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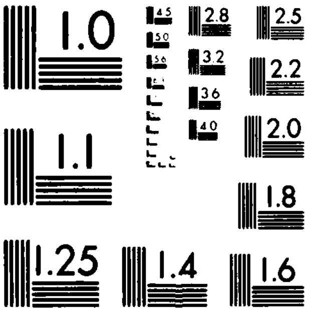

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EFFECT OF WATER ON AXIAL FLOW COMPRESSORS

PART I ANALYSIS AND PREDICTIONS

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June 81

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Final Report for Period 15 December 1977 - 30 September 1980

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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The subject of air-water mixture flow in axial compressors of jet engines is of practical interest in two contexts of water ingestion: during take-off from rough runways with puddles of water and during flight through rain storms. The change in the compressor performance in turn produces changes in the performance of other components and of the engine as a whole. During the current investigation, (i) an analysis of the effects of water ingestion into a compressor has been carried out leading to the development of a predictive code, the PURDU-WICSTK program and (ii) a series of tests have been carried

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out on a small test compressor with mixtures of gases (containing methane gas to simulate steam) and with air-water droplet mixtures. The experimental results have been compared with predictions. It is concluded that the basic effects of water ingestion into compressors arise through (2) blockage, (b) distortion and (c) heat and mass transfer processes, the changes in blade aerodynamic performance being relatively small. In the case of a compressor of small mass flow and pressure ratio and high operating speed, increased quantities of water ingestion give rise to large quantities of water in the tip region. When the pressure ratio and air mass flow are large and the operating speed is correspondingly small, there arises a possibility of water evaporation, especially towards the hub, which gives rise to changes in gas phase mass flow and temperature. The changes in compressor performance are large at high speeds and high flow rates; there also arises a change in the surge characteristics. In light of the nature of changes produced by water ingestion, a preliminary analysis has been carried out on the possible changes in engine performance.

FOREWARD

This final report presents the results of research undertaken at Purdue University under Air Force Contract No. F33615-78-C-2401. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Project 3066, Task 306604 and Work Unit 30660454, with Mr. Larry E. Crawford, AFAPL/TBC, as Project Engineer.

Two earlier publications of direct relevance to the project are as follows:

i) "Water Ingestion into Axial Flow Compressor", Report No. AFAPL-TR-76-77, August, 1976; and

ii) "Analysis of Water Ingestion Effects in Axial Flow Compressors", Report No. AFAPL-TR-78-35, June, 1978.

The research reported in the current report pertains to a further development of a prediction code for the performance of an axial compressor with water ingestion, experimental studies on a small engine-driven axial compressor with water ingestion and an analysis of the results.

The final report consists of three parts, Part I entitled Analysis and Predictions, Part II entitled Computational Program and Part III entitled Experimental Results and Discussion. Each part is presented in a separate volume.

Dr. Bruce A. Reese, currently Chief Scientist at the Arnold Engineering Development Center, Arnold Air Force Base, who was Professor and Head, School of Aeronautics and Astronautics, Purdue University, up to June 30, 1979, participated in the conduct of research from January, 1978 until June 30, 1979.

The Drive Engine and the Test Compressor provided by the Air Force for the experimental studies under this project were manufactured by the Detroit Diesel Allison of Indianapolis. They refurbished the units during this program under a subcontract. In that work and in a variety of ways the DDA and several of their personnel have been most helpful and have given their time and advice generously to the investigators.

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NOMENCLATURE

A	compressor flow area
A_p	droplet project area
a	acoustic speed
C_D	drag coefficient
C_{D_f}	drag coefficient corresponding to loss due to water film formed on blade surface
C_{D_r}	drag coefficient corresponding to loss due to rough film surface of water on blade surface
C_w	water vapor concentration
C_{wb}	water vapor concentration at droplet surface
c	blade chord length
c_p	specific heat at constant pressure
c_w	specific heat of water
c_s	humid heat for air-water mixture
D	droplet diameter
D_d	droplet diameter

D_v	diffusivity
D_{eq}	equivalent diffusion ratio
$D_{eq}{}^*$	equivalent diffusion ratio at minimum loss point
d_{max}	largest stable droplet diameter
g_c	Newton constant relating force and mass
h_h	heat transfer coefficient
h_m	mass transfer coefficient
i	incidence angle
i^*	incidence angle at minimum loss point
J	constant relating heat and work
K_a	thermal conductivity of air
K_d	thermal conductivity of gaseous film surrounding an evaporating droplet
K_v	thermal conductivity of water vapor
k	thermal conductivity
k_g	thermal conductivity of gaseous phase
M	absolute Mach number
M_a	assumed value of Mach number

M_r	relative Mach number
M_c	calculated value of Mach number
$\dot{m}$	mass flow rate
$\dot{m}_{film}$	mass flow rate of water film formed on blade surface
mw	molecular weight
N	rotor rotational speed
N_d	number of droplet
Nu	Nusselt number
P_{01}	total pressure at rotor inlet
P_{02}	total pressure at rotor outlet
P_{03}	total pressure at stator outlet
$P_{01,r}$	relative total pressure at rotor inlet
$P_{02,r}$	relative total pressure at rotor outlet
$P_{02,ri}$	ideal relative total pressure at rotor outlet
PR	pressure ratio
Pr	Prandtl number
p_{ref}	reference pressure
p_1	static pressure at rotor inlet
p_2	static pressure at rotor outlet

p_3	static pressure at stator outlet
R	gas constant
Re	Reynolds number
r	rudius
s	pitch
Sc	Schmidt number
Sh	Sherwood number
SN	stability number
T	static temperature
T_o	total temperature
T_{ref}	reference temperature
$T_{o1,r}$	relative total temperature at rotor inlet
$T_{02,r}$	relative total temperature at rotor outlet
TR	temperature ratio
U_{tip}	blade tip speed
U	blade speed
V_z	axial velocity

V	absolute velocity
V_θ	tangential component of absolute velocity
V_{film}	velocity of film formed on blade surface
W	relative velocity
W_θ	tangential component of relative velocity
We	Weber number
x_g	mass fraction of gas phase
x_w	mass fraction of liquid phase

Greek Letters

α	absolute flow angle
β	relative flow angle
γ	specific heat ratio
η	adiabatic efficiency
ΔH_v	latent heat of vaporization
ΔH_0	rise in total enthalpy
$(\Delta H_0)_1$	work input to gaseous phase
$(\Delta H_0)_2$	work input absorbed by water droplets which do not impinge upon blade surface

$(\Delta H_0)_3$	work input absorbed by water droplets which impinge upon blade surface, adhere to form a film and are re-entrained from the trailing edge
$(\Delta H_0)_4$	work input absorbed by droplets which impinge upon blade surface and rebound
ΔT_0	rise in total temperature
ΔT_g	rise in overall temperature of gaseous phase
$(\Delta T_g)_{ht}$	drop in temperature of gaseous phase due to heat transfer
$(\Delta T_g)_{wk}$	rise in temperature of gaseous phase due to work done
ΔT_w	rise in overall temperature of droplet
$(\Delta T_w)_{ht}$	rise in temperature of droplet due to heat transfer
$(\Delta T_w)_{wk}$	rise in temperature of droplet due to work done
δ	deviation angle
δ	boundary layer displacement thickness
δ	corrected pressure ($\delta=p/p_{ref}$)
θ	boundary layer momentum thickness
θ	corrected temperature ($\theta=T/T_{ref}$)
μ	viscosity
ρ	density

σ	surface tension of droplet
σ	solidity
σ_V	particulate liquid volume fraction
τ	equivalent temperature ratio
ϕ	flow coefficient
ψ	equivalent pressure ratio
ω	rotor angular velocity
$\bar{\omega}$	total pressure loss coefficient
$\bar{\omega}_{g,R}$	total pressure loss coefficient across rotor due to gas phase
$\bar{\omega}_{g,S}$	total pressure loss coefficient across stator due to gas phase
$\bar{\omega}_{\theta,R}$	total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer over a rotor blade surface
$\bar{\omega}_{\theta,S}$	total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer over a stator blade surface
$\bar{\omega}_{f,R}$	total pressure loss coefficient due to the momentum gained by thick water film moving over a rotor blade surface
$\bar{\omega}_{f,S}$	total pressure loss coefficient due to the momentum gained by thick water film moving over a stator blade surface
$\bar{\omega}_{r,R}$	total pressure loss coefficient due to turbulent flow of mixture over the rough film surface of rotor blade

$\bar{\omega}_{r,S}$	total pressure loss coefficient due to turbulent flow of mixture over the rough film surface of stator blade
$\bar{\omega}_{s,R}$	total pressure loss coefficient due to the Stokesian drag of droplets in rotor passage
$\bar{\omega}_{s,S}$	total pressure loss coefficient due to the Stokesian drag of droplets in stator passage

Subscript

a	pertaining to assumed value
c	pertaining to calculated value
D	pertaining to design point
g	pertaining to gas phase
i	pertaining to ideal process
l	pertaining to liquid phase
m	pertaining to mixture
r	pertaining to relative value with respect to rotor
ref	pertaining to reference value
R	pertaining to rotor
S	pertaining to stator

w	pertaining to water droplet
0	pertaining to stagnation value
1	pertaining to rotor inlet
2	pertaining to rotor outlet
3	pertaining to stator outlet

Superscript

*	pertaining to minimum loss point
-	pertaining to average value

SUMMARY

The PURDU-WICSTK program developed for predicting the performance of an axial flow compressor operating with mixtures of gases and water droplets has been described in detail. The utilization of the program has been illustrated with a test case.

CHAPTER I

INTRODUCTION

Water ingestion into an aircraft gas turbine arises due to two circumstantial reasons:

(1) wheel-generated spray clouds entering the engine inlet during take-off and landing from a rough runway with puddles of water; and

(2) rain, occasionally mixed with hail, entering the engine inlet during various parts of a flight in a rain storm.

A number of studies (Refs. 1-6) have shown that adverse effects can arise in engine performance due to such ingestion of water at engine inlet, when the engine has been designed for operation with air flow. In particular the engine may surge and may suffer blow-out or unsteadiness in the main burner or the after-burner. Simple corrective steps, such as resetting the throttle, have generally been ineffective in overcoming the problems of loss of power and nonsteady behaviour of the engine. In the case of wheel-spray ingestion, it has again become clear that basic changes in engine installation may be necessary in relation to inlets and landing wheels.

In the current investigation, there is no particular emphasis on the precise cause for the presence of water at the engine inlet. Water is assumed to enter the compressor along with air in droplet form. The droplet (nominal) diameters may be in the range of 20 to 1,300 microns. The water content by weight may be in the range of 2.5 to 15.0 per cent. In case of rain through which an aircraft may have to fly (Refs. 7-9) the droplet sizes may be of the order of 100 to 1,500 microns, although 3,000 micron size droplets have also been reported (Fig. 1.1). On the other hand, 15.0 per cent of water by weight is probably to be considered as a large amount of ingestion into the inlet, corresponding to flight through storm conditions. Under such extreme conditions there may also be hail and snow ingestion into the engine. However, only water ingestion effects are examined here.

A comprehensive investigation of the problem of water ingestion into engines during flight should take into account details of the engine, its installation and the engine and aircraft controls. In the current investigation attention is focussed on the engine and its control.

Furthermore, it is felt that the response of the compressor in the engine to water ingestion plays a determining and crucial role in the response of the engine as a whole in view of two considerations.

(1) The compressor receives the ingested water directly and, as a rotating machine, is most strongly affected by the ingested water, and also changes the "state of water" before the fluid enters the burner.

(2) The compressor performance most directly affects the operating point of the engine under steady and transient state conditions.*

However, the compressor performance is affected by the presence of an inlet through the changes in the flow field introduced by it, especially the distortion of the compressor inlet flow field. While noting such strong interaction between the inlet and the compressor flow fields, the

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* It may be pointed out that the operating point of an engine is determined by the matching between all of the components of the engine. Thus, the swallowing capacity of the turbine and nozzle, for example in a simple jet engine, at a given engine speed and turbine entry temperature, determine the engine operating point on the compressor map. However, any changes in the compressor outlet conditions affect the engine operating point most directly with a given turbine and nozzle. In particular, during water ingestion, the compressor map becomes completely changed, causing at least a change in the surge margin for a possible operating point and, in extreme cases, a total mismatch between the components. Even with a turbine and nozzle that have variable-area capability, it may become necessary to regulate the compressor outlet conditions independently.

most important aspect of the problem of water ingestion into an engine is still considered to be that pertaining to changes in the compressor performance itself.

In the case of turbofan engines, the air-water mixture upon entering the inlet becomes divided between the fan and the compressor. In particular cases, the compressor stream may have a different water content and droplet size distribution from that of the compressor stream in the absence of a fan. The effects of water ingestion are important both in the fan and the core engine compressor, although, perhaps, more so in the latter. When there is an after-burner in the fan stream or when a "mixing" Nozzle is employed, water ingestion into the fan stream may, however, become critically important.

From practical operational and design points of view, the effects of water ingestion in a compressor are as follows:

(1) changes in temperature ratio, pressure ratio and efficiency of the compressor;
(2) changes in surge line and operating line, and therefore the surge margin under given operating conditions;
(3) blade deformation and erosion due to impact of droplets;
(4) blade and casing deformation due to differential thermal expansion under transient conditions;
(5) oscillation of pressure ratio and flow; and
(6) changes in dynamic loading including aero-elastic effects.

For given entry conditions, the response of the compressor is determined by the following:

(1) compressor geometry;
(2) blade loading;
(3) machine rotational speed; and
(4) parameters of the engine of which the compressor is a part.

The latter pertain to engine matching and should include not only the steady state performance parameters but also the mechanical, aerodynamic and thermal inertia of the various components of the engine under transient conditions. It should be noted that in particular cases, the engine components may include a fan, an after-burner or a second nozzle as part of the engine.

In establishing the response of a compressor to water ingestion, it seems therefore useful to divide the total problem into two parts.

(1) The compressor as a machine itself; and
(2) The compressor as a part of the engine system.

In that fashion, one can separate the problems associated with engine matching (steady or transient) from those dependent upon the design of the compressor itself. Once the latter have been understood in detail, the engine as a whole may be studied from a system point of view. This is the approach adopted in the current investigation, since it is also especially convenient in conducting experimental studies.

A number of parameters pertaining to the air-water mixture entering a compressor during water ingestion are the following:

(1) amount of water approaching and actually entering a blade row as a fraction of the total mass flow of fluid entering compressor;
(2) form in which water is present, film and droplets;
(3) temperature and pressure of air, temperature of water and temperature of machine;
(4) vapor content;
(5) turbulence; and
(6) distortion, radial and circumferential.

Water vapor is always present in air-water mixtures ingested into an engine. The water vapor content changes in the compressor because of changes in pressure and temperature and because of transfer processes between the two phases. In particular, in a multi-stage compressor of large pressure ratio, there is a possibility of some of the water reaching local saturation temperature and undergoing a phase change due to boiling causing addition of large quantities of vapor to the gas phase.

It will be observed that each of the afore-mentioned six parameters changes after each blade row and the cumulative changes are therefore especially significant in a multi-stage machine. Furthermore, both time-dependent changes during sudden and sporadic ingestion, as well as steady state changes, as, for example, may arise in a laboratory experiment, need consideration. Thus, a detailed study of this problem should result in the determination and verification of methods for establishing (a) the changes in the performance of a compressor with water ingestion and (b) the changes in the state of fluid between the inlet and the outlet of the compressor. Such a study requires investigations both on a single row of blades (stationary and rotating) as well as on a unit with several rows of blades, under steady, transient, and distorted flow conditions. The latter is a means of establishing the response of a blade row to the flow generated by a preceding row. Furthermore, in order to examine the occurrence and effects of phase change in a blade row, the entry conditions to the blade row have to be selected such that they are suitable for such phase change. In a multi-stage compressor of large pressure ratio, there is, of course, a considerable change in air temperature at design conditions.

However, at this stage there are still considerable problems in conducting detailed measurements of two-phase flows in rotating machinery. It has therefore been felt in this investigation that one should aim at establishing overall performance changes and fluid flow changes in a compressor for given entry conditions of state of the two-phase fluid. Once such overall changes are established and related to verifiable models for performance prediction, it is felt one can proceed to more detailed measurements and modeling.

For a given compressor, the variables of interest during water ingestion are the following:

(1) speed of the machine;
(2) throttle setting;
(3) stagnation pressure
(4) temperature of air and water;

(5) amount of water as a fraction of total mixture flow;
(6) droplet size and number density distribution, and
(7) vapor content.

The variables (3) to (7) have a spanwise and circumferential distribution at compressor inlet, which may or may not be uniform.

The overall performance parameters of a compressor with two-phase flow are the following:

(1) pressure ratio temperature ratio and efficiency;
(2) changes in total water content and droplet size across the compressor; and
(3) changes in vapor content across the compressor.

Each of these varies along the span of a compressor blade. Both the measurements and prediction of these is beset with considerable difficulties at this time. In particular the determination of water and vapor content and of droplet size distribution requires further advances in instrumentation, data acquisition and data processing.

On establishing and demonstrating predictive methods for the estimation of such overall performance parameters for a compressor, an analysis can be carried out for an engine operating with water ingestion. Under steady conditions, the equilibrium running of a simple engine depends upon the following parameters:

(1) engine speed;
(2) mass flow;
(3) compressor performance with air-water mixture;
(4) ratio of turbine entry temperature to inlet temperature;
(5) turbine operational point (choked or unchoked); and
(6) thrust nozzle geometry.

Regarding the latter, a fixed geometry thrust nozzle with a constant area turbine restricts the number of variables for equilibrium running of a simple engine to a single parameter, namely engine speed or mass flow. In a variable geometry engine which permits changes in area of the turbine and the thrust nozzle, one can select, at least in principle, three variables independently for equilibrium running; engine speed, mass flow and turbine entry temperature.

An analysis of steady state equilibrium running of an engine with water ingestion can be expected to reveal the following:

(1) whether equilibrium running is feasible under a given set of operating conditions,
(2) changes in surge margine, and
(3) effect of fuel scheduling and bleed of working fluid.

The latter, along with other aspects of engine operation, is dependent upon the type of engine control incorporated in the system.

Even when attention is focussed on the performance of a compressor by itself, several aspects of the performance may come to light only when it is operated as a part of an engine. However, if engine matching and its effect on compressor performance are not included, one can test a compressor as a separate unit by driving it, for example, with an aerodynamically-independent drive engine. This has been the basis for experimental studies in the current investigation.

1.1 Objectives and Scope of the Investigation

The principal objectives of the present investigation are as follows:

(1) Establishment and demonstration of a predictive method for the calculation of the performance of an isolated compressor driven by an external drive unit and operating with air-water mixture flow; and
(2) Obtaining and correlating experimental data on a multistage compressor with air-water mixture flow.

In both of the above, the vapor content of the mixture is taken into account, both initial humidity and changes in vapor content due to phase change of water droplets.

The other objectives of the present investigation are as follows:

(1) Determination of the manner in which engine performance becomes affected by water droplet ingestion into the engine compressors; and

(2) Providing a review of instrumentation suitable in compressor.

1.1.1 Analytical-Predictive Investigations

The analytical-predictive investigations are divided into two parts; (1) investigation on the performance of a compressor with water ingestion, and (2) analysis of a simple gas turbine engine with water ingestion.

Part I: Performance of Compressor with Water Ingestion

The analytical-predictive investigations on performance of compressor with water ingestion are divided into three parts:

(1) Setting up the general aero-thermodynamic equations for compressor with air-water mixture flow and deduction of a one-dimensional model.

(2) Establishing one-dimensional models for the estimation of performance of a compressor in four limiting cases as follows:

  (i) Ingestion of mixtures of gases directly into a compressor at inlet, without water droplets.

  (ii) Ingestion of small droplets that can be assumed to follow gas motion and hence absorb angular momentum.

  (iii) Ingestion of large droplets that can be assumed to move with equal probability in all directions and that cause a loss of compressor performance due to drag forces acting on them; and

  (iv) Injection of water with sudden phase change into steam at an appropriate stage in the compressor.

(3) Adapting and exercising a three-dimensional streamline computer code, the UD-0300 computer code (Ref.10), for the case of direct ingestion of mixtures of gases into a compressor.

Part II: Analysis of Gas Turbine Engine with Water Ingestion

The objectives of Part II are as follows:

(1) Establishing a model for steady state engine matching with water ingestion; and

(2) Establishing a model for calculation of flight performance with water ingestion.

1.1.2. Experimental Investigation

The experimental investigations have been conducted on a specially built Test Compressor. The experimental investigations may be divided into the following three parts:

(1) Tests with air as the working fluid;

(2) Tests with air-methane mixture as the working fluid; and

(3) Tests with air-water droplet mixture as the working fluid.

The Air Force System Command has provided the Test Compressor and a T-63 Drive Engine for the experimental investigations. The predictive methods developed for estimating compressor performance with two phase flow have also been employed to calculate the performance of the Test Compressor.

Details regarding the Test Compressor and Drive Engine are provided in Appendix 1 to this Report.

The Test Compressor, it will be observed, has several limitations:

(1) the annulus and the blade heights are small and only overall performance parameters at one or at most two radial locations at the exit plane can be measured.

(2) the overall pressure and temperature ratios, even at design point, are too small to cause evaporation of more than 2.5 per cent of water (by weight) although the inlet temperature is raised to as high a value as $185^{\circ}F$ ($85^{\circ}C$).

(3) the compressor assembly permits little flexibility in locating instrumentation, especially at the compressor exit.

Since the Test Compressor casing has a plastic coating that does not withstand high temperatures, the Test Compressor has been tested at low inlet temperatures in the range of 70°F to 100°F (about 20°C to 40°C). Such inlet temperatures do not cause water evaporation within the Test Compressor. The test program has therefore been conducted in two parts:

(1) With a mixture of gases to simulate air-steam mixture flow corresponding to (a) high humidity in the air and (b) operation of different stages with air-steam mixture following complete evaporation of water, and

(2) With air-water droplet mixture flow.

In examining the effects of presence of water vapor on a compressor performance, it is clear that another gas, such as methane, can be substituted for water vapor so long as the desired similarity laws with respect to Reynolds and Mach numbers, are satisfied. A comparison of properties for steam and methane is presented in Table 1.1. In view of the similar properties, experimental studies have been undertaken in this investigation utilizing air-methane mixtures.

The tests with air-water droplet mixtures have been conducted utilizing the following variables: mixture temperature, mixture composition and droplet size.

1.1.3 Measurements and Predictions

The results of the experimental investigation have been compared with prediction from models from the point of view of examining selected assumptions introduced in the models. It is clear that in view of limitations on the feasibility of measurements and the nature of assumptions introduced in modeling, comparison of analytical predictions with experimental results is restricted to certain overall performance parameters, in particular, the effects of mechanical-aero-thermodynamic interactions are established indirectly from overall compressor performance parameters and changes in water and vapor content.

TABLE 1.1

COMPARISON OF PROPERTIES FOR STEAM AND METHANE

	Steam	Methane
Chemical Formula	H_2O	CH_4
Molecular Weight	18.016	16.043
Specific Heat at Constant Pressure		
(Btu/lbm-°F)	0.445**	0.531*
(kJ/kg-°C)	1.863**	2.223*
Ratio of Specific Heats*	1.329**	1.304*
Enthalpy Increase		
(Btu/lbm)	62.70$^+$	69.96$^+$
(kJ/kg)	145.84$^+$	162.73$^+$

*pressure = 1 atm; temperature = 78°F(26°C)

**pressure = 1 atm; temperature = 212°F (100°C)

$^+$ pressure ratio, $P_{02}/P_{01} = 2.6$; $T_{01} = 68°F$ (20°C)

1.1.4 Measurement Techniques

A brief review of instrumentation suitable for use in axial flow compressors and cascades operating with two phase fluid flow has been undertaken.

Two important overall performance parameters in compressors are the stagnation pressure ratio and the stagnation temperature ratio. A probe for the measurement of stagnation pressure in two phase flow has been developed. Its possible use in a compressor flow field has been examined. The development of a similar probe for the measurement of stagnation temperatures has been considered.

1.1.5 Engine Performance

The engines considered are those that have been designed for air flow through the inlet. Engines in which there may be injection of water at gas flow part locations beyond the compressor or in other stream such as fan ducts or after-burners are not under consideration. Specifically water ingestion effects have been examined in the case of simple turbo-jet and turbo-fan engines that have originally been designed for air flow operation only. Thus (a) the adverse flow effects due to water ingestion and (b) possible methods of mitigating such effects are of interest.

The response of an engine to water ingestion depends upon the following:

(a) component geometrical constraints;
(b) component performance characteristics; and
(c) nature of control incorporated into the engine.

The performance characteristics that are of major interest are the following:

(a) Changes in component performance characteristics due to water injection, in particular the compressor;
(b) Changes in operating characteristics of engine under conditions of equilibrium running;

(c) Changes in surge margin; and
(d) Limiting conditions of operation.

The foregoing have been analyzed in order to establish general performance trends without reference to specific engine configurations.

It may be noted that, because of the aero-thermo-mechanical processes arising on account of water ingestion, one may also expect, at least in extreme cases, aero-elastic processes becoming significant. However, the manner in which flutter, for example may be altered during two phase flow in compressors is not included for study in the current investigation.

1.2 Effects of Water Ingestion

The two critical factors during water ingestion may be said to be the following: (a) the aero-thermo-mechanical processes associated with two phase flow and (b) the centrifugal action on droplets in the compressor. The first of these includes droplet disintegration and evaporation processes. The latter gives rise to a change in gas phase mass flow as well as reduction in gas phase temperature. The centrifugal action introduces a radial distortion in the flow and fluid properties, and the distortion changes in every stage of a multistage compressor. In particular, the spanwise distribution of the composition and properties of the fluid, in terms of air, water vapor and water droplets (both content and size distribution), undergoes changes continuously along the compressor flow path. The effects (a) and (b) should be examined in a compressor in relation to the following:

(i) Formation of a water film in the tip region, that may flow into the diffuser;
(ii) Possibility of choking hub sections and stalling tip sections with redistributed gas and liquid phase mass flow; and
(iii) Nonuniform distribution of water vapor in the radial direction.

The foregoing will in turn affect engine performance depending upon engine-matching and the type of control in the engine.

In order to reduce the effects of water ingestion, one can consider the following in order of increasing complexity.

(i) Bleeding of gas or liquid phase flow at appropriate locations in the compressor;

(ii) Resetting stator blades;

(iii) Modifying engine control; and

(iv) Introduction of variable geometry nozzle and also turbine.

The results of some preliminary studies on bleeding and also gas injection have been reported in Ref. 11.

1.2.1. Relation to Other Two-Phase Flow Problems in Turbo-Machinery

The current investigation deals with air-water droplet mixture ingestion into engines. On the other hand there has also been considerable interest in the problem of dust particle ingestion into engines (Refs. 12-13). In the latter case the principal interest is in erosion of blades and nozzles, although there is some loss in aerodynamic performance.

It is generally considered that the solid particulates may agglomerate but not disintegrate during dust ingestion. Furthermore the heat and mass transfer processes between the two phases are considered negligible.

Solid particulates are also of interest in certain rocket motor nozzle and plume flows (Refs. 14-16). In this case, in addition to erosion and particulate drag effects it is generally necessary to take into account heat and mass transfer processes, as well as condensation, solidification and other phase change processes. However, in this case there is not strong centrifugal action, although there may be some swirl in the flow.

The low pressure stages of a steam turbine (Refs. 17-19) may operate, as is well known, with steam-water droplet mixture, the droplets arising through condensation. However, in this case, while erosion, loss of aerodynamic performance, and consequences of strong centrifugal action are important, one does not have the problems of stalling and surging. A compressor is prone to surging and the surge margin with respect to operating line when it is part of an engine is an extremely important parameter in engine operation. Hence the problem of water ingestion into an engine compressor attains a leval of complexity and significance much larger than the two phase flow problem in steam turbines. One should also note that a turbine is basically a nozzle, while a compressor flow (both past a blade and through a blade passage) involves diffusion and complicated blade wake interactions.

The current investigation does not take into account geometrical changes in a compressor because of, say, differential contraction of rotor and casing upon water ingestion. In general one can expect a change in clearance between rotor and stator. If a compressor has been designed with optimum clearance, one has to examine both aerodynamic and mechanical effects caused by changes in clearance. This aspect of water ingestion should be examined in relation to the general problems of gas flow path integrity (Ref. 20).

While nonsteady state operation is not considered in the current investigation, one of the most important aspects of water ingestion into compressors and engines is transient state operation. The aero-thermo-mechanical interactions including differential contraction of casing and rotor under transient conditions are significant in evolving various means of reducing the effects of water ingestion.

Finally, it is recognized that the entry conditions into a compressor are not uniform radially and circumferentially. The effects of distortion with respect to pressure, temperature, velocity and turbulence continue to be a subject of concern even with air flowing alone (Ref. 21). During water ingestion, one can expect, in general, distortion both at entry and to the compressor and at entry to each stage. The sensitivity of an engine to water ingestion should include consideration of inlet distortion with regard to water content and water droplet size distribution. This problem has been entirely neglected in the current investigation. It may be pointed out that even under uniform inlet flow conditions, radial distortion, of course, arises within the compressor due to centrifuging and heat and mass transfer processes.

1.3 Implications of Models

The models derived in the current investigation may be divided into four groups:

(i) Model for the calculation of stage performance with air flow.
(ii) Model for droplet motion across a blade row.
(iii) Model for centrifuging of water, and
(iv) Model for heat and mass transfer processes, including droplet disintegration.

Experimental investigations have been conducted in order to determine overall compressor performance changes for given initial and operating conditions. A comparison between predictions and measurements therefore yields no detailed verification of the models. It is in any case doubtful if detailed verification of all aspects of the models can be obtained even if one attempted additional measurements.

The performance of a compressor stage with two phase flow depends upon the following parameters:

(i) geometrical design of blade and blade passage,
(ii) spacing between blade rows,
(iii) leading and trailing edge geometry,
(iv) casing geometry,
(v) rotor and stator blade junctions,
(vi) incoming flow conditions, and
(vii) operating speed and throttle setting

The foregoing determine (a) the stage work input, (b) the states of gas and liquid phases, (c) the efficiency of compressor, (d) the redistribution of water and vapor and (e) limiting condition of steady state operation of compressor. When the compressor is part of an engine, the operating characteristics of all other components of the engine and of the engine as a whole are also determined by the compressor design and initial conditions. It is clear that while the models developed can be employed to determine the performance of any compressor under a set of reasonable operating conditions, there is need to establish relations that can be employed to scale the performance of a compressor with respect to design, initial and operating conditions. Such scaling laws have to be based on characteristic lengths, characteristic times, and blade, blade passage and blade row characteristics of the compressor and, when the compressor is part of an engine, the characteristics of other components such as diffuser, burner, turbine and nozzle. Under certain assumptions an attempt has been made to establish scaling laws for both a compressor and a simple jet engine.

1.4 Organization of Report

The final report is being issued in three parts:

Part I: Analysis and Predictions
Part II: Computational Programs; and
Part III: Experimental Results and Discussion

This report constitutes Part II of the Final Report. Chapter I is the introduction. Chapter II is devoted to a discussion of overall program structure, and Chapter III presents a detailed description of the subroutines and external functions. The description of input data is given in Chapter IV while a description of the output is presented in Chapter V. Finally, a test case is discussed in Chapter VI.

CHAPTER II

OVERALL PROGRAM DESCRIPTION

The numerical-computational work undertaken in the current investigation may be divided into two parts as follows.

(1) Modification of UD-0300 computer program for use with mixtures of gases; and

(2) Development and use of PURDU-WICSTK program for the calculation of performance of axial compressors operating with air-water droplet mixture, based on one-dimensional flow analysis.

The modification of UD-0300 program for use with mixtures of gases is described in detail in Ref. 22. Typical performance results for the Test Compressor employed in this investigation, based on the UD-0300 program, are also presented in Ref. 22.

The PURDU-WICSTK program is described in the following.

2.1 Description of PURDU-WICSTK Program

The one-dimensional flow equations for two phase flow in axial compressors have been derived in detail and presented in Ref. 22. 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 is based on those equations. For given initial conditions at the entry to a stage, the outlet conditons can be calculated using those equations.

The PURDU-WICSTK 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, water vapor or steam, and methane. The water droplets may be "small" and "large" diameter 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. In the general two-phase mixture that is considered as the working fluid in the compressor, the proportion of the five constituents (namely, three 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 methane and of small droplets are 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 Ref.22. However, a further description is included in Appendix 2 of this report regarding the model for the calculation of stage performance with respect to gaseous phase and water droplets.

The general procedure for calculation is the same as described in Ref. 22. 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. Details are provided in Ref. 22. 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 then one obtains the 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. Regarding off-design performance calculation, further details are provided in Appendix 2 of this report.

The Code is also suitable for the calculation of compressor performance with (a) bleeding of working fluid at different stages in the compressor and (b) resetting stator blades. It may be recalled that two of the recommended methods for mitigating the effects of water ingestion in compressors consist in (a) bleeding of working fluid and (b) resetting of stator blades.

The program is written for calculation of performance both in British and metric units.

2.2 Main Program

The program consists of a main program, twenty seven subroutines and thirteen external functions.

The main computer code routine is entitled MAIN. It calls all of the major subroutines in the code.

MAIN first reads all of the input data and prints them out. Then MAIN calls the subroutine WICSPD to calculate the design point performance.

At the compressor inlet the overall mixture mass flow rate is determined from the inputed initial overall flow coefficient and selected compressor operating speed. In order to calculate the stage performance, it is necessary to establish the stage axial velocity and stage flow coefficient at the entry to the stage. The axial velocity and therefore the stage flow coefficient are determined by the composition of the mixture. The influence of mixture composition arises through (a) the density of the mixture and (b) the proportion of large droplets in the mixture, the large droplets, it may be recalled, having random motion with respect to the gas phase and the small droplets. Details regarding stage flow coefficient are provided in Ref. 22 and Appendix 2 of this report.

2.2.1 Work Done in Stage

The stage performance calculation may be carried out in one of three ways by setting the input parameter IPERFM equal to 1,2, or 3: (1) WICSPA is called to utilize inputed stage characteristics; (2) WICSPB is called to utilize the analytical/correlation method(Appendix 2) for small droplets; and (3) WICSPC is called to utilize method described in Appendix 2 for large (or general) droplets. The program is written such that if more than 20 per cent of droplets belong to the class of large droplets, WICSPC is always used.

The foregoing stage performance calculation refers only to the determination of work done by the stage on the fluid that is assumed to absorb work input into the stage. The state of the fluid at the exit of the stage is then obtained by accounting for (1) the centrifugal action on droplets leading to a redistribution of liquid phase, (2) heat and mass transfer processes leading to a redetermination of mass flow and temperature of both gas phase and liquid phase.

2.2.2 Droplet Impingement Processes

In order to perform calculations pertaining to impingement of droplets on rotor blades and rebound of droplets, MAIN calls subroutine WICIRS and WICIRL for small and large droplets, respectively. The small and large droplet trajectories are different by assumption and their impingement on blades, therefore, has to be calculated in different ways. For stator blade, the subroutines WICISS and WICISL are called for small and large droplets, respectively.

The rebound of droplets is treated parametrically as a fraction of the droplets that impact a blade. The unrebound droplets are assumed to move over the blade surface and to be reingested into the blade wake at the blade trailing edge. Details regarding these processes may be found in Ref. 22.

2.2.3 Droplet Drag

The stage performance calculation described earlier yields a value of gas phase pressure at the stage exit. This to be corrected for droplet drag in the case of large droplets. The droplet drag due to large droplets is accounted for by calling the subroutine WICDRG. The pressure loss due to drag depends upon (a) the chosen drag coefficient, and (b) the number of droplets taken into consideration. The latter in turn depends upon the droplet impingement and rebound processes. Further details may be found in Ref. 22.

2.2.4 Droplet Size Adjustment

At the trailing edge of a blade, it is necessary to establish (a) the size of droplets that re-entrained into a blade surface and (b) the nominal size of all of the droplets. In both cases, the droplet size is assumed to be determined by the critical value of Weber number. The subroutine WICWAK yields the size of droplets that are re-entrained. Regarding the nominal size of all of the droplets in the blade wake region, the WICSIZ is called to determine it. It may be observed that the droplets attain an equilibrium size in the blade wake region only after traversing a distance since the droplets undergo an accelerating motion starting from the blade trailing edge till they attain momentum equilibrium with respect to the gas phase.

