NSTA NASA 158
BET2M(I,1) = BET2M(I,1) / RAD NASA 159
WRITE (6,2120) NASA 160
WRITE (6,2052) (NSTAGE(I), I=1,12), (PCTSPD(I), (DPSIS(I,J), I=1,NSPE) NASA 161
2052 FORMAT (20X,27H DPSIS(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER// 
18H PCT SPD,12(15,3X)//(13F8.4)) NASA 162
DO 60 I=1,NSTA NASA 163
PSII(I,J,K) = PSID2(I,J,K) NASA 164
PSI3(I,J,K) = PSID3(I,J,K) NASA 165
PSI4(I,J,K) = PSID4(I,J,K) NASA 166
PSI5(I,J,K) = PSI5(I,J,K) NASA 167
PSI5(I,J,K) = PSI5(I,J,K) NASA 168
PSI5(I,J,K) = PSI5(I,J,K) NASA 169
PSI5(I,J,K) = PSI5(I,J,K) NASA 170
PSI5(I,J,K) = PSI5(I,J,K) NASA 171
PSI5(I,J,K) = PSI5(I,J,K) NASA 172
PSI5(I,J,K) = PSI5(I,J,K) NASA 173
PSI5(I,J,K) = PSI5(I,J,K) NASA 174
PSI5(I,J,K) = PSI5(I,J,K) NASA 175
PSI5(I,J,K) = PSI5(I,J,K) NASA 176
PSI5(I,J,K) = PSI5(I,J,K) NASA 177
PSI5(I,J,K) = PSI5(I,J,K) NASA 178
PSI5(I,J,K) = PSI5(I,J,K) NASA 179
PSI5(I,J,K) = PSI5(I,J,K) NASA 180
PSI5(I,J,K) = PSI5(I,J,K) NASA 181
PSI5(I,J,K) = PSI5(I,J,K) NASA 182
PSI5(I,J,K) = PSI5(I,J,K) NASA 183
PSI5(I,J,K) = PSI5(I,J,K) NASA 184
ETA(I,J,K) = ETADES(I,J,K) NASA 185
60 CONTINUE NASA 186
DO 70 I=1,NSTA NASA 187
WRITE (6,2120) NASA 188
WRITE (6,2060) NSTAGE(I),((PHI(I,J,K),PSI(I,J,K), ETA(I,J,K), J=4,6), K=1,NPTS) NASA 189
2060 FORMAT (20X,g3SH COMPUTED CHARACTERISTICS FOR STAGE NO.I// 
13(30H PHI PSI ETA) // (9F8.4)) NASA 190
70 CONTINUE NASA 191
2060 FORMAT (20X,g3SH COMPUTED CHARACTERISTICS FOR STAGE NO.I// 
13(30H PHI PSI ETA) // (9F8.4)) NASA 192
2120 FORMAT (1HO///) NASA 193
RETURN NASA 194
END NASA 195
C *** OPTION TO ALTER FLOW COEFFICIENT FOR OFF DESIGN SPEEDS NASA 196
C *** SUBROUTINE CSINPT READS AND WRITES THE INPUT DATA NASA 197
C *** ALL INPUT DATA MUST BE ENGLISH UNIT NASA 198
C *** VALUE OF INPUT DATA #SPEED# MUST ALWAYS BE 1.0 NASA 199
C *** VALUE OF INPUT DATA #UNITS# MUST ALWAYS BE 0.0 NASA 200
C *** COMMON #VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12), NASA 201
C *** CRS(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), NASA 202
C *** XPSESIDES(12,9,8), ETADESIDES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9 NASA 203
C *** X,8), DPHIA(12), DPSIA(12), ETA(12), NSTAGE(12), PCTSPD(9), NASA 204
C *** XTRO(12), ETAO(12), BETM(12,9,8), UZ2M(12,9), UZ3M(12,9), AREA2(12) NASA 205
C *** AREF(12), RM2(12), RM3(12), RT2(12), RT3(12), UM2(12), UM3(12) NASA 206
C *** XDPSESIDES(12,9,8), RT2(12), UM2(12), UM3(12), CB2M(12), CB2MR(12), NASA 207
C *** CB3M(12), CB3MR(12), RDP(12), SK2M(12), SK3M(12), BET2M(12,9,8) NASA 208
C *** X,9), PHIFIX(12,12), DPHIF(12), CPREF(12), GFIREF(12), ETAINP(12) NASA 209
C *** XFLUCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DBMR NASA 210
C *** X(12,9), CB2M(12,9), SPEEDF, FLOWIN, V3DV2R(12), V2U3(12), DB3MRG(12) NASA 211
C ++ SUBROUTINE CSINPT NASA 212
C *** COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12), NASA 213
C *** CRS(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8), NASA 214
C *** XPSESIDES(12,9,8), ETADESIDES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9 NASA 215
C *** X,8), DPHIA(12), DPSIA(12), ETA(12), NSTAGE(12), PCTSPD(9), NASA 216
C *** XTRO(12), ETAO(12), BETM(12,9,8), UZ2M(12,9), UZ3M(12,9), AREA2(12) NASA 217
C *** AREF(12), RM2(12), RM3(12), RT2(12), RT3(12), UM2(12), UM3(12) NASA 218
C *** XDPSESIDES(12,9,8), RT2(12), UM2(12), UM3(12), CB2M(12), CB2MR(12), NASA 219
C *** CB3M(12), CB3MR(12), RDP(12), SK2M(12), SK3M(12), BET2M(12,9,8) NASA 220
C *** X,9), PHIFIX(12,12), DPHIF(12), CPREF(12), GFIREF(12), ETAINP(12) NASA 221
C *** XFLUCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9), DB3M(12,9), DBMR NASA 222

READ(5,1000) (TITLE(I),I=1,12)
WRITE(6,2000) (TITLE(I),I=1,12)

1000 FORMAT (12A6)
2000 FORMAT (1H1///20X,30H ** STAGE STACKING PROGRAM ** ///20X,112A6///)
4444 FORMAT (72H STAGES SPEEDS POINTS PO TO DESRPM, DESFLO, UNITS

READ(5,1000) (TITLE(I),I=1,12)
WRITE(6,2000) (TITLE(I),I=1,12)

1000 FORMAT (12A6)
2000 FORMAT (1H1///20X,30H ** STAGE STACKING PROGRAM ** ///20X,112A6///)
4444 FORMAT (72H STAGES SPEEDS POINTS PO TO DESRPM, DESFLO, UNITS