2.2.5 Centrifugal Action

The spanwise redistribution of droplets due to centrifugal action is based on the theory developed in Ref.22. The centrifugal action arises due to (a) the whirl component of velocity of droplets and (b) the rotational motion of blades in a rotor. In the case of small droplets, centrifugal action thus applies to (i) droplets in blade passages with respect to the whirl component of velocity and (ii) droplets on blade surfaces with respect to the blade rotational velocity. In the case of large droplets, on the other hand, centrifugal action arises only for droplets that impact the blade and are not rebound; in other words, for droplets that impinge on a blade and remain on it.

The centrifugal action arises both in a stator and a rotor for small droplets, while it arises only in a rotor for large droplets. This is again based on the earlier postulated difference between small and large droplet motion.

The centrifugal action is determined utilizing the subroutine WICCEN.

It may be pointed out that the spanwise redistribution of droplets due to centrifugal action is a time-dependent process. In other words, the total effect of centrifugal force is proportional to the length of time over which the force acts. It is assumed in the model adopted here that the time over which centrifugal force action arises on a droplet during its passage through a blade row is the mean length of time required for transit through the blade row. Thus, the particles at the trailing edge of a blade row, as they come out of a blade row, are assumed to be centrifuged at that location over a period of time equal to the time of passage through the blade row under consideration. A similar assumption applies if a complete stage is being considered. Further detalis are available in Ref. 22.

2.2.6. Heat and Mass Transfer Processes

The heat and mass transfer processes between the two phases are also time-dependent processes. The mean duration of time for heat and mass transfer processes across a blade row or a stage is again calculated on the basis of mean transit time through a blade row or a stage. The heat transfer is from the gas phase to the liquid phase. The mass transfer arises due to two reasons as follows.

(i) The change of pressure and temperature in a stage and the resulting change in thermodynamic equilibrium conditions and,

(ii) the evaporation of water when conditions are appropriate.

The details of models for heat and mass transfer calculations are presented in Ref. 22.

The heat and mass transfer calculations are carried out by calling the subroutines WICHET and WICMAS, respectively, at the exit of a stage.

The stage exit conditions are thus fully established and are printed out.

2.2.7. Multi-Stage Compressor Performance

When there is a stage following the stage for which exit conditions have been determined, the inlet conditions to the following stage are determined taking into account changes in the geometry of the interstage spacing. Utilizing those conditions as the input conditions, the performance of the following stage is established in terms of final exit conditions from that stage. The procedure is the same as that described for the first stage.

This procedure is continued for all of the stages in the case of a multi-stage compressor and the exit conditions from the last stage are printed out as the output conditions of the compressor for given initial conditions into the first stage of the compressor at the chosen operating speed.

2.3 Off-Design Performance

In order to calculate the performance of a stage at an off-design point, with respect to speed and/or mass flow, one utilizes the subroutine WICSPA, WICSPB, or WICSPC by setting the input parameter IPERFM = 1, 2, or 3. The utilization of the three subroutines is the same as at the design point.

It may be pointed out that the profile loss calculation procedure set out in the subroutine WICGSL is considered especially suitable for the case of the Test Compressor employed in the current investigation. In another case, appropriate modifications or even a replacement of this procedure may become necessary.

2.3.1. Corrections at Stage Exit

In Section 2.2, the methods of applying corrections to the basic stage performance with respect to the following have been discussed.

(1) droplet impingement processes,
(2) droplet drag loss,
(3) droplet size adjustment,
(4) centrifugal action, and
(5) heat and mass transfer process.

It may be recalled that the corrections are related to (a) the assumed distinctions between small and large droplets, and (b) the parametrization of droplet impingement, rebound and reingestion.

In performing off-design performance calculations, the procedure is the same as described in Section 2.2. The distinctions between small and large droplets remain the same. One can, of course, introduce desired values for droplet impingement, rebound and reingestion at each calculation point.

2.4 Bleeding and Injection

At the exit of any stage of a compressor, the output yields the composition of the mixture of gases and liquid droplets. In establishing inlet conditions into the following stage, in addition to taking into account changes due to the geometry of inter-stage spacing, one can take into account bleeding or injection of any component of the mixture by adjusting the mass flow and the mixture ratios.

2.5 Stator Blade Setting

The program includes a provision for blade setting as feature of off-design performance calculations. Further details are provided in Appendix 2.

2.6 Calculation of Stage Losses

The calculation of stage losses is fully described in Appendix 2. A summary is provided here.

The stage loss calculation consists of the following five subroutines:

(1) Subroutine WICGSL
single-phase (gas) flow profile loss calculated using the analytical/correlation method;

(2) Subroutine WICSDL
loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets;

(3) Subroutine WICSTL
loss due to Stokesian drag of droplets in the free stream of blade passage;

(4) Subroutine WICFML
loss due to film formed on blades when large droplets are present either by themselves or along with small droplets; and

(5) Subroutine WICRSL
loss due to the mixture boundary layer formed over the rough film surface referred to in (4).

The calculation schemes for various types of working fluids are as follows.

(a) In dealing with the flow of gas phase along, two options exist as follows.

(1) Using inputed stage characteristics by utilizing subroutine WICSPA; or

(2) Using analytical/correlation method by utilizing the relevant part of subroutine WICSPB and WICGSL.

(b) In dealing with the flow of a mixture of gas and small droplets, again two options exist as follows.

(1) Using inputed stage characteristics through the use of WICSPA and correct for the pressure of droplets by using the subroutine WICSDL; or

(2) Using analytical/computational method according to subroutines WICSPB, WICGSL, and WICSDL.

(c) Finally, in dealing with the flow of a mixture of gas and large or large and small droplets, one proceeds by using the subroutines WICSPC, WICGSL, WICSTL, WICFML, and WICRSL.

2.7 Overall Program Structure

The overall program structure is presented in Fig. 2.1 and also described below step by step.

Step 1: Read input data.

Step 2: Printout inputed data.

Step 3: Calculate the design point performance by calling WICSPD.

Step 4: Read initial flow coefficient.

Step 5: Calculate mass flow rate of gas phase and liquid phase from the inputed initial flow coefficient. The subroutine WICPRP and WICMAS are called.

Step 6: Calculate stage performance in one of the following five cases:

(i) If there is no liquid phase, and the inputed stage characteristic curves are to be used, WICSPA is called.

(ii) If there is no liquid phase, and analytical/correlation method is to be used, WICSPB is called.

(iii) If more than 80 per cent of droplets belongs to "small" droplet, and the inputed stage characteristic curves are to be used, WICSPA is called.

(iv) If more than 80 per cent of droplets belongs to "small" droplet and the analytical/correlation method is to be used, WICSPB is called.

(v) If more than 20 per cent of droplet belongs to "large" droplet, WICSPC is called.

Step 7: Calculation of droplet impingement on rotor blade:
For small droplets, WICIRS is called.
For large droplets, WICIRL is called.

Step 8: Droplet size adjustment at rotor outlet: WICWAK and WICSIZ are called.

Step 9: Calculation of centrifugal action and spanwise redistribution of droplets:
For small droplet,WICCEN and WICDMS are called.
For large droplet, WICCEN and WICDML are called.

Step 10: Calculation of droplet impingement on stator blade:
For small droplet, WICISS is called.
For large droplet, WICISL is called.

Step 11: Droplet size adjustment at stator outlet: WICWAK AND WICSIZ are called.

Step 12: Calculation of heat transfer:
WICHET is called.

Step 13: Calculation of mass transfer:
WICMAS is called.

Step 14: Printout stage performance.

Step 15: Repeat steps (6) ∿ (14) until the complete stage performance is obtained.

Step 16: Calculate the overall performance and print them out.

Step 17: Repeat steps (4) ∿ (16) for a new value of initial flow coefficient.

CHAPTER III

SUBROUTINES AND EXTERNAL FUNCTIONS

There are 27 subroutines and 13 external functions in this program. The following is the list of subroutines and external functions. Only brief descriptions of these subprograms are given here. A more detailed description of each subprogram is presented in Appendix 3.

Subroutine WICSPA: calculation of stage performance based on the imputed stage characteristic curves.

Subroutine WICSPB: calculation of stage performance based on the analytical/correlation method for small droplet.

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 pressure ratio, equivalent temperature rise ratio, and stage adiabatic efficiency for a particular stage based on the imputed 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 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

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

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

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

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

Subroutine WICDRG: calculation of drag force on droplet.

Subroutine WICMAC: calculation of Mach number.

Function WICASD: calculation of acoustics 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 WICHET: 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 iterative 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.

CHAPTER IV

INPUT DATA

All input data that are needed to use PURDU-WICSTK computer code are decribed in this section. The input data are presented in the same sequence as they are used in the program. The units for the input data can be selected as either all Metric or all English by choosing the value of IUNIT as shown in Table 4.1.

The following is a list of the input data as they are read in MAIN. Figures 4.1 and 4.2 show the geometry of compressor stage and angles associated with a typical rotor blade element.

Card No.	Input Data	Comment	Format
1	NS	number of stage	I1
2	RRHUB(I)	hub radius at Ith stage rotor inlet. I = 1 ∿ NS Unit: inch or cm	F5.3
3	RC(I)	chord length of Ith stage rotor I = 1 ∿ NS Unit: inch or cm	F 5.3
4	RBLADE(I)	number of blade for Ith stage rotor. I = 1 ∿ NS	F 5.2
5	STAGER(I)	stager angle for Ith stage rotor I = 1 ∿ NS Unit: degree	F 5.2
6	SRHUB(I)	hub radius at Ith stage stator inlet. I = 1 ∿ NS, I = NS+1 for IGV Unit: inch or cm	F 5.3
7	SC(I)	chord length of Ith stage stator I= 1 ∿ NS, I=NS+1 for IGV Unit: inch or cm	F 5.3

TABLE 4.1 INDEX FOR UNIT SELECTION

IUNIT	Unit of Input data	Unit of Output Variables
1	English	English
2	Metric	Metric
3	English	Metric
4	Metric	English

Card No.	Input Data	Comment	Format
8	SBLADE(I)	number of blade for Ith stage stator. I=1∿ NS, I=NS+1 for IGV	F 5.2
9	SIGUMR(I)	solidity of Ith stage rotor I = 1∿ NS	F 5.3
10	SIGUMS(I)	solidity of Ith stage stator I=1∿NS, I=NS+1 for IGV	F 5.3
11	FNF	fraction of design corrected rotor speed for a particular speed	F 8.2
12	XDIN	initial water content (mass fraction) of small droplet	F 5.3
12	ICENT	index for centrifugal calculation of small droplet ICENT = 1 when XDIN = 0.0 otherwise ICENT = 2	I1
12	XDDIN	initial water content (mass fraction) of large droplet	F 5.3
12	IICNET	index for centrifugal calculation of large droplet IICENT=1 when XDDIN=0.0 otherwise IICENT = 2	I1
13	TOG	total temperature of gas phase at compressor inlet Unit: Rankin or Kelvin	F 7.2
13	TOW	temperature of droplet at compressor inlet Unit: Rankin or Kelvin	F 7.2
13	PO	total pressure at compressor inlet Unit: lbf/ft^2 or N/m ^{2}	F 7.2
14	DIN	initial diameter of small droplet Unit: µm	F 6.1
14	DDIN	initial diameter of large droplet Unit: µm	F 6.1

Card No.	Input Data	Comment	Format
15	FND	rotor corrected speed at design point Unit: RPM	F 7.1
15	T01D	compressor inlet temperature at design point Unit: Rankin or Kelvin	F 7.2
15	P01D	compressor inlet pressure at design point Unit: lbf/ft^2 or N/m^2	F 7.2
16	XCH4	initial methane content (mass fraction)	F 5.3
16	RHUMID	initial relative humidity Unit: per cent	F 10.5
17	FMWA	molecular weight of air	F 7.3
17	FMWV	molecular weight of steam	F 7.3
17	FMWC	molecular weight of methane	F 7.3
18	PREB	percent of water droplet that rebound after impingement on blade surface	F 5.1
18	DLIMIT	maximum diameter for small droplet Unit: μm	F 7.1
19	STAGES(I)	stager angle for Ith stage stator $I=1 \sim NS$, $I=NS+1$ for IGV Unit: degree	F 5.2
20	GAPR(I)	gap between Ith stage rotor and (I-1)th stage stator $I = 1 \sim NS$ Unit: inch or cm	F 7.5
21	GAPS(I)	gap between rotor blade and stator blade for Ith stage $I = 1 \sim NS$ Unit: inch or cm	F 7.5

Card No.	Input Data	Comment	Format
22	RRTIP(I)	blade tip radius at Ith stage rotor inlet I = 1 ∼NS Unit: inch or cm	F 6.3
23	SRTIP(I)	blade tip radius at Ith stage stator inlet I = 1 ∼NS Unit: inch or cm	F 6.3
24	IPERFM	index for stage performance calculation IPERFM=1: subroutine WICSPA is used IPERFM=2: subroutine WICSPA is used IPERFM=3: subroutine WICSPA is used	I1
24	IUNIT	index for unit IUNIT=1:Input=English,Output=English IUNIT=2:Input=Metric, Output=Metric IUNIT=3:Input=English,Output=Metric IUNIT=4:Input=Metric, Output=English	I1
25	IRAD	index for radius at which calculation is carried out IRAD = 1: performance at tip IRAD = 2: performance at mean IRAD = 3: performance at hub	I1
26	RT(I)	rotor inlet radius at which tip performance calculation is carried out I = 1 ∼NS Unit: inch or cm	F 5.3
27	RM(I)	rotor inlet radius at which mean line performance calculation is carried out I = 1 ∼NS Unit: inch or cm	F 5.3
28	RH(I)	rotor inlet radius at which hub performance calculation is carried out I = 1 ∼NS Unit: inch or cm	F 5.3
29	ST(I)	stator inlet radius at which tip performance calculation is carried out I = 1 ∼NS Unit: inch or cm	F 5.3

Card No.	Input Data	Comment	Format
30	SM(I)	Stator inlet radius at which mean line performance is carried out I=1 $\sim$ NS Unit: inch or cm	F 5.3
31	SH(I)	stator inlet radius at which hub performance calculation is carried out I = 1 $\sim$ 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	DMASS	mass flow rate at design point Unit: lb_m/s or kg/s	F 10.6
39	PR12D(I)	total pressure ratio for the Ith stage rotor at design point; I=1$\sim$ NS	F 5.3
40	PR13D(I)	total pressure ratio for Ith stage at design point; I = 1$\sim$ NS	F 5.3

Card No.	Input Data	Comment	Format
41	ETARD(I)	adiabatic efficiency for Ith stage rotor	F 5.3
42	SAREA(I)	stream tube area Ith stage rotor inlet Unit: ft^2 or m^2	F 10.7
43	SAREAS(I)	stream tube area for Ith stage stator inlet Unit: ft^2 or m^2	F 10.7
44	DELB1R(I)	change of blade metal angle for Ith stage rotor resetting I= 1∿ NS Unit: degree	F 5.2
45	DELB1S(I)	change of blade metal angle for Ith stage stator resetting I=1∿NS, I=NS+1 for IGV	F 5.2
46	XG1BLD(I)	amount of bleed or injection of air at Ith stage outlet I = 1∿ NS XG1BLD(I) < 0 for bleed XG1BLD(I) = 0 for no bleed or injection XG1BLD(I) > 0 for injection	F 5.3
47	XG2BLD(I)	amount of bleed or injection of steam at Ith stage outlet I= 1 ∿ NS XG2BLD(I) < 0 for bleed XG2BLD(I) = 0 for no bleed or injection XG2BLD(I) > 0 for injection	F 5.3
48	XG3BLD(I)	amount of bleed or injection of methane at Ith stage outlet I = 1 ∿ NS XG3BLD(I)< 0 for bleed XG3BLD(I) =0 for no bleed or injection XG3BLD(I) > 0 for injection	F 5.3

Card No.	Input Data	Comment	Format
49	XWBLD(I)	amount of bleed or injection of small droplet at Ith stage outlet I = 1 ∿ NS XWBLD(I) < 0 for bleed XWBLD(I) = 0 for no bleed or injection XWBLD(I) > 0 for injection	F 5.3
50	XWWBLD(I)	amount of bleed or injection of large droplet at Ith stage outlet I = 1 NS XWWBLD(I) <0 for bleed XWWBLD(I) =0 for no bleed or injection XWWBLD(I) >0 for injection	F 5.3
51	BET2SS(I)	absolute flow angle at Ith stage stator outlet I = 1 ∿ NS, I=NS1 for IGV	F 5.2
52	FAI	initial flow coefficient. The user can input FAI as many as one wants. However, one card must contain only one FAI and the last card must be 9.99999	F 7.5

CHAPTER V

OUTPUT

The user can select the units for output variables by choosing the value of the input variable IUNIT as shown in Table 4.1.

There are two kinds of output in this program code--regular output and diagnositic output. The regular output consists of four parts as follows:

(1) output of the inputed data;
(2) output of design point performance;
(3) output of stage performance; and
(4) output of overall performance.

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: (ft^2) or (m^2)
(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/ft^2) or (N/m^2)
(3) static temperature: (R) or (K)
(4) static pressure: (lbf/ft^2) or (N/m^2)
(5) static density: (lbm/ft^3) or (kg/m^3)
(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/ft^2) or (N/m^2)
(16) absolute flow angle: (degree)
(17) relative flow angle: (degree)
(18) stream tube area:(ft^2) or (m^2)
(19) radius at which caculation 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/ft^2) or (N/m^2)
(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: AINCSR(I) (degree)
(11) deviation for rotor: ADEVSR (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 : AINCSS(I) (degree)
(15) deviation for stator: ADEVSS(I) (degree)
(16) stage inlet temperature: TD(I) (R) or (K)
(17) total pressure loss coefficient for stator: OMEGS(I)
(18) total pressure loss coefficient for rotor : OMEGR(I)

5.3 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 parts 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: WWMASS (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/ft^3) or (Kg/m^3)

(21) density of mixture: RHOM (lbm/ft^3) or (Kg/m^3)

(22) density of gaseous phase: RHOG (lbm/ft^3) or (Kg/m^3)

(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/ft^2) or (N/m^2)

(27) boiling point: TB (R) or (K)

(28) dew point: TDEW (R)or (K)

5.4 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/ft^2) or (N/m^2)

*(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)

5.5 Diagnostic Printout

At the inlet of each stage, the flow coefficient is calcualted. If the flow coefficient gives the value of equivalent pressure ratio which is less than 1.0 or the value of stage adiavatic efficiency which is less than 0.0, the following message will appear. "FAI IS TOO BIG OR TOO SMALL AT STAGE=." If this message appears, the computation for the particular initial flow coefficient will be terminated and the next initial flow coefficient will be read.

The iterative procedure is used to determine the Mach number. If the desired accuracy can not be obtained after 50 times of iteration , the following message will appear. "M DOES NOT CONVERGE AT STAGE=." If this message appears, the final value of Mach number will be used and computation will be continued.

When the axial velocity become either higher than local acoustic speed or negative, the following message will appear: "VZ IS TOO HIGH OR TOO LOW." If this message appears, the computation for the particular initial flow coefficient will be terminated and the next initial flow coefficient will be read.

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* The mass flow rate corresponds to stream tube area specified in input data. The mass flow rate which corresponds to compressor total flow area is also printed out in the brackets.

CHAPTER VI

A TEST CASE

The application of the PURDU-WICSTK program is illustrated with a test case pertaining to the Test Compressor described in Appendix 1. The Test Compressor consists of the six axial stages of the ALLISON T63-A-5 engine compressor. The design point overall pressure ratio (mass averaged) is 2.9 with 3.0 lbm/sec of mass flow rate, and the design rotor speed is 51120 RPM.

The test case consists of the following predictions for the Test Compressor.

(i) Part I: Operation with air flow at a selected speed and throttle setting.

(ii) Part II: Operation with air-small droplet mixture flow at a selected speed and throttle setting; and

(iii) Part III: Operation with air-large droplet mixture flow at a selected speed and throttle setting.

The test case has been reproduced in Appendix 5.

6.1 Test Case Part I

The Test Case Part I demonstrates the use of the code for predicting the performance of a compressor which operates with air flow (only) at a selected speed and throttle setting. The performance prediction has been presented at the mean line of the Test Compressor.

6.1.1 Input Data

The input data for Test Case Part I are listed below as they are read in program MAIN.

Card 1: NS = 6

Card 2: RRHUB(1) = 0.770 inch
RRHUB(2) = 1.035 inch
RRHUB(3) = 1.232 inch
RRHUB(4) = 1.378 inch
RRHUB(5) = 1.489 inch
RRHUB(6) = 1.572 inch

Card 3: RC(1) = 0.605 inch
RC(2) = 0.554 inch
RC(3) = 0.534 inch
RC(4) = 0.510 inch
RC(5) = 0.483 inch
RC(6) = 0.456 inch

Card 4: RBLADE(1) = 16.00
RBLADE(2) = 20.00
RBLADE(3) = 20.00
RBLADE(4) = 25.00
RBLADE(5) = 28.00
RBLADE(6) = 32.00

Card 5: STAGER(1) = 34.25 degree
STAGER(2) = 29.96 degree
STAGER(3) = 27.37 degree
STAGER(4) = 28.30 degree
STAGER(5) = 29.17 degree
STAGER(6) = 29.75 degree

Card 6: SRHUB(1) = 0.923 inch
SRHUB(2) = 1.145 inch
SRHUB(3) = 1.311 inch
SRHUB(4) = 1.445 inch
SRHUB(5) = 1.538 inch
SRHUB(6) = 1.580 inch
SRHUB(7) = 0.774 inch

Card 7: SC(1) = 0.442 inch
SC(2) = 0.412 inch
SC(3) = 0.412 inch
SC(4) = 0.412 inch
SC(5) = 0.412 inch
SC(6) = 0.412 inch
SC(7) = 1.100 inch

Card 8: SBLADE(1) = 14.00
SBLADE(2) = 26.00
SBLADE(3) = 28.00
SBLADE(4) = 32.00
SBLADE(5) = 36.00
SBLADE(6) = 30.00
SBLADE(7) = 7.00

Card 9: SIGUMR(1) = 1.052
SIGUMR(2) = 1.120
SIGUMR(3) = 1.037
SIGUMR(4) = 1.182
SIGUMR(5) = 1.211
SIGUMR(6) = 1.283

Card 10: SIGUMS(1) = 0.640
SIGUMS(2) = 1.061
SIGUMS(3) = 1.093
SIGUMS(4) = 1.199
SIGUMS(5) = 1.311
SIGUMS(6) = 1.087
SIGUMS(7) = 0.858

Card 11: FNF = 1.00

Card 12: XDIN = 0.000
ICENT = 1
XDDIN = 0.000
IICENT = 1

Card 13: TOG = 518.70 R
TOW = 513.70 R
PO = 2116.80 lb_f/ft^2

Card 14: DIN = 20.0 µm
DDIN = 600.0 µm

Card 15: FND = 51120.0 RPM
T01D = 518.70 R
P01D = 2116.80 lb_f/ft^2

Card 16: XCH4 = 0.000
RHUMID = 0.00001 per cent

Card 17: FMWA = 28.964
FMWV = 18.016
FMWX = 16.043

Card 18: PREB = 50.00 per cent
DLIMIT = 100.0 µm

Card 19: STAGES(1) = 23.67 degree
STAGES(2) = 25.62 degree
STAGES(3) = 26.94 degree
STAGES(4) = 28.41 degree
STAGES(5) = 29.82 degree
STAGES(6) = 38.99 degree
STAGES(7) = 10.99 degree

Card 20: GAPR(1) = 0.125 inch
GAPR(2) = 0.125 inch
GAPR(3) = 0.125 inch
GAPR(4) = 0.125 inch
GAPR(5) = 0.125 inch
GAPR(6) = 0.125 inch

Card 21: GAPS(1) = 0.125 inch
GAPS(2) = 0.125 inch
GAPS(3) = 0.125 inch
GAPS(4) = 0.125 inch
GAPS(5) = 0.125 inch
GAPS(6) = 0.125 inch

Card 22: RRTIP(1) = 2.16 inch
RRTIP(2) = 2.16 inch
RRTIP(3) = 2.16 inch
RRTIP(4) = 2.16 inch
RRTIP(5) = 2.16 inch
RRTIP(6) = 2.16 inch

Card 23: SRTIP(1) = 2.16 inch
SRTIP(2) = 2.16 inch
SRTIP(3) = 2.16 inch
SRTIP(4) = 2.16 inch
SRTIP(5) = 2.16 inch
SRTIP(6) = 2.16 inch

Card 24: IPERFM = 2
IUNIT = 1

Card 25: IRAD = 2

Card 26: RT(1) = 2.149 inch
RT(2) = 2.151 inch
RT(3) = 2.148 inch
RT(4) = 2.149 inch
RT(5) = 2.149 inch
RT(6) = 2.147 inch

Card 27: RM(1) = 1.426 inch
RM(2) = 1.575 inch
RM(3) = 1.642 inch
RM(4) = 1.722 inch
RM(5) = 1.789 inch
RM(6) = 1.836 inch

Card 28: RH(1) = 0.781 inch
RH(2) = 1.056 inch
RH(3) = 1.252 inch
RH(4) = 1.411 inch
RH(5) = 1.533 inch
RH(6) = 1.621 inch

Card 29: ST(1) = 0.934 inch
ST(2) = 1.152 inch
ST(3) = 1.318 inch
ST(4) = 1.453 inch
ST(5) = 1.548 inch
ST(6) = 1.592 inch

Card 30: SM(1) = 1.502 inch
SM(2) = 1.573 inch
SM(3) = 1.637 inch
SM(4) = 1.712 inch
SM(5) = 1.766 inch
SM(6) = 1.784 inch

Card 31: SH(1) = 2.147 inch
SH(2) = 2.138 inch
SH(3) = 2.127 inch
SH(4) = 2.123 inch
SH(5) = 2.118 inch
SH(6) = 2.100 inch

Card 32: BLOCK(1) = 0.983
BLOCK(2) = 0.976
BLOCK(3) = 0.967
BLOCK(4) = 0.949
BLOCK(5) = 0.923
BLOCK(6) = 0.902

Card 33: BLOCKS(1) = 0.978
BLOCKS(2) = 0.966
BLOCKS(3) = 0.945
BLOCKS(4) = 0.928
BLOCKS(5) = 0.908
BLOCKS(6) = 0.863

Card 34: BET1MR(1) = 42.72 degree
BET1MR(2) = 42.74 degree
BET1MR(3) = 41.62 degree
BET1MR(4) = 42.85 degree
BET1MR(5) = 44.00 degree
BET1MR(6) = 45.07 degree

Card 35: BET2MR(1) = 25.79 degree
BET2MR(2) = 17.17 degree
BET2MR(3) = 13.12 degree
BET2MR(4) = 13.76 degree
BET2MR(5) = 14.33 degree
BET2MR(6) = 14.43 degree

Card 36: BET1MS(1) = 35.15 degree
BET1MS(2) = 40.11 degree
BET1MS(3) = 43.36 degree
BET1MS(4) = 45.00 degree
BET1MS(5) = 46.31 degree
BET1MS(6) = 48.71 degree
BET1MS(7) = 0.00 degree

Card 37: BET2MS(1) = 12.19 degree
BET2MS(2) = 11.13 degree
BET2MS(3) = 10.51 degree
BET2MS(4) = 11.81 degree
BET2MS(5) = 13.32 degree
BET2MS(6) = 29.28 degree
BET2MS(7) = 21.99 degree

Card 38: DMASS = 0.375538 lbm/sec

Card 39: PR12D(1) = 1.154
PR12D(2) = 1.165
PR12D(3) = 1.221
PR12D(4) = 1.237
PR12D(5) = 1.230
PR12D(6) = 1.215

Card 40: PR13D(1) = 1.152
PR13D(2) = 1.159
PR13D(3) = 1.213
PR13D(4) = 1.228
PR13D(5) = 1.221
PR13D(6) = 1.208

Card 41: ETARD(1) = 0.966
ETARD(2) = 0.966
ETARD(3) = 0.968
ETARD(4) = 0.965
ETARD(5) = 0.962
ETARD(6) = 0.954

Card 42: SAREA(1) = 0.0103647 ft^2
SAREA(2) = 0.0092977 ft^2
SAREA(3) = 0.0080300 ft^2
SAREA(4) = 0.0069214 ft^2
SAREA(5) = 0.0059094 ft^2
SAREA(6) = 0.0051110 ft^2

Card 43: SAREAS(1) = 0.0098704 ft^2
SAREAS(2) = 0.0084051 ft^2
SAREAS(3) = 0.0070775 ft^2
SAREAS(4) = 0.0060735 ft^2
SAREAS(5) = 0.0052626 ft^2
SAREAS(6) = 0.0046691 ft^2
SAREAS(7) = 0.0105669 ft^2

Card 44: DELB1R(1) = 0.00
DELB1R(2) = 0.00
DELB1R(3) = 0.00
DELB1R(4) = 0.00
DELB1R(5) = 0.00
DELB1R(6) = 0.00

Card 45: DELB1S(1) = 0.00
DELB1S(2) = 0.00
DELB1S(3) = 0.00
DELB1S(4) = 0.00
DELB1S(5) = 0.00
DELB1S(6) = 0.00

Card 46: XG1BLD(1) = 0.000
XG1BLD(2) = 0.000
XG1BLD(3) = 0.000
XG1BLD(4) = 0.000
XG1BLD(5) = 0.000
XG1BLD(6) = 0.000

Card 47: XG2BLD(1) = 0.000
XG2BLD(2) = 0.000
XG2BLD(3) = 0.000
XG2BLD(4) = 0.000
XG2BLD(5) = 0.000
XG2BLD(6) = 0.000

Card 48: XG3BLD(1) = 0.000
XG3BLD(2) = 0.000
XG3BLD(3) = 0.000
XG3BLD(4) = 0.000
XG3BLD(5) = 0.000
XG3BLD(6) = 0.000

Card 49: XWBLD(1) = 0.000
XWBLD(2) = 0.000
XWBLD(3) = 0.000
XWBLD(4) = 0.000
XWBLD(5) = 0.000
XWBLD(6) = 0.000

Card 50: XWWBLD(1) = 0.000
XWWBLD(2) = 0.000
XWWBLD(3) = 0.000
XWWBLD(4) = 0.000
XWWBLD(5) = 0.000
XWWBLD(6) = 0.000

Card 51: BET2SS(1) = 21.89 degree
BET2SS(2) = 19.09 degree
BET2SS(3) = 19.33 degree
BET2SS(4) = 20.18 degree
BET2SS(5) = 21.15 degree
BET2SS(6) = 34.86 degree
BET2SS(7) = 15.61 degree

Card 52: FAI = 0.5000

Card 53: FAI = 9.99999

6.1.2 Output

The output for Test Case Part I is presented in Appendix 5. The details of the output obtained are described in Chapter V.

6.2 Test Case Part II

The Test Case Part II demonstrates the use of the code for predicting the performance of a compressor which operates with air-small droplet mixture flow at a selected speed and throttle setting. The water content of small droplet has been specified as four per cent by weight. The performance prediction has been presented at the mean line of the Test Compressor.

6.2.1 Input Data

The input data for Test Case Part II are the same as those for Test Case Part I except in regard to the following.

Card 12: XDIN = 0.040
ICENT = 2
XDDIN = 0.000
IICENT = 1

6.2.2 Output

The output for Test Case Part II is presented in Appendix 5. The details of the output obtained are described in Chapter V.

6.3 Test Case Part III

The Test Case Part III demonstrates the use of the code for predicting the performance of a compressor which operates with air-large droplet mixture flow at a selected speed and throttle setting. The water content of large droplet has been specified as four per cent by weight. The performance prediction has been presented at the mean line of the Test Compressor.

6.3.1 Input Data

The input data for Test Case Part III are the same as those for Test Case Part I except in regard to the following.

Card 12: XDIN = 0.000
ICENT = 1
XDDIN = 0.040
IICENT = 2

6.3.2 Output

The output for Test Case Part III is presented in Appendix 5. The details of the output properties are described in Chapter V.