READ(5,1000) (TITLE(I),I=1,12)
WRITE(6,2000) (TITLE(I),I=1,12)
READ (5,1010) (RK2M(I), I=1,NSTA)          CSINPT 89
READ(5,1010) (RK3M(I),I=1,NSTA)          CSINPT 90
READ (5,1010) (RSOLM(I), I=1,NSTA)          CSINPT 91
READ (5,1010) (SK2M(I), I=1,NSTA)          CSINPT 92
READ (5,1010) (PR(I), I=1,NSTA)            CSINPT 93
READ (5,1010) (ETAINP(I),I=1,NSTA)        CSINPT 94
READ (5,1010) (PHIINP(I),I=1,NSTA)         CSINPT 95
WRITE (6,2030) (NSTAGE(I),RT2(I),RH2(I),RT3(I),RH3(I),BET2R(I),I=1,NSTA)     CSINPT 96
XCB2M(I),CB3MR(I),RSOLM(I),SK2M(I),I=1,NSTA) CSINPT 97
2030 FORMAT (11H STAGE RT2 RH2 RT3 RH3)          CSINPT 98
X BETEM  CB2M  CB3MR  RK2M  RSOLM;10H          CSINPT 99
XSK2M//(5X,15,4F10.4,5F10.2,F10.4,F10.2))      CSINPT 100
WRITE (6,2120)                                CSINPT 101
WRITE (6,2031) (NSTAGE(I), PR(I), ETAISP(I), I=1,NSTA) CSINPT 102
2031 FORMAT (30H STAGE PR ETAISP//(5X,15,2F10.4)) CSINPT 103
READ(5,1010) (PCTSPD(J),J=1,NSPE)          CSINPT 104
PCTSPD(I)=1.0                                CSINPT 105
2120 FORMAT (1HO///)                            CSINPT 106
READ (5,1010) (ETARQT(J),J=1,NSPE)          CSINPT 107
WRITE (6,2120)                                CSINPT 108
WRITE (6,2121) (PCTSPD(J),ETARQT//(2F10.4))  CSINPT 109
2121 FORMAT (201-l PCTSPD ETARQT//(2F10.4))  CSINPT 110
DO 21 I=1,NSTA                                 CSINPT 111
READ (5,1010) (BLEED(I,J),J=1,NSPE)          CSINPT 112
WRITE (6,2120)                                CSINPT 113
WRITE (6,2041) (NSTAGE(I),I=1,12)             CSINPT 114
WRITE (6,2041) (PCTSPD(I),I=1,12)             CSINPT 115
WRITE (6,2041) (ETAINP(I),I=1,12)             CSINPT 116
2041 FORMAT (20X,27H BLEED(STAGE,PCT SPD) TRBLE//40X, 13H STAGE NUMBER/ 13(30H PHIDES PSIDES ETADES)/(SFl 13(2F10.4)) CSINPT 117
DO 30 I=1,NSTA                                 CSINPT 118
PHIDES(I,K)=PHIDES(I,K)/PHIINP(I)            CSINPT 119
ISPDP=IFIX(SPEED*100.0)                      CSINPT 120
DELPHI=PHIIPHI*DELPHI                        CSINPT 121
PHIDES(I,K)=PHIIPHI*PHIIPHI*PHIIPHI          CSINPT 122
30 CONTINUE                                     CSINPT 123
DO 300 I=1,NSTA                                CSINPT 124
DO 301 K=1,NPTS                                CSINPT 125
PHIPI=PHIDES(I,K)*PHIINP(I)                   CSINPT 126
ISPDP=IFIX(SPEED*100.0)                      CSINPT 127
DELPHI=PHIIPHI*DELPHI                        CSINPT 128
PHIDES(I,K)=PHIIPHI*PHIIPHI*PHIIPHI          CSINPT 129
301 CONTINUE                                    CSINPT 130
300 CONTINUE                                    CSINPT 131
30 CONTINUE                                    CSINPT 132
1011 FORMAT (8F10.0)                            CSINPT 133
1012 FORMAT (8F10.0)                            CSINPT 134
1013 FORMAT (8F10.0)                            CSINPT 135
DO 50 I=1,NSTA                                 CSINPT 136
WRITE (6,2120)                                CSINPT 137
WRITE(6,2050) NSTAGE(I),((PHIDES(I,J,K),PSIDES(I 1,J,K),ETADES(I,J,K),J=1,1),K=1,NPTS) CSINPT 138
IF(NSPE.LT.4) GO TO 50                        CSINPT 139
WRITE (6,2120)                                CSINPT 140
WRITE(6,2050) NSTAGE(I),((PHIDES(I,J,K),PSIDES(I 1,J,K),ETADES(I,J,K),J=1,4),K=1,NPTS) CSINPT 141
IF(NSPE.LT.7) GO TO 50                        CSINPT 142
WRITE (6,2120)                                CSINPT 143
WRITE(6,2050) NSTAGE(I),((PHIDES(I,J,K),PSIDES(I 1,J,K),ETADES(I,J,K),J=1,5),K=1,NPTS) CSINPT 144
50 CONTINUE                                     CSINPT 145
2050 FORMAT (20X,41H INPUT DESIGN CHARACTERISTICS FOR STAGE--I3// 13(30H PHIDES PSIDES ETADES)/(SFl 20.4)) CSINPT 146
C *** CHANGE METRIC INPUT INTO ENGLISH UNITS
IF (UNITS.NE.1.0) GO TO 53                     CSINPT 147
PO = PO/0.689476                              CSINPT 150
TO = TO*9.0/5.0                               CSINPT 151
DESFLO = DESFLU/0.453592                       CSINPT 152
DO 51 I=1,NSTA                                 CSINPT 153
RT2(I) = RT2(I)/2.54                          CSINPT 154
C
RH2(I) = RH2(I)/2.54
RT3(I) = RT3(I)/2.54
RH3(I) = RH3(I)/2.54
DO 52 J = 1,NSPE
52 BLEED(I,J) = BLEED(I,J)/0.453592
CONTINUE
RETURN
END

Subroutine CSPREF calculates parameters at design speed and flow conditions.

Calculations at rotor inlet.
IF (PSIREF(I).EQ.0.0) GO TO 71
PR(I) = (1.0 + PSIREF(I)*UT3(I)*UT3(I) - GJ*CP*TT(I)**GF2

71 CONTINUE
IF (ETAREF(I).EQ.0.0) ETAREF(I) = ETAINP(1)
TR(I) = 1.0 + (PR(I)**GF3 - 1.0)/ETAREF(I)
TT(I+1) = TT(I)*TR(I)
IF (PSIREF(I+1).EQ.0.0) PSIREF(I+1) = GJ*CP*(TT(I+1) - TT(I))*ETAREF(I)

X/UT3(I)**2
P(I+1) = PT(I)**PR(I)
TR(I+1) = TT(I+1)/TR(I)
PR(I+1) = PT(I+1)/PR(I)
I = I+1
IF (I .LE. NSTA) GO TO 20
DO 80 I = 1, NSTA

UT2M = UZ2M(I,J)*TAN(BET2M(I,J))
UT2MR = UM2(I)*UT2M(I)
BAT2MR(I,J) = ATAN2(UT2MR, UZ2M(I,J))
TS = TT(I+1)
RHOT = PT(I+1)/(TT(I+1)*RG)
RHOS = RHOT
CALCULATIONS AT ROTOR OUTLET
UZ3M(I,J) = DESFLO/RHOS*QREA3(I)
UT3M = (CPs(TT(I+1) - TT(I)) = GJ + UM2(I)*UT2M(I))/UM3(I)
U = SQRT(UZ3M(I,J)**2 + UT3M**2)
CP = CPFNM(TS)
RHOS = RHOT*(1.0 - U*U/(G2J*CP**TT(I+1)))*GF1
TS = TT(I+1)*RHOS/RHOT*GF1
WCAL = RHOS*AREA3(I)*UZ3M(I,J)