FIGURES

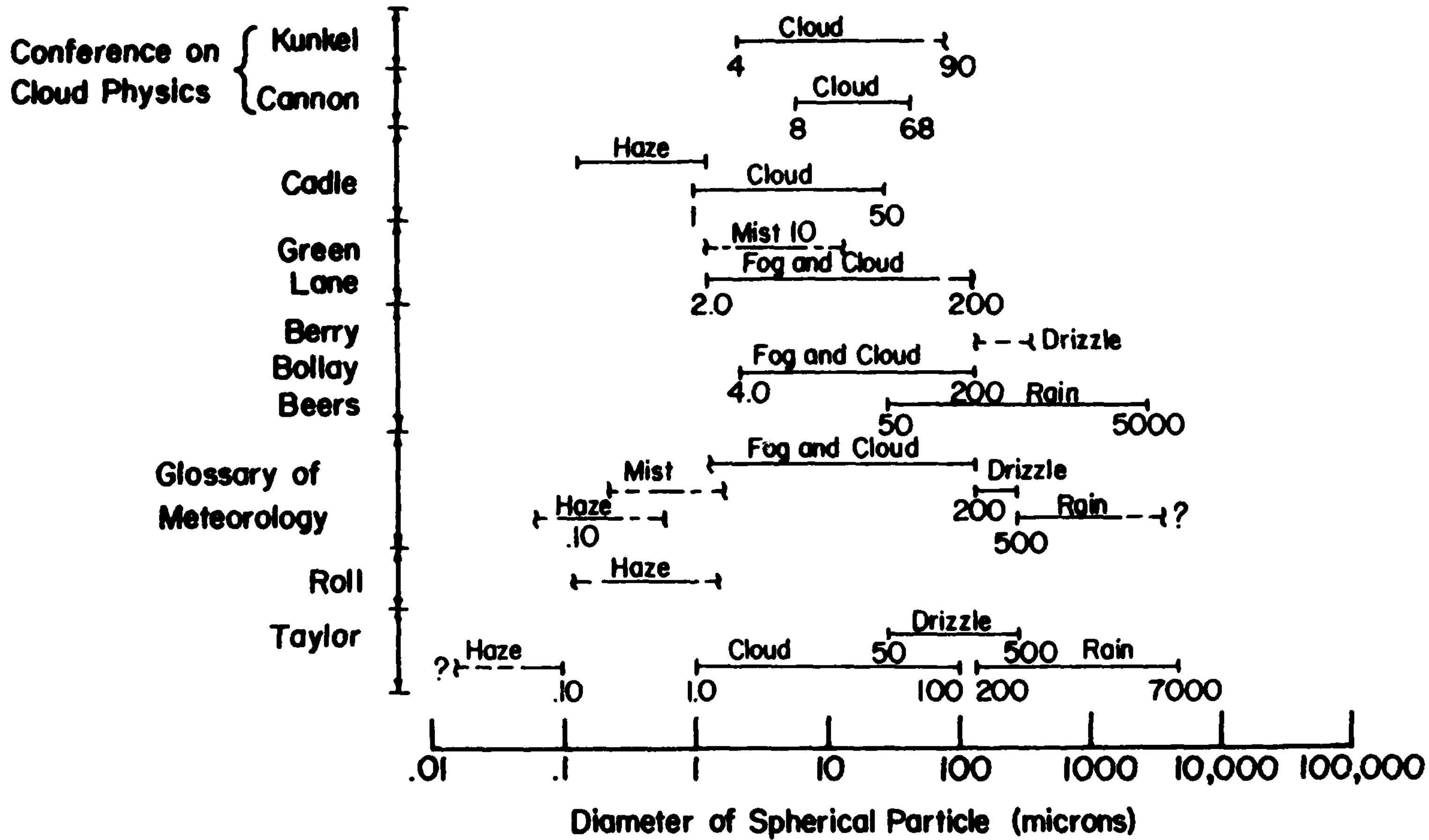

Fig. 1.1 Atmospheric Particle Size Ranges

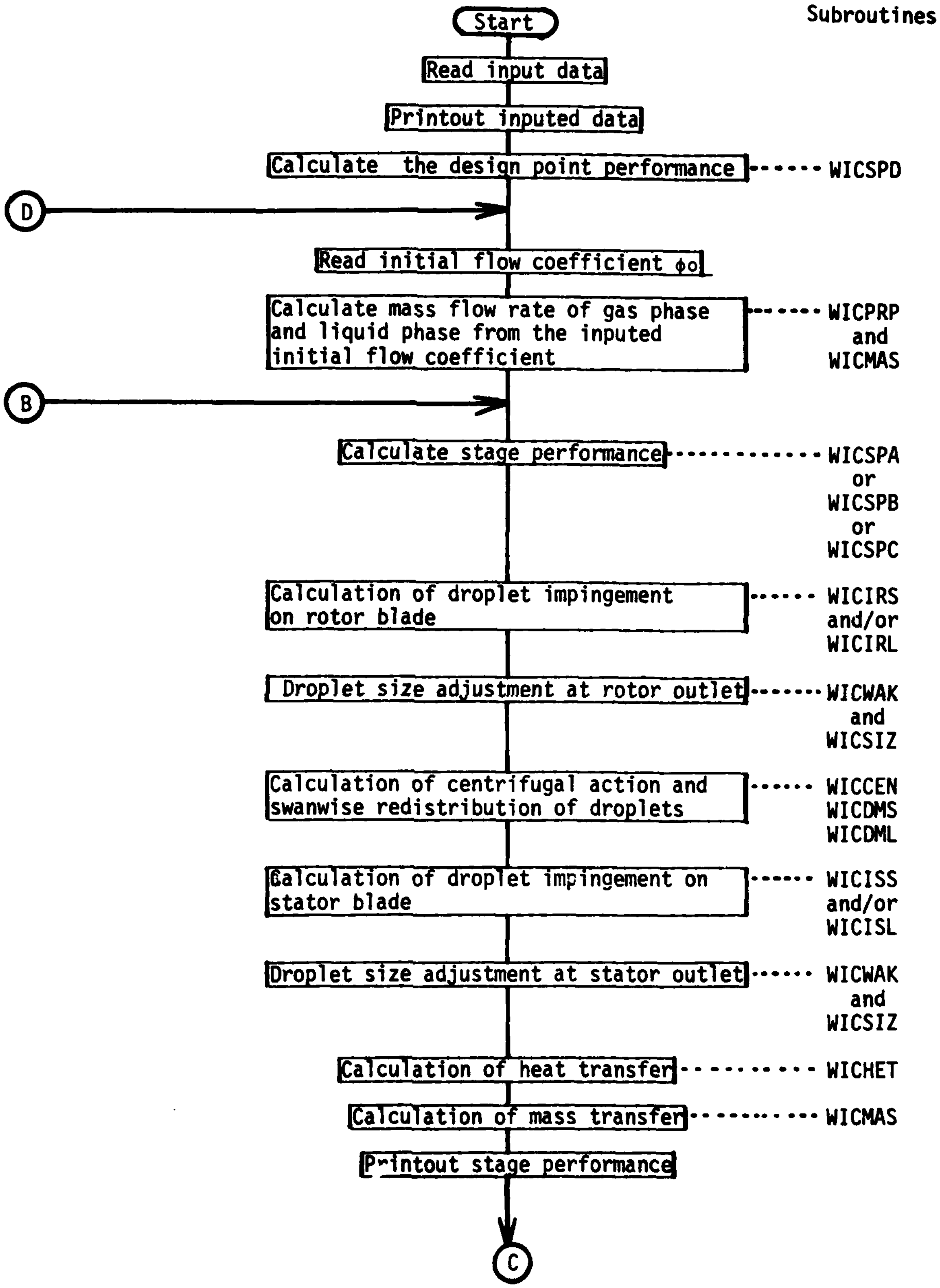

Figure 2.1 Flow Chart of of Overall Program Structure

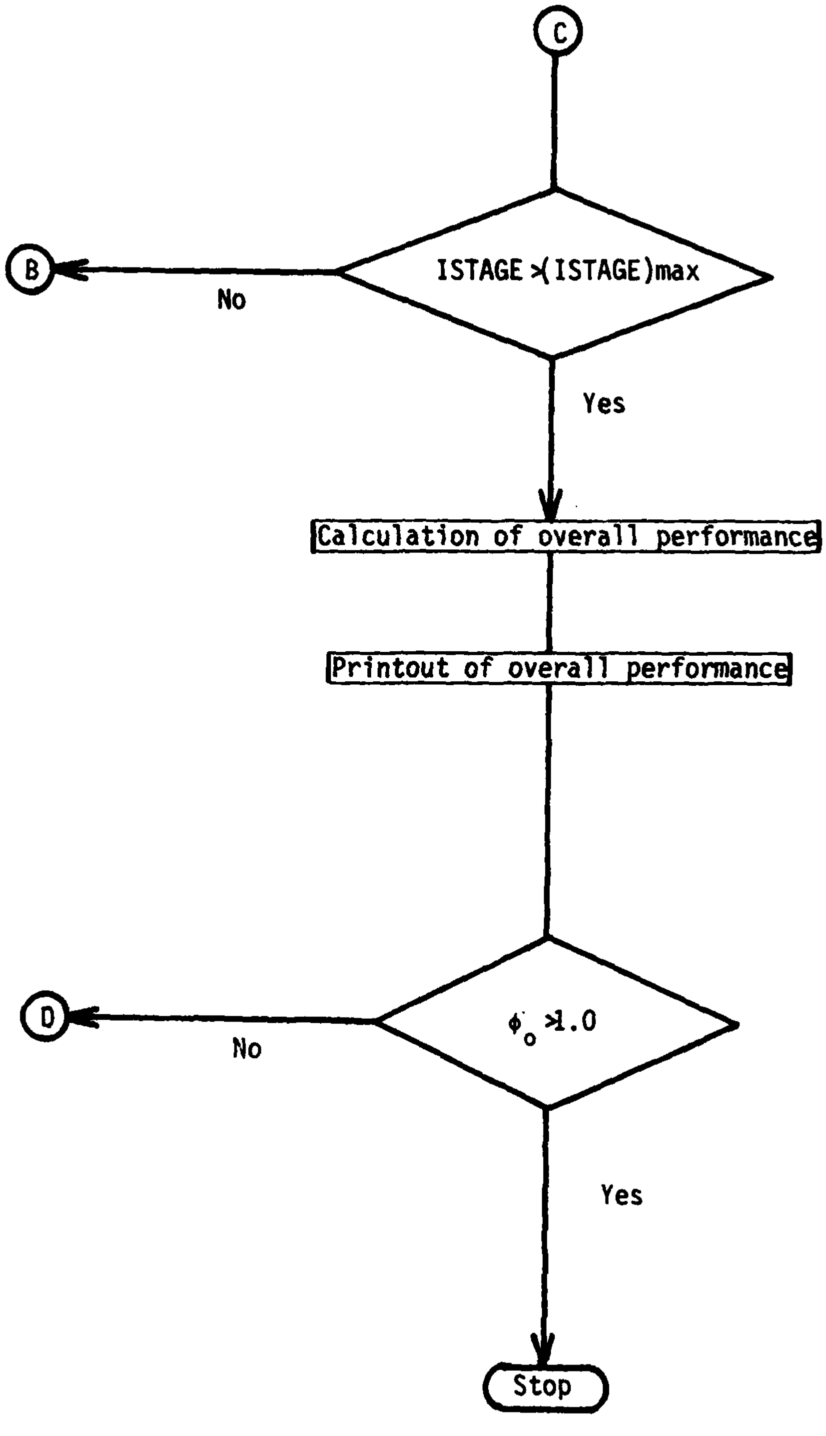

Figure 2.1 Flow Chart of Overall Program Structure (Continued)

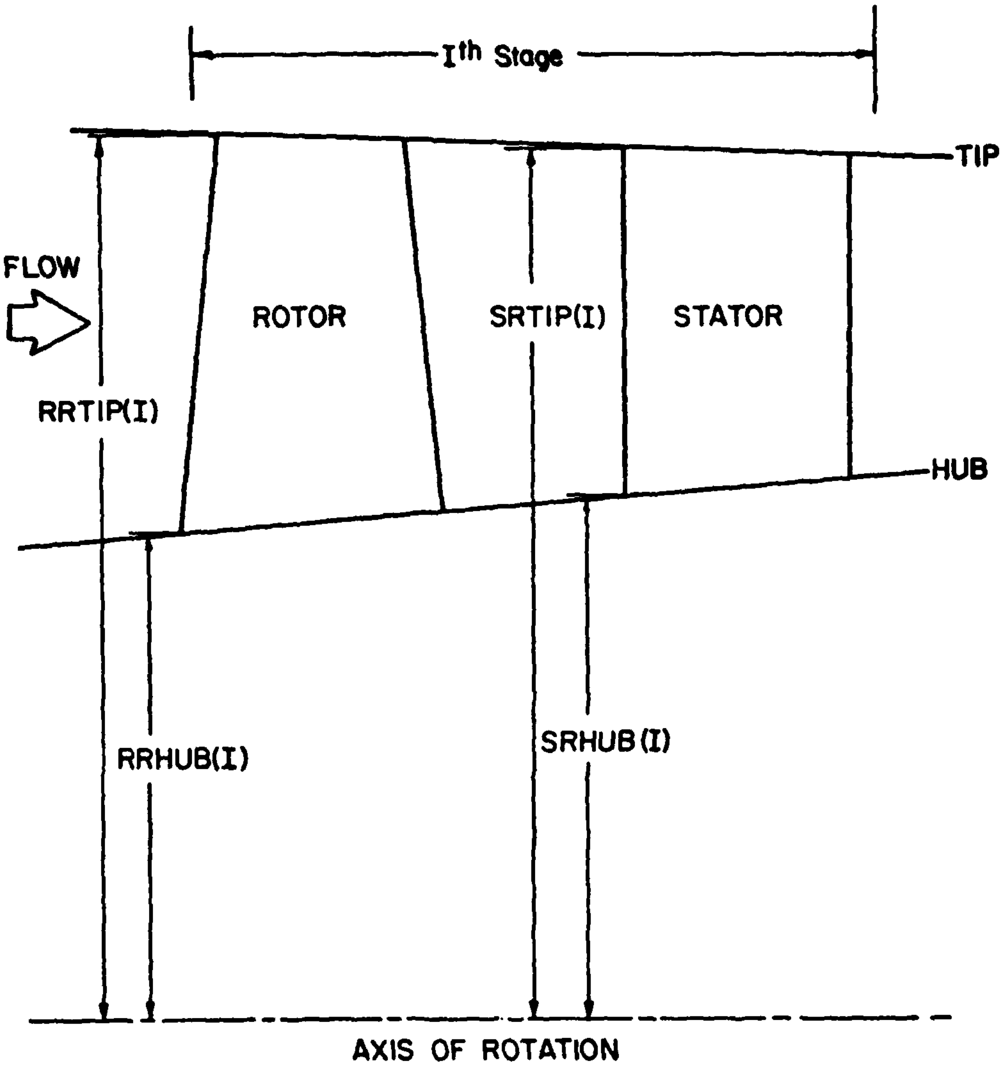

Fig. 4.1 Geometry of Compressor Stage

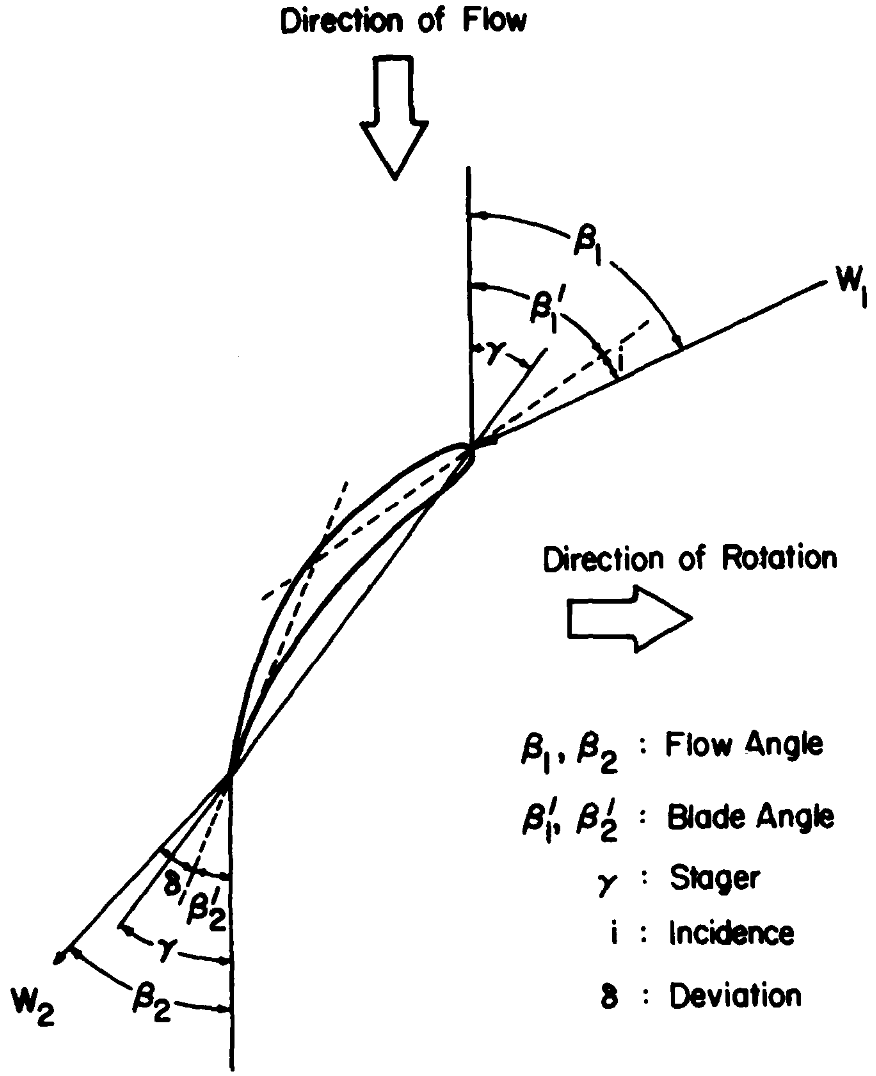

Fig. 4.2 Angles Associated With a Typical Rotor Blade Element

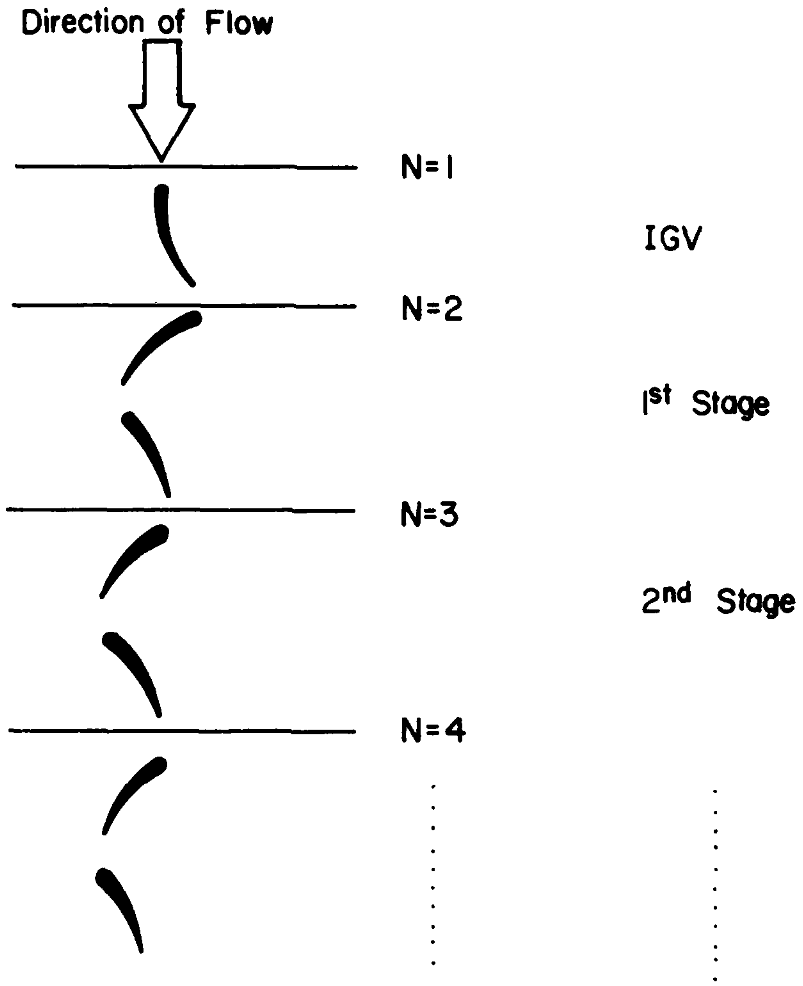

Fig. 5.1 Station Number in Compressor Stages

APPENDIX 1

DETAIL OF TEST COMPRESSOR AND DRIVE ENGINE

1. Drive Engine

A T63-A-5 engine is used to drive the Test Compressor. The specifications, limits, and performance ratings for the Drive Engine are as follows:

Design power output: 250 shp
Ram power rating: 275 shp

Design speeds:

Gas producer	51120 rpm (100%)
Power turbine	35000 rpm (100%)
Power output shaft	6000 rpm

Fuel Specification : MIL-J-5624E(JP-4)

The Drive Engine power turbine drives the Test Compressor through mechanical gearing. The power turbine speed has been increased to an output of 9,643 rpm at 100 per cent speed from the normal rating of 6,000 rpm. The Test Compressor is operated at 110 per cent (56,251.7 rpm) while the engine operates at 100 per cent or 51,120 rpm. One power turbine tachometer is used to monitor the Test Compressor speed. The ratio of the tachometer speed to the Test Compressor speed is 0.119676.

2. Test Compressor

The Test Compressor consists of the six axial 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, ψ , equivalent temperature ratio, τ, and stage adiabatic efficiency, η, are presented in terms of flow coefficient, ϕ. The definitions of these parameters are as follows:

(i) flow coefficient: ϕ

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio: ψ

$$\psi = \left\{ \left(\frac{U_{tip}^2}{T_{01}}\right)_D \cdot \left(\frac{T_{01}}{U_{tip}^2}\right) \left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} -1 \right] + 1 \right\}^{\gamma/(\gamma-1)}$$

(iii) equivalent temperature ratio: τ

$$\tau = \left(\frac{U_{tip}}{T_{01}}\right)^2_D \cdot \left(\frac{\Delta T_0}{U_{tip}^2}\right)$$

TABLE A.1.1

Test Compressor Design Velocity Diagram Values

Stage	1	2	3	4	5	6	
R	2.161	2.161	2.161	2.161	2.161	2.161	
U	963.5	963.5	963.5	963.5	963.5	963.5	
V_{z1}	508.4	544.1	547.0	554.9	554.1	543.7	↑
$V_{\theta 1}$	236.5	310.0	365.1	349.3	338.8	338.8	
$W_{\theta 1}$	727.0	653.5	598.4	614.2	624.7	629.9	Rotor Inlet
α_1	25.0	29.7	33.7	32.2	31.6	31.5	
β_1	54.9	50.3	47.6	47.9	48.5	49.3	
M_{1abs}	0.513	0.563	0.578	0.560	0.538	0.512	
M_{1rel}	0.812	0.765	0.713	0.707	0.692	0.658	↓
V_{z2}	507.0	554.9	551.0	554.5	548.9	544.6	↑
$V_{\theta 2}$	405.2	501.3	598.8	614.6	625.1	630.3	
$W_{\theta 2}$	558.3	462.2	364.7	348.9	338.4	333.2	Rotor Outlet
α_2	38.6	42.1	47.4	47.9	48.7	49.2	
β_2	47.8	39.8	33.6	32.2	31.7	31.5	
M_{2abs}	0.588	0.665	0.706	0.698	0.680	0.660	
M_{2rel}	0.683	0.643	0.574	0.552	0.528	0.506	↓

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

R	Radius, inches
U	Rotor speed at R, ft/sec.
V_z	Air axial velocity, ft/sec.
V_θ	Air absolute tangential velocity, ft/sec.
W_θ	Air relative tangential velocity, ft/sec.
α	Air absolute flow angle, degrees
β	Air relative flow angle, degrees
M	Mach number
Subscript	
1	rotor inlet
2	rotor outlet
abs	absolute
rel	relative

TABLE A.1.3

Test Compressor Design Data (Rotor)

Stage		1	2	3	4	5	6
Radius	R	2.161	2.161	2.161	2.161	2.161	2.161
Camber Angle	θ	22.6	15.9	18.0	19.7	20.9	22.0
Stagger	γ	46.1	42.3	36.5	36.1	36.0	36.3
Incidence	i	0.0	2.0	2.0	2.0	2.0	2.0
Deviation	δ	7.3	5.4	6.0	6.0	6.1	6.2
Chord	c	0.605	0.554	0.534	0.510	0.483	0.456
Solidity	σ	0.713	0.815	0.787	0.941	0.997	1.075
Max. Thickness	t	0.036	0.039	0.037	0.036	0.034	0.032
Thickness-Chord Ratio	t/c	0.060	0.070	0.070	0.070	0.070	0.070
No. of Blades	n	16	20	20	25	28	32

Note: R, c, t in [inches] and θ, γ, δ, i in [degrees]

TABLE A.1.4

Test Compressor Design Data (Stator)

Stage		IGV	1	2	3	4	5	6
Radius	R	2.161	2.161	2.161	2.161	2.161	2.161	2.161
Camber Angle	θ	31.7	22.4	25.6	26.2	24.4	24.7	17.3
Stagger	γ	-15.9	31.3	36.3	36.6	36.8	37.4	42.6
Incidence	i	0.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
Deviation	δ	6.7	9.6	5.2	8.0	7.9	7.5	5.6
Chord	c	1.395	0.442	0.412	0.412	0.412	0.412	0.412
Solidity	σ	0.719	0.456	0.789	0.850	0.972	1.093	0.910
Max. Thickness	t	0.170	0.040	0.025	0.025	0.025	0.025	0.025
Thickness-Chord Ratio	t/c	0.122	0.09	0.06	0.06	0.06	0.06	0.06
No. of Blades	n	7	14	26	28	32	36	30

Note: R, c, t in [inches] and θ, γ, δ, i in [degrees]

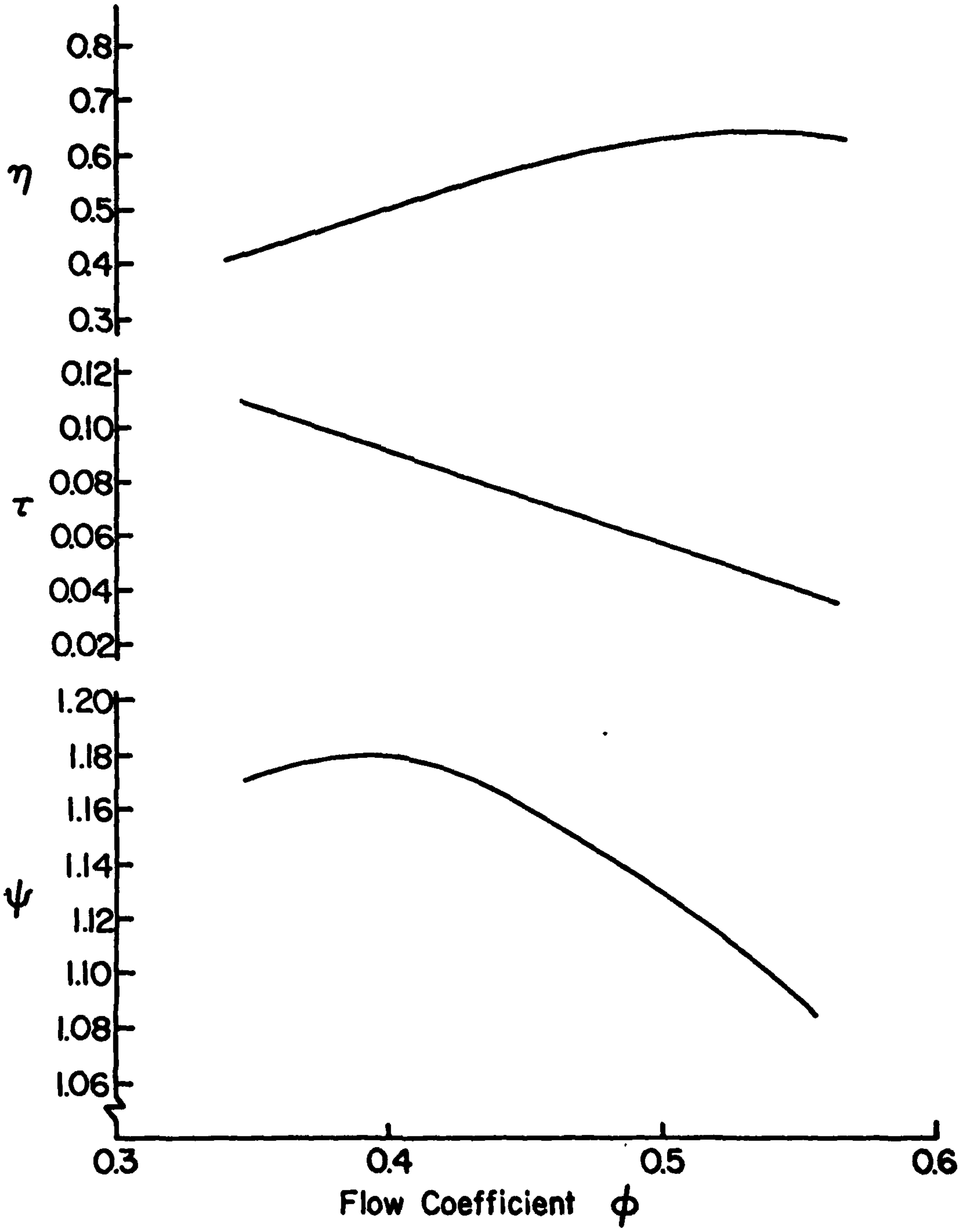

Fig. A.1.1 Performance Characteristics of Test Compressor (1st Stage)

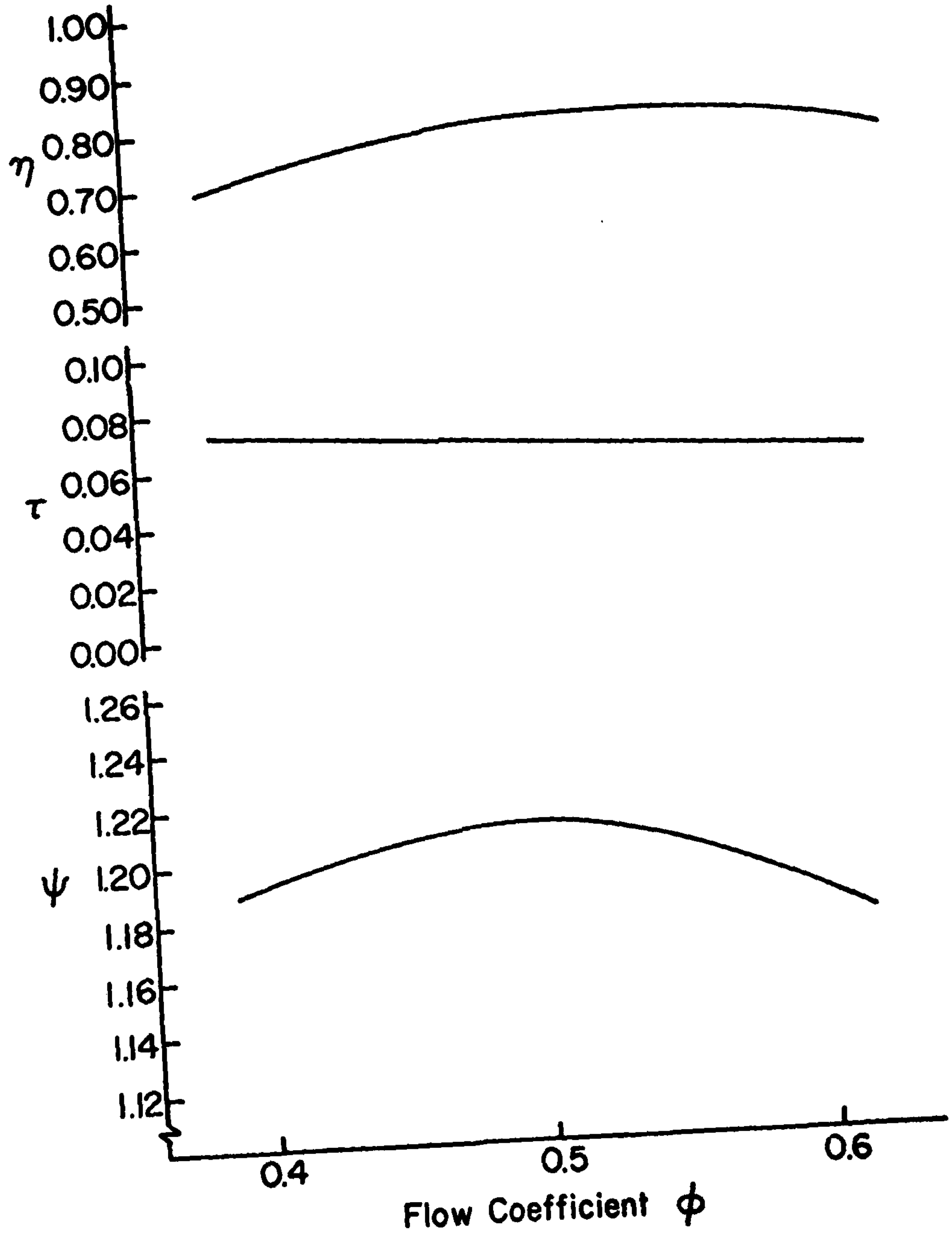

Fig. A.1.2 Performance Characteristics of Test Compressor (2nd Stage)

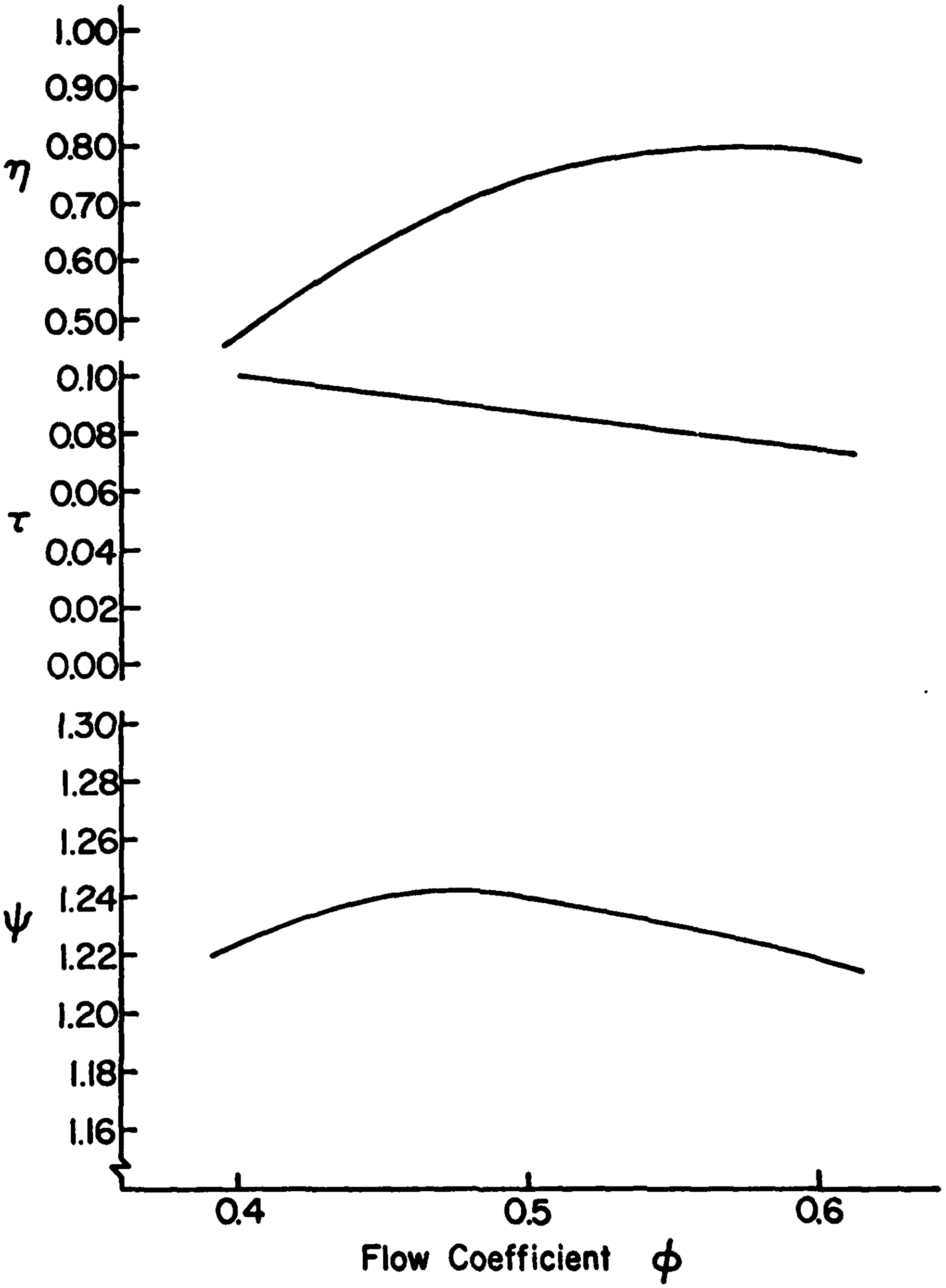

Fig. A.1.3 Performance Characteristics of Test Compressor
(3rd Stage)

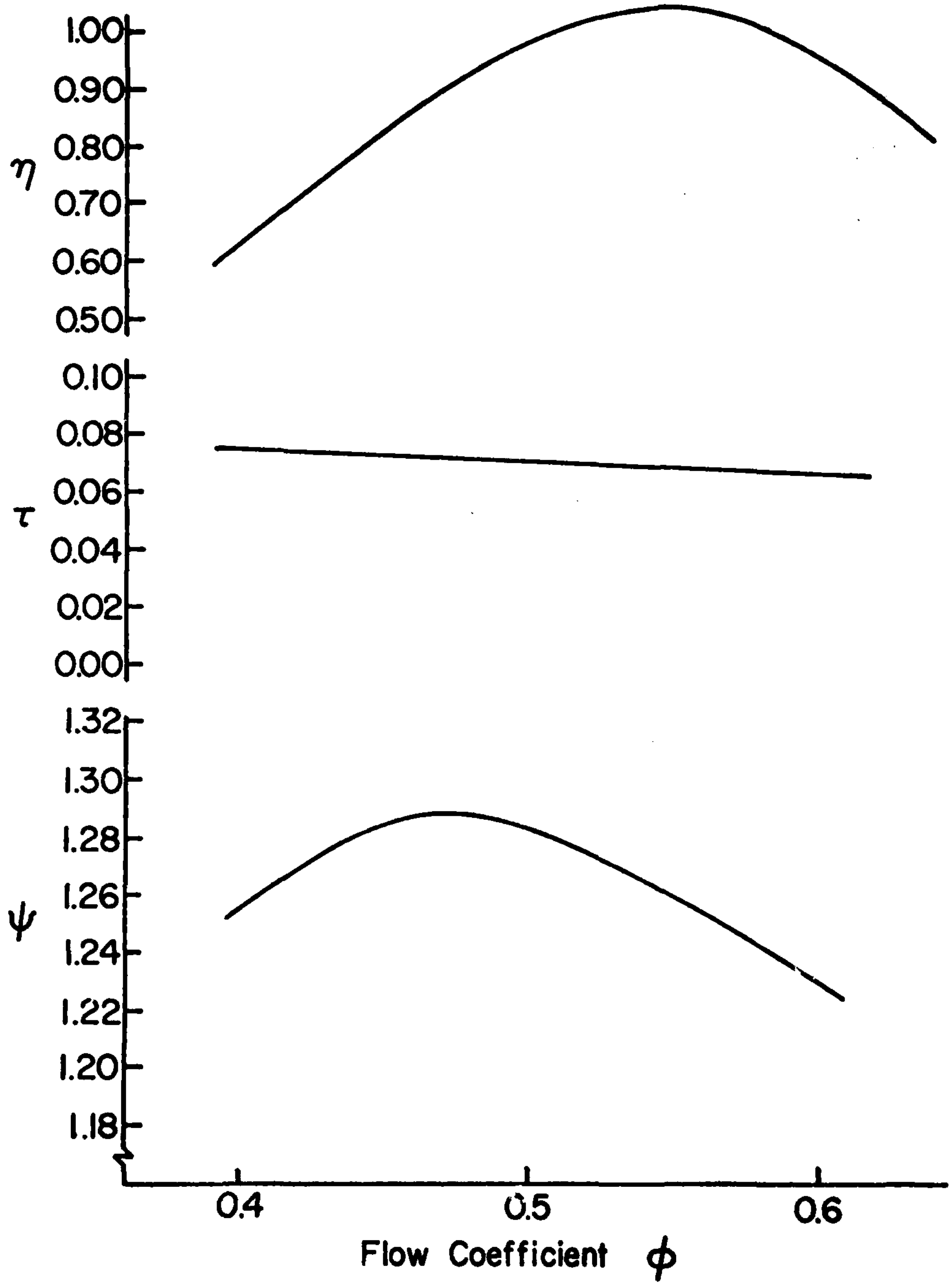

Fig. A.1.4 Performance Characteristics of Test Compressor (4th Stage)

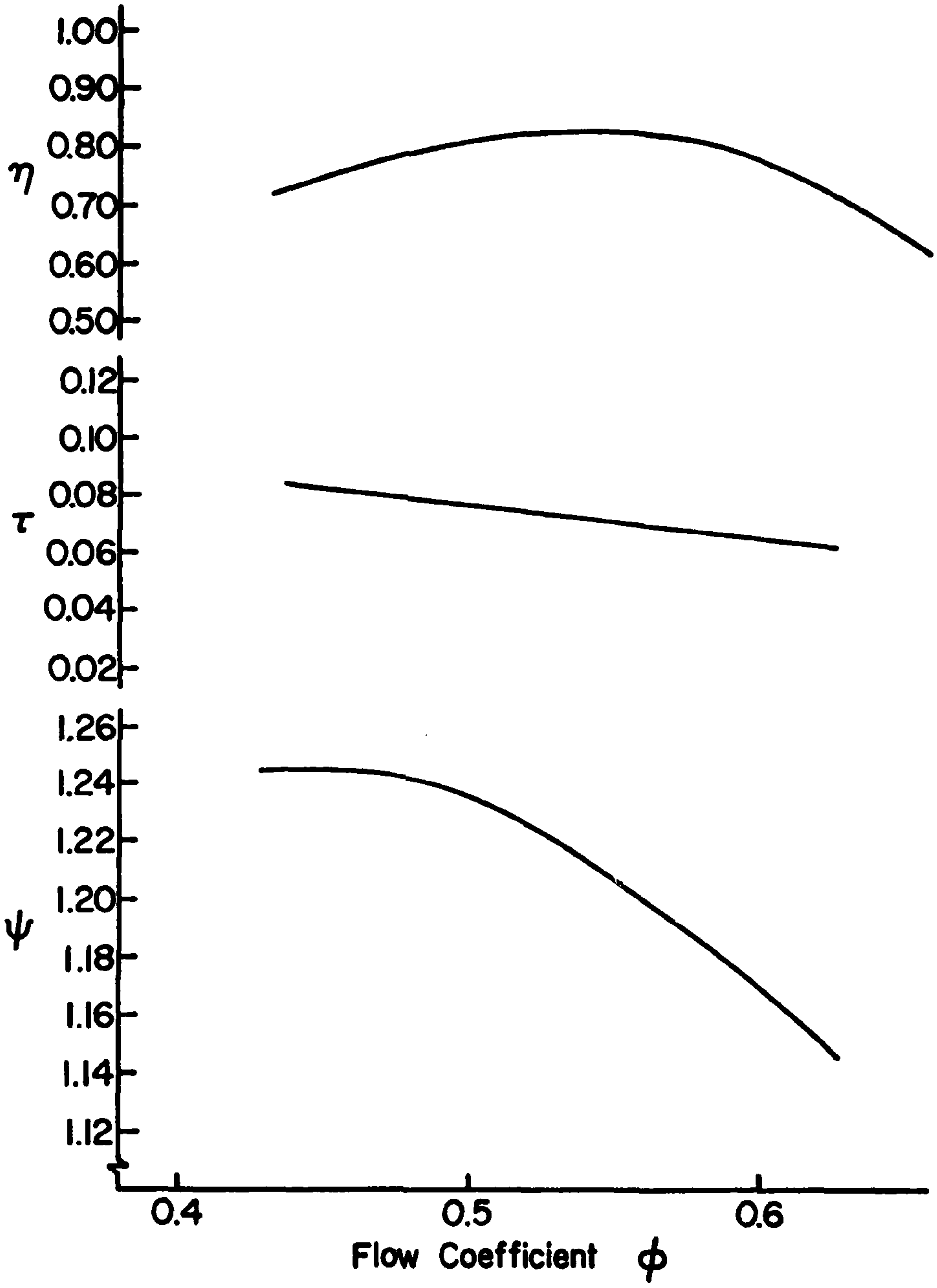

Fig. A.1.5 Performance Characteristics of Test Compressor (5th Stage)

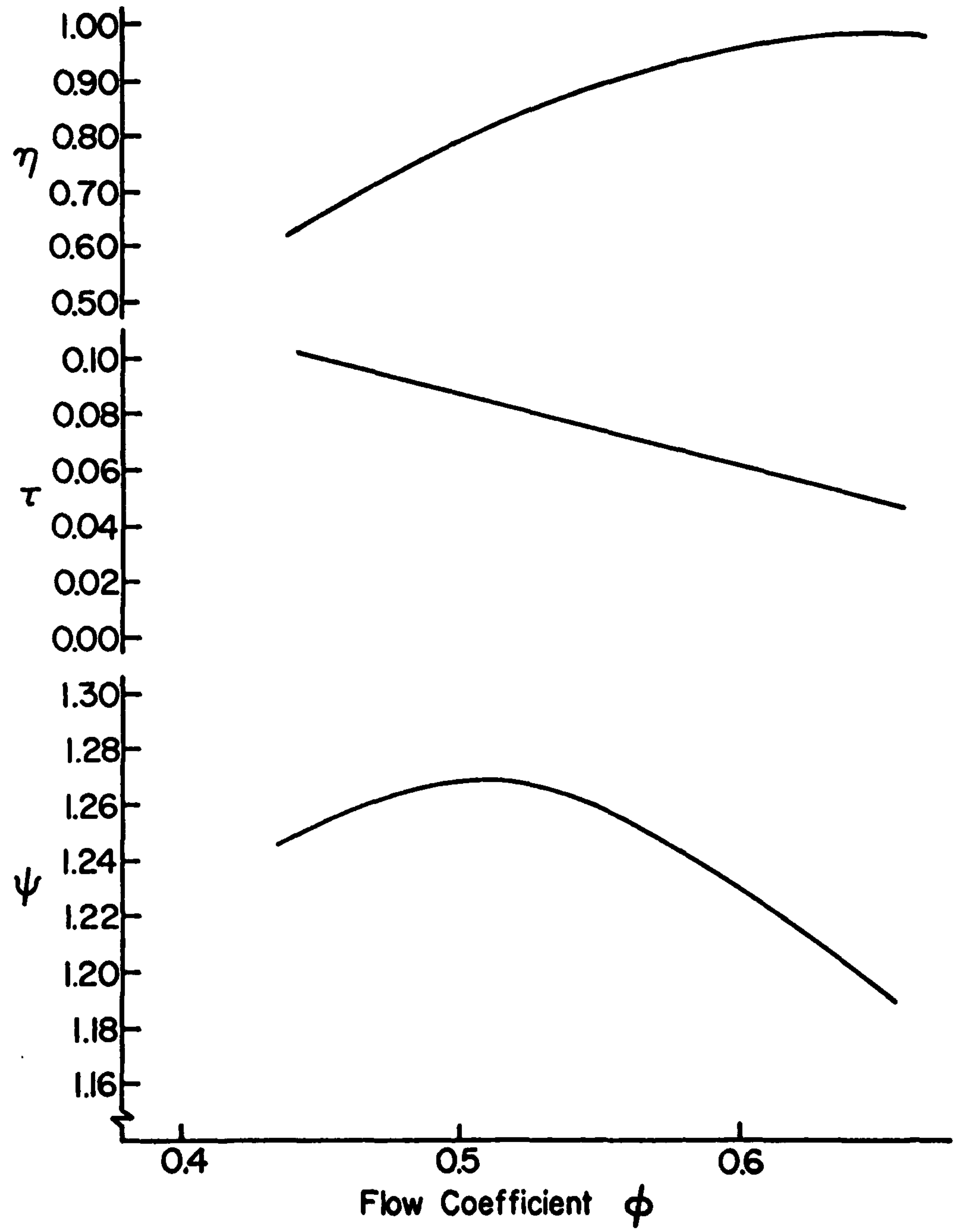

Fig. A.1.6 Performance Characteristics of Test Compressor (6th Stage)

(iv) stage adiabatic efficiency: η

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

where ΔT_0 is stage total temperature rise, P_0 total pressure, T_0 total temperature, V_z axial velocity, U_{tip} blade tip wheel speed, γ 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 $= \frac{\dot{m}\sqrt{\theta}}{\delta}$

where $\dot{m}$ = mass flow rate
T_{01} = compressor inlet pressure
P_{01} = compressor inlet temperature
θ = T_{01}/T_{ref}
δ = P_{01}/P_{ref}
T_{ref} = $58.7^{\circ}F(15.2^{\circ}C)$
P_{ref} = 14.7 psi ($1.0132 \times 10^5 N/m^2$)

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

where N = rotor speed (RPM)

(3) Overall total pressure ratio $= P_{02}/P_{01}$

where P_{01} = compressor inlet total pressure
P_{02} = compressor outlet total pressure

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

where T_{01} = compressor inlet total temperature
ΔT_0 = compressor total temperature rise

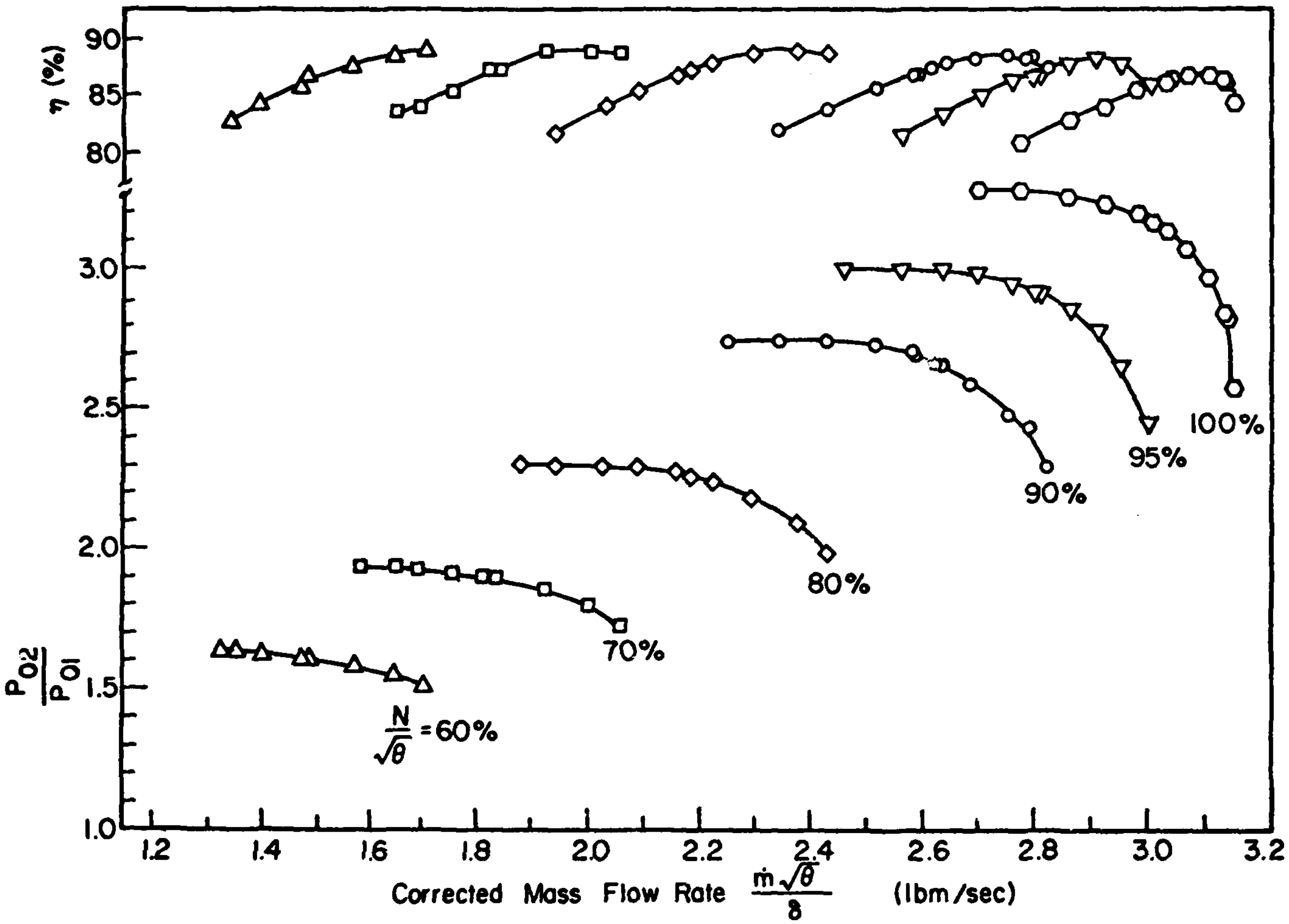

Fig. A.I.7 Overall Performance of Test Compressor

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EFFECT OF WATER ON AXIAL FLOW COMPRESSORS. PART I. ANALYSIS AND--ETC(U)
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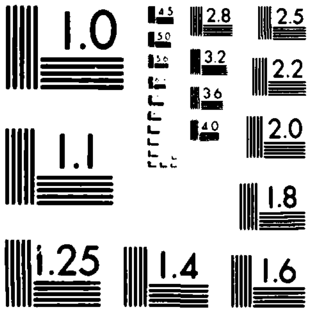

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P_{02}/P_{01} = overall total pressure ratio
γ = ratio of specific heats

3. Limitations

The Test Compressor is driven, through a mechanical gear train, by the power turbine of the Drive Engine. The 6-stage Test Compressor has been utilized in the past for up to 30 hours. The available lifetime for further use of that Test Compressor has been uncertain.

The Test Compressor has a plastic coating on the casing that supports the stator blade rings. The mechanical and thermal strength of the coating has been uncertain since the casing was built over ten years ago and may have aged. At design point, the Test Compressor temperature rise is about 192°F, (106°C) when the inlet-air temperature is 58.7°F, (15.2°C). A casing has been replaced by a second casing during preliminary testing.

The throttle regulating the Test Compressor mass flow at any given speed of operation consists of a conical center piece that can be set at any desired location concentrically in a diverging section which is then opened to atmospheric conditions following a straight duct. The center piece can be moved utilizing an electric motor. The throttle (annulus) area that is available during center piece motion is shown in Fig. A.1.8. It is possible to set the throttle to within a tenth of an inch (about 2.0 mms) during horizontal traverse of the throttle centerpiece. At a given Test Compressor speed, a chosen throttle setting may yield one of two types of performance: (i) when it is unchoked, the pressure ratio across the throttle (the downstream pressure being related to the atmospheric pressure) determines the mass flow throughout the Test Compressor; and (ii) when the throttle area is too large for passing the mass flow through the Test Compressor with a particular set of inlet conditions, the Compressor will operate under free-wheeling conditions.

The Test Compressor assembly with the gear box connecting it to the Drive Engine is such that there is no simple access to its outlet section for locating adequate instrumentation or adjusting probes to establish compressor outlet conditions. The gear box disassembly and removal of the compressor outlet ducting are required each time any access is desired to the compressor outlet section.

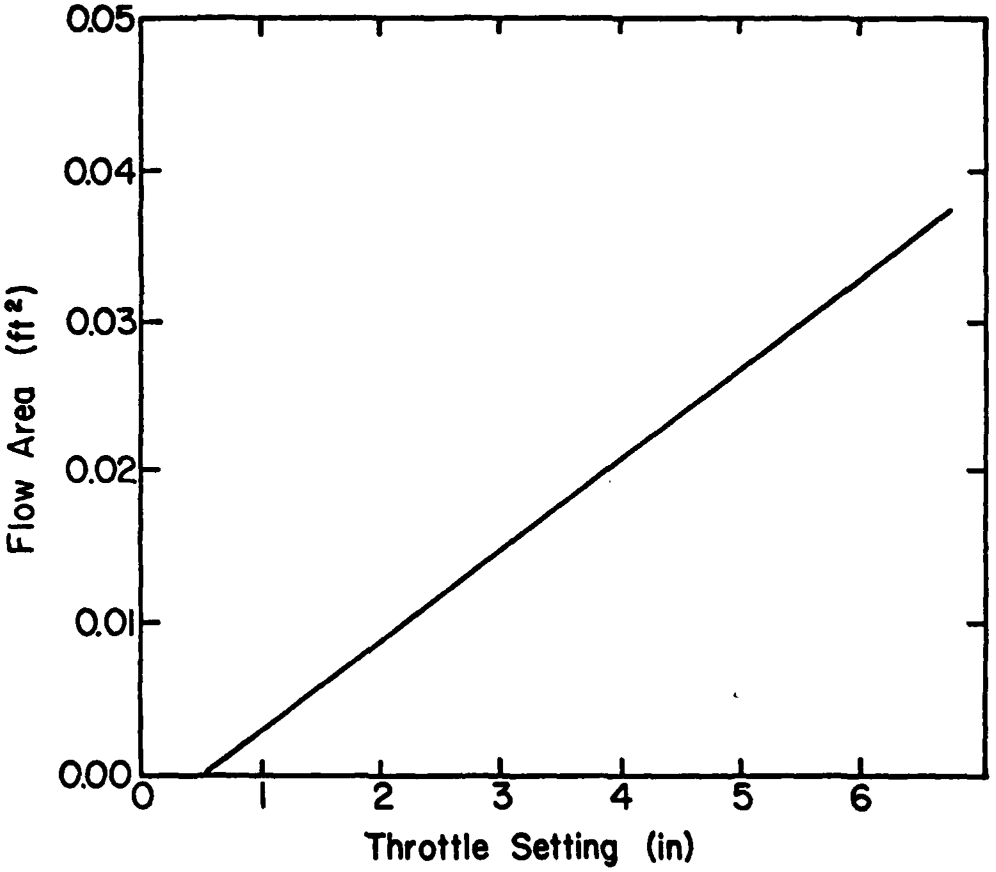

Fig. A.1.8 Flow Area vs. Throttle Setting

3.1 Refurbishment

The Drive Engine and the Test Compressor have been refurbished in the following respects by the Detroit Diesel Allison of Indianapolis, who are the original manufacturers of both the units.

(1) Engine fuel flow control;
(2) Drive shaft interconnecting the Drive Engine and the Test Compressor;
(3) Test Compressor gear box;
(4) Test Compressor bearings; and
(5) The 6-stage assembly of Test Compressor, including balancing.

Following this refurbishment and additional work undertaken at Purdue University, proof-runs undertaken on the Drive Engine - Test Compressors installation showed feasibility of satisfactory operation of the test unit.

APPENDIX 2

STAGE PERFORMANCE CALCULATION

There are two options in the PURDU-WICSTK Code for the calculation of stage performance:

(1) based on given stage characteristics, and

(2) through the estimation of work done and losses in a stage, based on an analytical model.

In both cases, several approximations are required. It may also be recalled that the stage performance calculation being discussed here pertains only to establishing the stage work done, and the consequent temperature and pressure rise, and the stage losses as they occur between the leading and trailing edges of a blade. As stated in Chapter II, and also in Reference 22, the final exit conditions from a stage are established after correcting the stage outlet conditions for various two phase flow effects.

In calculating the stage performance, it is necessary to take into account the presence of droplets in the fluid, and their motion, particularly their impact on the blades. Such impaction leads to the formation of a film on the blade surface, composed of water from unrebound droplets, and a change in the boundary layer and separation characteristics. Thus, the stage characteristics become different for a droplet-laden gas flow from those for a single phase gas. The change in stage characteristics arises through modification of (a) momentum thickness of boundary layer, (b) diffusion factor and (c) deviation angle.

It may be stated at the outset that no correlations of compressor, cascade or even single airfoil performance data are available for two phase flow. It is therefore necessary to model compressor flow based on a number of approximations, in turn related to physical process models.

In order to account for various drop sizes that may arise in a spray, it has been suggested, in Reference 22 and again in Chapter 11, that two classes of droplets be identified, one referred to as "small"and the other as "large." In adjusting droplet sizes for any reason, it is assumed that small droplets may only remain small, while large droplets may become small enough to belong to the small droplet class. From the point of view of blade passage flow, the principal distinction between small and large droplets is, as has been mentioned earlier, that small droplets are sufficiently small and follow the gas phase streamlines; but large droplets, which are in order of about 100 μm in diameter, are assumed to have equal probability of motion in all directions in the forward sector. In addition, it is assumed that only small droplets may absorb part of the work input. Other distinctions between the two classes of droplets arise from the foregoing and are taken into account in developing compressor flow models for the two classes of droplets.

In order to simplify calculations of stage losses, three procedures have been developed as follows:

(1) procedure when the compressor operate with a single (gas) phase;
(2) procedure when only small droplets are present; and
(3) procedure when large droplets are present either by themselves or along with small droplets.

Typical velocity diagram for an axial compressor stage is presented in Fig.A.2.1.

A.2.1. Procedure of Gas Phase Operation

One can use either (1) available stage characteristics or (2) an analytical/correlation method for obtaining stage characteristics. For the Test Compressor employed in this investigation, the analytical/ correlation method recommended is based on References 23 and 24.

A.2.1.1. Use of Available Stage Characteristics

The stage performance calculation for gas phase operation, with use of available stage characteristics, are carried out as follows:

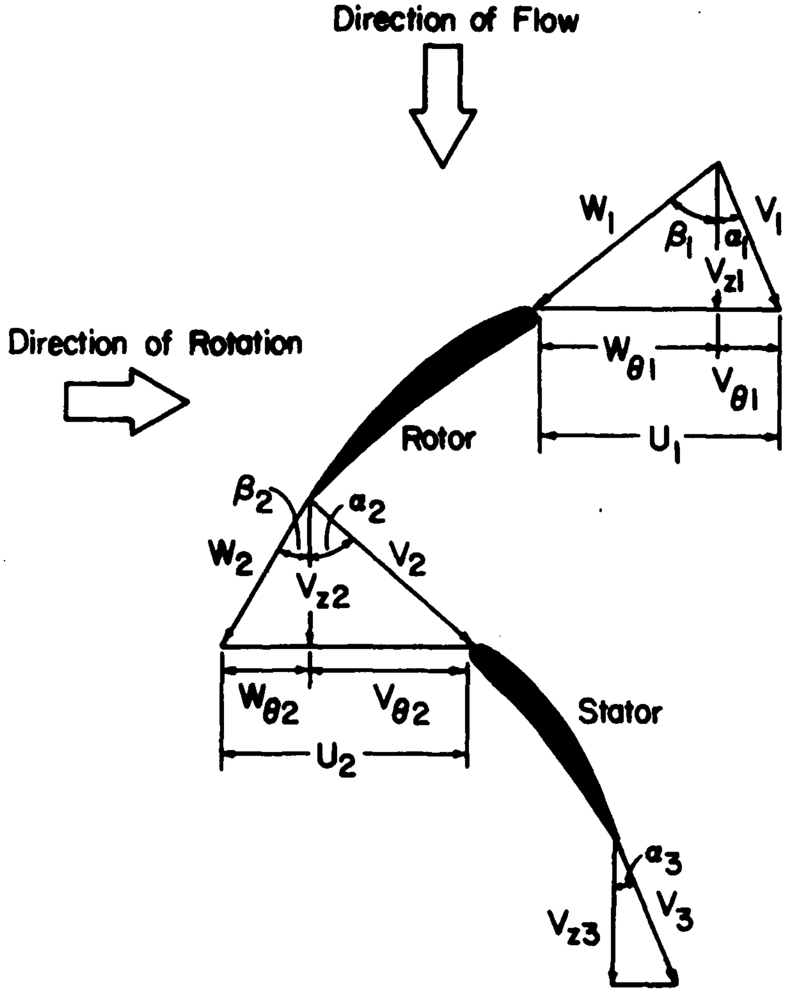

Fig. A.2.1 Typical Velocity Diagram for a Compressor Stage

(1) From given inlet conditions or the previous stage outlet conditions, the total temperature, T_{01} , and the total pressure, P_{01} , are known.

(2) Calculate the density based on T_{01} and P_{01}

$$\rho_{01} = P_{01}/R_m T_{01}$$

(3) Assume Mach number M_a.

(4) Calculate static temperature, T, and density, ρ .

$$\rho = \left\{1 + (\gamma - 1)M_a^2/2\right\}^{-1/(\gamma - 1)} \cdot \rho_{01}$$

$$T = \left\{1 + (\gamma - 1)M_a^2/2\right\}^{-1} \cdot T_{01}$$

(5) Calculate acoustic speed

$$a = (\gamma R_m T g_c)^{1/2}$$

(6) Calculate the axial velocity

$$V_z = \dot{m}_m/\rho A$$

(7) Calculate the absolute velocity at rotor inlet, V_1.

$$V_1 = V_z/\cos \alpha_1$$

(8) Calculate Mach number

$$M = V_1/a = M_c$$

(9) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_c agrees within prescribed limits with M_a, proceed to the next step. Otherwise, steps 3 to 9 should be repeated until a satisfactory accuracy is obtained.

(10) Calculate the flow coefficient, ϕ, at the entrance to the stage under consideration.

$$\phi = V_z/U_{tip}$$

(11) Enter the stage characteristics curve at the value of ϕ and obtain the equivalent pressure ratio, ψ, equivalent temperature ratio, τ, and stage adiabatic efficiency, η.

The definitions of ψ, τ, and η are as follows:

(i) flow coefficient: ϕ

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio:

$$\psi = \left\{ \left(\frac{U_{tip}^2}{T_{01}}\right)_D \left(\frac{T_{01}}{U_{tip}^2}\right) \left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} - 1\right] + 1 \right\}^{\gamma/(\gamma-1)}$$

(iii)equivalent temperature ratio: τ

$$\tau = \left(\frac{U_{tip}^2}{T_{01}}\right)_D \cdot \left(\frac{\Delta T_0}{U_{tip}^2}\right)$$

(iv) stage adiabatic efficiency:

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

where ΔT_0 is stage total temperature rise, P_0 total pressure, T_0 total temperature, V_z axial velocity, U_{tip} blade tip wheel speed, γ specific heat ratio. The subscripts 1 and 2 mean inlet and outlet, respectively, and D design value.

The equivalent pressure ratio, ψ, equivalent temperature ratio, τ, and stage adiabatic efficiency, η, may be expressed in terms of flow coefficient as follows:

$$\psi = A_1 + B_1\phi + C_1\phi^2 + D_1\phi^3 + E_1\phi^4 + F_1\phi^5 + G_1\phi^6$$

$$\eta = A_2 + B_2\phi + C_2\phi^2 + D_2\phi^3 + E_2\phi^4 + F_2\phi^5 + G_2\phi^6$$

$$\tau = A_3\phi + B_3$$

(12) Once the values of ψ, τ, and η corresponding to ϕ are obtained, the stage outlet properties can be calculated from their definitions. Actually two of them are enough to determine the stage outlet properties. In the present calculation scheme, the equivalent temperature rise ratio, τ , and the stage adiabatic efficiency, η , are used. The stage total temperature rise, ΔT_0 , stage and total temperature ratio, $T_{0\,2}/T_{0\,1}$, and stage total pressure ratio, $P_{0\,2}/P_{0\,1}$, are given by the following:

$$\Delta T_0 = \tau U_{tip}^2 / (U_{tip}/T_{0\,1})_D$$

$$T_{0\,2}/T_{0\,1} = 1 + \Delta T_0 / T_{0\,1}$$

$$P_{0\,2}/P_{0\,1} = (1 + \eta\, \Delta T_0 / T_{0\,1})^{\gamma/(\gamma-1)}$$

A.2.1.2. Use of Analytical/Correlation Method

The stage performance calculation for gas phase operation is carried out using the analytical/correlation method as follows:

(1) From given inlet conditions or the previous stage exit conditions, the total temperature, $T_{0\,1}$, and total pressure, $P_{0\,1}$, are obtained.

(2) Calculate specific heat ratio corresponding to the temperature.

(3) Calculate the stagnation density

$$\rho_{0\,1} = P_{0\,1}/RT_{0\,1}$$

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density and temperature.

$$\rho_1 = \left\{1 + (\gamma-1)M_a^2/2\right\}^{-1/(\gamma-1)} \cdot \rho_{0\,1}$$

$$T_1 = \left\{1 + (\gamma-1)M_a^2/2\right\}^{-1} \cdot T_{0\,1}$$

(6) Calculate the acoustic speed

$$a_1 = (\gamma R T_1 g_c)^{0.5}$$

(7) Calculate the axial velocity

$$V_{z1} = \dot{m}/\rho_1 A_1$$

(8) Calculate the absolute velocity

$$V_1 = V_{z1}/\cos \alpha_1$$

(9) Calculate the Mach number, M_c.

$$M_c = V_{z1}/a_1$$

(10) Compare the assumed value of Mach number, M_a, with the calculated one, M_c. If M_a agrees within prescribed limits with M_c, proceed to the next step. Otherwise, steps (4) to (9) must be repeated.

(11) Calculate the components of velocity from the velocity diagram at rotor inlet as follows:

$$V_1 = V_{z1}/\cos \alpha_1$$

$$V_{\theta 1} = V_{z1} \tan \alpha_1$$

$$W_{\theta 1} = U_1 - V_{\theta 1}$$

$$W_1 = (V_{z1}^2 + W_{\theta 1}^2)^{0.5}$$

$$\beta_1 = \tan^{-1}(W_{\theta 1}/V_{z1})$$

(12) Calculate relative Mach number at rotor inlet

$$M_{r1} = W_1/a_1$$

(13) Calculate static pressure at rotor inlet

$$p_1 = (T_{01}/T_1)^{-\gamma/(\gamma-1)} \cdot P_{01}$$

(14) Calculate total pressure at rotor inlet based on the relative Mach number, M_r.

$$P_{01,r} = \left\{ 1 + (\gamma-1)M_{r1}^2/2 \right\}^{\gamma/(\gamma-1)} . P_1$$

(15) Assuming V_{z_2} , calculate the total pressure loss coefficient across rotor and rotor outlet flow angle.

(16) Calculate the components of velocity at rotor outlet as follows:

$$W_{\theta 2} = V_{z2} \tan \beta_2$$

$$V_{\theta 2} = U_2 - W_{\theta 2}$$

$$W_2 = (V_{z2}^2 + W_{\theta 2}^2)^{0.5}$$

$$V_2 = (V_{z2}^2 + V_{\theta 2}^2)^{0.5}$$

$$\alpha_2 = \tan^{-1} (V_{\theta 2}/V_{z2})$$

(17) Calculate the total temperature at rotor outlet.

$$T_{02} = T_{01} + (U_2 V_{\theta 2} - U_1 V_{\theta 1})/c_p g_c J$$

(18) Calculate static temperature at rotor outlet.

$$T_2 = T_{02} - V_2^2/2c_p g_c J$$

(19) Calculate acoustic speed at rotor outlet.

$$a_2 = (\gamma R T_2 g_c)^{0.5}$$

(20) Calculate absolute and relative Mach number at rotor outlet.

$$M_2 = V_2/a_2$$

$$M_{r_2} = W_2/a_2$$

(21) Calculate total pressure loss factor across rotor.

$$\frac{P_{02,r}}{P_{01,r}} = \frac{P_{02,ri}}{P_{01,r}} = \bar{\omega}_R \ (1 - \frac{p_1}{P_{01,r}})$$

where

$$\frac{P_{02,ri}}{P_{01,r}} = (\frac{T_{02,r}}{T_{01,r}})^{\frac{\gamma}{\gamma-1}}$$

$$= \left\{1 + \frac{\gamma-1}{2} \ \frac{U_2^2}{RT_{01,r}} \left[1 - (\frac{r_1}{r_2})^2\right]\right\}^{\frac{\gamma}{\gamma-1}}$$

(22) Calculate total pressure ratio across rotor, and total and static pressure at rotor outlet.

$$\frac{P_{02}}{P_{01}} = (\frac{T_{02}}{T_{01}})^{\frac{\gamma}{\gamma-1}} \cdot (\frac{P_{02,r}}{P_{01,r}}) \cdot (\frac{P_{02,ri}}{P_{01,r}})^{-1}$$

$$P_{02} = (\frac{P_{02}}{P_{01}}) \ P_{01}$$

$$P_2 = (1 + \frac{\gamma-1}{2} M_2^2)^{-\gamma/(\gamma-1)} \cdot P_{02}$$

(23) Calculate density at rotor outlet.

$$P_2 = P_2/RT_2$$

(24) Calculate the axial velocity at rotor outlet.

$$V_{z2} = \dot{m}/\rho_2 A_2$$

(25) Compare the calculated value of V_{z2} in (24) with the assumed V_{z2} in (15). Iterate steps (15) to (24) until a desired accuracy is obtained.

(26) Calculate total pressure at rotor outlet.

$$P_{02} = \left\{ 1 + (\gamma - 1)M_2^2/2 \right\}^{\gamma/(\gamma-1)} \cdot p_2$$

(27) Calculate the total pressure loss coefficient across stator, $\overline{\omega}_S$, and stator outlet angle α_3.

(28) Calculate total pressure loss factor across stator.

$$\frac{P_{03}}{P_{02}} = 1 - \overline{\omega}_S \left(1 - \frac{P_2}{P_{02}}\right)$$

(29) Calculate the total pressure ratio and total temperature ratio across the stage.

$$PR = \frac{P_{03}}{P_{01}} = \left(\frac{T_{03}}{T_{01}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,r}}{P_{01,r}}\right) \cdot \left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1} \cdot \left(\frac{P_{03}}{P_{02}}\right)$$

$$TR = T_{03}/T_{01}$$

(30) Obtain total pressure and temperature at stator outlet.

$$P_{03} = \left(\frac{P_{03}}{P_{02}}\right) \cdot P_{02}$$

$$T_{03} = T_{02}$$

(31) Calculate the average value of specific heat ratio.

(32) Calculate the stage efficiency.

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

A.2.2 Procedure when Small Droplets are Present.

When all of the droplets present at entry to a stage can be categorized as small droplets, the following assumptions are introduced.

(1) Droplets follow gas phase streamlines.

(2) A fraction of the droplets impacting the blades undergo rebound. The balance of impacting droplets move over the blade surface in the form of a thin film. The momentum of the thin film is negligible.

(3) The development of the boundary layer over the blade surface can be based on Reference 25. The following assumptions are made in that Reference: (i) droplets do not interact with one another; (ii) a two phase boundary layer exists; and (iii) the momentum thickness for the two phases can be superposed after they are obtained in two parts.

(4) The deviation angle remains the same in two phase flow as in single phase flow. The reasoning is that diffusion and transport of particles can be neglected as being small and, in any case, as balancing each other.

(5) The loss coefficient for two phase flow is thus the sum of the loss coefficient for each phase. The loss coefficient for the liquid phase may also be added in an appropriate form to the stage efficiency for a stage obtained during operation with air in order to obtain the stage efficiency for two phase flow.

(6) Considering a blade passage flow, between two neighboring blades, away from solid boundaries, the drag due to droplets can be calculated assuming Stokes drag relation. The number of droplets suffering such drag is the sum of the number of non-impacting droplets and the number of rebound droplets.

(7) The overall loss is obtained by adding the losses described under (5) and (6).

A.2.2.1 Use of Available Stage Characteristics

In dealing with a mixture containing small droplets, it is assumed that (a) gas phase and the small droplets behave in the same fashion in absorbing work input as a gas, and (b) the influence of small droplets arises in the determination of (a) the flow coefficient and (b) the stage losses.

In using gas flow stage characteristics for a mixture with small droplets, the pressure rise for the gas phase, the temperature rise of water and efficiency are determined for the relevant value of flow coefficient from the gas phase characteristics, and then, the efficiency is further modified to account for the presence of small droplets.

The stage performance calculation for a mixture with small droplets can thus be carried out using the available stage characteristics as follows:

(1) From the previous stage outlet properties, the gas phase total temperature, $T_{01,g}$, and the total pressure, P_{01}, are known.

(2) Calculate the gas constant, specific heat at constant pressure, and specific heat ratio of the gas phase.

(3) Calculate the stagnation density of gas phase.