C *** SUBROUTINE CPFNM(TS) CALCULATES SPECIFIC HEAT FROM STATIC
FUNCTION CPFNM(TS)
RETURN
END
*PSIDIL(12,2,8), PSID2(12,2,8), PSID3(12,2,8), PSID4(12,2,8) CPFM 19
*PSIDS(12,2,8), PSIS(12,2,8), PSIS2(12,2,8), PSIS3(12,2,8) CPFM 20
*PSIIL(12,2,8), PSIIS(12,2,8), PSIIS2(12,2,8), PSIIS3(12,2,8) CPFM 21
*PSIDIL(12,2,8), PSIDIL2(12,2,8), PSIDIL3(12,2,8) CPFM 22
*PSIDIL(12,2,8), PSIDIL(12,2,8), PSI2L(12,2,8) CPFM 23
*PSI2L(12,2,8), PSI3L(12,2,8), PSI4L(12,2,8), PSI5L(12,2,8) CPFM 24
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS CPFM 26
X, CP, GAMMA, GMX, GM2, GM3, SPDPHI, SPDPHI, DREV, DDEV, DREV3, DREV4 CPFM 27
X, XAR, XMET, XSTM CPFM 28
X, STAGEN, CPEDCN, CHAPTS, WTMOLEC CPFM 29
CPFM 30
CPFM 31
CPFM 32
CPFM 33
CPFM 34
CPFM 35
CPFM 36
CPFM 37
CPFM 38
CPFM 39
CPFM 40
CPFM 41
CPFM 42
CPFM 43
CPFM 44
CPFM 45
C ********SUBROUTINE CSETA GENERATES ADIABATIC EFFICIENCY VERSUS FLOW********** C 1
C *** COMMON /VECTOR/ CPO(6), TITLE(12), RT2(12), RT3(12), CPFMT 5
XH(12), PHIFR2(12), TAREF(12), ETAREF(12), PHIDE(12) CPFMT 6
CPFMT 7
CPFM 8
CPFM 9
CPFM 10
CPFM 11
CPFM 12
CPFM 13
CPFM 14
CPFM 15
CPFM 16
CPFM 17
CPFM 18
CPFM 19
CPFM 20
CPFM 21
CPFM 22
CPFM 23
CPFM 24
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS CPFMT 26
X, CP, GAMMA, GMX, GM2, GM3, SPDPHI, SPDPHI, DREV, DREV3, DREV4 CPFMT 27
X, XAR, XMET, XSTM CPFMT 28
X, STAGEN, CPEDCN, CHAPTS, WTMOLEC CPFMT 29
CPFM 30
CPFM 31
CPFM 32
CPFM 33
CPFM 34
CPFM 35
CPFM 36
CPFM 37
CPFM 38
CPFM 39
CPFM 40
CPFM 41
CPFM 42
RETURN CPFMT 43
END CPFMT 44
C ******** SUBROUTINE CSETA GENERATES ADIABATIC EFFICIENCY VERSUS FLOW ********** C 1
C C** COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RT3(12), CPFMT 5
XH(12), PHIFR2(12), TAREF(12), ETAREF(12), PHIDE(12) CPFMT 6
CPFMT 7
CPFML 8
CPFM 9
CPFM 10
CPFM 11
CPFM 12
CPFM 13
CPFM 14
CPFM 15
CPFM 16
CPFM 17
CPFM 18
CPFM 19
CPFML 20
CPFML 21
CPFML 22
CPFML 23
CPFML 24
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS CPFMT 26
X, CP, GAMMA, GMX, GM2, GM3, SPDPHI, SPDPHI, DREV, DREV3, DREV4 CPFMT 27
X, XAR, XMET, XSTM CPFMT 28
X, STAGEN, CPEDCN, CHAPTS, WTMOLEC CPFMT 29
CPFML 30
CPFML 31
CPFML 32
CPFML 33
CPFML 34
CPFML 35
CPFML 36
CPFML 37
CPFML 38
CPFML 39
CPFML 40
CPFML 41
CPFML 42
CPFML 43
CPFML 44
CPFML 45
C *** COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RT3(12), CPFMT 5
XH(12), PHIFR2(12), TAREF(12), ETAREF(12), PHIDE(12) CPFMT 6
CPFM 7
CPFML 8
CPFML 9
CPFML 10
CPFML 11
CPFML 12
CPFML 13
CPFML 14
CPFML 15
CPFML 16
CPFML 17
CPFML 18
CPFML 19
CPFML 20
CPFML 21
CPFML 22
CPFML 23
CPFML 24
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS CPFMT 26
X, CP, GAMMA, GMX, GM2, GM3, SPDPHI, SPDPHI, DREV, DREV3, DREV4 CPFMT 27
X, XAR, XMET, XSTM CPFMT 28
X, STAGEN, CPEDCN, CHAPTS, WTMOLEC CPFMT 29
CPFML 30
CPFML 31
CPFML 32
CPFML 33
CPFML 34
CPFML 35
CPFML 36
CPFML 37
CPFML 38
CPFML 39
CPFML 40
CPFML 41
CPFML 42
CPFML 43
CPFML 44
CPFML 45
11 ETADES(I,J,K) = (AS + PHIDES(I,J,K) + BS) * PHIDES(I,J,K) + CS
12 ETADES(I,J,K) = ETAREF(I)
13 ETADES(I,J,K) = (kCr - PHIDES(I,J,K) + BC * PHIDES(I,J,K) + CC + PHIDES(I,J,K) - PHIREF(I)) - (3.0 / PHIRES(I,J,NPTS) - PHIREF(I)) * 3.0 * RM ETAREF(I)

20 CONTINUE
10 CONTINUE
RETURN
END
TS = TTA3*(RHOS/RHOT)**GM1
WCAL = RHOS*AREA3(I)*UZ3M(I,J)
IF (TRA.GE.1.O) GO TO 12
DT = 0.0
GO TO 13
12 ID = ID + 1
UZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
U3MR = UZ3M(I,J)/COS(BET3MR(I,J))
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN FLOW
C COEFFICIENT
IF(LORS.EQ.1) CALL CSDEUS(V3MR,U3MR,U3DU2R(I),I,FK)
IF(LORS.EQ.2) CALL CSDEUSL(V3MR,U3MR,U3DU2R(I),I,FK)
IF (DRDEU.EQ.1.O)
XDB3MRP(I,K)=-(FK/RAD)+(V3MR/U2MR-U3DU2R(I))
BET3MR(I,J) = DB3MR(I,J)+DB3MRP(I,K)
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN FLOW
C COEFFICIENT
IF (ABS(WCAL-DESFLC)/WCAL).LT.0.005) GO TO 11
DUMMY=ETADSI(I,J,K)
IF(LORS.EQ.1) CALL CSETA1(I,J,K,XWN,PHIDES(I,J,K),PHIREF(I),DUMMY)
IF(LORS.EQ.2) CALL CSETAL(I,J,K,XWN,PHIREF(I),PHIDES(I,J,K),
DUMMY,ETAREF(I))
13 PSIDES(I,J,K) = GJ*CP*DT*DLJMY**2
DU3DU2 = U3DU2R(I)
FU3DU2 = U3MR**2
IF(I.EQ.NSTA) GO TO 100
B2M=DB2M(I+1)
303 UZ2=UZ3M(I,J)
301 U2M=UZ2/COS(B2M)
U2MS=U2M**2
RHOT=PTA3/(TTA3*RG)
RHOS=RHOT*(1.0-U2MS)
IF((ABS(UZ2-UZ2C)/UZ2).LT.0.005) GO TO 300
300 IF(LORS.EQ.1) CALL CSDEUS(V3M,U2M,U3M,U3DU3,1,FK)
IF(LORS.EQ.2) CALL CSDEUSL(V3M,U2M,U3M,U3DU3,1,FK)
B2MC=DB2M(I+1)+2.0
GO TO 301
301 I=I+1
IF(I.LE.NSTA) GO TO 10
100 CONTINUE
RETURN
END
SUBROUTINE CSDEUS(VXH,VXU,V3M,U3U3,1,FK)
T=U2M/V3M-U3U3
FK=26.0+0.12/(V3M/U3M-U3U3)
B2M=DB2M(I+1)+2.0
GO TO 302
302 V12K=VU2(I+1)-UZ2*TAN(B2M)
B2MR=ATAN2(V12K,V22M)
I=I+1
IF(I.LE.NSTA) GO TO 10
100 CONTINUE
RETURN
END
SUBROUTINE CSDEUSL(VXH,VXU,V3M,U3U3,1,FK)
T=U2M/V3M-U3U3
FK=26.0+0.12/(V3M/U3M-U3U3)
B2M=DB2M(I+1)+2.0
GO TO 302
302 V12K=VU2(I+1)-UZ2*TAN(B2M)
B2MR=ATAN2(V12K,V22M)
I=I+1
IF(I.LE.NSTA) GO TO 10
100 CONTINUE
RETURN
END
201 A1=-3.70
B1=-0.11
AF0=25.0
IF(T1.LT.-0.05) T1=-0.05
GO TO 204
202 A1=-3.73
B1=-0.13
AF0=30.0
IF(T1.LT.-0.05) T1=-0.05
GO TO 204
203 A1=1.80
B1=0.23
AF0=-10.0
IF(T1.GT.0.05) T1=0.05
GO TO 204

204 T2=A1*XW+B1
FK=T2/T1+AF0
DK=0.0
IF (T1.GT.0.0) GO TO 205
ISPD=IFIX(SPEEDF*100.0)
IF (ISPD.EQ.70.0) DK=DELK70(I,T1)
IF (ISPD.EQ.79) DK=DELK80(I,T1)
IF (ISPD.EQ.99) DK=DELK90(I,T1)
205 FK = FK - DK
RETURN
END
FUNCTION DELK70(I,T1)
IF (I.EQ.1) GO TO 1
IF (I.EQ.2) GO TO 2
IF (I.EQ.3) GO TO 3
IF (I.EQ.4) GO TO 4
IF (I.EQ.5) GO TO 5
IF (I.EQ.6) GO TO 6
RETURN
END
FUNCTION DELK80(I,T1)
IF (I.EQ.1) GO TO 1
IF (I.EQ.2) GO TO 2
IF (I.EQ.3) GO TO 3
IF (I.EQ.4) GO TO 4
IF (I.EQ.5) GO TO 5
IF (I.EQ.6) GO TO 6
RETURN
END
FUNCTION DELK90(I,T1)
IF (I.EQ.1) GO TO 1
IF (I.EQ.2) GO TO 2
IF (I.EQ.3) GO TO 3
IF (I.EQ.4) GO TO 4
IF (I.EQ.5) GO TO 5
IF (I.EQ.6) GO TO 6
RETURN
END
FUNCTION DELK70(I,T1)
  IF (I.EQ.1) GO TO 1
  IF (I.EQ.2) GO TO 2
  IF (I.EQ.3) GO TO 3
  IF (I.EQ.4) GO TO 4
  IF (I.EQ.5) GO TO 5
  IF (I.EQ.6) GO TO 6
  A = -9093750.0
  B = -227083.0
  C = -14094.0
  D = -87.0
  E = 19.0
  GO TO 100
1 A = -140625.0
  B = -262500.0
  C = -12219.0
  D = 311.0
  E = 39.0
  GO TO 100
2 A = -312500.0
  B = -35417.0
  C = 1875.0
  D = 84.0
  E = 36.0
  GO TO 100
3 A = -598972.0
  B = -43583.0
  C = -21588.0
  D = 199.0
  E = 26.0
  GO TO 100
4 A = -1953125.0
  B = -377083.0
  C = -20109.0
  D = 93.0
  E = 33.0
  GO TO 100
5 A = -1953125.0
  B = -377083.0
  C = -20109.0
  D = 93.0
  E = 33.0
  GO TO 100
6 A = -1953125.0
  B = -377083.0
  C = -20109.0
  D = 93.0
  E = 33.0
  GO TO 100
100 DELK70 = A*T1**4 + B*T1**3 + C*T1**2 + D*T1 + E
RETURN
END
B = 183333.0
C = 22052.0
D = 1217.0
E = 33.0
GO TO 100

6 A = 1953124.0
B = 504167.0
C = 47047.0
D = 1920.0
E = 38.0
GO TO 100

100 DELK80=A*T1**4+B*T1**3+C*T1**2+D*T1+E
RETURN
END

FUNCTION DELK10(I,T1)
IF (I.EQ.1) GO TO 1
IF (I.EQ.2) GO TO 2
IF (I.EQ.3) GO TO 3
IF (I.EQ.4) GO TO 4
IF (I.EQ.5) GO TO 5
IF (I.EQ.6) GO TO 6
1 A = -755208.0
B = -189583.0
C = -19932.0
D = -1161.0
E = -38.0
GO TO 100

2 A = -234375
B = -66667.0
C = -7891.0
D = -528.0
E = -20.0
GO TO 100

3 A = -1927083.0
B = -487500.0
C = -44948.0
D = -1921.0
E = -42.0
GO TO 100

4 A = -1510417.0
B = -350000.0
C = -30665.0
D = -1390.0
E = -36.0
GO TO 100

5 A = -4479167.0
B = -1050000.0
C = -69336.0
D = -3420.0
E = -60.0
GO TO 100

6 A = -1562500.0
B = -393750.0
C = -38375.0
D = -1826.0
E = -42.0
GO TO 100

FUNCTION DPHI(I,ISPD)
IF (I.EQ.1) GO TO 1
IF (I.EQ.2) GO TO 2
IF (I.EQ.3) GO TO 3
1 IF (ISPD.EQ.70.0 OR ISPD.EQ.69) DPHI = -0.0357
IF (ISPD.EQ.60.0 OR ISPD.EQ.68.0) DPHI = -0.0357
IF (ISPD.EQ.59.0 OR ISPD.EQ.61.0) DPHI = 0.0
GO TO 100

2 IF (ISPD.EQ.70.0 OR ISPD.EQ.69) DPHI = -0.0286
IF (ISPD.EQ.80 .OR. ISPD.EQ.79) DPHI = -0.0286
IF (ISPD.EQ.90 .OR. ISPD.EQ.89) DPHI = 0.0
GO TO 100
3 IF (ISPD.EQ.70 .OR. ISPD.EQ.69) DPHI = -0.0333
IF (ISPD.EQ.80 .OR. ISPD.EQ.79) DPHI = -0.0333
IF (ISPD.EQ.90 .OR. ISPD.EQ.89) DPHI = 0.0
IF (ISPD.EQ.100 .OR. ISPD.EQ.99) DPHI = -0.0333
100 RETURN

SUBROUTINE CSETAD(I,J,K,XW,PHID,PHIR,ETAD)
IF (I.EQ.1 .AND. XW.LT.0.04) Y=0.4575*XW
IF (I.EQ.1 .AND. XW.GE.0.04) Y=0.12*XW+0.0135
T3=PHID-PHIR
IF (I.EQ.1) GO TO 304
IF (I.EQ.2 .AND. T3.LT.-0.08) GO TO 300
IF (I.EQ.2 .AND. T3.GE.-0.08) GO TO 301
IF (I.EQ.3) GO TO 302
GO TO 303

300 A=0.0
B=0.5*XW
IF (XW.GT.0.04) A=-0.982*XW+0.0393
IF (XW.GT.0.04) B=0.02
GO TO 303
301 A=3.125*XW
B=0.265*XW
IF (XW.GT.0.04) A=-0.7375*XW+0.165
IF (XW.GT.0.04) B=0.125
GO TO 303
302 A=5.04*XW
B=0.625*XW
IF (XW.GT.0.04) A=-2.25*XW+0.0393
IF (XW.GT.0.04) B=0.02
GO TO 303
303 Y=A*XW+B
RETURN