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density and static temperature of the gas phase.

(6) Calculate the acoustic speed in the gas phase.

(7) Calculate the acoustic speed in the mixture, a.

(8) Calculate the density of the mixture.

$$\rho_m = \left(\frac{x_g}{\rho_g} + \frac{x_w}{\rho_w}\right)^{-1}$$

(9) Calculate the axial velocity.

$$V_z = \dot{m}_m/\rho_m A$$

(10) Calculate the absolute velocity.

$$V_1 = V_z/\cos \alpha_1$$

where α_1= air outlet angle of the previous stage stator.

(11) Calculate the Mach number, M_c.

$$M_c = V_1/a$$

(12) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_a agrees reasonably well with M_c, proceed to the next step. Otherwise, steps (4) to (11) must be repeated.

(13) Calculate the flow coefficient at the entrance of the stage

$$\phi = V_z/U_{tip}$$

(14) Enter the stage characteristic curve at the foregoing value of ϕ.

The compressor stage characteristics, described in A.2.1.1., which apply to air flow through the compressor, have been utilized in this calculation for obtaining the stage temperature ratio and stage adiabatic efficiency for the mixture of air and small droplets. It may be recalled that the stage temperature rise corresponding to a mixture flow coefficient has to be apportioned between the gas and the liquid phases. The gas phase then undergoes a change in temperature and pressure while the liquid phase undergoes only a temperature change.

Utilizing the stage temperature ratio and adiabatic efficiency, one can then calculate the stage pressure ratio and the change in water temperature. In the current method of calculating stage performance for two phase flow, all of the other effects due to the presence of droplets are taken into account at the exit of the stage under consideration.

(15) Apportion energy input into the mixture.

Regarding apportionment of energy input into the mixture in a stage, one proceeds as follows. The work input is expressed by the following relations:

$$\Delta H_0 = (\Delta H_0)_1 + (\Delta H_0)_2 + (\Delta H_0)_3 + (\Delta H_0)_4$$

where

ΔH_0 : actual work input in rotor;
$(\Delta H_0)_1$: work input to gas phase;
$(\Delta H_0)_2$: work input absorbed by droplets which do not impinge upon blade surface;
$(\Delta H_0)_3$: work input absorbed by water droplets which impinge upon blade surface, adhere to form a film and are re-entrained from the trailing edge; and
$(\Delta H_0)_4$: work input absorbed by droplets which impinge upon blade surface and rebound.

Defining mass fractions as follows:

x_g : mass fraction of gas phase.
x_{w_1} : mass fraction of water which does not impinge upon blade surface
x_{w_2} : mass fraction water which impinges on the blade surface and rebounds
x_{w_3} : mass fraction of water which is re-entrained from the trailing edge.

and noting that

$$x_g + x_{w1} + x_{w2} + x_{w3} = 1,$$

one can express the work input fractions as follows in terms of the stage work done factor, λ .

$$(\Delta H_0)_1 = \lambda U_2(W_{\theta 1} - W_{\theta 2})\, x_g$$

$$(\Delta H_0)_2 = \lambda U_2(W'_{\theta 1} - W'_{\theta 2})\, x_{w1}$$

where $W_{\theta 1}$ and $W'_{\theta 1}$ are relative inlet whirl velocities of the gas phase and water droplets which do not impinge upon the blade surface, respectively, and $W'_{\theta 2}$ and $W_{\theta 2}$ are the same velocities at outlet. Also, from physical considerations, the angular momentum change of water which impinges on the surface and adheres to form films and is finally re-entrained from the trailing edge can be considered to be negligible. Therefore,

$$(\Delta H_0)_3 = 0$$

Then, $(\Delta H_0)_4$ can be calculated by writing

$$(\Delta H_0)_4 = \Delta H_0 - (\Delta H_0)_1 - (\Delta H_0)_2$$

The total work input, ΔH_0, is calculated from the stage performance curves. In the present analysis, since we are considering small droplets, the velocity lag between gas phase and water droplet can be considered to be negligible. Accordingly $W'_{\theta 1}$ and $W'_{\theta 2}$ can be set to be the same as as $W_{\theta 1}$ and $W_{\theta 2}$.

From $(\Delta H_0)_1$, $(\Delta H_0)_2$, $(\Delta H_0)_3$, and $(\Delta H_0)_4$, the total temperature rise can be calculated for each phase.

(16) Obtain the total pressure loss because of the increase in momentum thickness of the boundary layer due to the existence of small droplets in the boundary layer.

(17) Obtain the total pressure loss due to the Stokesian drag of water droplets outside boundary layer.

(18) Calculate the stage outlet total pressure as follows:

$$P_{02} = P_{01} - \Delta P_{\theta} - \Delta P_{S}$$

where P_{02} is the stage outlet total pressure obtained from the available stage characteristics, ΔP_{θ} is the the total pressure loss due to the increase in momentum thickness because of the existence of small droplets in the boundary layer, and ΔP_{S} is the total pressure loss due to the Stokesian drag of water droplets in the free stream outside the boundary layer.

It may be pointed out that in view of the assumption pertaining to motion of small droplets (with zero relative velocity with respect to gas phase), the correction to stage pressure rise due to Stokesian drag becomes zero for small droplets.

(19) Calculate the stage total pressure ratio.

A.2.2.2 Use of Analytical/Correlation Method

In using the analytical/correlation method for the flow of a mixture with small droplets, the basic procedure is the same as when utilizing available stage characteristics, Appendix Section A.2.2. The pressure rise for the gas phase and the termperature rise of water are determined from the mixture turning angle over a blade. The losses are established based on (a) the relation (due to Lieblein) between the loss coefficient and the pressure loss; the loss coefficient in turn related to the momentum thicknesses of the blade boundary layer due to the gas phase and the droplets; and (b) the Stokesian drag of droplets in the free stream. The latter, of course, is zero for small droplets, by definition.

The stage performance calculation for a mixture with small droplets is carried out using the analytical/correlation method as follows:

(1) From the given inlet condition or the previous stage properties, the gas phase total temperature, $T_{01,g}$, and total pressure, P_{01}, are obtained.

(2) Calculate the gas constant, R_g, specific heat constant pressure, c_{pg} and specific heat ratio of gas phase, γ .

(3) Calculate the stagnation density of gas phase.

$$P_{01,g} = P_{01}/R_g T_{01,g}$$

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density and temperature of gas phase.

$$\rho_{g_1} = \left[1+ (\gamma - 1)M_{a_2}^2/2\right]^{-1/(\gamma - 1)} . \rho_{01,g}$$

$$T_{g_1} = \left[1+ (\gamma - 1)M_a^2/2\right] . T_{01,g}$$

(6) Calculate the acoustic speed in the gas phase a_{g_1}.

$$a_{g_1} = (\gamma R_g T_{g_1} g_c)^{0.5}$$

(7) Calculate the acoustic speed in the mixture, a_1 .

(8) Calculate the density of the mixture

$$\rho_m = \left(\frac{x_g}{\rho_g} + \frac{x_w}{\rho_w} \right)^{-1}$$

(9) Calculate the axial velocity

$$V_{z_1} = \dot{m}_m/\rho_1 A_1$$

(10) Calculate the absolute velocity

$$V_1 = V_{z_1}/\cos\alpha_1$$

(11) Calculate the Mach number, M_c.

$$M_c = V_1/a_1$$

(12) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_a agrees within prescribed limits with M_c, proceed to the next step. Otherwise, steps (4) to (11) must be repeated.

(13) Calculate the components of velocity at rotor inlet as follows:

$$V_1 = V_{z_1}/\cos\alpha_1$$

$$V_{\theta 1} = V_{z_1}/\tan\alpha_1$$

$$W_{\theta 1} = U_1 - V_{\theta 1}$$

$$W_1 = (V_{z_1}^2 + W_{\theta 1}^2)^{1/2}$$

$$\beta_1 = \tan^{-1}(W_{\theta 1}/V_{z_1})$$

(14) Calculate relative Mach number at rotor inlet

$$M_{r_1} = W_1/a_1$$

(15) Calculate static pressure at rotor inlet

$$p_1 = (T_{01,g}/T_{g1})^{-\gamma/(\gamma-1)} \cdot P_{01}$$

(16) Calculate total pressure at rotor inlet based on the relative Mach number, M_{r_1} .

$$P_{01,r} = \{1 + (\gamma - 1)M_{r_1}/2\}^{\gamma/(\gamma - 1)} \cdot p_1$$

(17) Assuming V_{z_2} the total pressure loss coefficient across rotor due to gas phase, $\overline{\omega}_{g,R}$, and rotor outlet angle β_2.

(18) Obtain the total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer over a rotor blade surface $\overline{\omega}_{\theta,R}$.

(19) Obtain the total pressure loss across rotor due to the Stokesian drag of water droplets outside boundary layer $\overline{\omega}_{s,R}$.

(20) Calculate the components of velocity at rotor outlet as follows:

$$W_{\theta_2} = V_{z2}\tan\beta_2$$

$$V_{\theta_2} = U_2 - W_{\theta 2}$$

$$W_2 = (V_{z2}^2 + W_{\theta 2}^2)^{0.5}$$

$$V_2 = (V_{z2}^2 + V_{\theta 2}^2)^{0.5}$$

$$\alpha_2 = \tan^{-1}(V_{\theta 2}/V_{z2})$$

(21) Calculate the work input.

$$\Delta H_0 = (U_2V_{\theta 2} - U_1V_{\theta 1})/g_cJ$$

(22) Apportion work input to the mixture constituents as described in item (14) of A.2.2.1.

(23) Calculate static temperature of gas phase at rotor outlet.

$$T_{g_2} = T_{0\,2,g} - V_2^2/c_{pg}\, g_c\, J$$

(24) Calculate acoustic speed in gas phase.

$$a_{g_2} = (\gamma\, R_g T_{g2}\, g_c)^{0.5}$$

(25) Assume $\rho_{g2} = \rho_{g1}$ and calculate the acoustic speed in the mixture, a_2.

(26) Calculate absolute and relative Mach numbers at rotor outlet.

$$M_2 = V_2/a_2$$

$$M_{r_2} = W_2/a_2$$

(27) Calculate total pressure loss factor across rotor.

$$\frac{P_{0\,2,r}}{P_{0\,1,r}} = \frac{P_{0\,2,ri}}{P_{0\,1,r}} - (\bar{\omega}_{g,R} + \bar{\omega}_{\theta,R} + \bar{\omega}_{s,R}) \cdot \left(1 - \frac{P_1}{P_{0\,1,r}}\right)$$

(28) Calculate total pressure ratio across rotor, and total and static pressures at rotor outlet.

$$\frac{P_{02}}{P_{01}} = \left(\frac{T_{0\,2,g}}{T_{0\,1,g}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{0\,2,r}}{P_{0\,1,r}}\right) \cdot \left(\frac{P_{0\,2,ri}}{P_{0\,1,r}}\right)^{-1}$$

$$P_{02} = \left(\frac{P_{0\,2}}{P_{0\,1}}\right) P_{01}$$

$$P_2 = \left(1 + \frac{\gamma-1}{2} M_2^2\right)^{\frac{-\gamma}{\gamma-1}} P_{02}$$

(29) Calculate static density at rotor outlet.

$$\rho_{g_2} = p_2/R_g T_{g2}$$

(30) Compare the calculated value of ρ_{g2} in (29) with the assumed value of ρ_{g2} in (25). Iterate steps (25) to (29) until a desired accuracy is obtained.

(31) Calculate the density of mixture at rotor outlet.

$$\rho_{m2} = \left(\frac{x_g}{\rho_{g2}} + \frac{x_w}{\rho_w} \right)^{-1}$$

(32) Calculate the axial velocity at rotor outlet.

$$V_{z2} = \dot{m}_m/\rho_m A$$

(33) Compare the calculated value of V_{z2} in (32) with the assumed value of V_{z2} in (17). Iterate steps (17) to (32) until a desired accuracy is obtained.

(34) Calculate total pressure at rotor outlet.

$$P_{02} = \left\{ 1 + (\gamma - 1) M_2^2/2 \right\}^{\gamma/(\gamma-1)} . P_2$$

(35) Calculate the total pressure loss coefficient across stator due to gas phase, $\overline{\omega}_{g,S}$, and stator outlet angle, α_3.

(36) Obtain the total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer on a stator blade surface, $\overline{\omega}_{\theta,S}$.

(37) Obtain the total pressure loss across stator due to the Stokesian drag of water droplets in the free stream outside boundary layer $\bar{\omega}_{s,S}$. It may be noted that Stokesian drag is zero in the case of small droplets by definition.

(38) Calculate total pressure loss factor across stator.

$$\frac{P_{03}}{P_{02}} = 1 - (\bar{\omega}_{g,S} + \bar{\omega}_{\theta,S} + \bar{\omega}_{s,S})\ (1 - \frac{P_2}{P_{02}})$$

(39) Calculate the total pressure ratio and gas phase total temperature ratio across stage.

$$PR = \frac{P_{03}}{P_{01}} = \left(\frac{T_{03,g}}{T_{01,g}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,r}}{P_{01,r}}\right) \cdot \left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1} \cdot \left(\frac{P_{03}}{P_{02}}\right)$$

$$TR = T_{03,g}/T_{01,g}$$

(40) Obtain total pressure and gas phase total temperature at stator outlet.

$$P_{03} = \left(\frac{P_{03}}{P_{02}}\right) P_{02}$$

$$T_{03,g} = T_{02,g}$$

(41) Calculate the average value of specific heat ratio.

(42) Calculate the stage efficiency.

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

A.2.3 Procedure when Large or Large and Small Droplets are Present

It is postulated that when large droplets are present, they always play the more dominant role.

The following assumptions are introduced.

(1) Droplets move with equal probability in all directions in the forward sector.

(2) A fraction of the droplets impacting the droplets undergo rebound. The balance of impacting droplets move over the blade surface in the form of a thick film. The momentum of the thick film is appreciable and represents a loss of mixture momentum.

(3) The development of the boundary layer can be estimated based on the following reasoning: (a) The thick film presents a continuous rough surface; (b) the roughness is at most of the order of droplet thickness; and (c) the boundary layer is fully turbulent and extends over the chord length. A coefficient of friction for the flow can then be based on Ref. 26.

(4) The deviation angle remains the same as in the case of single phase flow.

(5) Considering a blade passage flow, between two neighboring blades, away from solid boundaries, the drag due to droplets can be calculated assuming Stokes drag relation, The number of droplets suffering such drag is the sum of the number of non-impacting droplets and the number of rebound droplets.

(6) The overall loss is therefore obtained by adding the losses described under (2), (3) and (5).

It may be observed that the foregoing procedure for large droplets precludes the use of available stage characteristics and subsequent correction of efficiency due to the presence of droplets. The procedure is also different from the Lieblein analytical/correlation method used in the case of small droplets in that no simple superposition of blade profile losses is feasible in the case of large droplets. The loss due to Stokesian drag of large droplets in the free stream, of course, is accounted for by simple addition to other losses.

A.2.3.1. Details of Procedure

The stage performance, when large droplets are present, with or without small droplets, is carried out as follows. It may be pointed out that the determination of stage pressure ratio follows the same procedure as in the case of a mixture with small droplets only, Appendix Section A.2.2.2. The determination of the loss coefficient when large droplets are present is wholly different.

(1) From given initial conditions or from the previous stage properties the gas phase total temperature, $T_{01,g}$ and total pressure, P_{01}, are obtained.

(2) Calculate the gas constant, R_g, specific heat at constant pressure, c_{pg}, and specific heat ratio, γ .

(3) Calculate the stagnation density of gas phase,

$$\rho_{01,g} = P_{01}/R_g T_{01,g}$$

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density, and temperature of gas phase, as follows,

$$\rho_1 = \left\{ 1 + (\gamma - 1)M_{a2}^2/2 \right\}^{-1/(\gamma-1)} . \rho_{01,g}$$

$$T_{g_1} = \left\{ 1+(\gamma -1)\, M_{a_2}^2/2 \right\}^{-1} . T_{01,g}$$

(6) Calculate the acoustic speed in the gas phase, a_{g1}.

$$a_{g1} = (\gamma R_g T_{g1} g_c)^{0.5}$$

(7) Calculate the acoustic speed in the mixture, a_1.

(8) Calculate the density of the mixture.

$$\rho_m = \left(\frac{x_g}{\rho_g} + \frac{x_w}{\rho_w}\right)^{-1}$$

(9) Calculate the axial velocity.

$$V_{z1} = \dot{m}_m / \rho_m A$$

(10) Calculate the absolute velocity.

$$V_1 = V_{z1}/\cos \alpha_1$$

(11) Calculate the Mach number, M_c.

$$M_c = V_1/a_1$$

(12) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_a agrees within prescribed limits with M_c, proceed to the next step. Otherwise steps (4) to (11) must be repeated.

(13) Calculate the components of velocity at rotor inlet as follows:

$$V_1 = V_{z1}/\cos\alpha_1$$

$$V_{\theta_1} = V_{z1}\tan\alpha_1$$

$$W_{\theta 1} = U_1 - V_{\theta 1}$$

$$W_1 = (V_{z1}^2 + W_{\theta 1}^2)^{1/2}$$

$$\beta_1 = \tan^{-1}(W_{\theta 1}/V_{z1})$$

(14) Calculate relative Mach number at rotor inlet.

$$M_{r_1} = W_1/a_1$$

(15) Calculate static pressure at rotor inlet.

$$p_1 = \left\{ (T_{01,g}/T_g) \right\}^{-\gamma/(\gamma-1)} \cdot P_{01}$$

(16) Calculate total pressure at rotor inlet based on M_r.

$$P_{01,r} = \left\{ 1 + (\gamma - 1) M_{r_1}/2 \right\}^{\gamma/(\gamma-1)} \cdot P_1$$

(17) Assuming V_{z_2}, calculate the total pressure loss due to gas phase, $\bar{\omega}_{g,R}$, and rotor outlet angle β_2

(18) Calculate the total pressure loss coefficient due to the momentum gained by thick water film moving over the rotor blade surface, $\bar{\omega}_{f,R}$.

(19) Calculate the total pressure loss coefficient due to turbulent flow of mixture over the rough film surface of rotor blade , $\bar{\omega}_{r,R}$.

(20) Calculate the total pressure loss coefficient due to the Stokesian drag of water droplets in rotor passage, $\bar{\omega}_{s,R}$.

(21) Calculate the components of velocity diagram at rotor outlets as follows:

$$W_{\theta 2} = V_{z2} \tan \beta_2$$

$$V_{\theta 2} = U_2 - W_{\theta 2}$$

$$W_2 = (V_{z2}^2 + W_{\theta 2}^2)^{0.5}$$

$$V_2 = (V_{z2}^2 + V_{\theta 2}^2)^{0.5}$$

$$\alpha_2 = \tan^{-1}(V_{\theta 2}/V_{z2})$$

(22) Calculate the work input.

$$\Delta H_0 = (U_2 V_{\theta 2} - U_1 V_{\theta 1})/g_c J$$

(23) Apportion the energy input in the mixture as described in item (15) of A.2.2.1.

(24) Calculate static temperature of gas phase at rotor outlet.

$$T_{g2} = T_{02,g} - V_2^2/2c_{pg} g_c J$$

(25) Calculate the acoustic speed in gas phase.

$$a_{g_2} = (\gamma R_g T_{g2} g_c)^{0.5}$$

(26) Assume $\rho_{g_2} = \rho_{g_1}$ and calculate the acoustic speed in the mixture a_2.

(27) Calculate absolute and relative Mach number at rotor outlet.

$$M_2 = V_2/a_2$$

$$M_{r_2} = W_2/a_2$$

(28) Calculate total pressure loss factor across rotor.

$$\frac{P_{02,r}}{P_{01,r}} = \frac{P_{02,ri}}{P_{01,r}} - (\bar{\omega}_{g,R} + \bar{\omega}_{f,R} + \bar{\omega}_{r,R} + \bar{\omega}_{s,R}) \cdot (1 - \frac{p_1}{P_{01,r}})$$

(29) Calculate total pressure ratio across rotor, and total static pressure at rotor outlet.

$$\frac{P_{02}}{P_{01}} = (\frac{T_{02,g}}{T_{01,g}})^{\frac{\gamma}{\gamma-1}} \cdot (\frac{P_{02,r}}{P_{01,r}}) \cdot (\frac{P_{02,ri}}{P_{01,r}})^{-1}$$

$$P_{02} = (\frac{P_{02}}{P_{01}})\, P_{01}$$

$$p_2 = (1 + \frac{\gamma - 1}{2} M_2^2)^{\frac{-\gamma}{\gamma-1}}\, P_{02}$$

(30) Calculate static density at rotor outlet.

$$\rho_{g_2} = p_2/R_g T_{g2}$$

(31) Compare the calculated ρ_{g_2} in (27) with the assumed ρ_{g2} in (23). Iterate steps (23) to (27) until a desired accuracy is obtained.

(32) Calculate the density of mixture.

$$\rho_{m_2} = \left(\frac{x_g}{g} + \frac{x_w}{w} \right)^{-1}$$

(33) Calculate the axial velocity at rotor outlet.

$$V_{z_2} = \dot{m}_m/\rho_m A_2$$

(34) Compare the calculated V_{z_2} in (33) with the assumed V_{z_2} in (34). Iterate steps (17) to (33) until the desired accuracy is obtained.

(35) Calculate total pressure at rotor outlet.

$$P_{0\,2} = \left\{ 1 + (\gamma - 1) M_2^2/2 \right\}^{\gamma/(\gamma - 1)} \cdot p_2$$

(36) Calculate the total pressure loss coefficient across stator due to gas phase, $\bar{\omega}_{g,S}$, and stator outlet angle, α_3.

(37) Calculate the the total pressure loss coefficient due to the momentum gained by thick water film on the stator blade surface, $\bar{\omega}_{f,S}$.

(38) Calculate the total pressure loss coefficient due to turbulent friction over a rough film surface over the stator blade, $\bar{\omega}_{r,S}$.

(39) *Obtain the total pressure loss across stator due to Stokesian* drag of large water droplets in the free stream outside boundary layer, $\bar{\omega}_{s,S}$.

(40) Calculate total pressure loss factor across the stator.

$$\frac{P_{0\,3}}{P_{0\,2}} = 1 - (\bar{\omega}_{g,S} + \bar{\omega}_{f,S} + \bar{\omega}_{r,S} + \bar{\omega}_{s,S}) \left(1 - \frac{P_2}{P_{0\,2}}\right)$$

(41) Calculate the total pressure ratio and gas phase total temperature ratio across stage.

$$PR = P_{0\,3}/P_{0\,1} = \left(\frac{T_{0\,3,g}}{T_{0\,1,g}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{0\,2,g}}{P_{0\,1,r}}\right) \cdot \left(\frac{P_{0\,2,ri}}{P_{0\,1,r}}\right)^{-1} \cdot \left(\frac{P_{0\,3}}{P_{0\,2}}\right)$$

$$TR = T_{0\,3,g}/T_{0\,1,g}$$

(42) Obtain total pressure and gas phase total temperature at stator outlet.

$$P_{03} = \left(\frac{P_{03}}{P_{02}}\right) \cdot P_{02}$$

$$T_{03,g} = T_{02,g}$$

(43) Calculate the average value of the specific heat ratio.

(44) Calculate the stage efficiency.

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

APPENDIX 3

DETAILED DESCRIPTION OF SUBROUTINES AND EXTERNAL FUNCTIONS

There are 27 subroutines and 13 external functions in this program. Brief descriptions of these subprograms are presented in Chapter III. A more detailed description of each subprograms is presented here. Each of the subroutines and external functions is presented as follows: (1) Description, (2) Input variables, (3) Output variables, and (4) Usage.

SUBROUTINE WICSPA

(1) Description:

The subroutine WICSPA is used for the calculation of performance based on the inputed stage characteristic curves. A detailed descriptions of calculation procedure is presented in Appendix 2.

(2) Input Variables:

FAIO	initial flow coefficient
ISTAGE	stage at which performance calculation is carried out
MMASS	mass flow rate of mixture.
ALFA1	absolute flow angle at outlet of the previous stage stator
WKDONE	work done factor
DAVE	nominal diameter of small droplet
XDIN	initial water content of small droplet
AK1	constant in Eq. (A.3.6)'
AK3	constant in Eqs. (A.3.1)' and (A.3.2)'

(3) Output Variables:

ETA	stage adiabatic efficiency
BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet
VZ	axial velocity

ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
DELTG	rise in total temperature of gas phase across a stage
DELTW	rise in temperature of small droplet across a stage
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
V1	absolute velocity at rotor inlet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICSPA (FAIO, ISTAGE, MMASS, ALFA1 ,WKDONE, DAVE,XDIN
            ETA, BETA1,BETA2, VZ, ALFA2, ALFA3, DELTG,DELTW
            W1,W2, V1,V2,V3, AK1, AK3)
```

SUBROUTINE WICSPB

(1) Description:

The subroutine WICSPB is used for the calculation of stage performance based on the analytical/correlation method for small droplet. A detailed description of calcualtion procedure is presented in Appendix 2.

(2) Input Variables:

FAIO	initial flow coefficient
ISTAGE	stage at which performance calculation is carried out
MMASS	mass flow rate of mixture
ALFA1	absolute flow angle at outlet of the previous stage stator
WKDONE	work done factor
DAV	nominal diameter of small droplets

DELV	relative velocity between gas phase and large droplets
XMAS	mass flow rate of small droplets
N	station number (Fig. 5.1)
AK1	constant in Eq. (A.3.6)'
AK2	constant in Eq. (A.3.7)' and (A.3.8)'
AK3	constatn in Eq. (A.3.1)' and (A.3.2)'

(3) Output Variables:

OMEGA1	total pressure loss coefficient due to single-phase (gas) flow profile loss in rotor
OMEGA2	total pressure loss coefficient due to loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets in rotor
OMEGA3	total pressure loss coefficient due to Stokesian drag of small droplets in the free stream of blade passage in rotor
OMEGA4	total pressure loss coefficient due to single-phase (gas) flow profile loss in stator
OMEGA5	total pressure loss coefficient due to loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets in stator
OMEGA6	total pressure loss coefficient due to Stokesian drag of small droplets in the free stream of blade passage in stator
OMEGAT	sum of total pressure loss coefficients

BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet
VZ	axial velocity
ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
DELTG	rise in total temperature of gas phase across a stage
DELTW	rise in temperature of small droplet across a stage
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
V1	absolute velocity at rotor inlet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICSPB (FAIO, ISTAGE, MMASS, ALFA1, WKDONE, DAV,
            DELV, WMAS, N, OMEGA1, OMEGA2, OMEGA3,
            OMEGA4, OMEGA5, OMEGA6, OMEGAT, BETA1,
            BETA2, VZ,ALFA2, ALFA3, DELTG, DELTW, W1,
            W2, V1, V2, V3, AK1, AK2, AK3)
```

SUBROUTINE WICSPC

(1) Description:

The subroutine WICSPC is used for the calculation of stage performance based on the analytical/correlation method for large droplet. A detailed description of calculation procedure is presented in Appendix 2.

(2) Input Variables:

FAIO	initial flow coefficient
ISTAGE	stage at which performance calculation is carried out
MMASS	mass flow rate of mixture
ALFA1	absolute flow angle at outlet of the previous stage stator
WKDONE	work done factor
DAV	nominal diameter of large droplets
DELV	relative velocity between gas phase and large droplets
WMAS	mass flow rate of small droplets
WWMAS	mass flow rate of large droplets
N	station number (Fig. 5.1)
REAVE	Average Reynolds number

DELVU2	relative velocity between gas phase and droplet
DELVL2	relative velocity between gas phase and droplet
AK1	constant in Eq. (A.3.6.)'
AK2	constant in Eq. (A.3.7)' and (A.3.8)'
AK3	constant in Eq. (A.3.1)' and (A.3.2)'

(3) Output Variables:

OMEGA1	total pressure loss coefficient due to the mixture boundary layer formed over rough film surface in rotor
OMEGA2	total pressure loss coefficient due to film formed on rotor blade surface
OMEGA3	total pressure loss coefficient due to Stokesian drag of large droplets in the free stream of blade passage in rotor
OMEGA4	total pressure loss coefficient due to the mixture boundary layer formed over rough film surface in stator
OMEGA5	total pressure loss coefficient due to film formed on stator blade surface
OMEGA6	total pressure loss coefficient due to Stokesian drag of large droplets in the free stream of blade passage in stator

OMEGAT	sum of total pressure loss coefficient
BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet
VZ	axial velocity
ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
DELTG	rise in total temperature of gas phase across a stage
DELTW	rise in temperature of small droplet across a stage
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
V1	absolute velocity at rotor inlet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICSPC (FAIO, ISTAGE , MMASS, ALFA1, WKDONE, DAV,
            DELV, WMAS, WWMAS, N, OMEGA1, OMEGA2, OMEGA3,
             OMEGA4, OMEGA5, OMEGA6, OMEGAT, BETA1, BETA2,
             VZ, ALFA2, ALFA3, DELTG, DELTW, W1, W2, V1, V2,
             V3, REAVE, DELVU2, DELVL2, AK1, AK2, AK3)
```

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 WICSCC

(1) Description:

Subroutine WICSCC calculates the equivalent pressure ratio, stage adiabatic efficiency, and equivalent temperature ratio for a particular stage from the inputed stage characteristic curves. The equivalent pressure ratio, ψ, equivalent temperature ratio, τ, and stage adiabatic efficiency, η have been expressed in terms of the stage flow coefficient as follows:

$$\psi = A_1 + B_1\phi + C_1\phi^2 + D_1\phi^3 + E_1\phi^4 + F_1\phi^5 + G_1\phi^6$$

$$\eta = A_2 + B_2\phi + C_2\phi^2 + D_2\phi^3 + E_2\phi^4 + F_2\phi^5 + G_2\phi^6$$

$$\tau = A_3\phi + B_3$$

The definitions of these parameters are as follows:

(i) flow coefficient: ϕ

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio ψ

$$\psi = \left\{ \left(\frac{U_{tip}^2}{T_{01}}\right)_D \left(\frac{T_{01}}{U_{tip}^2}\right) \left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} - 1 \right] + 1 \right\}^{\gamma/(\gamma-1)}$$

(iii) equivalent temperature ratio:

$$\tau = \left(\frac{U_{tip}^2}{T_{01}}\right)_D \cdot \left(\frac{\Delta T_0}{U_{tip}^2}\right)$$

where subscript D indicates the design point.

It should be noted here that the subroutine WICSCC is only suitable for the case of Test Compressor employed in the current investigation. In another case, a replacement of this subroutine is necessary.

(2) Input Variables:

FAI	stage flow coefficient
ISTAGE	stage number

(3) Output Variables:

SAI	equivalent pressure ratio
ETA	stage adiabatic efficiency
TAU	equivalent temperature ratio

(4) Usage:

```
CALL WICSP (FAI, SAI, ETA, TAU, ISTAGE)
```

SUBROUTINE WICGSL

(1) Description:

The subroutine WICGSL is used for the calculation of single-phase (gas) flow loss. In the current model, the concept of the equivalent diffusion ratio by Lieblein (Ref.23) and Swan's correlation (Ref.24) have been employed in order to estimate the blade outlet flow angle and loss due to turbulent flow of gaseous phase over the rigid blade surface.

Lieblein has show that the design point loading factor, the Diffusion Factor, does not represent a suitable criterion for loading at off-design conditions, except possibly at other minimum loss points. This is due to the fact that the basic derivation of the Diffusion Factor has been based on a flow model which corresponds to operation at or near minimum loss. He has therefore suggested a generalized loading parameter. This parameter, the Equivalent Diffusion Ratio, is based on the ratio of the maximum suction surface velocity and trailing edge velocity for a given section cascade. Lieblein has deduced an expression which approximates this velocity ratio in terms of measured overall performance. The Equivalent Diffusion Ratio is suitable for correlation of low speed data. For the general case where the axial velocity ratio may be large, such as in a rotor or stator cascade, the Equivalent Diffusion Ratio, D_{eq}, has been defined as follows:

$$D_{eq} = \frac{\cos\beta_2 V_{z_1}}{\cos\beta_1 V_{z_2}} \left[1.12 + k\,(i-i^*)^{1.43} + 0.61 \frac{\cos^2\beta}{\sigma} \cdot K \right] \quad \text{(A.3.1)}$$

where $K = \tan\beta_1 - \frac{r_2}{r_1} \frac{V_{z_2}}{V_{z_1}} \cdot \tan\beta_2 - \frac{\omega r_1}{V_{z_1}} \left(1 - \frac{r_2^2}{r_1^2}\right)$

and $k = 0.0117$ for the NACA 65 (A_{10}) blades and $k = 0.007$ for the C_4 circular-arc blades. The Equivalent Diffusion Ratio at minimum loss, D_{eq}^*, is obtained by dropping the term representing the incidence angle effects, that is as follows.

$$D_{eq}^* = \frac{\cos\beta_2 V_{z_1}}{\cos\beta_1 V_{z_2}} \left\{ 1.12 + 0.61 \frac{\cos^2\beta_1}{\sigma} \cdot K \right\} \quad \text{(A.3.2)}$$

The wake momentum thickness can be expressed nondimensionally as follows:

$$\frac{\theta}{c} = \frac{\bar{\omega}\cos\beta_2}{2\sigma} \left(\frac{\cos\beta_1}{\cos\beta_2} \right)^2 \quad \text{(A.3.3)}$$

where c is the chord length of the blades.

At minimum loss, Eq. (A.3.3) yields

$$(\frac{\theta}{c}) = \frac{\bar{\omega}^*\cos\beta_2}{2\sigma}\left[\frac{\cos\beta_2^*}{\cos\beta_1^*}\right] \qquad (A.3.4)$$

Also, from Eq. (A.3.3), the total pressure loss coefficient $\bar{\omega}$, can be expressed as follows:

$$\bar{\omega} = (\frac{\theta}{c})\frac{2\sigma}{\cos\beta_2}\left[\frac{\cos\beta_1}{\cos\beta_2}\right]^2 \qquad (A.3.5)$$

From the cascade test data, the deviation angle, δ, and the non-dimensional wake momentum thickness, $\frac{\theta}{c}$, are expressed in terms of the D_{eq}, D_{eq}^*, $(\frac{\theta}{c})^*$, and inlet Mach number, M, as follows:

$$\delta = \delta^* + \left[6.40 - 9.45(M_1 - 0.60)\right](D_{eq} - D_{eq}^*) \,.\, AK1 \qquad (A.3.6)$$

$$\frac{\theta}{c} = (\frac{\theta}{c})^* + (0.827M_1 - 2.692M_1^2 - 2.675M_1^3)(D_{eq} - D_{eq}^*)^2 \,.\, AK2 \qquad (A.3.7)$$

for $D_{eq} D_{eq}^*$

$$\frac{\theta}{c} = (\frac{\theta}{c})^* + (2.80M_1 - 8.71M_1^2 + 9.36M_1^3)(D_{eq} - D_{eq}^*)^2 \,.\, AK2 \qquad (A.3.8)$$

for D_{eq} D_{eq}^*

Using these empirical expressions, the air angle at blade outlet and total pressure loss coefficient at an off-design point can be determined as follows:

(i) Calculate the inlet angle, β_1, and the inlet Mach number, M_1.

(ii) Calculate the Equivalent Diffusion ratio at minimum loss, D_{eq}^*.

(iii) Calculate the nondimensional wake momentum thickness at minimum loss, $(\frac{\theta}{c})^*$.

(iv) Assume the fluid outlet angle, $(\beta_2)_a$.

(v) Calculate the incidence angle, i, $i=\beta_1-\beta_1^*+i^*$.

(vi) Calculate the Equivalent Diffusion Ration D_{eq}.

(vii) Calculate the deviation angle, δ.

(viii) Calculate the fluid outlet angle, $(\beta_2)_c$, $(\beta_2)_c = \beta_2^* - \delta^* + \delta$.

(ix) Compare the assumed value of fluid outlet angle, $(\beta_2)_a$, with the calculated value of that, $(\beta_2)_c$ to check if $|(\beta_2)_a - (\beta_2)_c| < \varepsilon$ where ε is the desired accuracy. Iterate step (iv) to step (ix) until satisfactory accuracy is obtained.

(x) Calculate the nondimensional wake momentum thickness, $\frac{\theta}{c}$.

(xi) Calculate the total pressure loss coefficient $\overline{\omega}$.

Figure (A.3.1) shows the flow chart of the calculation procedure to predict the outlet angle and total pressure loss coefficient.

The program also includes a provision for modifying the equations given in Ref.23 and 24. Equations (A.3.1), (A.3.2), (A.3.6), (A.3.7), and (A.3.8) can be modified by introducing constants AK1, AK2, and AK3 as follows.

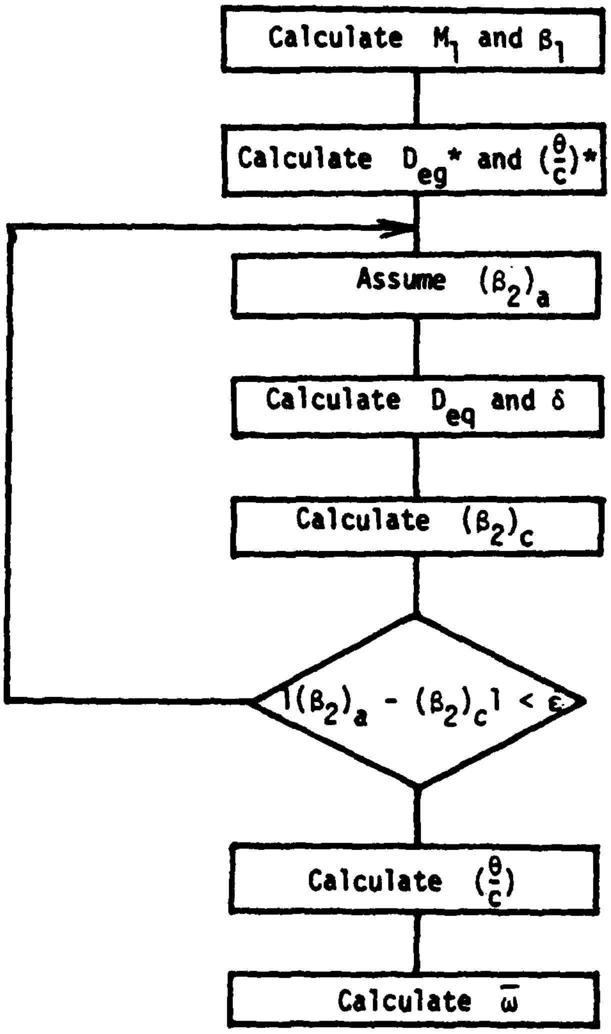

Fig. A.3.1 Procedure for Prediction of Total Pressure Loss Coefficient

$$D_{eq} = \frac{\cos\beta_2}{\cos\beta_1} \frac{V_{z1}}{V_{z2}} \left[1.12 + k\,(i-i^*)^{1.43} + 0.61\,\frac{\cos^2\beta_1}{\alpha}K\right] \cdot AK3 \qquad (A.3.1)'$$

$$D_{eq}^* = \frac{\cos\beta_2}{\cos\beta_1} \frac{V_{z1}}{V_{z2}} \left[1.12 + 0.61\frac{\cos^2\beta_1}{\alpha}\right] \cdot AK3 \qquad (A.3.2)'$$

$$\delta = \delta^* + \left[6.40 - 9.45\,(M_1 - 0.60)\right] (D_{eq} - D_{eq}^*) \cdot AK1 \qquad (A.3.6)'$$

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (0.827M_1 - 2.692M_1^2 - 2.695M_1^3)\,(D_{eq} - D_{eq}^*)^2 \cdot AK2 \quad \text{for } D_{eq} > D_{eq}^* \qquad (A.3.7)'$$

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (2.80M_1 - 8.71M_1^2 + 9.36M_1^3)\,(D_{eq} - D_{eq}^*)^2 \cdot AK2 \quad \text{for } D_{eq} < D_{eq}^* \qquad (A.3.8)'$$

(2) Input Variables:

OMEGAS	total pressure loss coefficient
SIGUMA	solidity
BETA1S	blade inlet flow angle at design point
BETA2S	blade outlet flow angle at design point
AINCIS	incidence at design point
ADEVIS	deviation at design point
AMACH1	blade inlet Mach number
BET1	blade inlet flow angle

X	Mach number below which the effect of Mach number disappears in estimating deviation angle. The value of 0.6 is recommended by Swan (Ref.24).
IDESIN	Index for design point calculation
AK1	constant in Eq.(A.3.6)'
AK2	constant in Eq.(A.3.7)' and (A.3.8)'
AK3	constant in Eq.(A.3.1)' and (A.3.2)'
VZ1	axial velocity at blade inlet
VZ2	axial velocity at blade outlet
UR1	rotor blade speed at blade inlet
R1	radius at blade inlet
R2	radius at blade outlet

(3) Output Variables:

DEQS	equivalent diffusion ratio at design point, D_{eq}^*
DEQN	equivalent diffusion ratio , D_{eq}
SITACS	dimensionless momentum thickness at design point, $(\frac{\theta}{c})^*$
SITACN	dimensionless momentum thickness, $(\frac{\theta}{c})$
BET2N	blade outlet angle
OMEGAN	total pressure loss coefficient

(4) Usage:

```
CALL WICGSL(OMEGAS, SIGUMA, BET1S, BET2S, AINCIS, ADEVIS,
        AMACH1, BET1, DEQS, DEQN, SITACS, SITACN,
        BET2N, OMEGAN, X IDESIN, AK1, AK2, AK3, VZ1,
        VZ2, UR1, R1, R2)
```

SUBROUTINE WICSDL

(1) Description:

The subroutine WICSDL is used for the calculation of loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets.

In order to estimate the loss pertaining to the increase of momentum thickness due to the existence of small droplets in the boundary layer, Soo's boundary layer analysis for a gas-solids suspension is introduced (Ref. 25). In an isothermal incompressible system, Soo has derived the following equation for suspended particles under the assumption that the number of collisions among particles is negligible when compared to that with the wall,

$$a = \left(\frac{a}{b}\right)\left(\frac{\delta}{x}\right) - \frac{4a^2}{3b^2}\left(\frac{\delta}{x}\right)^{3/4} + \frac{4a^3}{3b^3}\left(\frac{\delta}{x}\right)^{1/2} - \frac{4a^4}{b}\left(\frac{\delta}{x}\right)^{1/4} + \frac{4a^5}{b^5}\ln\left[1 + \frac{b}{a}\left(\frac{\delta}{x}\right)^{1/4}\right] \qquad (A.3.9)$$

where

$$a = \frac{0.0225\left(\frac{\bar{\mu}}{U\rho_o x}\right)^{1/4}}{0.1402\left(\frac{\rho_{p_0}}{\rho_0}\right) + 0.0972}$$

$$b = \frac{\frac{1}{2\sqrt{\pi}} \frac{\rho_{p_0}}{\rho_0} \frac{U_{pw}\sqrt{\langle U_{pw}^2 \rangle}}{U^2}}{0.1402 \left(\frac{\rho_{p_0}}{\rho} \right) + 0.0972}$$

Neglecting shear due to impact of solid particles, Soo derived the following equation.

$$\frac{\delta}{x} = 0.37 \left(\frac{Ux\rho_0}{\mu}\right)^{-1/5} \Big/ \left(1+1.442\,\rho_{p_0}/\rho_0\right)^{0.8} \qquad \text{(A.3.10)}$$

The boundary layer thickness, δ, can be obtained from Eqs. (A.3.9) or (A.3.10). In the present model, Eq. (A.3.10) was used.

The momentum thickness, due to liquid phase, θp, is given by

$$\frac{\theta_p}{\delta} = \left(\frac{U_p - U_{pw}}{U_p} \right)^2 \frac{m}{(1+m)\ (2+m)} - \left(\frac{\rho_{p_0} - \rho_{pw}}{\rho_{p_0}} \right) \cdot \frac{U_{pw}}{U_p} \cdot \frac{1}{\alpha+1}$$

$$+ \left(\frac{\rho_{p_0} - \rho_{pw}}{\rho_{p_0}} \right) \left(\frac{U_p - U_{pw}}{U_p} \right)^2$$

$$\times \left[\frac{\Gamma(\frac{2}{m}+1)\ .\ \Gamma(\alpha+1)}{\Gamma(\frac{2}{m}+\alpha+2)} - \frac{\Gamma(\frac{1}{m}+1)\ .\ \Gamma(\alpha+1)}{\Gamma(\frac{1}{m}+\alpha+2)} \right] \qquad \text{(A.3.10)}$$

where α and m are constants associated with distribution of velocity and density of liquid phase in the boundary layer namely

$$u_p = U_{pw} + (U_p - U_{pw}) \left(\frac{y}{\delta}\right)^{1/m}$$

$$\rho_p = \rho_{pw} - (\rho_{p_0} - \rho_{pw}) \left(1 - \frac{y}{\delta}\right)^{\alpha}$$

For the case of solid, spherical particles of 100 and 200μm in diameter in air moving at room conditions with a velocity of 50 to 100 fps, Soo has obtained the following values for the various quantities.

$n = 7$, $m = 1.25$, $\alpha = 2.30$,

$$\frac{U_p - U_{pw}}{U_p} = 0.812, \quad \frac{\rho_{pw}}{\rho_{p_0}} = 1.451$$

Utilizing the above values, Eq. (A.3.10) becomes

$$\frac{\theta_p}{\delta} = 0.1402$$

Following the procedure of Lieblein, the total pressure loss coefficient due to the increase of momentum thickness, $\theta_{p,R}$, because of the existence of small droplets in the boundary layer over rotor blade surface, $\bar{\omega}_{\theta,R}$, can be expressed as follows:

$$\omega_{\theta,R} = \left(\frac{\theta_{p,R}}{c}\right) \frac{2\,\sigma}{\cos\beta_2} \left(\frac{\cos\beta_1}{\cos\beta_2}\right)^2$$

Similarly, the total pressure loss coefficient due to the increase of momentum thickness, $\theta_{p,S}$, because of the existence of small droplets in the boundary layer on stator blade surface $\bar{\omega}_{\theta,S}$, can be expressed as follows:

$$\omega_{\theta,S} = \left(\frac{\theta_{p,S}}{c}\right) \frac{2\sigma}{\cos\alpha_3} \left(\frac{\cos\alpha_2}{\cos\alpha_3}\right)^2$$

The stagnation pressure losses corresponding to $\bar{\omega}_{\theta,r}$ and $\bar{\omega}_{\theta,S}$ can be written as follows.

$$\Delta P_{\theta,R} = \frac{1}{2}\rho_1 W_1^{2}\bar{\omega}_{\theta,R}$$

$$\Delta P_{\theta,S} = \frac{1}{2}\rho^{2} V_2^{2}\bar{\omega}_{\theta,S}$$

Thus, the total pressure loss across a stage due to the increase of momentum thickness because of the existence of small droplets in a boundary layer is given by

$$\Delta P_{\theta} = \Delta P_{\theta,R} + \Delta P_{\theta,S}$$

(2) Input Variables

CHORD	chord length
SIGUMA	solidity
BETA1	blade inlet flow angle
BETA2	blade outlet flow angle
UG	average flow velocity
RHOG	density
AMASSW	mass flow rate
AREA	flow area
VZ	axial velocity
IPRINT	index for printout

(3) Output Variables:

OMEGAP	total pressure loss coefficient

SUBROUTINE WICSTL

(1) Description:

The subroutine WICSTL is used for the calculation of loss due to Stokesian drag of droplets in the free stream of blade passage.

In view of the assumption pertaining to motion of small droplets (with zero relative velocity with respect to gas phase), the total pressure loss due to Stokesian drag becomes zero for small droplets.

For large droplets, the model introduced is described below.

The large droplets move with substantial relative velocity with respect to the gas phase and have equal probability of motion in all directions. However, regarding the latter aspect, the droplets are divided into two subclasses with a direction of motion for each class, specified with respect to the gas phase velocity vector. The number of droplets impacting on the blade surface is then proportional to the blade surface area projection normal to the velocity vectors for the two subclasses of droplets.

Referring to Fig. A.3.2., the two subclasses are shown as (1) and (2) which have direction of motion given by γ_1,and γ_2 relative to the gas phase velocity vector. The total number of droplets in subclass (1) is proportional to angle $2\gamma_1$ and those in subclass (2) is proportional to angle $2\gamma_1$ $(180 - 2\gamma_1)$. The relative velocity between the gas phase and droplets of subclass (1) is given by the difference between V_{g_1} and the component of V_p (the velocity of drop-

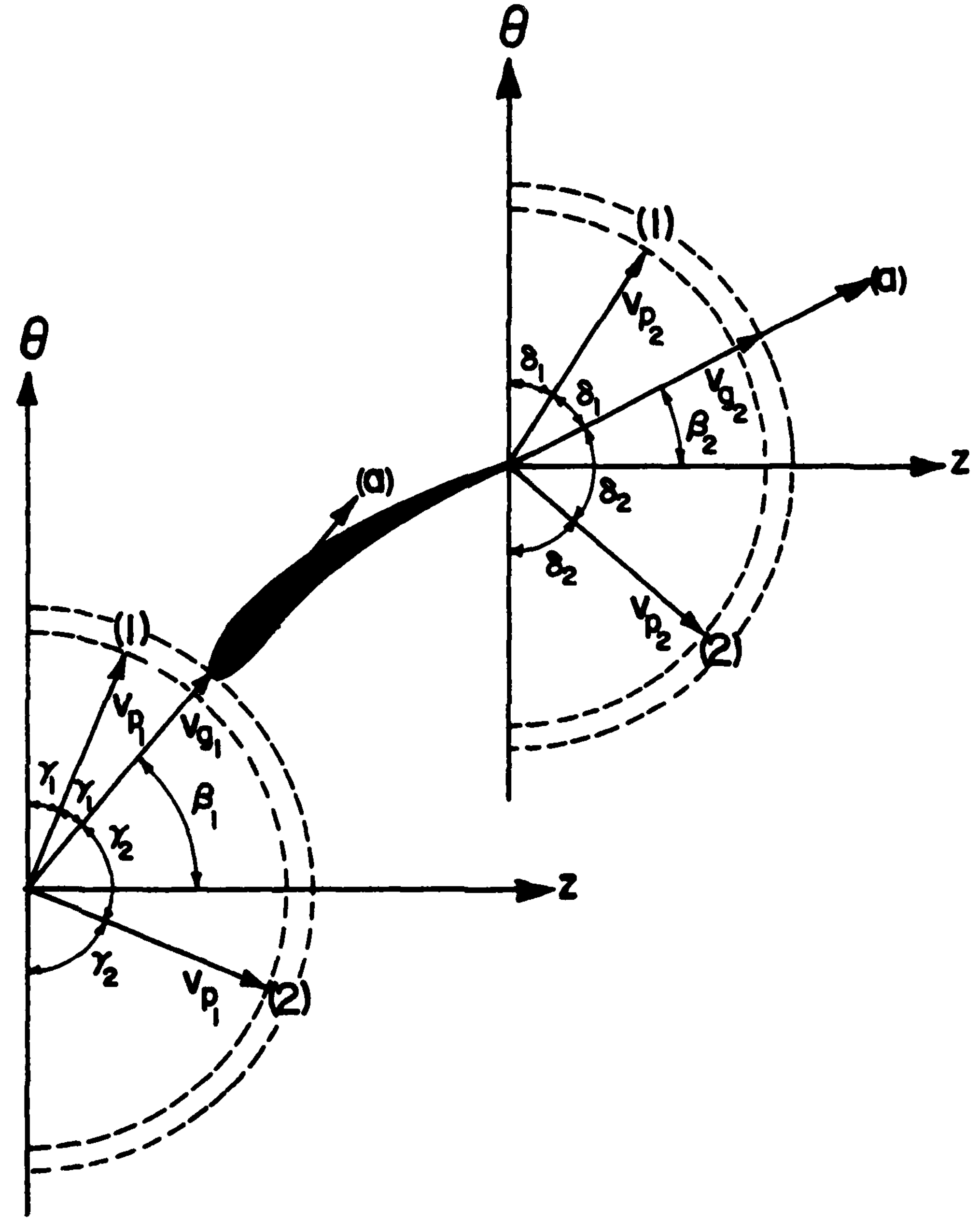

Fig. A.3.2 Model for Motion of Large Droplet lets in subclass (1) in the direction of V_{g_1}. Similarly the relative velocity between the gas phase and the droplets of subclass (2) is given by the difference between V_{g_1} and the component of V_{p_2} in the direction of V_{g_1}. Thus for droplets of subclass (1) the relative velocity is given by the relation,

$$V_{g_1} - V_{p_1} \cos \gamma_1$$

and for droplets of subclass (2), the relative velocity is given by the relation,

$$V_{g_1} - V_{p_2} \cos\gamma_2$$

In Fig. A.3.2, the blade outlet conditions are also shown. As at the blade inlet section the relative velocities between the gas phase and droplets of subclasses (1) and (2) may be written as follows:

$V_{g_2} - V_{p_1} \cos \delta_1$ for subclass (1), and

$V_{g_2} - V_{p_2} \cos \delta_2$ for subclass (2).

where δ_1 is the inclination of the mean velocity vector for subclass (1) and δ_2 , the inclination of the mean velocity vector at outlet, designated V_{g_2}. Once again, at the outlet section, the number of droplets in subclass (1) is proportional to angle $2\delta_1$, and the number of droplets in subclass (2) is proportional to angle $2\delta_2$, or $(180-2\delta_1)$. It is clear that the total number of droplets is divided into two new subclasses at the outlet, based on the directions of motion of droplets relative to the gas phase velcocity. The two subclasses at the outlet are the output from the blade row for the given initial and operating conditions.

Based on the foregoing model of motion of large droplets the total pressure loss coefficient due to the Stokesian drag of large water droplets in a rotor passage, $\overline{\omega}_{s,R}$, can be estimated as follows:

The Stokesian drag of water droplets across a rotor blade is given by

$$D = C_D \frac{1}{2} \rho_{g_1} (W_{g_1} - W_{p_1})^2 A_p N_{d,r}$$

Where W_{g_1} and W_{p_1} are relative velocities of gaseous phase and droplets at rotor inlet, A_p, the project area of a droplet, and $N_{d,r}$, the number of droplets that exist in rotor passage. Referring to Fig. A.3.3, the Stokesian drag, D, can also be written as

$$D = (P_{01,r} - P_{02,r})\, A_R$$

where $P_{01,r}$ and $P_{02,r}$ are total pressure at station (1) and (2) in rotor coordinate system, and A_R is the average flow area in a rotor blade passage.

From the above equations, the total pressure loss across a rotor blade due to the Stokesian drag, $\Delta P_{s,R}$ becomes

$$P_{s,R} = c_D \frac{1}{2} \rho_{g_1} (W_{g_1} - W_{p_1})^2 A_p N_{d,R}/A_R = D/A_R$$

By definition, the total pressure loss coefficient across a rotor blade due to Stokesian drag, $\overline{\omega}_{s,R}$, can be obtained as follows:

$$\overline{\omega}_{s,R} = \frac{\Delta P_{s,R}}{\frac{1}{2}\rho_1 W_{g_1}^2} = c_D (W_{g_1} - W_{p_1})^2 A_p N_{d,R}/W_{g_1}^2 A_R = \frac{D/A_R}{\frac{1}{2}\rho_1 W_{g_1}^2}$$

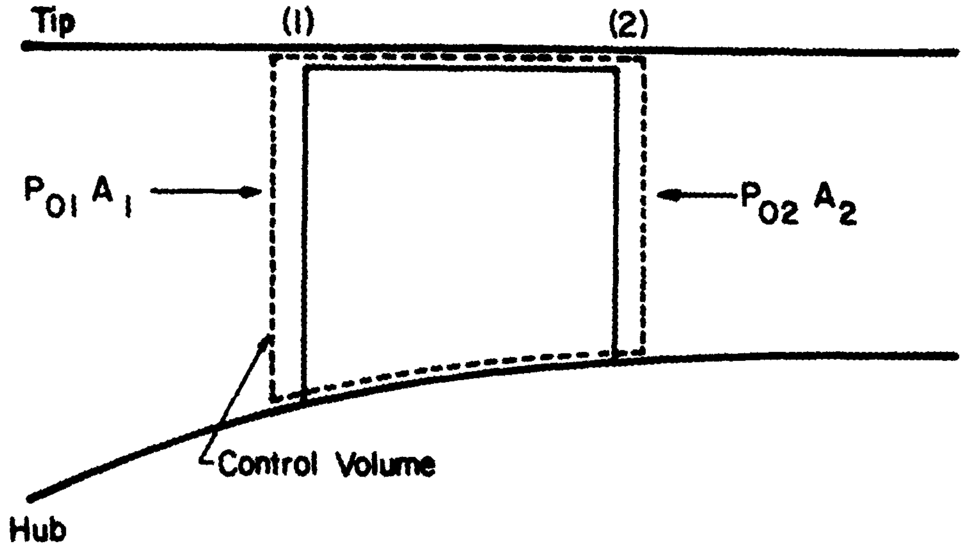

Fig. A.3.3 Control Volume across a Blade

Similarly, the total pressure loss across a stator blade due to Stokesian drag, $\Delta P_{s,S}$ becomes

$$\Delta P_{s,S} = c_D \frac{1}{2} \rho_{g_2} (V_{g_2}^2 - V_{p_2}^2) A_p N_{d,S}/A_S$$

and the total pressure loss coefficient across a stator blade due to the Stokesian drag, $\bar{\omega}_{s,S}$, can be obtained as follows:

$$\bar{\omega}_{s,S} = \frac{\Delta P_{s,S}}{\frac{1}{2}\rho_2 V_2^2} = c_D (V_{g_2}^2 - V_{p_2}^2) A_p N_{d,S}/A_S$$

Thus, the total pressure loss across a stage due to Stokesian drag is given by

$$\Delta P_s = \Delta P_{s,R} + \Delta P_{s,S}$$

(2) Input Variables:

ISTAGE	stage at which performance calculation is carried out
IROTOR	index for rotor or stator
DAV	nominal droplet diameter
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
DELV	relative velocity between gas phase and droplet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet
WMASS	mass flow rate of droplet
VZ	axial velocity
N	station number (Fig.5.1)
BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet

ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
MMASS	mass flow rate of mixture

(3) Output Variables:

DELVU2	relative velocity between gas phase and large droplet in subclass (1) at blade outlet
DELVL2	relative velocity between gas phase and large droplet in subclass (2) at blade outlet
OMEGRU	total pressure loss coefficient across rotor due to Stokesian drag in subclass (1)
OMEGRL	total pressure loss coefficient across rotor due to Stokesian drag in subclass(2)
OMEGSU	total pressure loss coefficient across stator due to Stokesian drag in subclass (1)
OMEGSL	total pressure loss coefficient across stator due to Stokesian drag in subclass (2)
DRAGRU	drag force due to large droplet in subclass(1)
DRAGRL	drag force due to large droplet in subclass(2)
DRAGSU	drag force due to small droplet in subclass(1)
DRAGSL	drag force due to small droplet in subclass (2)
REAVE	average Reynolds number

(4) Usage:

```
CALL WICSTL (ISTAGE, IROTOR, DAV, W1,W2, DELV, V2, V3,
            WMASS, VZ, N, BETA1, BETA2, ALFA2, ALFA3,
            MMASS, DELVU2, DELVL2, OMEGRU, OMEGRL, OMEGSU,
            OMEGSL, DRAGRU, DRAGRL, DRAGSU, DRAGSL, REAVE)
```

SUBROUTINE WICFML

(1) Description:

The subroutine WICFML is used for the calculation of loss due to film formed on blade surface when large droplets are present either by themselves or along with small droplets.

The momentum gained by the thick water film on the rotor blade surface is given by $\dot{m}_{film}V_{film}$ per unit blade length, where $\dot{m}_{film}$ is the mass flow rate of water film on the rotor blade per unit blade length and V_{film} is the mean velocity of water film.

Considering the difference in viscosity between the two phases, the velocity of water film can be estimated as follows:

$$V_{film} = \frac{1}{2}\,\overline{W}_g\,\frac{\mu_g}{\mu_1}$$

where $\overline{W}_g$ is the mean velocity of gaseous phase, and μ_g and μ_1 are the viscosities of gaseous and liquid phases, respectively.

The foregoing momentum can be transformed into an equivalent drag coefficient as follows.

$$c_{D_f} = \dot{m}_{film}\,V_{film}/\frac{1}{2}\,\rho_{g_1}\overline{W}_g^2\,c$$

where ρ_{g_1} is blade inlet density of gaseous phase, and c is the chord length of the blade.

The drag coefficient can then be expressed in the form of a total pressure loss coefficient as follows:

$$c_{D_f}\frac{1}{2}\rho_{g_1}\overline{W}_{g_1}^{2}c = \Delta P_f\ .s\ .\ \cos\beta_m$$

where s is the blade pitch and β_m is mean flow angle. Noting that $V_z = \overline{W}_g \cos \beta_m$, one obtains the relation, namely

$$\Delta P_f/\frac{1}{2} \rho_{g_1} V_z^2 = c_{D_f} \left(\frac{c}{s}\right) \frac{1}{\cos^3 \beta_m}$$

Since $\overline{W}_{g_1} = V_z/\cos\beta_1$, the total pressure loss coefficient due to the momentum gained by the thick film on the rotor blade surface can be written as follows:

$$\overline{\omega}_f = \Delta P_f/\frac{1}{2} \rho_{g_1} W_{g_1}^2 = c_{Df} \left(\frac{c}{s}\right) \frac{\cos^2 \beta_1}{\cos^3 \beta_m}$$

(2) Input Variables:

WG1	flow velocity at blade inlet
WG2	flow velocity at blade outlet
FMASS	mass flow rate of water film on blade surface per unit blade length
RHOG1	density
CHORD	chord length
SIGUMA	solidity
BETA1	blade inlet flow angle
BETA2	blade outlet flow angle

(3) <u>Output Variables</u>:

CDF	drag coefficient
OMEGAF	total pressure loss coefficient

(4) Usage:

```
CALL WICFML (WG1,WG2, FMASS, RHOG1, CHORD, SIGUMA, BETA1,
           BETA2, CDF, OMEGAF)
```

SUBROUTINE WICRSL

(1) Description:

The subroutine WICRSL is used for the calculation of loss due to the rough surface when large droplets are presented either by themselves or along with small droplets.

Using the experimental results on pipes roughened with sand, L. Prandtl and H. Schlichting carried out a correlation to obtain the friction coefficient on a rough place (Ref. 26). The correlation was based on the logarithmic velocity distribution law for rough pipes in the form, namely

$$\frac{u}{v^*} = 2.5 \ln(\frac{y}{k}) + B$$

where v* is friction velocity; k is roughness of surface, and B is a roughness function which depends on the roughness parameter, v*k/r.

In the completely rough regime, they obtained the following relation for the drag coefficient for a plate.

$$c_{Dr} = (1.81 + 1.62 \log_{10} \frac{x}{k})^{-2.5}$$

In the present case, x is replaced by the chord length, c, and the surface roughness k is assumed to be the same as the order of mean diameter of large droplets.

Thus, the total pressure loss coefficient due to turbulent friction over a rough film surface on a rotor becomes the following.

$$\bar{\omega}_r = c_{Dr} (\frac{c}{s}) \frac{\cos^2 \beta_1}{\cos^3 \beta_m}$$

(2) Input Variables:

SIGUMA	solidity
BETA1	blade inlet flow angle
BETA2	blade outlet flow angle
CHORD	chord length
DL	droplet diameter

(3) Output Variables:

CDR	drag coefficient
OMEGAR	total pressure loss coefficient

(4) Usage:

```
CALL WICRSL (SIGUMA, BETA1, BETA2, CHORD, DL, CDR,
                 OMEGAR)
```

SUBROUTINE WICVT

(1) Description:

The subroutine WICVT is used for the calculation of velocity triangle components and angles. Typical velocity diagram for a compressor stage is presented in Fig. A.2.1.

(2) Input Variables:

ISTAGE	stage at which performance calculation is carried out
ASPEED	acoustic speed

ALFA1	absolute flow angle at rotor inlet
VZ	axial velocity
AK1	constant in Eq. (A.3.6)'
AK3	constant in Eq. (A.3.1)' and (A.3.2)'

(3) Output Variables:

V1	absolute velocity at rotor inlet
VS1	tangential component of V1
WS1	tangential component of W1
BETA1	relative flow angle at rotor inlet
W1	relative velocity at rotor inlet
BETA2	relative flow angle at rotor outlet
WS2	tangential component of W2
VS2	tangential component of V2
ALFA2	absolute flow angle at rotor outlet
W2	relative velocity at rotor outlet
VZ	absolute velocity at rotor outlet
ALFA3	absolute flow angle at stator outlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICVT (ISTAGE, ASPEED, ALFA1, VZ, V1, VS1, WS1,
           BETA1, W1, BETA2, WS2, VS2, ALFA2, W2, V2,
           ALFA3, V3, AK1, AK3)
```

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 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, buoyancy 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 ω, the angular velocity. The acceleration can also be written as follows:

$$a_e = V_\theta^2/r$$

where V_θ is the circumferential velocity of the droplet. For droplets passing through a rotor blade passage, the circumferential component of the relative velocity, W_θ , should be used in place of V_θ . 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 ρ_w is the density of water and ρ_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,

$$F_d = C_D \frac{\rho_g u^2}{2\, g_c} A_p$$

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:

$$\frac{du}{dt} = A/r - B\,u^{2-n}$$

where

$$A = (W_\theta)^2_{ave} \cdot (1 - \rho_g/\rho_w),$$

$$B = 3\,u^n b_1 \rho_g^{1-n}/4\rho_w\,D^{1+n},$$ and

D being the average droplet diameter. Over a small time interval, the equation of motion can be written as follows:

$$\Delta u = (A/r - B \cdot u^{2-n})\,\Delta t$$

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 Δt.

(v) Calculate the new velocity u_2.

$$u_2 = u_1 + \Delta u$$

(vi) Calculate the change in location of droplet in terms of Δr.

$$\Delta r = (u_1 + u_2)/2.0 \, . \, \Delta t$$

(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 this Report, the length between the leading and trailing edges of a blade is divided into ten steps. The time interval Δt is then given by the relation, namely

$$\Delta t = \frac{\text{chord}}{V} \times \frac{1}{10}$$

where V is the velocity of moisture 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
VZTIME	time in which flow pass through a stage

(4) Usage:

```
CALL WICCEN (RZERO, VZERO, DD, VZ, DELZZ, ALFAAV, FN,IRS,
            RHOGAS, RHUB, R2, U2, ITIP, VZTIME, 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 left 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) CALL WICDML (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1, R2, STAREA, RSTAVE, RTIP, DMIN, DMOUT, AMASW2, DELMAS)

SUBTROUTINE WICDRG

(1) Description:

The subroutine WICDRG is used for the calculation of drag force on droplet.

(2) Input Variables:

D	droplet nominal diameter
DELV1	relative velocity between droplet and gas phase at blade inlet
RHGAS1	density of gas phase at blade inlet
RHGAS2	density of gas phase at blade outlet

(3) Output Variables:

CD2	drag coefficient
DELV2	relative velocity between droplet and gas phase at blade outlet
DRAG1	drag force
RE	Reynolds number

(4) Usage:

```
CALL WICDRG (D, DELV1, RHGAS1, RHGAS2, CD2, DELV2, DRAG1,
             RE)
```

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.

$$t = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} T_{01}$$

$$\rho = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1/(\gamma-1)} P_{01}/RT_{01}$$

(ii) Calculate acoustic speed in gaseous phase

$$a_g = (\gamma R t g_c)^{0.5}$$

(iii) Calculate the axial velocity

$$V_z = \dot{m}/\rho A$$

(iv) Calculate absolute velocity

$$V_1 = V_3/\cos \alpha_1$$

(v) Calculate Mach number

$$M_1 = V_1/a_g$$

Compare the calculated Mach number with the assumed value in (i). Iterate steps (i) to (v) until the desired accuracy is obtained. After determing the acoustic speed in gaseous phase, Fucnction WICASD is called to determine the acoustic speed in droplet-laden gas flow.

(2) Input Variables:

ISTAGE	stage number
AMASSM	mixture mass flow rate

T01G	total temperature of gaseous phase
PRES	total pressure
XW1	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 (ISTAGE, AMASSM, T01G, PRES, M, VZ, C, XW1,
            ALFA, RMIX, CPMIX)
```

FUNCTION WICASD

(1) Description:

Function WICASD calculates the acoustic speed in droplet-laden gas flow. The following equation is used (Ref.27).

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

where

a_g = acoustic speed in gaseous phase

a_w = acoustic speed in water

ρ_g = density of gaseous phase

ρ_w = density of water

σ_v = particulate liquid volume fraction

x_w = particulate liquid mass fraction

$$\sigma_v = x_w \rho_g / \left[\rho_w - x_w \left(\rho_w - \rho_g \right) \right]$$

(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 WICBOA

(1) Description:

Subroutine WICBOA calculates the blade outlet flow angle based on Swan's correlation curves (Ref.24). Swan's curves and the concept of equivalent diffusion ratio are also described in Subroutine WICGSL.

(2) Input Variables:

OMEGAS	total pressure loss coefficient at design point
SIGUMA	solidity
BET1S	blade inlet angle at design point
BET2S	blade outlet angle at design point
AINCIS	incidence at design point
ADEVIS	deviation at design point
AMACH1	blade inlet Mach number
BET1	blade inlet flow angle

(3) Output Variables:

DEQS	equivalent diffusion ratio at design point
DEQN	equivalent diffusion ratio
SITACS	ratio of wake momentum thickness to chord design point
SITACN	ratio of wake momentum thickness to chord
BET2N	blade outlet angle

(4) Usage:

```
CALL WICBOA (OMEGAS, SIGUMA, BET1S, BET2S, AINCIS, ADEVIS,
            AMACH1, BET1, DEQS, DEQN, SITACS, SITACN, BET2N)
```

SUBROUTINE WICEDD

(1) Description:

Subroutine WICEDD is called in Subroutine WICBOA and WICGSL. The equivalent diffusion ratio at design point, D^*_{eq}, and the ratio of wake momentum thickness to chord at design point, $(\frac{\theta}{c})^*$, are obtained from the following equations:

$$D^*_{eq} = \frac{\cos\beta_2}{\cos\beta_1} \frac{V_{z1}}{V_{z2}} \left(1.12 + 0.61 \frac{\cos^2\beta_1}{\sigma} K\right) \cdot AK3$$

$$\left(\frac{\theta}{c}\right) = \frac{\bar{\omega}^* \cos\beta_2^*}{2\sigma} \left(\frac{\cos\beta_2^*}{\cos\beta_1^*}\right)^2$$

where

$$K = \tan\beta_1^* - \frac{r_1}{r_1} \frac{V_{z2}}{V_{z1}} \tan\beta_1^* - \frac{\omega r_1}{V_{z1}} \left(1 - \frac{r_2^2}{r_1^2}\right)$$

(2) Input Variables:

AK3	constant, normally one
VZ1	axial velocity at blade inlet
VZ2	axial velocity at blade outlet
UR1	rotor blade speed at rotor inlet
R1	radius at blade inlet
R2	radius at blade outlet
BET1S	blade inlet flow angle at design point
BET2S	blade outlet flow angle at design point
SIGUMA	solidity
OMEGAS	total pressure loss coefficient at design point

(3) Output Variables:

DEQS	equivalent diffusion ratio at design point
SITACS	ratio of wake momentum thickness to chord at design point

(4) Usage:

```
CALL WICEDD (AK3, VZ1, VZ2, UR1, R1, R2, BET1S, BET2S,
             SIGUMA, OMEGAS, DEQS, SITACS)
```

FUNCTION WICED

(1) Description:

Function WICED is called in Subroutines WICBOA and WICGSL. The equivalent diffusion ratio is obtained from the following equation.

$$D_{eq} = \frac{\cos\beta_2}{\cos\beta_1} \frac{V_{z_1}}{V_{z_2}} \left[1.12 + k\,(i-i^*)^{1.43} + 0.61\,\frac{\cos\beta_1}{\sigma} K \right] . \ AK3$$

where

$$K = \tan\beta_1 - \frac{r_2}{r_1} \frac{V_{z_2}}{V_{z_1}} \tan\beta_1 - \frac{\omega r_1}{V_{z_1}} \left(1 - \frac{r_2^2}{r_1^2}\right)$$

and where $k = 0.0117$ for NACA 65 (A_{10}) blades and $k = 0.007$ for the C4 airfoils.