SUBROUTINE CSETAL(I,J,K,XW,PHID,PHIR,ETAD)
IF (I.EQ.1 .OR. I.EQ.2) GO TO 10
IF (I.EQ.3) GO TO 20
GO TO 30

10 IF (T.LT.0.88) Y=1.25*XW
IF (T.LT.0.88 .AND. XW.LT.0.04) Y=0.4364*XW+0.03544
IF (T.LT.0.88 .AND. XW.GE.0.04) Y=-27.0*(T-0.934)**2+1.1352*XW+0.0787
IF (T.LT.0.88) Y=-27.0*(T-0.934)**2+0.5067*XW+0.1040
GO TO 40

20 IF (T.LT.0.87) Y=1.050*XW
IF (T.LT.0.87 .AND. XW.LT.0.04) Y=0.2333*XW+0.033
IF (T.LT.0.87 .AND. XW.GE.0.04) Y=-11.90*(T-0.94)**2+1.0158*XW+0.058
$3
IF (T.LT.0.87) Y=-11.90*(T-0.94)**2+0.7333*XW+0.0880
GO TO 40

30 IF (T.LT.0.92) Y=0.450*XW
IF (T.LT.0.92 .AND. XW.LT.0.04) Y=0.05967*XW+0.0142
IF (T.LT.0.92 .AND. XW.GE.0.04) Y=3.215*XW-T-2.5075*XW
IF (T.LT.0.92) Y=(0.440*XW+0.1110)*T-0.3325*XW-$0.0870
GO TO 40

40 IF (XW.LT.0.000000001) Y=0.0
RETURN
END

C++++++++++++++++++++++++++
SUBROUTINE CSPSD
C *** SUBROUTINE CSPSD ALTERS PRESSURE RISE COEFFICIENTS FOR OFF DESIGN SPEEDS
C
COMMON DPHIDES(12,9,0), ETADES(12,9,0), PHI(12,9,0), PSI(12,9,0), ET(12,9)
C
COMMON /SCALER/ RU, PI, G, QJ, RAD, RGe DCP, GJ, G2J, RPMRAD, NSTA
X NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
X CP, GAMMA, GM1, GF1, GF2, GF3, SPDPSI, SPDPI, DRDEUG, DRDEUN, DRDEV
X VAR, XMET, XSTM
X STAGEN, SPEEDN, CHAPTS, WMOLE
DO 100 J=1,NSPE
   I = 1
   TT(I) = TO
   PT(I) = PO
10   UZ3M(I,J) = UZ2M(I,J) * SPEEDF
    U2MR = UZ2M(I,J) / COS(DB2MR(I,1))
    BET3MR(I,J) = DB3MR(I,J)
    IN = N
    UT2M = UZ2M(I,J) * SPEEDF * TAN(DB2M(I,1))
    U2S = UT2M**2 + UZ2M(I,J)**2
    RHMT = PT(I) / (TT(I) * RG)
    RHOS = RHOT * (1.0 - U2S / (G2J * CPREF(I) * TT(I))**GF1)
    DESFLEC = RHOS * AREA2(I) * UZ3M(I,J)
    TS = TT(I)
11   UT3M = UZ3M(I,J) * SPEEDF - UZ3M(I,J) * TAN(BET3MR(I,J))
    CP = CPFM(TS)
    DT = (UM3(I,J) - UM2(I,J) * UT2M) / (GJ * CP) * SPEEDF
    TRA = (DT + TT(I)) / TT(I)
    PT3A = PT(I) * (1.0 + ETAREF(I) * (TRA - 1.0)) / GF2
    TT3A = DT + TT(I)
    RHOT = PT3A / (TT3A * RG)
    V3S = UT3M**2 + UZ3M(I,J)**2
    RHOS = RHOT * (1.0 - V3S / (G2J * CP * TT3A)) / GF1
    TS = TT3A * RHOS / RHOT / CM1
    WCAL = RHOS * AREA3(I) * UZ3M(I,J)
    IF (I.NE.1) GO TO 12
    DU23M = UZ2M(I,J)
12   CONTINUE
    ID = ID + 1
    UZ3M(I,J) = DESFLEC / RHOS AREA3(I)
    U3MR = UZ3M(I,J) / COS(BET3MR(I,J))
    IF (DRDEVN.EQ.1.0) GO TO 10
    DB3MRRN(I,J) = -(10.00 / RAD) * (V3MR / VMR - V3DU2R(I))
    BET3MR(I,J) = DB3MR(I,J) + DB3MRRN(I,J)
    IF ((ABS(WCAL) - DESFLEC) / WCAL GT 0.005) GO TO 11
    DIPSIS(I,J) = CP * (1.0 + ETAREF(I)) / UT3(I) / SPEEDF / GR2 - PSIREF(I)
    DIPSIS(I,J) = DIPSIS(I,J) / DIPSIS(I,J)
    I = I + 1
    IF (I.LT.NSTAG) GO TO 10
100 CONTINUE
RETURN
XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9)
X, PHI(12,9), DPHIA(12,9), DPSIA(12,9,1), DETA(12), NSTA(12), PRO(12),
XTRD(12,9), ETA0(12,9,12), BET3MR(12,9,12), UZM(12,9,12), AREA(12,9)
X, AREA3(12,9), RME(12,9), ULM(12,9), U3M(12,9), U3(12,9), U3(12,9)
X, BAT2MR(12,9), DPHIA(12,9), PHI(12,9), PSI(12,9), ETA(12,9), DPHIA(12)
X, DETA(12), ETA0(12,12), BET3MR(12,12), UZM(12,12), AREA(12,9)
X, ETADES(12,9,8), ETADES(12,9,8), ETADES(12,9,8,1)
X, ETADES(12,9,8), ETADES(12,9,8,1,8), ETADES(12,9,8,1,8,8), ETADES(12,9,8,1,8,8,8)
X, ETADES(12,9,8,1,8,8,8,8)

X, NOCF, NTSM, TO, BET3MR, DESFL, UNITS
X, CP, GAMMA, GI, GF1, GF2, GF5, SPDPSI, SPDPSI, SPDPHI, DRDEUG, DRDEUN, DRDEUP
X, XAR, XMET, XSTM
X, STAGEN, SPEED, CHAPTS, WTMOLE

J=1
I=1
TT(I) = TT(I)
PT (I) = PT(I)

90 TS = TT(I)
WPHIA(I) = 0.0
DPSIA(I) = 0.0
DETA(I) = 0.0
IF((CDBM(I) + CBMR(I)) + CBMR(I)) .EQ. 0.0) GO TO 93
BET3MR(I,J) = DB2M(I,J) + CB2MR(I)

C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR BLADE RESET
XDB3MRG(I) = -(1.0/RAD)*(U3MR/U2MR - U3MR/U2R(I))
BET3MR(I,J) = DB3MR(I,J) + CB3MR(I)

93 I = I + 1
IF(I.LT.NSTA) GO TO 90
RETURN
END
SUBROUTINE CSOUPT(FAIO, ISTAGE, FLOWl, ALFA1, BETA1, BETA2, C)
C PERFORMANCE PARAMETERS
COMMON /PERFUM/ JPERFM, RHOG(3), RERUP, RERLOU, RESUP, RESLOW
X, PREB, RTIP(8), RRTIP(B), SRTIP(B), AAA1, AAA2, AAA3, SAREAS(8), SAREAS(7)
X, R(C), XUZ(3), XUZ(3), XCH4, XU3(3), XW3(3), XHT(3), TN(3), TW(3)
X, OMEGS(7), OMEGR(6), GAPR(6), GAPS(6)
X, RRAHUB(6), RC(6), RPLANE(6), STAGER(6)
X, SRHUB(7), SC(7), SBLADE(7), STAGES(7)
X, SIGMUR(6), BET1SR(6), BET2SR(6), AINCSR(6), ADEUSR(6)
X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
X, CP, GAMMA, GM1, GF1, GF2, GF3, SDPDI, SDPHI, DRDEUG, DRDEUN, DRDEUP
X, XAR, XMET, XSTM
X, STAGEN, SPEED, CHAPTS, WTMOLE
FLOWIN=FLOW1
DFlow=FLOW1
FLOWI=FLOW1
IF (UNITS.NE.1.0) GO TO 81
FLOWIN = FLOWIN/0.453592
DFLOW = DFLOW/0.453592
FLOWI = FLOWI/0.453592
81 CONTINUE
JS=1
DO 82 J=1, NSPE
IF (SPEED.EQ.PCTSPD(J)) JS=J
82 CONTINUE
C *** CALCULATE THE OUTPUT
I=ISTAGE
TC(I)=TG(1)
PT(I)=P(1)
WFLOW = FLOW1
RHT = PT(I)/(TC(I)*GT)
TST = T(I)
RHS = RHT
RHDW = 62.3
RHDSM = 1.0/(1.0-XHT(I))/RHDS*XHT(I)/RHOW
WFLOW = WFLOW - FLOWIN*BLEED(I,JS)
U2 = UT2(I)*SPEED
U3 = UT3(I)*SPEED
UMW2 = UM2(I)*SPEED
241
100 UZ=WTFLOW/(RHOSM*AREA2(I))
V= UZ/COS(BET2M(I,1))
CP=CFPM(TS)
RHOS= RHOT*(1.0-U*U/(GJ*CP*TT(I)))**GF1
RHOS=1.0/(1.0-XWT(I))/RHOS*XWT(I)/RHOS)
IF ((U*U).GT.(GJ*CP*TT(I))) GO TO 113
TS= TTI(I)*/(RHOS/RHOT)**GM1
RHOS=RHOS
TS=TS
PSI=PT(I)*TT(I)/TS1)**(-GF2)
WCAL=RHOSM*UZ*AREA2(I)
IF (ABS(WCAL-WTFLOW).GT.0.005) GO TO 100
IF (PHIC.GT.PHI(I,JS,NPTS)) GO TO 120
DO 200 I=1,NSTA
DO 200 J=1,NSPE
DO 200 K=1,NPTS
PSI(I,J,K)=PSI(I,J,K)
PSI(I,J,K)=PSI2(I,J,K)
PSI(I,J,K)=PSI3(I,J,K)
PSI(I,J,K)=PSI4(I,J,K)
CONTINUE
I=ISTAGE
DO 130 K=2,NPTS
IF (PHIC-PHI(I,JS,K)) 1150,130
CONTINUE
K=NPTS
PSIC= PSI(I,JS,K)
ETAC= ETA(I,JS,K)/PHIC-PHI(I,JS,K) GO TO 160
150 PSIC= PSI(I,JS,K)
ETAC= ETA(I,JS,K)
160 CONTINUE
CALL CSETAl(I,J,K,XW(I),PHIC,PHIREF(I),ETAC)
PR(I)=(1.0+PSIC*U3=U3/ (GJ*CP*TT(I)))**GF2
TAU= PSIC/ETAC
TR(I)= 1.0+(PR(I)**GF3-1.0)/ETAC
TT(I+1)= TT(I)*TR(I)
PT(I+1)= PT(I) *PR(I)
TRO(I)= TT(I+1)/TI
PRO(I)= PT(I+1)/PO
GF30= (GF3 + GF3S)/2.0
ETA(I)= (PRO(I)**GF30 - 1.0)/(TRO(I) - 1.0)
UZ2M = UZ * TAN(DCT2M(I,1))
UZ2M= UZ * TAN(DCT2M(I,1))
UZ2M= UZ * TAN(DCT2M(I,1))
RAT2MR= BAT2MR(I,JS) = RAD - RK2M(I)
U2MR= UZ/COS(BAT2MR(I,JS))
RHOT= PTC(I+1)/(TT(I+1)*RG)
TS= TT(I+1)
RHOS= RHOT
RHOSM=1.0/(1.0-XWT(I))/RHOS*XWT(I)/RHOS)
161 UZSM(I,J)=WTFLOW/(RHOSM*AREA(I))
TTSM= (CP*XSM(I,JS)+TT(I))/XSM(I,JS)+TT(I)/XSM(I,JS)
US= UZSM(I,J)**2 + UTSM**2
CP=CFPM(TS)
RHOS= RHOT*(1.0-US/(GJ*CP*TT(I)))**GF1
RHOSM=1.0/(1.0-XWT(I))/RHOS*XWT(I)/RHOS)
IF ((U*U).GT.(GJ*CP*TT(I))) GO TO 113
TS= TT(I+1) * (RHOS/RHOT)**GM1
RHOS=RHOS
TS=TS
PS2=PT(I+1)*TT(I+1)/TS2)**(-GF2)
WCAL=RHOSM*AREA(I)*UPSM(I,JS)
IF (ABS(WCAL-WTFLOW).GT.0.005) GO TO 161
BET3M(I,JS) = ATAN2(UT3M, U3M(I,JS)) / COS(BET3M(I,JS))
UT3MR = UT3M - UT3M
BET3MR(I,JS) = ATAN2(UT3MR, U3M(I,JS)) / COS(BET3M(I,JS))

RDF3(I) = 1.0 - U3MR * U3MR + (R3M(I) * U3M - R2M(I) * U2M) / (R3M(I) + R2M(I))

RDFM(I) = 1.0 - RDFM(I) * RDFM(I) + (R3M(I) * U3M - R2M(I) * U2M) / (R3M(I) + R2M(I))

IF (UNITS.EQ.1.0) WTFLOW = WTFLOW * 0.453592

PRATIO = PR(I)
TRATIO = TR(I)
FAI1 = PHIC
FAI2 = U2M(I,JS)