(2) Input Variables:

AK3	constant, normally one
VZ1	axial velocity at blade inlet
VZ2	axial velocity at blade outlet
UR1	rotor blade speed at rotr inlet
R1	radius at blade inlet
R2	radius at blade outlet
BET1	blade inlet flow angle
BET2	blade outlet flow angle
SIGUMA	solidity
AINCIS	incidence at design point
AINCI	incidence

(3) Output Variable:

WICED	equivalent diffusion ratio

(4) Usage:

WICED (AK3, VZ1, VZ2, UR1, R1, R2, BET1, BET2, SIGUMA,
AINCIS, AINCI)

FUNCTION WICMTK

(1) Description:

Function WICMTK is called in Subroutines WICBOA and WICGSL. The ratio of wake momentum thickness and chord are obtained from the following equations.

$$\frac{\theta}{c} = (\frac{\theta}{c})^* + (0.827\ M_1 + 2.675\ M\ )\ (D_{eq} - D_{eq}{*})^2 .\ AK2$$

for $D_{eq} > D_{eq}{*}$

$$\frac{\theta}{c} = (\frac{\theta}{c})^* + (2.80\ M_1 - 8.71\ M_1^2 + 9.36\ M_1^3)\ (D_{eq} - D_{eq}{*})^2 .\ AK2$$

for $D_{eq} < D_{eq}{*}$

(2) Input Variables:

AK2	constant, normally one
SITACS	ratio of wake momentum thickness to chord at design point
AMACH1	blade inlet Mach number
DELDEQ	difference between equivalent diffusion ratio and equivalent diffusion ratio at design point.

(3) Output Variables:

WICMTK	ratio of wake momentum thickness to chord

(4) Usage:

WICMTK (SI[illegible], AMACH1, DELDEQ, AK2)

FUNCTION WICLOS

(1) Description;

Function WICLOS is called in Subroutine WICGSL and calculates the total pressure loss coefficient from the following equation:

$$\bar{\omega} = \left(\frac{\theta}{c}\right) \frac{2\sigma}{\cos\beta_2} \left(\frac{\cos\beta_1}{\cos\beta_2}\right)^2$$

(2) Input Variables:

BET1	blade inlet flow angle
BET2	blade outlet flow angle
SIGUMA	solidity
SITA	ratio of momentum thickness to chord

(3) Output Variable;

WICLOS	total pressure loss coefficient

(4) Usage:

WICLOS (BET1, BET2, SIGUMA, SITA)

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
RHQG1	density of gaseous phase
BETA1	rotor inlet relative flow angle
W1	rotor inlet relative velocity

(3) Output Variables:

WW1	amount of water that impacts stagnation region of blade
WW2	amount of water that impact aft of blade
WW	total amount of water that impact 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
PHOG1	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 impact lower surface of blade
WW	total amount of water that impact 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
RTIPIN	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
W1	stator inlet absolute velocity

(3) Output Variables;

WW1	amount of water that impact stagnation region of blade
WW2	amount of water that impact off of blade
WW	total amount of water that impact the blade

(4) Usage:

```
CALL WICISS (ISTAGE TRIPIN, XW, XG RHOG1, ALFA2, W1,
            WW1, 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 Variable:

ISTAGE	stage number
RTIPIN	blade tip radius
XW	mass fraction of large droplet
XG	mass fraction of gaseous phase
RHOG1	density of gaseous phase
ALFA2	stator inlet absolute flow angle
W1	stator inlet absolute velocity

(3) Output Variables:

WW1	amount of water that impact upper surface of blade
WW2	amount of water that impact lower surface of blade

WW	total amount of water that impact 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.

The size of droplet which is re-entrained into the wake at the blade trailing edge is calculated as follows:

(i) Assume a value for a droplet diamter, d, that is re-entrained into wake.

(ii) Calculate the stability number, SN.

$$SN = \mu_f^2 / \rho_g \sigma d g_c$$

(iii) Calculate the critical Weber number

$$W_e = 12 \left(1 + (SN)^{0.36} \right)$$

(iv) Calculate the largest stable droplet diameter

$$d_{max} = \frac{W_e}{\rho_g} \frac{\sigma g_c}{V_g^2}$$

(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^3)
DWAKEM	droplet size that re-entrained at trailing edge in (μm)

(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

$$\frac{dh}{dt} = h_h A \left(T_g - T_w\right)$$

where h_h 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:

$$h_h = \frac{k_a}{D_d} \bullet Nu$$

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;

$$Nu = 2.0 + 0.6\,(Re)^{0.50}(Pr)^{0.33}$$

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 .

$$N_d = \frac{\dot{m}_w}{\rho_w \frac{4}{3} \pi (D_d/2)^3} \cdot \frac{\Delta z}{V_z}$$

where $\dot{m}_w$ is the mass flow rate of water phase, ρ_w, the density of water, V_z , the axial direction velocity, and Δz, 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 of gas and water due to work done by rotor.

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

$$\Delta H = h_h A (T_{g2} - T_{w2})$$

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

$$(\Delta H_g)_{ht} = \Delta H/m_g C_s$$

$$(\Delta H_w)_{ht} = \Delta H/m_w C_w$$

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.

$$T_{g_2} = T_{g_1} + (\Delta T_g)_{wk} - (\Delta T_g)_{ht}$$

$$T_{w_2} = T_{w_1} + (\Delta T_w)_{wk} + (\Delta T_w)_{ht}$$

(X) Using the temperature calculated in step (ix), repeat the steps (vii) to (ix) until a desired accuracy is obtained.

(2) Input Variables:

TG1	temperature of gaseous phase at stage inlet
TG3	temperature of gaseous phase at stage outlet
TW1	temperature of droplet at stage inlet
TW3	temperature of droplet at stage outlet
DAVEN2	droplet nominal diameter at stage inlet
DEVEN	droplet nominal diameter at stage outlet
DELZI	length of stage
VZ	axial velocity
WMASS1	mass flow rate of water
VMASS1	mass flow rate of water vapor

AMASS	mass flow rate of dry air
CHMASS	mass flow rate of methane
DPG	specific heat constant pressure to gaseous phase
CPW	specific heat of water
RE	Reynolds number based on relative velocity between droplet and gaseous phase.

(3) Output Variables:

DELIGH	temperature drop in gaseous phase due to heat transfer between water droplet and gaseous phase
DELTWH	temperature rise in droplet due to heat transfer between water droplet and gaseous phase

(4) Usage:

```
CALL WICHET (TG1, TG3, TW3, DAVEN2, DAVEN, DELZI, VZ,
            WMASS1, VMASS1, AMASS, CHMASS, CPG, CPW,
            DELIGH, DELTWH, RE)
```

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 28)

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

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 the molecular weights of constituents A and B. For water-air systems, the numerical values of V_A, V_B, M_A and M_B are given as follows:

$$V_A = V_{air} = 29.9 \qquad M_A = M_{air} = 28.9$$

$$V_B = M_{water} = 18.8 \qquad M_B = M_{water} = 18.0$$

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: 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:

$$Sh = 2.0 + k\,(Re)^x (Sc)^y$$

where Re is the Reynolds number based on relative velocity, which expresses the ratio of inertial force to viscous force, and Sc is the Schmidt number, which expressed 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

$$Sh = 2.0 + 0.6\,(Re)^{0.50}(Sc)^{0.33}$$

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 the new value of water mass flow rate.

$$\dot{m}_w = \dot{m}_w - \frac{dm}{dt}$$

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

$$\dot{m}_v = \dot{m}_v + \frac{dm}{dt}$$

(xii) Calculate the specific humidity, W.

$$W = \dot{m}_v/\dot{m}_a$$

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:

$$W = 0.6219 \frac{P_w}{P - P_w}$$

(2) 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 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

(3) 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

(4) Usage:

```
CALL WICMAS (HW1, TW1, TW2, PP1, PP2, TG1, TG2, DZ, PWB1,
            PWB2, PW1, PW2, VZ, DDAVE1, DDAVE2, HW2,
            VMASS1, VMASS2, WMASS1, WMASS2, DMDTAV,
            AMASS, RE)
```

FUNCTION WICMTR

(1) Description:

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

(2) Input Variables:

TTG	temperature of gaseous phase
TTW	temperature of water droplet
PPP	pressure of gaseous phase
DAVW	droplet nominal diameter
VZ	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 is a function at temperature as follows:

$$\log_{10} p_s = A - B/T$$

where units are (Kg/cm^2) for p_s and (K) for T. The values of constant A and B are given as follows:

$A = 5.97780, \quad B = 2224.4 \quad \text{when } 20^{\circ}C < T < 100^{\circ}C$

$A = 5.64850, \quad B = 2101.1 \quad \text{when } 100^{\circ}C < T < 200\ C$

$A = 5.45142, \quad B = 2010.8 \quad \text{when } 200^{\circ}C < T < 350^{\circ}C$

(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. Figure A.3.2. shows how to determine the new trial value.

(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)

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EFFECT OF WATER ON AXIAL FLOW COMPRESSORS. PART I. ANALYSIS AND--ETC(U)
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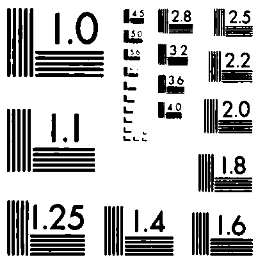

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FUNCTION WICSH

(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 WICSIZ

(1) Description:

Subroutine WICSIZ 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 WICSIZ 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:

$$R_{mix} = x_a . R_a + x_v . R_v + x_c . R_c$$

$$c_{pmix} = x_a \cdot c_{pa} + x_v \cdot c_{pv} + x_c \cdot c_{pc}$$

$$\gamma_{mix} = \left(1.0 - \frac{R_{mix}}{c_{pmix} J}\right)^{-1}$$

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_{mix} = gas constant of mixture
c_{pa} = specific heat constant pressure for air
c_{pv} = specific heat constant pressure for water vapor
c_{pc} = specific heat at constant pressure for methane

c_{pmix} = specific heat at constant pressure for mixture

r_{mix} = specific heat ratio for mixture

(2) Input Variables:

XAIR	mass fraction of air in gaseous mixture
XH2O	mass fraction of water vapor in gaseous mixture
XCH4	mass fraction of methane in gaseous mixture
T	temperature of gaseous mixture

(3) Output Variables:

RMIX	gas constant of gaseous mixture
CPMIX	specific heat constant pressure for gaseous mixture
GAMMA	specific heat ratio of gaseous mixture
G1	value for GAMMA/ (GAMMA - 1.0)
G2	value for (GAMMA - 1.0)/2.0
G3	value for -1.0/(GAMMA - 1.0)

(4) Usage:

```
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 29)

$$c_p = (a + aT = cT^2 + dt^3 + eT^4)R$$

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 29)

$$c_p = (a + bT + cT^2 + dT^3 + eT^4)R$$

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 temperature

(3) Output Variable:

WICCPH specific heat at constant pressure

(4) Usage:

WICCPH (T)

FUNCTION WICCPC

(1) Description:

Function WICCPC calculates the specific heat at constant pressure for methane as a function of temperature as follows: *(Reference 29)*

$$c_p = (a + bT + cT^2 + dT^3 + eT^4)R$$

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:

$a = 3.82619$

$b = -3.97946 \times 10^{-3}$

$c = 24.5583 \times 10^{-6}$

$d = -22.7329 \times 10^{-9}$

$e = 6.92760 \times 10^{-12}$

(2) Input Variable:

T temperature

(3) Output Variable:

WICCPC	specific heat constant pressure

(4) Usage:

WICCPC (T)

APPENDIX 4

PROGRAM SOURCE LIST

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C PROGRAM PURDU-WICSTK
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C ABSTRACT:
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 CONSISTES 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 FORTRAN COMPUTER 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 THIS COMPUTER PROGRAM CADE HAS BEEN DEVELOPED AT PURDUE UNIVERSITY,
C THERMAL SCIENCE AND PROPULSION CENTER,WEST LAFAYETTE,INDIANA 47906,
C UNDER AIR FORCE CONTRACT F33615-78-C-2401,PRINCIPAL INVESTIGATOR:DR.
C S.N.B.MURTHY. THE AUTHER OF THIS PROGRAM CODE IS TOSHIAKI TSUCHIYA,
C PURDUE UNIVERSITY , DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS,
C GRADUATE INSTRICTOR IN RESEARCH.
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      REAL ND,NU,KA,M,MMASS,MMASS1
      REAL MMASSO
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
      COMMON SRHUB(7) , SC(7) , SBLADE(7),STAGES(7)
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UDU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      DIMENSION D(20,3) , XD(20,3) , XXD(20,3)
      DIMENSION WS(3),WMASS(3),VMASS(3),RHOA(3),RHOM(3),TB(3)
      DIMENSION DELZ(6),ETAA(6)
      DIMENSION XXA(3),XXV(3),DAVE(20)
      DIMENSION TDEW(3)
      DIMENSION DDAVE(20),WWMASS(3),WTMASS(3)
      DIMENSION TMASS(3),GMASS(3),XAIR(3),XMETAN(3),XGAS(3),FAISTL(6)
      DIMENSION DELB1R(7),DELB1S(7),XG1BLD(7),XG2BLD(7),XG3BLD(7),
     $XWBLD(7),XWWBLD(7)
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C READ IUPUT DATA                                                     C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,99) NS
   99 FORMAT(I1)
      NS1=NS+1
      READ(5,100) (RRHUB(I),I=1,NS)
  100 FORMAT (6F5.3)
      READ(5,111)(RC(I),I=1,NS)
  111 FORMAT(6F5.3)
      READ(5,112) (RBLADE(I),I=1,NS)
  112 FORMAT(6F5.2)
      READ(5,113)(STAGER(I) ,I=1,NS)
  113 FORMAT(6F5.2)
      READ(5,114)(SRHUB(I),I=1,7)
  114 FORMAT(7F5.3)
      READ(5,115) (SC(I),I=1,7)
  115 FORMAT(7F5.3)
```

```
      READ(5,116)(SBLADE(I),I=1,7)
  116 FORMAT(7F5.2)
      READ(5,117)(SIGUMR(I),I=1,NS)
  117 FORMAT(6F5.3)
      READ(5,122)(SIGUMS(I) ,I=1,NS1)
  122 FORMAT(7F5.3)
      READ(5,127) FNF
  127 FORMAT(F8.2)
      READ(5,128) XDIN,ICENT,XDDIN,IICENT
  128 FORMAT(F5.3,I1,F5.3,I1)
      READ(5,129) TOG,TOW,PO
  129 FORMAT(3F7.2)
      READ(5,130) DIN,DDIN
  130 FORMAT(2F6.1)
      READ(5,132) FND,T01D,P01D
  132 FORMAT(F7.1,2F7.2)
      READ(5,133) XCH4,RHUMID
  133 FORMAT(F5.3,F10.5)
      READ(5,134) FMWA,FMWV,FMWC
  134 FORMAT(3F7.3)
      READ(5,135) PREB,DLIMIT
  135 FORMAT(F5.1,F7.1)
      READ(5,140) (STAGES(I),I=1,NS1)
  140 FORMAT(7F5.2)
      READ(5,141) (GAPR(I),I=1,NS)
  141 FORMAT(6F7.5)
      READ(5,142) (GAPS(I),I=1,NS)
  142 FORMAT(6F7.5)
      READ(5,146) (RRTIP(I),I=1,NS)
  146 FORMAT(6F6.3)
      READ(5,147) (SRTIP(I),I=1,NS1)
  147 FORMAT(7F6.3)
      READ(5,148) IPERFM,IUNIT
  148 FORMAT(2I1)
      READ(5,1491) IRAD
 1491 FORMAT(I1)
      READ(5,1492) (RT(I),I=1,NS)
 1492 FORMAT(6F5.3)
      READ(5,1493) (RM(I),I=1,NS)
 1493 FORMAT(6F5.3)
      READ(5,1494) (RH(I),I=1,NS)
 1494 FORMAT(6F5.3)
      READ(5,1495) (ST(I),I=1,NS)
 1495 FORMAT(6F5.3)
      READ(5,1496) (SM(I),I=1,NS)
 1496 FORMAT(6F5.3)
      READ(5,1497) (SH(I),I=1,NS)
 1497 FORMAT(6F5.3)
      READ(5,1498) (BLOCK(I),I=1,NS)
 1498 FORMAT(6F5.3)
      READ(5,1499) (BLOCKS(I),I=1,NS1)
 1499 FORMAT(7F5.3)
      READ(5,1502) (BET1MR(I),I=1,NS)
 1502 FORMAT(6F5.2)
      READ(5,1503) (BET2MR(I),I=1,NS)
 1503 FORMAT(6F5.2)
      READ(5,1504) (BET1MS(I),I=1,NS1)
 1504 FORMAT(7F5.2)
      READ(5,1505) (BET2MS(I),I=1,NS1)
 1505 FORMAT(7F5.2)
      READ(5,1506) DSMASS
 1506 FORMAT(F10.6)
      READ(5,1507) (PR12D(I),I=1,NS)
 1507 FORMAT(6F5.3)
      READ(5,1508) (PR13D(I),I=1,NS)
 1508 FORMAT(6F5.3)
      READ(5,1509) (ETARD(I),I=1,NS)
 1509 FORMAT(6F5.3)
      READ(5,1511) (SAREA(I),I=1,NS)
 1511 FORMAT([illegible]F10.7)
```

```
      READ(5,1512) (SAREAS(I),I=1,NS1)
 1512 FORMAT(7F10.7)
      READ(5,1513) (DELB1R(I),I=1,NS)
 1513 FORMAT(6F5.2)
      READ(5,1514) (DELB1S(I),I=1,NS1)
 1514 FORMAT(7F5.2)
      READ(5,1515) (XG1BLD(I),I=1,NS)
 1515 FORMAT(6F5.2)
      READ(5,1516) (XG2BLD(I),I=1,NS)
 1516 FORMAT(6F5.2)
      READ(5,1517) (XG3BLD(I),I=1,NS)
 1517 FORMAT(6F5.2)
      READ(5,1518) (XWBLD(I),I=1,NS)
 1518 FORMAT(6F5.2)
      READ(5,1519) (XWWBLD(I),I=1,NS)
 1519 FORMAT(6F5.2)
      READ(5,1520) (BET2SS(I),I=1,NS1)
 1520 FORMAT(7F5.2)
      CFL=2.54
      CFT=1.0/1.8
      CFP=47.880258
      CFD=16.018463
      CFM=0.45359237
      CFV=0.3048
      CFA=0.09290304
      IF(IUNIT.NE.3) GO TO 850
      DO 1560 I=1,NS
      RRHUB(I)=RRHUB(I)*CFL
      RC(I)=RC(I)*CFL
      GAPR(I)=GAPR(I)*CFL
      GAPS(I)=GAPS(I)*CFL
      RRTIP(I)=RRTIP(I)*CFL
      RT(I)=RT(I)*CFL
      RM(I)=RM(I)*CFL
      RH(I)=RH(I)*CFL
      ST(I)=ST(I)*CFL
      SM(I)=SM(I)*CFL
      SH(I)=SH(I)*CFL
      SAREA(I)=SAREA(I)*CFA
 1560 CONTINUE
      DO 1570 I=1,NS1
      SRHUB(I)=SRHUB(I)*CFL
      SC(I)=SC(I)*CFL
      SRTIP(I)=SRTIP(I)*CFL
      SAREAS(I)=SAREAS(I)*CFA
 1570 CONTINUE
      TOG=TOG*CFT
      TOW=TOW*CFT
      P0=P0*CFP
      T01D=T01D*CFT
      P01D=P01D*CFP
      DSMASS=DSMASS*CFM
      IUNIT=2
  850 CONTINUE
      IF(IUNIT.NE.4) GO TO 851
      DO 1561 I=1,NS
      RRHUB(I)=RRHUB(I)/CFL
      RC(I)=RC(I)/CFL
      GAPR(I)=GAPR(I)/CFL
      GAPS(I)=GAPS(I)/CFL
      RRTIP(I)=RRTIP(I)/CFL
      RT(I)=RT(I)/CFL
      RM(I)=RM(I)/CFL
      RH(I)=RH(I)/CFL
      ST(I)=ST(I)/CFL
      SM(I)=SM(I)/CFL
      SH(I)=SH(I)/CFL
      SAREA(I)=SAREA(I)/CFA
 1561 CONTINUE
      DO 1571 I=1,NS1
```

```
      SRHUB(I)=SRHUB(I)/CFL
      SC(I)=SC(I)/CFL
      SRTIP(I)=SRTIP(I)/CFL
      SAREAS(I)=SAREAS(I)/CFA
 1571 CONTINUE
      TOG=TOG/CFT
      TOW=TOW/CFT
      PO=PO/CFP
      TO1D=TO1D/CFT
      PO1D=PO1D/CFP
      DSMASS=DSMASS/CFM
      IUNIT=1
  851 CONTINUE
      FNFN=FNF*100.0
      CRPM=FNF*FND
      IF(IUNIT.EQ.1) FN=FND*FNF*SQRT(TOG/518.7)
      IF(IUNIT.EQ.2) FN=FND*FNF*SQRT(TOG/288.17)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C PRINT OUT OF INPUT DATA                                              C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      WRITE(6,1600)
 1600 FORMAT(1H1,5X,≠***************************** INPUT DATA **********
     $***************************≠)
      WRITE(6,1610) NS
 1610 FORMAT(1H0,1X,≠NS(NUMBER OF STAGE)=≠,I2)
      IF(IUNIT.EQ.1) WRITE(6,1601)
 1601 FORMAT(1H ,1X,≠UNIT=ENGLISH UNIT≠)
      IF(IUNIT.EQ.2) WRITE(6,1602)
 1602 FORMAT(1H ,1X,≠UNIT=METRIC UNIT≠)
      WRITE(6,1603) IPERFM
 1603 FORMAT(1H ,1X,≠IPERFM=≠,I1)
      IF(IRAD.EQ.1) WRITE(6,1604)
 1604 FORMAT(1H ,1X,≠PERFORMANCE AT TIP≠)
      IF(IRAD.EQ.2) WRITE(6,1605)
 1605 FORMAT(1H ,1X,≠PERFORMANCE AT MEAN≠)
      IF(IRAD.EQ.3) WRITE(6,1606)
 1606 FORMAT(1H ,1X,≠PERFORMANCE AT HUB≠)
      WRITE(6,1620)
 1620 FORMAT(1H0,14X,≠1≠,5X,≠2≠,5X,≠3≠,5X,≠4≠,5X,≠5≠,5X,≠6≠,4X,≠IGV≠)
      WRITE(6,1630) (RRHUB(I),I=1,NS)
 1630 FORMAT(1H ,1X,≠RRHUB(I)≠,3X,6(F5.3,1X))
      WRITE(6,1640) (RC(I),I=1,NS)
 1640 FORMAT(1H ,1X,≠RC(I)≠,6X,6(F5.3,1X))
      WRITE(6,1650) (RBLADE(I),I=1,NS)
 1650 FORMAT(1H ,1X,≠RBLADE(I)≠,2X,6(F5.2,1X))
      WRITE(6,1660) (STAGER(I),I=1,NS)
 1660 FORMAT(1H ,1X,≠STAGER(I)≠,2X,6(F5.2,1X))
      WRITE(6,1661) (STAGES(I),I=1,NS)
 1661 FORMAT(1H ,1X,≠STAGES(I)≠,2X,6(F5.2,1X))
      WRITE(6,1670) (SRHUB(I),I=1,NS1)
 1670 FORMAT(1H ,1X,≠SRHUB(I)≠,3X,7(F5.3,1X))
      WRITE(6,1680) (SC(I),I=1,NS)
 1680 FORMAT(1H ,1X,≠SC(I)≠,6X,6(F5.3,1X))
      WRITE(6,1690) (SBLADE(I),I=1,NS)
 1690 FORMAT(1H ,1X,≠SBLADE(I)≠,2X,6(F5.2,1X))
      WRITE(6,1700) (SIGUMR(I),I=1,NS)
 1700 FORMAT(1H ,1X,≠SIGUMR(I)≠,2X,6(F5.3,1X))
      WRITE(6,1750) (SIGUMS(I),I=1,NS)
 1750 FORMAT(1H ,1X,≠SIGUMS(I)≠,2X,6(F5.3,1X))
      WRITE(6,1795) (GAPR(I),I=1,NS)
 1795 FORMAT(1H ,1X,≠GAPR(I ≠,4X,6(F5.3,1X))
      WRITE(6,1796) (GAPS(I),I=1,NS)
 1796 FORMAT(1H ,1X,≠GAPS(I)≠,4X,6(F5.3,1X))
      WRITE(6,1798) (RRTIP(I),I=1,NS)
 1798 FORMAT(1H ,1X,≠RRTIP(I)≠,3X,6(F5.2,1X))
      WRITE(6,1799) (SRTIP(I),I=1,NS1)
 1799 FORMAT(1H ,1X,≠SRTIP(I)≠,3X,7(F5.2,1X))
```

```
      WRITE(6,1801) (RT(I),I=1,NS)
 1801 FORMAT(1H ,1X,≠RT(I)≠,6X,6(F5.3,1X))
      WRITE(6,1802) (RM(I),I=1,NS)
 1802 FORMAT(1H ,1X,≠RM(I)≠,6X,6(F5.3,1X))
      WRITE(6,1803) (RH(I),I=1,NS)
 1803 FORMAT(1H ,1X,≠RH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1804) (ST(I),I=1,NS)
 1804 FORMAT(1H ,1X,≠SH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1805) (SM(I),I=1,NS)
 1805 FORMAT(1H ,1X,≠SM(I)≠,6X,6(F5.3,1X))
      WRITE(6,1806) (SH(I),I=1,NS)
 1806 FORMAT(1H ,1X,≠SH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1807) (BLOCK(I),I=1,NS)
 1807 FORMAT(1H ,1X,≠BLOCK(I)≠,3X,6(F5.3,1X))
      WRITE(6,1808) (BLOCKS(I),I=1,NS)
 1808 FORMAT(1H ,1X,≠BLOCKS(I)≠,2X,6(F5.3,1X))
      WRITE(6,1811) (BET1MR(I),I=1,NS)
 1811 FORMAT(1H ,1X,≠BET1MR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1812) (BET2MR(I),I=1,NS)
 1812 FORMAT(1H ,1X,≠BET2MR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1813) (BET1MS(I),I=1,NS1)
 1813 FORMAT(1H ,1X,≠BET1MS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1814) (BET2MS(I),I=1,NS1)
 1814 FORMAT(1H ,1X,≠BET2MS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1815) (PR12D(I),I=1,NS)
 1815 FORMAT(1H ,1X,≠PR12D(I)≠,3X,6(F5.3,1X))
      WRITE(6,1816) (PR13D(I),I=1,NS)
 1816 FORMAT(1H ,1X,≠PR13D(I)≠,3X,6(F5.3,1X))
      WRITE(6,1817) (ETARD(I),I=1,NS)
 1817 FORMAT(1H ,1X,≠ETARD(I)≠,3X,6(F5.3,1X))
      WRITE(6,1818)
 1818 FORMAT(1H1,5X,≠******************************* INPUT DATA ********
     $********************≠)
      WRITE(6,1800) FNF
 1800 FORMAT(1H0,1X,≠FNF(FRACTION OF DESIGN CORRECTED SPEED)=≠,F5.3)
      WRITE(6,1810) XDIN,XDDIN,RHUMID,XCH4
 1810 FORMAT(1H0,1X,≠XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=≠,F5.3
     $,/,2X,≠XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=≠,F5.3,/,
     $2X,≠RHUMID(INITIAL RELATIVE HUMIDITY)=≠,F6.2,1X,≠PER CENT≠,/,
     $2X,≠XCH4(INITIAL METHANE CONTENT)=≠,F5.3)
      WRITE(6,1820) TOG,TOW,PO
 1820 FORMAT(1H0,1X,≠TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)=≠,
     $F7.2,/,2X,≠TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)=≠,F7.2,/,
     $2X,≠PO(COMPRESSOR INLET TOTAL PRESSURE)=≠,F10.2)
      WRITE(6,1830) DIN,DDIN
 1830 FORMAT(1H0,1X,≠DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=≠,
     $F6.1,/,2X,≠DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)=≠,F6.1)
      WRITE(6,1850) FND
 1850 FORMAT(1H0,1X,≠FND(DESIGN ROTATIONAL SPEED)=≠,F7.1)
      WRITE(6,1851) DSMASS
 1851 FORMAT(1H0,1X,≠DSMASS(DESIGN MASS FLOW RATE)=≠,F10.4)
      WRITE(6,1860) TOG
 1860 FORMAT(1H0,1X,≠COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE)≠ ,
     $F7.2)
      WRITE(6,1870) PO
 1870 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      WRITE(6,1880) PREB
 1880 FORMAT(1H0,1X,≠PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE
     $MENT)=≠,F5.1,1X,≠PERCENT≠)
      WRITE(6,1900) FN
 1900 FORMAT(1H0,1X,≠ROTOR SPEED=≠,F7.1,1X,≠RPM≠)
      WRITE(6,1910) CRPM,FNFN
 1910 FORMAT(1H0,1X,≠CORRECTED ROTOR SPEED= ≠,F7.1,1X,≠RPM≠,≠(≠,2X,F5.1,
     $≠PER CENT OF DESIGN CORRECTED SPEED)≠)
      IF(IUNIT.NE.2) GO TO 852
      DO 156 I=1,NS
      RRHUB(I)=RRHUB(I)/CFL
      RC(I)=RC(I)/CFL
      GAPR(I)=GAPR(I)/CFL
      GAPS(I)=GAPS(I)/CFL
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      RRTIP(I)=RRTIP(I)/CFL
      RT(I)=RT(I)/CFL
      RM(I)=RM(I)/CFL
      RH(I)=RH(I)/CFL
      ST(I)=ST(I)/CFL
      SM(I)=SM(I)/CFL
      SH(I)=SH(I)/CFL
      SAREA(I)=SAREA(I)/CFA
  156 CONTINUE
      DO 157 I=1,NS1
      SRHUB(I)=SRHUB(I)/CFL
      SC(I)=SC(I)/CFL
      SRTIP(I)=SRTIP(I)/CFL
      SAREAS(I)=SAREAS(I)/CFA
  157 CONTINUE
      TOG=TOG/CFT
      TOW=TOW/CFT
      P0=P0/CFP
      T01D=T01D/CFT
      P01D=P01D/CFP
      DSMASS=DSMASS/CFM
  852 CONTINUE
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C OTHER INPUT DATA
      WKDONE=1.0
      IPRINT=1
      DO 153 I=1,NS
      FMR1(I)=0.6
      FMA2(I)=0.6
  153 CONTINUE
      AK1=1.0
      AK2=1.0
      AK3=1.0
      AAAIGV=SAREA(1)
      RU=1545.3
      RHOW=62.54
      CPW=1.00
      RA=RU/FMWA
      RV=RU/FMWV
      RCH=RU/FMWC
      DELV=0.0
      DELVU2=10.0
      DELVL2=10.0
      GC=32.174
      AJ=778.16
      PAI=3.1415926
      DO 150 I=1,NS
      AAREA(I)=PAI*((RRTIP(I)/12.0)**2-(RRHUB(I)/12.0)**2)*BLOCK(I)
      AAREAS(I)=PAI*(SRTIP(I)**2-SRHUB(I)**2)/144.0*BLOCKS(I)
      DELZ(I)=(RC(I)+SC(I))/12.0
  150 CONTINUE
      NS1=NS+1
      AAREAS(NS1)=PAI*(SRTIP(NS1)**2-SRHUB(NS1)**2)/144.0*BLOCKS(NS1)
      AAAR1T=AAREA(1)
       DO 152 I=1,NS
      AREA(I)=SAREA(I)
      AREAS(I)=SAREAS(I)
  152 CONTINUE
      AREAS(NS1)=SAREAS(NS1)
      OT01G=TOG
      OT01D=TOW
      OP01=P0
      DO 151 I=1,NS
      UTIP(I)=RT(I)/12.0*2.0*PAI*FND/60.0
      UTIPG(I)=RRTIP(I)/12.0*2.0*PAI*FND/60.0
      UTIP2(I)=ST(I)/12.0*2.0*PAI*FND/60.0
      UTIPD(I)=RT(I)/12.0*2.0*PAI*FND/60.0
      UOU(I)=(UTIP(I)/UTIPD(I))**2
      UMEAN(I)=RM(I)/12.0*2.0*PAI*FND/60.0
      UMEAN2(I)=SM(I)/12.0*2.0*PAI*FND/60.0
```

```
      UHUB(I)=RH(I)/12.0*2.0*PAI*FND/60.0
      UHUB2(I)=SH(I)/12.0*2.0*PAI*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) RADI1(I)=RT(I)
      IF(IRAD.EQ.1) RADI2(I)=ST(I)
      IF(IRAD.EQ.2) RADI1(I)=RM(I)
      IF(IRAD.EQ.2) RADI2(I)=SM(I)
      IF(IRAD.EQ.3) RADI1(I)=RH(I)
      IF(IRAD.EQ.3) RADI2(I)=SH(I)
  151 CONTINUE
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C BLADE RESETTING
      DO 154 I=1,NS
      BET1MR(I)=BET1MR(I)+DELB1R(I)
      BET2MR(I)=BET2MR(I)+DELB1R(I)
      STAGER(I)=STAGER(I)+DELB1R(I)
      BET1MS(I)=BET1MS(I)+DELB1S(I)
      BET2MS(I)=BET2MS(I)+DELB1S(I)
      STAGES(I)=STAGES(I)+DELB1S(I)
  154 CONTINUE
      TG(1)=T01D
      P(1)=P01D
      CALL WICSPD(DSMASS,ISTAGE)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C ROTER SPEED AND RADIUS                                               C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DO 155 I=1,NS
      UTIP(I)=RT(I)/12.0*2.0*PAI*FN/60.0
      UTIPG(I)=RRTIP(I)/12.0*2.0*PAI*FN/60.0
      UTIP2(I)=ST(I)/12.0*2.0*PAI*FN/60.0
      UTIPD(I)=RT(I)/12.0*2.0*PAI*FND/60.0
      UOU(I)=(UTIP(I)/UTIPD(I))**2
      UMEAN(I)=RM(I)/12.0*2.0*PAI*FN/60.0
      UMEAN2(I)=SM(I)/12.0*2.0*PAI*FN/60.0
      UHUB(I)=RH(I)/12.0*2.0*PAI*FN/60.0
      UHUB2(I)=SH(I)/12.0*2.0*PAI*FN/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) RADI1(I)=RT(I)
      IF(IRAD.EQ.1) RADI2(I)=ST(I)
      IF(IRAD.EQ.2) RADI1(I)=RM(I)
      IF(IRAD.EQ.2) RADI2(I)=SM(I)
      IF(IRAD.EQ.3) RADI1(I)=RH(I)
      IF(IRAD.EQ.3) RADI2(I)=SH(I)
  155 CONTINUE
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C MASS FLOE RATE                                                       C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  901 READ(5,200) FAI
  200 FORMAT(F7.5)
      ISTAGE=0
      N=1
      IF(FAI.GT.1.0) GO TO 998
      IF(IPRINT.EQ.2) WRITE(6,197) FAI
  197 FORMAT(1H1,2X,≠FAI=≠,F7.5)
```