WRITE(6,404) FAIO, ISTAGE

*** WRITE THE OUTPUT
WRITE(6,404) FAIO, ISTAGE
$6X$, STAGE ADIABATIC EFFICIENCY\#1, F12.5
WRITE(6,402) FAII1, U111, T31STG1E(ISTAGE)
$6X$, AXIAL VELOCITY\#F7.2, /
$6X$, ROTOR SPEED\#F7.2, /
WRITE(6,405) P(1), P(2), P(3)
405 FORMAT(1H0, 24X, *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*#)
WRITE(6,406) P(1), P(2), P(3)
406 FORMAT(1H, 1X, *TOTAL PRESSURE\#10X, 3(F10.4, 5X))
WRITE(6,407) PS1, PS2
407 FORMAT(1H, 1X, *STATIC PRESSURE\#5X, 2(F10.4, 5X))
WRITE(6,408) TG(1), TG(2), TG(3)
408 FORMAT(1H, 1X, *TOTAL TEMPERATURE(GAS)\#3X, 3(F10.4, 5X))
WRITE(6,409) TS1, TS2
409 FORMAT(1H, 1X, *STATIC TEMPERATURE(GAS)\#1X, 2(F10.4, 5X))
WRITE(6,410) RHOG(1), RHOG(2)
410 FORMAT(1H, 1X, *STATIC DENSITY(GAS)\#5X, 2(F10.4, 5X))
WRITE(6,411) VZ1, U22
411 FORMAT(1H, 1X, *AXIAL VELOCITY\#10X, 2(F10.4, 5X))
WRITE(6,413) U1, U2
413 FORMAT(1H, 1X, *ABSOLUTE VELOCITY\#7X, 2(F10.4, 5X))
WRITE(6,414) WI, W2
414 FORMAT(1H, 1X, *RELATIVE VELOCITY\#7X, 2(F10.4, 5X))
WRITE(6,415) U(ISTAGE), U(ISTAGE), U(ISTAGE)
415 FORMAT(1H, 1X, *BLADE SPEED\#13X, 3(F10.4, 5X))
WRITE(6,416) MS1, MS2
416 FORMAT(1H, 1X, *TANG. COMP. OF ABS. VEL.\#2(F10.4, 5X))
WRITE(6,417) MS1, MS2
417 FORMAT(1H, 1X, *TANC. COMP. OF REL. VEL.\#2(F10.4, 5X))
WRITE(6,418) ASPED1, ASPED2
418 FORMAT(1H, 1X, *ACOUSTIC SPEED\#10X, 2(F10.4, 5X))
WRITE(6,419) AMAC1, AMAC2
419 FORMAT(1H, 1X, *ABSOLUTE MACH NUMBER\#4X, 2(F10.4, 5X))
WRITE(6,420) AMAC1, AMAC2
420 FORMAT(1H, 1X, *RELATIVE MACH NUMBER\#4X, 2(F10.4, 5X))
WRITE(6,421) FAI1, FAI2
421 FORMAT(1H, 1X, *FLOW COEFFICIENT\#8X, 2(F10.4, 5X))
WRITE(6,422) AAA1, AAA2
422 FORMAT(1H, 1X, *FLOW AREA\#15X, 2(F10.4, 5X))
WRITE(6,423) ALFA1, ALFA2, ALFA3
423 FORMAT(1H, 1X, *FLOW ANGLE\#5X, 3(F10.4, 5X))
WRITE(6,424) BETAI, BETAI
424 FORMAT(1H, 1X, *RELATIVE FLOW ANGLE\#5X, 3(F10.4, 5X))
WRITE(6,425) AINCIR1, AINCIS
425 FORMAT(1H, 1X, *INCIDENCE\#16X, 2(F10.4, 5X))
WRITE(6,426) ADECIR
426 FORMAT(1H, 1X, *DEVIATION\#30X, 1(F10.4, 5X))
IF (UNIT\# EQ 1.0) WTFLOW = WTFLOW\*0.453592
CN To 111
WRITE(6,2100) I, PHIC
2100 FORMAT(10H FOR STAGE\#13, 18H, COMPUTED PHI IS\#F8.4, 06H STALL)
GO TO 111
WRITE(6,2110) I, PHIC
2110 FORMAT(10H FOR STAGE\#13, 18H, COMPUTED PHI IS\#F8.4, 06H CHoke)
GO TO 113
110 FORMAT(1H, 1X, FLOW\# FLOW IN\# FLOW IN)
IF (UNITS.EQ.1.0) WFLOW = WFLOW*0.453552
RDEV(I)=BET3MR(I,JS)*RAD-RK3M(I)
BAT2M(I,JS)=BAT2M(I,JS)*RAD
BET3MR(I,JS)=BET3MR(I,JS)*RAD
RDEF(I)=BAT2M(I,JS)-BET3MR(I,JS)
SOA1=SQR(GAMMA*RG*G*TS1)
SOA2=SQR(GAMMA*RG*G*TS2)
AM2=U/SOA1
AM3=SQR(U)/SOA2
AM3R=U2MR/SOA1
AM3R=U3MR/SOA2
PRATIO=PR(I)
TRATIO=TR(I)
FAI1=PHIC
FAI2=U23M(I,JS)
UZ1=U2
UTIPG(I)=U2
P(1)=PT(I)
P(2)=PT(I+1)
P(3)=P(2)
TG(1)=TR(I)
TG(2)=TT(I+1)
TG(3)=TG(2)
DELTG=TG(2)-TG(1)
DELT=0.0
RHOG(1)=RHOS1
RHOG(2)=RHOS2
UZ2=U23M(I,JS)
U1=U2
U2=SQR(U)
W1=U23R
W2=U3R
ASPED1=SOA1
ASPED2=SOA2
AMAC1=AM2
AMAC2=AM3
AMACH1=AM2R
AMACH2=AM3R
ALFA1=BET2M(I,1)*RAD
ALFA2=BET3M(I,JS)*RAD
ALFA3=0.0
IF(I.LT.NSTA) ALFA3=BET2M(I+1,1)*RAD
BETAl=BAT2MR(I,JS)
AINCIR=RINCM(I)
AINCIS=SINCM(I)
ADEUIR=RDEU(I)

WRITE(6,404) FAI0,ISTAGE
404 FORMAT(1HL,1X,ANITAL FLOW COEFFICIENT=,1X,F5.3,1X,STAGE=,12,1X,
405 FORMAT(1H0,24X,ROTOR INLET*,*ROTOR OUTLET*,*STATOR OUTLET*)

C *** WRITE THE OUTPUT
WRITE(6,401) PRATIO,TRATIO,ETAC
401 FORMAT(1H0,5X,*STAGE TOTAL PRESSURE RATIO=,*F12.5,/
402 FORMAT(1H0,5X,*STAGE TOTAL TEMPERATURE RATIO=,*F12.5,/
403 FORMAT(1H0,5X,*STAGE ADIABATIC EFFICIENCY=,*F12.5,/
404 FORMAT(1H0,5X,*STAGE FLOW COEFFICIENT=,*F5.3,/
405 FORMAT(1H0,24X,*ROTOR INLET*,*ROTOR OUTLET*,*STATOR OUTLET*)

245
TS = TT(I)*(RHOS/RHOT)**GM1
RHOS1 = RHOS
T1 = TA
PSI1 = PT(I)*(TT(I)/TS1)**(-GF2)
WCAL = RHOS1*UZ/AREA2(I)
IF((ABS(WCAL-WTFL0W)/WCAL).GT.0.05) GO TO 100
PHIC = UZ/U2
IF(PHIC.GT.PHI(I,JS,NPTS)) GO TO 120
DO 200 I=1,NSTA
DO 200 J=1,NSPE
DO 200 K=1,NPTS
PSI(I, J, K) = PSI1L(I, J, K)
IF(XWW(I).GT.O.05.AND.XWW(I).LE.O.10) PSI(I, J, K) = PSI2L(I, J, K)
IF(XWW(I).GT.O.10.AND.XWW(I).LE.O.15) PSI(I, J, K) = PSI3L(I, J, K)
IF(XWW(I).GT.O.15) PSI(I, J, K) = PSI4L(I, J, K)
200 CONTINUE
I = ISTAGE
DO 130 K=2,NPTS
IFCPHIC-PHI(I,JS,K)) 140 150, 130
130 CONTINUE
K = NPTS
140 PSI = PSI(I, J, K, XWW(I), PHIREF(I), PHIC, ETA(I, JS, K), ETAREF(I))
PR(I) = (1.0 + PSI*I3*U3/ (GJZ*CPT(TT(I)))*GF2
RAU = PSI/ETAC
TR(I) = 1.0 + (PR(I)**GF3-1.0)/ETAC
TT(I+1) = TT(I)/TR(I)
PT(I) = PT(I)/PR(I)
TRO(I) = TT(I+1)/TR(I)
PRO(I) = PT(I+1)/FO
GF3S = GF3
GF30 = (GF3 + GF3S)/2.0
ETAC(I) = (PR(I)**GF3 - 1.0)/TO
UT2M = UZ * TAN(BET2M(I, JS))
UT3M = (CP9(TT(I+1)-TT(I))**GJ + U2M2 *UT2M)/UM3
U2MR = UZ*COS(ETAC(I, JS))
RMH = PT(I+1)/(TT(I+1)-RG)
TS = TT(I+1)
RHO = RHOH
RHOH = 1.0 - (1.0-XWT(I))/RHOH+XT(I)/RHOH
161 U3M = (CP*(TT(I+1)-TT(I))**GJ + UMM2 * UTM2)/UM3
US = U3M(I, JS)**2 + U3M2**2
CP = CF9M(TS)
RHOS = RHOH*(1.0-US*(GJ+CP*TT(I+1)))*GF1
RHOH = 1.0 - (1.0-XWT(I))/RHOH+XT(I)/RHOH
IF((US).GT.(RMH**GF3 - 1.0)) GO TO 113
TS = TT(I+1) * (RHOH*RHOH)**GM1
RHOH = RHOH
TS2 = TS
PS = PT(I+1)*(TT(I+1)/TS2)**(-GF2)
WCAL = RHOS**AREA3(I)*UZ3M(I, JS)
IF((ABS(WCAL-WTFL0W)/WCAL).GT.0.005) GO TO 161
BET3M(I, JS) = ATAN2(U3M, U3M2(I, JS))
SINCM(I) = BET3M(I, JS)*RAD - SKEM(I)
UT3MR = UMM3 - UT3M
BET3MR(I, JS) = ATAN2(U3MR, U3M2(I, JS))
US3MR = U3M2(I, JS)*COS(BET3MR(I, JS))
RDFM(I) = 1.0 - U3MR/U3MR + (RM3(I)*UT3M - RM2(I)*UT2M)/(RM3(I) + XRM2(I))*RDOLM(I)/U2MR
WRITE(6,406) P(1), P(2), P(3)

406 FORMAT (1H, 1X, "TOTAL PRESSURE", 10X, 3(F10.4, 5X))
WRITE(6,407) T(1), T(2), T(3)

407 FORMAT (1H, 1X, "STATIC PRESSURE", 5X, 2(F10.4, 5X))
WRITE(6,408) TSI, TS2

408 FORMAT (1H, 1X, "TOTAL TEMPERATURE (GAS)", 3X, 3(F10.4, 5X))
WRITE(6,409) TG(1), TG(2), TG(3)

409 FORMAT (1H, 1X, "STATIC TEMPERATURE (GAS)", 1X, 2(F10.4, 5X))
WRITE(6,410) RHOG(1), RHOG(2)

410 FORMAT (1H, 1X, "STATIC DENSITY (GAS)", 5X, 2(F10.4, 5X))
WRITE(6,412) U2, U2

412 FORMAT (1H, 1X, "AXIAL VELOCITY", 10X, 2(F10.4, 5X))
WRITE(6,413) V1, V2

413 FORMAT (1H, 1X, "ABSOLUTE VELOCITY", 7X, 2(F10.4, 5X))
WRITE(6,414) W1, W2

414 FORMAT (1H, 1X, "RELATIVE VELOCITY", 7X, 2(F10.4, 5X))
WRITE(6,415) UI, U2

415 FORMAT (1H, 1X, "RELATIVE VELOCITY", 7X, 2(F10.4, 5X))
WRITE(6,416) U1, U2

416 FORMAT (1H, 1X, "RELATIVE VELOCITY", 7X, 2(F10.4, 5X))
WRITE(6,417) U1, U2

417 FORMAT (1H, 1X, "RELATIVE VELOCITY", 7X, 2(F10.4, 5X))
WRITE(6,418) ASPE1, ASPE2

418 FORMAT (1H, 1X, "ACOUSTIC VELOCITY", 10X, 2(F10.4, 5X))
WRITE(6,419) AMAC1, AMAC2

419 FORMAT (1H, 1X, "ABSOLUTE MACH NUMBER", 4X, 2(F10.4, 5X))
WRITE(6,420) AMAC1, AMAC2

420 FORMAT (1H, 1X, "ABSOLUTE MACH NUMBER", 4X, 2(F10.4, 5X))
WRITE(6,421) FAI1, FAI2

421 FORMAT (1H, 1X, "FLOW COEFFICIENT", 5X, 2(F10.4, 5X))
WRITE(6,422) AAA1, AAA2

422 FORMAT (1H, 1X, "FLOW AREA", 15X, 2(F10.4, 5X))
WRITE(6,423) ALFA1, ALFA2, ALFA3

423 FORMAT (1H, 1X, "ABSOLUTE FLOW ANGLE", 5X, 3(F10.4, 5X))
WRITE(6,424) BETAI, BETA2

424 FORMAT (1H, 1X, "RELATIVE FLOW ANGLE", 5X, 3(F10.4, 5X))
WRITE(6,425) AINCIR1, AINCIR2

425 FORMAT (1H, 1X, "INCIDENCE", 16X, 2(F10.4, 5X))
WRITE(6,426) ADEVIR

426 FORMAT (1H, 1X, "DEVIATION", 30X, 1(F10.4, 5X))
IF (UNITS.EQ.1.0) HTFLOW = HTFLOW/0.453592
GO TO 111
110 WRITE(6,2100) I, PHIC
2100 FORMAT (1H, 1X, "FOR STAGE", 13X, 18H, "COMPUTED PHI IS", F8.4, 6SH STALL)
GO TO 111
120 WRITE(6,2110) I, PHIC
2110 FORMAT (1H, 1X, "FOR STAGE", 13X, 18H, "COMPUTED PHI IS", F8.4, AH CHNKF)
GO TO 113
111 FLOWIN = FLOWIN + DFLOW
IF (FLOWIN.LE.FLOWF) GO TO 81
113 CONTINUE
DO 112 L = 1, NSTFA
DO 112 J = 1, NSPE
112 DPSIS(I,J) = 0.0
RETURN
END
WISGSK - A COMPUTER CODE FOR THE PREDICTION OF A MULTISTAGE AXIAL COMPRESSOR PERFORMANCE WITH WATER INGESTION

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Final report. Project Manager, Ronald J. Steinke, Fluid Mechanics and Acoustics Division, NASA Lewis Research Center, Cleveland, Ohio 44135.

A computer code is presented for the prediction of off-design axial flow compressor performance with water ingestion. Four processes have been considered to account for the aero-thermo-mechanical interactions during operation with air-water droplet mixture flow: (i) blade performance change, (ii) centrifuging of water droplets, (iii) heat and mass transfer process between the gaseous and the liquid phases and (iv) droplet size redistribution due to break-up. Stage and compressor performance are obtained by a stage stacking procedure using representative velocity diagrams at a rotor inlet and outlet mean radii. The Code has options for performance estimation with (a) mixtures of gas and (b) gas-water droplet mixtures, and therefore can take into account the humidity present in ambient conditions. A test case illustrates the method of using the Code. The Code follows closely the methodology and architecture of the NASA-STGSTK Code for the estimation of axial-flow compressor performance with air flow.

Compressor off-design
Axial-flow compressor
Multistage compressor
Two phase flow

Water ingestion
Water droplets
Stage stacking

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