```
      FAIO=FAI
      VZ=UTIPG(1)*FAI
      TG(1)=OT01G
      UZERO=0.0
      UUZERO=0.0
      RZERO=RRHUB(1)
      RRZERO=RRHUB(1)
      ITIP=0
      IITIP=0
      DAVE(N)=0.0
      DDAVE(N)=0.0
      TW(1)=OT01D
      TWW(1)=OT01D
      IF(XDIN.GT.0.0) DAVE(N)=DIN
      IF(XDDIN.GT.0.0) DDAVE(N)=DDIN
      IF(XDIN.GT.0.0) TW(1)=OT01D
      IF(XDDIN.GT.0.0) TWW(1)=OT01D
      P(1)=OP01
      TB(1) = WICBPT(TG(1), P(1))
      WS(1) = WICSH(TG(1) , P(1) )*RHUMID/100.0
      PW=WS(1)*P(1)/(WS(1)+0.6219)
      TDEW(1)=WICBPT(TG(1),PW)
      XW(1)=XDIN
      XWW(1)=XDDIN
      XWT(1)=XW(1)+XWW(1)
      XWTO=XWT(1)
      XV(1)=WS(1)/(1.0+WS(1))*(1.0-XWT(1)-XCH4)
      XA=1.0-XWT(1)-XV(1)-XCH4
      XG=XA+XV(1)+XCH4
      XAIN=XA
      XCH4IN=XCH4
      ISTAGE=1
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMAI=GAMMA
      RHOG(1)=P(1)/RMIX/TG(1)
      RHOA(1)=P(1)/RA/TG(1)
      AMASSM=-1.0
      AAA2=AAAIGV
      AAA3=AAAIGV
      CALL WICMAC(ISTAGE,AMASSM,TG(1),P(1),M,VZ,C,XWT(1),BET2SS(NS1),
     $RMIX,CPMIX,AAA3)
      RHOG(1)=(1.0+G2*M**2)**G3*RHOG(1)
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)
      MMASS = RHOM(1)*FAI*UTIPG(1)*AAA3
      MMASSO=MMASS
      WMASSO=MMASSO*XDIN
      WWMASO=MMASSO*XDDIN
      IF(IPRINT.EQ.2) WRITE(6,5558) MMASSO,XDIN,WMASSO,MMASS
5558  FORMAT(1H0,2X,4(F10.5,2X))
      DAMY=OT01G/518.7
      DAMY2=OP01/(14.7*144.0)
      CMASS=MMASS*SQRT(DAMY)/DAMY2
      AMASS = XA * MMASS
      WMASS(1)=XW(1)*MMASS
      WWMASS(1)=XWW(1)*MMASS
      WTMASS(1)=XWT(1)*MMASS
      VMASS(1)=XV(1)*MMASS
      CHMASS=XCH4*MMASS
      GMASS(1)=MMASS-WTMASS(1)
      CMASS2=GMASS(1)*SQRT(DAMY)/DAMY2
      AMO=AMASS
      VMO=VMASS(1)
      CMO=CHMASS
      GMO=GMASS(1)
      WMO=WMASS(1)
      WWMO=WWMASS(1)
      WTMO=WTMASS(1)
      TLMO=GMO+WTMO
      TWMAS=WMASSO*AAAR1T/AAAIGV
      TWWMAS=WWMASO*AAAR1T/AAAIGV
```

```
      WMASTL=TWMAS+TWWMAS
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C INITIAL VALUES                                                       C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      TG(3)=TG(1)
      TW(3)=TW(1)
      TWW(3)=TWW(1)
      P(3)=P(1)
      TB(3)=TB(1)
      WS(3)=WS(1)
      TDEW(3)=TDEW(1)
      XV(3)=XV(1)
      XG=XA+XV(3)+XCH4
      XW(3)=XW(1)
      XWW(3)=XWW(1)
      VMASS(3)=VMASS(1)
      WMASS(3)=WMASS(1)
      WWMASS(3)=WWMASS(1)
      WCENT=WMASS0
      WWCENT=WWMAS0
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C IGV                                                                  C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C IGV IMPINGEMENT
      CALL WICISS(7,RADI1(1), XW(1) , XG , RHOG(1),0.0,VZ,WW1,WW2,WW)
      AMIMPS=WW
      AMWAKS = AMIMPS * (1.0-PREB)
      AMREBS=AMIMPS*PREB
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C IGV WAKE
      N=2
      DAVE(2)=DAVE(1)
      DDAVE(2)=DDAVE(1)
      ALFA3=BET2SS(NS1)*(FAID/FAI)**(1.0/7.0)
      DWAKEM=0.0
      IF(XDIN.GT.0.0.OR.XDDIN.GT.0.0) GO TO 628
      GO TO 629
  628 CALL WICWAK(RHOG(1),VZ,DWAKE,DWAKEM)
  629 CONTINUE
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C IGV OUTLET
      WMASS(3) = WMASS(1)
      XW(3) = XW(1)
      PRATIO=1.0
      TRATIO=1.0
      EFF=1.0
      AMIMPR=0.0
      AMREBR=0.0
      AMWAKR=0.0
      DELTGW=0.0
      DELTDW=0.0
      DELTGH=0.0
      DELTDH=0.0
      DELT=0.0
      DELP=0.0
      DMDTAV=0.0
      XV(3)=XV(1)
      XW(3)=XW(1)
      XWW(3)=XWW(1)
      WMASS(3) = WMASS(1)
      WWMASS(3)=WWMASS(1)
      VMASS(3) = VMASS(1)
      WS(3) = WS(1)
      TDEW(3)=TDEW(1)
```

```
      RHOA(3) = RHOA(1)
      RHOM(3) = RHOM(1)
      RHOG(3) = RHOG(1)
      TG(3) = TG(1)
      TW(3) = TW(1)
      TWW(3)=TWW(1)
      P(3) = P(1)
      TB(3) = TB(1)
      XV(2)=0.0
      XW(2) = 0.0
      XWW(2)=0.0
      WMASS(2) = 0.0
      WWMASS(2)=0.0
      VMASS(2) = 0.0
      WS(2) = 0.0
      RHOA(2)=0.0
      RHOM(2) = 0.0
      RHOG(2)= 0.0
      TG(2)=0.0
      TW(2) =0.0
      TWW(2)=0.0
      P(2) = 0.0
      TB(2) = 0.0
      TDEW(2)=0.0
      GAMMA0=GAMMA
      RHOG(2)=RHOG(1)
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C ROTER INLET                                                         C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  900 ISTAGE=ISTAGE+1
      IF(IPRINT.EQ.2) WRITE(6,8001) FAI0,ISTAGE
 8001 FORMAT(1H1,1X,≠**********************  ≠,1X,
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F5.3,1X,≠(ISTAGE= ≠,I2,1X,
     $≠)≠,2X,≠***********************≠)
      TG(1)=TG(3)
      TW(1)=TW(3)
      TWW(1)=TWW(3)
      P(1)=P(3)
      TB(1)=TB(3)
      RHOA(1)=P(1)/RA/TG(1)
      WS(1)=WS(3)
      TDEW(1)=TDEW(3)
      XV(1)=XV(3)
      XCH4=CHMASS/MMASS
      XA=AMASS/MMASS
      XG=XA+XV(1)+XCH4
      XAIR(1)=XA
      XMETAN(1)=XCH4
      XGAS(1)=XG
      XW(1)=XW(3)
      XWW(1)=XWW(3)
      XWT(1)=XW(1)+XWW(1)
      VMASS(1)=VMASS(3)
      WMASS(1)=WMASS(3)
      WWMASS(1)=WWMASS(3)
      WTMASS(1)=WMASS(1)+WWMASS(1)
      MMASS=AMASS+CHMASS+VMASS(1)+WTMASS(1)
      TMASS(1)=MMASS
      GMASS(1)=TMASS(1)-WTMASS(1)
      ALFA1=ALFA3
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMAS=GAMMA
      AAA1=AAA3
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C STAGE PERFORMANCE CALCULATION                                       C
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C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPERFM.EQ.1) JPERFM=1
      IF(IPERFM.EQ.2) JPERFM=2
      IF(IPERFM.EQ.3) JPERFM=3
      DAMY=0.0
      IF(WTMASS(1).GT.1.0E-4)
     $DAMY=WWMASS(1)/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,≠ )≠)
      IF(JPERFM.EQ.1) GO TO 1300
      IF(JPERFM.EQ.2) GO TO 1301
      IF(JPERFM.EQ.3) GO TO 1302
 1300 CALL WICSPA(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAVE(N),XDIN,ETA,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK3)
      GO TO 1303
 1301 CALL WICSPB(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAVE(N),DELV,WMASS(1)
     $,N,OMEGA1,
     $OMRGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,BETA1,BETA2,VZ,ALFA2,
     $ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK2,AK3)
      GO TO 1303
 1302 CALL WICSPC(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DDAVE(N),DELV,WMASS(
     $1),WWMASS(1),N,OMEGA1
     $,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,BETA1,BETA2,VZ,ALFA2,
     $ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,REAVE,DELVU2,DELVL2,AK1,AK2,
     $AK3)
 1303 CONTINUE
      DELTG1=DELTG
      DELTW1=DELTW
      IF(VZ.LT.0.0.OR.VZ.GT.1000.0) WRITE(6,1304) VZ
 1304 FORMAT(1H0,1X,≠AXIAL VELOCITY IS TOO HIGH OR TOO LOW≠,≠VZ=≠,
     $F10.5)
      IF(VZ.LT.0.0.OR.VZ.GT.1000.0) GO TO 901
      AAA2=AREAS(ISTAGE)
      AAA3=AREA(ISTAGE+1)
      IF(ISTAGE.EQ.NS) AAA3=AAA2
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C ROTOR IMPINGEMENT                                                     C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C ROTOR IMPINGEMENT(SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8010)
 8010 FORMAT(1H1,≠ ROTOR IMPINGEMENT(SMALL DROPLET)≠)
      CALL WICIRS(ISTAGE,RADI1(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,
     $WW2,WW)
      AMIMPR=WW
      IF(AMIMPR.LT.0.0) AMIMPR=0.0
      IF(AMIMPR.GT.WMASS(1)) AMIMPR=WMASS(1)
      AMREBR=AMIMPR*PREB/100.0
      AMWAKR=AMIMPR*(1.0-PREB/100.0)
      AMNOIR=WMASS(1)-AMIMPR
      XWNOIR=AMNOIR/MMASS
      XWREBR=AMREBR/MMASS
      XWWAKR=AMWAKR/MMASS
      IF(IPRINT.EQ.2) WRITE(6,609) AMIMPR,AMREBR,AMWAKR,AMNOIR,
     $XWNOIR,XWREBR,XWWAKR
  609 FORMAT(1H ,7(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C ROTOR IMPINGEMENT(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8020)
 8020 FORMAT(1H0,≠ ROTOR IMPINGEMENT(LARGE DROPLET)≠)
      CALL WICIRL(ISTAGE,RADI1(ISTAGE),XWW(1),XG,RHOG(1),BETA1,W1,WW1,WW
     $2,WW)
      BMIMPR=WW
      IF(BMIMPR.LT.0.0) BMIMPR=0.0
      IF(BMIMPR.GT.WWMASS(1)) BMIMPR=WWMASS(1)
      BMREBR=BMIMPR*PREB/100.0
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      BMWAKR=BMIMPR*(1.0-PREB/100.0)                                     MAIN
      BMNOIR=WWMASS(1)-BMIMPR                                            MAIN
      XWWB=0.0                                                           MAIN
      IF(WWMASS(1).GT.1.0E-6) XWWB=BMWAKR/WWMASS(1)                      MAIN
      XWWNOR=BMNOIR/MMASS                                                MAIN
      XWWRER=BMREBR/MMASS                                                MAIN
      XWWWAR=BMWAKR/MMASS                                                MAIN
      IF(IPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR,  MAIN
     $XWWRER,XWWWAR                                                      MAIN
 6090 FORMAT(1H ,7(F12.5,1X))                                            MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C ROTOR WAKE                                                           C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      IF(IPRINT.EQ.2) WRITE(6,8030)                                      MAIN
 8030 FORMAT(1H0,≠ ROTOR WAKE≠)                                          MAIN
      N=N+1                                                              MAIN
      ALFA=BETA2                                                         MAIN
      DWAKEM=0.0                                                         MAIN
      IF(AMWAKR.GT.0.0) GO TO 630                                        MAIN
      GO TO 631                                                          MAIN
  630 CALL WICWAK(RHOG(1),W2,DWAKE,DWAKEM)                               MAIN
  631 D1=DWAKEM                                                          MAIN
      IF(D1.LT.0.0) D1=0.0                                               MAIN
      IF(D1.GT.DIN) D1=DIN                                               MAIN
      AMING1=AMWAKR                                                      MAIN
      ALFA=BETA2                                                         MAIN
      RDELV1=DELVU2                                                      MAIN
      DWAKEM=0.0                                                         MAIN
      IF(BMWAKR.GT.0.0) GO TO 6310                                       MAIN
      GO TO 6311                                                         MAIN
 6310 CALL WICWAK(RHOG(1),RDELV1,DWAKE,DWAKEM)                           MAIN
 6311 D2=DWAKEM                                                          MAIN
      IF(D2.LT.0.0) D2=0.0                                               MAIN
      IF(D2.GT.DDIN) D2=DDIN                                             MAIN
      RUP2=(90.0-BETA2)/180.0                                            MAIN
      AMING2=BMWAKR*RUP2                                                 MAIN
      RDELV2=DELVL2                                                      MAIN
      DWAKEM=0.0                                                         MAIN
      IF(BMWAKR.GT.0.0) GO TO 6312                                       MAIN
      GO TO 6313                                                         MAIN
 6312 CALL WICWAK(RHOG(1),RDELV2,DWAKE,DWAKEM)                           MAIN
 6313 D3=DWAKEM                                                          MAIN
      IF(D3.LT.0.0) D3=0.0                                               MAIN
      IF(D3.GT.DDIN) D3=DDIN                                             MAIN
      RLOW2=(90.0+BETA2)/180.0                                           MAIN
      AMING3=BMWAKR*RLOW2                                                MAIN
      WMASSS=WMASS(1)-AMWAKR                                             MAIN
      WMASSL=WWMASS(1)-BMWAKR                                            MAIN
      CALL WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DDAVE(1             MAIN
     $),DAVE(1),D1,D2,D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)                   MAIN
      WWMASS(2)=AMLGE                                                    MAIN
      WMASS(2)=AMSLL                                                     MAIN
      IF(WMASS(2).LT.0.0) WMASS(2)=0.0                                   MAIN
      IF(WWMASS(2).LT.0.0) WWMASS(2)=0.0                                 MAIN
      WTMASS(2)=WWMASS(2)+WMASS(2)                                       MAIN
      VMASS(2)=VMASS(1)                                                  MAIN
      MMASS=AMASS+CHMASS+VMASS(2)+WTMASS(2)                              MAIN
      TMASS(2)=MMASS                                                     MAIN
      GMASS(2)=TMASS(2)-WTMASS(2)                                        MAIN
      DAVE(N)=DSLL                                                       MAIN
      DDAVE(N)=DLGE                                                      MAIN
      XW(2)=WMASS(2)/MMASS                                               MAIN
      XWW(2)=WWMASS(2)/MMASS                                             MAIN
      XWT(2)=WTMASS(2)/MMASS                                             MAIN
      XV(2)=XV(1)                                                        MAIN
      XCH4=CHMASS/MMASS                                                  MAIN
      XA=AMASS/MMASS                                                     MAIN
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      XG=XA+XV(2)+XCH4                                                   MAIN
      XAIR(2)=XA                                                         MAIN
      XMETAN(2)=XCH4                                                     MAIN
      XGAS(2)=XG                                                         MAIN
      WS(2)=VMASS(2)/AMASS                                               MAIN
      PW=WS(2)*P(2)/(WS(2)+0.6219)                                       MAIN
      TDEW(2)=WICBPT(TG(2),PW)                                           MAIN
      RHOA(2)=P(2)/RA/TG(2)                                              MAIN
      CALL WICPRP(XA,XV(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)         MAIN
      RHOG(2)=P(2)/RMIX/TG(2)                                            MAIN
      IF(JPERFM.NE.3) BMASS=MMASS                                        MAIN
      IF(JPERFM.EQ.3) BMASS=GMASS(2)                                     MAIN
      CALL WICMAC(ISTAGE,BMASS,TG(2),P(2),M,VZ,C,XWT(2),ALFA2,           MAIN
     $RMIX,CPMIX,AAA2)                                                   MAIN
      RHOG(2)=(1.0+G2*M**2)**G3*RHOG(2)                                  MAIN
      RHOM(2)=1.0/((1.0-XWT(2))/RHOG(2)+XWT(2)/RHOW)                     MAIN
      RHOA(2)=(1.0+G2*M**2)**G3*RHOA(2)                                  MAIN
      IF(IPRINT.EQ.2) WRITE(6,614) VZ,ALFA,D1,D2,D3,WWMASS(2),           MAIN
     $WMASS(2),VMASS(2),XW(2),XV(2)                                      MAIN
  614 FORMAT(1H ,10(F12.5,1X))                                           MAIN
      IF(IPRINT.EQ.2) WRITE(6,615)WS(2),DAVE(N),DDAVE(N),RHOM(2),RHOA    MAIN
     $(2),RHOM(2),RHOG(2)                                                MAIN
  615 FORMAT(1H ,7(F12.5,1X))                                            MAIN
      IF(VZ.LT.0.0.OR.VZ.GT.1500.0) WRITE(6,6150)                        MAIN
 6150 FORMAT(1H0,≠VZ IS TOO HIGH OR TOO LOW: VZ=≠,F10.4)                 MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C CENYRIFUGAL ACTION IN ROTOR                                          C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C CENTRIFUGAL EFFECT IN ROTOR(SMALL DROPLET)                             MAIN
      IF(IPRINT.EQ.2) WRITE(6,8040)                                      MAIN
 8040 FORMAT(1H0,≠CENTRIFUGAL ACTION IN ROTOR (SMALL DROPLET)≠)          MAIN
      DELMW=0.0                                                          MAIN
      DELMAS=0.0                                                         MAIN
      RW=0.0                                                             MAIN
      RWW=0.0                                                            MAIN
      IF(WTMASS(1).GT.1.0E-6) RW=WMASS(1)/WTMASS(1)                      MAIN
      IF(WTMASS(1).GT.1.0E-6) RWW=WWMASS(1)/WTMASS(1)                    MAIN
      AMASW=(WMASTL-WCENT-WWCENT)*RW                                     MAIN
      BMASW=(WMASTL-WCENT-WWCENT)*RWW*XWWB                               MAIN
      IF(DAVE(N-1).LT.1.0E-6) GO TO 996                                  MAIN
      DD=DAVE(N-1)                                                       MAIN
      DELZZ=RC(ISTAGE)/12.0                                              MAIN
      ALFAAV=(BETA1+BETA2)/2.0                                           MAIN
      IRS=2                                                              MAIN
      RHOGAS=RHOG(2)                                                     MAIN
      RHUB=RRHUB(ISTAGE)                                                 MAIN
      CALL WICCEN(RZERO,VZERO,DD,VZ,DELZZ,ALFAAV ,FN,IRS,RHOGAS,         MAIN
     1RHUB,R2,V2,ITIP,VZTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))             MAIN
      CALL WICDMS(IPRINT,IRAD,WMASS(1),AMASW,AMASW,RZERO,R2,AAREA(ISTA   MAIN
     $GE),RADI1(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)          MAIN
      WCENT=DELMAS                                                       MAIN
      RZERO=R2                                                           MAIN
      VZERO=V2                                                           MAIN
  996 DELMW=DELMAS                                                       MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   MAIN
C CENTRIFUGAL EFFECT IN ROTOR(LARGE DROPLET)                             MAIN
      IF(IPRINT.EQ.2) WRITE(6,8050)                                      MAIN
 8050 FORMAT(1H0,≠ CENTRIFUGAL ACTION IN ROTOR (LARGE DROPLET)≠)         MAIN
      DELMAS=0.0                                                         MAIN
      DELMWW=0.0                                                         MAIN
      IF(DDAVE(N-1).LT.1.0E-6) GO TO 9996                                MAIN
      DD=DDAVE(N-1)                                                      MAIN
      DELZZ=RC(ISTAGE)/12.0                                              MAIN
      ALFAAV=0.0                                                         MAIN
      IIRS=2                                                             MAIN
      RHOGAS=RHOG(2)                                                     MAIN
      RHUB=RRHUB(ISTAGE)                                                 MAIN
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      CALL WICCEN(RRZERO,UUZERO,DD,VZ,DELZZ,ALFAAV ,FN,IIRS,RHOGAS,
     1RHUB,R2,U2,IITIP,VZTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))
      CALL WICDML(IPRINT,IRAD,WWMASS(1),BMASW,BMASW,RRZERO,R2,AAREA(IS
     $TAGE),RADI1(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)
      RRZERO=R2
      UUZERO=U2
9996  DELMWW=DELMAS
      WM=WMASS(2)
      WWM=WWMASS(2)
      WMASS(2)=WMASS(2)+DELMW
      WWMASS(2)=WWMASS(2)+DELMWW
      WTMASS(2)=WMASS(2)+WWMASS(2)
      IF(WTMASS(2).GT.WMASTL) TT=WTMASS(2)/WMASTL
      IF(WTMASS(2).GT.WMASTL) WMASS(2)=WMASS(2)/TT
      IF(WTMASS(2).GT.WMASTL) WWMASS(2)=WWMASS(2)/TT
      DELMW=WMASS(2)-WM
      DELMWW=WWMASS(2)-WWM
      WTMASS(2)=WMASS(2)+WWMASS(2)
      DELMAS=WTMASS(2)-WTMASS(1)
      MMASS=MMASS+DELMAS
      XW(2)=WMASS(2)/MMASS
      XWW(2)=WWMASS(2)/MMASS
      XV(2)=VMASS(2)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(2)+XCH4
      DELVUM=RHOG(2)/RHOW*DELMAS
      AMASS=AMASS-DELVUM*(AMASS/GMASS(2))
      VMASS(2)=VMASS(2)-DELVUM*(VMASS(2)/GMASS(2))
      CHMASS=CHMASS-DELVUM*(CHMASS/GMASS(2))
      MMASS=AMASS+VMASS(2)+CHMASS+WTMASS(2)
      WS(2)=VMASS(2)/MMASS
      WCENT=WCENT+DELMW
      WWCENT=WWCENT+DELMWW
      IF(WMASS(2).LT.1.0E-6) DAVE(N)=0.0
      IF(WWMASS(2).LT.1.0E-6) DDAVE(N)=0.0
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C STATOR IMPINGEMENT                                                   C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C STATOR IMPINGEMENT(SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8060)
 8060 FORMAT(1H0,≠ STATOR IMPINGEMENT (SMALL DROPLET)≠)
      CALL WICISS(ISTAGE,RADI2(ISTAGE),XW(2),XG,RHOG(2),ALFA2,V2,
     $WW1,WW2,WW)
      AMIMPS=WW
      IF(AMIMPS.GT.WMASS(2)) AMIMPS=WMASS(2)
      IF(AMIMPS.LT.0.0) AMIMPS=0.0
      AMREBS=AMIMPS*PREB/100.0
      AMWAKS=AMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,617) XW(2),XG,RHOG(2),V2,WW,AMIMPS,AMRE
     $BS,AMWAKS
  617 FORMAT(1H ,8(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C STATOR IMPINGEMENT(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8070)
 8070 FORMAT(1H0,≠ STATOR IMPINGEMENT (LARGE DROPLET)≠)
      CALL WICISL(ISTAGE,RADI2(ISTAGE),XWW(2),XG,RHOG(2),ALFA2,V2,WW1
     $,WW2,WW)
      BMIMPS=WW
      IF(BMIMPS.LT.0.0) BMIMPS=0.0
      IF(BMIMPS.GT.WWMASS(2)) BMIMPS=WWMASS(2)
      BMREBS=BMIMPS*PREB/100.0
      BMWAKS=BMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2),XA,RHOA(2),VZ,WW,BMIMPS,BM
     $REBS,BMWAKS
 6617 FORMAT(1H ,8(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C STATOR WAKE                                                          C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPRINT.EQ.2) WRITE(6,8080)
 8080 FORMAT(1H0,≠ STATOR WAKE≠)
      N=N+1
      ALFA=ALFA3
      DWAKEM=0.0
      IF(AMWAKS.GT.0.0) GO TO 632
      GO TO 633
  632 CALL WICWAK(RHOG(2),V3,DWAKE,DWAKEM)
  633 D1=DWAKEM
      IF(D1.LT.0.0) D1=0.0
      IF(D1.GT.DIN) D1=DIN
      AMING1=AMWAKS
      ALFA=ALFA3
      SDELV1=DELVU2
      DWAKEM=0.0
      IF(BMWAKS.GT.0.0) GO TO 6330
      GO TO 6331
 6330 CALL WICWAK(RHOG(2),SDELV1,DWAKE,DWAKEM)
 6331 D2=DWAKEM
      IF(D2.LT.0.0) D2=0.0
      IF(D2.GT.DDIN) D2=DDIN
      SUP2=(90.0-ALFA3)/180.0
      AMING2=BMWAKS*SUP2
      SDELV2=DELVL2
      DWAKEM=0.0
      IF(BMWAKS.GT.0.0) GO TO 6332
      GO TO 6333
 6332 CALL WICWAK(RHOG(2),SDELV2,DWAKE,DWAKEM)
 6333 D3=DWAKEM
      IF(D3.LT.0.0) D3=0.0
      IF(D3.GT.DDIN) D3=DDIN
      SLOW2=(90.0+ALFA3)/180.0
      AMING3=BMWAKS*SLOW2
      WMASSS=WMASS(2)-AMWAKS
      WMASSL=WWMASS(2)-BMWAKS
      IF(WMASSS.LT.0.0) WMASSS=0.0
      IF(WMASSL.LT.0.0) WMASSL=0.0
      CALL WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DDAVE(2),DAVE(
     $2),D1,D2,D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)
      WWMASS(3)=AMLGE
      WMASS(3)=AMSLL
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0
      IF(WWMASS(3).LT.0.0) WWMASS(3)=0.0
      WTMASS(3)=WWMASS(2)+WMASS(2)
      VMASS(3)=VMASS(2)
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)
      TMASS(3)=MMASS
      GMASS(3)=TMASS(3)-WTMASS(3)
      DAVE(N)=DSLL
      DDAVE(N)=DLGE
      XW(3)=WMASS(3)/MMASS
      XWW(3)=WWMASS(3)/MMASS
      XWT(3)=WTMASS(3)/MMASS
      XV(3)=XV(2)
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(3)+XCH4
      XAIR(3)=XA
      XMETAN(3)=XCH4
      XGAS(3)=XG
      IF(WMASSO.LT.1.0E-6) WMASSO=WMASS(3)
      IF(WWMASO.LT.1.0E-6) WWMASO=WWMASS(3)
      IF(WTMASS(3).GT.0.0) RW=WMASS(3)/WTMASS(3)
      IF(WTMASS(3).GT.0.0) RWW=WWMASS(3)/WTMASS(3)
      TG(3)=TG(2)
```

```
      TW(3)=TW(2)                                                        MAIN
      IF(IPRINT.EQ.2) WRITE(6,619) RHOA(2),VZ,ALFA,D1,D2,WWMASS(3)       MAIN
     $,WMASS(3),VMASS(3),XW(3),XV(3)                                     MAIN
  619 FORMAT(1H ,10(F12.5,1X))                                           MAIN
      IF(IPRINT.EQ.2) WRITE(6,620) DAVE(N),TG(3),TW(3)                   MAIN
  620 FORMAT(1H ,3(F12.5,1X))                                            MAIN
      IF(WMASS(2).GT.0.0.AND.WWMASS(2).GT.0.0) GO TO 951                 MAIN
      IF(WMASS(2).GT.0.0) GO TO 951                                      MAIN
      IF(WWMASS(2).GT.0.0) GO TO 951                                     MAIN
      WS(3)=WS(2)                                                        MAIN
      TB(3)=TB(2)                                                        MAIN
      TDEW(3)=TDEW(2)                                                    MAIN
      DELTG2=0.0                                                         MAIN
      DELTG3=0.0                                                         MAIN
      DELTW2=0.0                                                         MAIN
      TRATIO=TG(3)/TG(1)                                                 MAIN
      DAVE(N)=0.0                                                        MAIN
      RHOA(3)=P(3)/RA/TG(3)                                              MAIN
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)         MAIN
      RHOG(3)=P(3)/RMIX/TG(3)                                            MAIN
      IF(JPERFM.NE.3) BMASS=MMASS                                        MAIN
      IF(JPERFM.EQ.3) BMASS=GMASS(3)                                     MAIN
      CALL WICMAC(ISTAGE,BMASS,TG(3),P(3),M,VZ,C,XWT(3),ALFA3,           MAIN
     $RMIX,CPMIX,AAA3)                                                   MAIN
      RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)                                  MAIN
      RHOM(3)=1.0/((1.0-XWT(3))/RHOG(3)+XWT(3)/RHOW)                     MAIN
      RHOA(3)=(1.0+G2*M**2)**G3*RHOA(3)                                  MAIN
      GO TO 950                                                          MAIN
  951 CONTINUE                                                           MAIN
      WTMASS(3)=WMASS(3)+WWMASS(3)                                       MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C HEAT TRANSFER CALCULATION                                            C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C HEAT-TRANSFER (SMALL DROPLET)                                          MAIN
      IF(IPRINT.EQ.2) WRITE(6,8120)                                      MAIN
 8120 FORMAT(1H0,≠ HEAT TRANSFER≠)                                       MAIN
      DELTGH=0.0                                                         MAIN
      DELTWH=0.0                                                         MAIN
      IF(DAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 8121                 MAIN
      GO TO 8122                                                         MAIN
 8121 RE=0.0                                                             MAIN
      XV1=(XV(1)+XV(3))/2.0                                              MAIN
      XW1=(XW(1)+XW(3))/2.0                                              MAIN
      WMASS1=(WMASS(1)+WMASS(3))/2.0                                     MAIN
      VMASS1=(VMASS(1)+VMASS(3))/2.0                                     MAIN
      CPG1=XA*WICCPA(TG(1))+XV(1)*WICCPH(TG(1))+XCH4*WICCPC(TG(1))       MAIN
      CPG3=XA*WICCPA(TG(3))+XV(3)*WICCPH(TG(3))+XCH4*WICCPC(TG(3))       MAIN
      CPG=(CPG1+CPG3)/2.0                                                MAIN
      CALL WICHET(TG(1),TG(3),TW(1),TW(3),DAVE(N-2),DAVE(N)              MAIN
     $,DELZ(ISTAGE),VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH         MAIN
     $,DELTWH,RE)                                                        MAIN
 8122 DELTG2=DELTGH                                                      MAIN
      DELTW2=DELTWH                                                      MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
C HEAT TRANSFER(LARGE DROPLET)                                           MAIN
      DELTGH=0.0                                                         MAIN
      DELTWH=0.0                                                         MAIN
      IF(DDAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 8123                MAIN
      GO TO 8124                                                         MAIN
 8123 RE=0.0                                                             MAIN
      IF(DDAVE(N-1).GT.0.0) RE=REAVE                                     MAIN
      XV1=(XV(1)+XV(3))/2.0                                              MAIN
      XW1=(XWW(1)+XWW(3))/2.0                                            MAIN
      WMASS1=(WWMASS(1)+WWMASS(3))/2.0                                   MAIN
      VMASS1=(VMASS(1)+VMASS(3))/2.0                                     MAIN
      CPG1=XA*WICCPA(TG(1))+XV(1)*WICCPH(TG(1))+XCH4*WICCPC(TG(1))       MAIN
      CPG3=XA*WICCPA(TG(1))+XV(3)*WICCPH(TG(3))+XCH4*WICCPC(TG(3))       MAIN
```

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      CPG=(CPG1+CPG3)/2.0
      CALL WICHET(TG(1),TG(3),TWW(1),TWW(3),DDAVE(N-2),DDAVE(N)
     $,DELZ(ISTAGE),VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH
     $,DELTWH,RE)
 8124 DELTG3=DELTGH
      DELTW3=DELTWH
      TG(3)=TG(1)+DELTG1-DELTG2-DELTG3
      TW(3)=TW(1)+DELTW1+DELTW2
      TWW(3)=TWW(1)+DELTW3
      TRATIO=TG(3)/TG(1)
      IF(IPRINT.EQ.2) WRITE(6,627) DELTG2,DELTW2,DELTG3,DELTW3,TG(3),
     $TW(3),TWW(3),TRATIO
  627 FORMAT(1H ,8(F15.6,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C MASS TRANSFER CALCULATION                                            C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPRINT.EQ.2) WRITE(6,8130)
 8130 FORMAT(1H0,≠ MASS TRANSFER≠)
      DAVEN2=DAVE(N-2)
      DAVEN=DAVE(N)
      DZ=DELZ(ISTAGE)
      RE=0.0
      DMDTAV=0.0
      IF(DAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 636
      GO TO 637
  636 CALL WICMAS(WS(1),TW(1),TW(3),P(1),P(3),TG(1),TG(3),DZ,PWB1,PWB2
     $,PW1,PW2,VZ,DAVEN2,DAVEN,HW2,VMASS(1),VMASS2,WMASS(1),WMASS2,
     $DMDTAV,AMASS,RE)
  637 DMDTA1=DMDTAV
      IF(DMDTA1.LT.0.0) DMDTA1=0.0
      DAVEN2=DDAVE(N-2)
      DAVEN=DDAVE(N)
      DZ=DELZ(ISTAGE)
      RE=0.0
      DMDTAV=0.0
      IF(DDAVE(N-1).GT.0.0.AND.DDAVE(N).GT.0.0) RE=REAVE
      IF(DDAVE(N-2).GT.0.0.AND.DDAVE(N).GT.0.0) GO TO 6360
      GO TO 6370
 6360 CALL WICMAS(WS(1),TWW(1),TWW(3),P(1),P(3),TG(1),TG(3),DZ,PWB1,PWB2
     $,PW1,PW2,VZ,DAVEN2,DAVEN,HW2,VMASS(1),VMASS2,WWMASS(1),WMASS2,
     $DMDTAV,AMASS,RE)
 6370 DMDTA2=DMDTAV
      IF(DMDTA2.LT.0.0) DMDTA2=0.0
      WMASS(3)=WMASS(3)-DMDTA1
      WWMASS(3)=WWMASS(3)-DMDTA2
      WMASTL=WMASTL-(DMDTA1+DMDTA2)*AAREAS(ISTAGE)/AAA2
      IF(WMASTL.LT.0.0) WMASTL=0.0
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0
      IF(WWMASS(3).LT.0.0) WWMASS(3)=0.0
      WTMASS(3)=WMASS(3)+WWMASS(3)
      VMASS(3)=VMASS(3)+DMDTA1+DMDTA2
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)
      TMASS(3)=MMASS
      GMASS(3)=TMASS(3)-WTMASS(3)
      XW(3)=WMASS(3)/MMASS
      XWW(3)=WWMASS(3)/MMASS
      XWT(3)=WTMASS(3)/MMASS
      XV(3)=VMASS(3)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(3)+XCH4
      XAIR(3)=XA
      XMETAN(3)=XCH4
      XGAS(3)=XG
      WS(3)=VMASS(3)/AMASS
      PW=WS(3)*P(3)/(WS(3)+0.6219)
      TDEW(3)=WICBPT(TG(3),PW)
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      RHOA(3)=P(3)/RA/TG(3)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      RHOG(3)=P(3)/RMIX/TG(3)
      IF(JPERFM.NE.3) BMASS=MMASS
      IF(JPERFM.EQ.3) BMASS=GMASS(3)
      CALL WICMAC(ISTAGE,BMASS,TG(3),P(3),M,VZ,C,XWT(3),ALFA3,
     $RMIX,CPMIX,AAA3)
      RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)
      RHOM(3)=1.0/((1.0-XWT(3))/RHOG(3)+XWT(3)/RHOW)
      RHOA(3)=(1.0+G2*M**2)**G3*RHOG(3)
      TB(3)=WICBPT(TG(3),P(3))
      IF(IPRINT.EQ.2) WRITE(6,624) WWMASS(3),XWW(3),DDAVE(N),WMASS(3),
     $VMASS(3),XW(3),XV(3),WS(3),DAVE(N)
  624 FORMAT(1H ,9(F12.5,1X))
      IF(IPRINT.EQ.2) WRITE(6,625) RHOA(3),RHOM(3),RHOG(3),DMDTA1,DMD
     $TA2,PW2,TW(3),TG(3)
  625 FORMAT(1H ,8(F12.5,1X))
  950 DELTGW=DELTG1
      DELTDW=DELTW1
      DELTGH=-DELTG2-DELTG3
      DELTDH=DELTW2
      DELP=P(3)-P(1)
      GAMMAO=GAMMA
      TB(3)=WICBPT(TG(3),P(3))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C OUTPUT(STAGE PERFORMANCE)                                            C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IUNIT.NE.2) GO TO 853
      WMASS(1)=WMASS(1)*CFM
      WMASS(3)=WMASS(3)*CFM
      WWMASS(1)=WWMASS(1)*CFM
      WWMASS(3)=WWMASS(3)*CFM
      WTMASS(1)=WTMASS(1)*CFM
      WTMASS(3)=WTMASS(3)*CFM
      AMASS=AMASS*CFM
      CHMASS=CHMASS*CFM
      VMASS(1)=VMASS(1)*CFM
      VMASS(3)=VMASS(3)*CFM
      GMASS(1)=GMASS(1)*CFM
      GMASS(3)=GMASS(3)*CFM
      TMASS(1)=TMASS(1)*CFM
      TMASS(3)=TMASS(3)*CFM
      RHOA(1)=RHOA(1)*CFD
      RHOA(2)=RHOA(2)*CFD
      RHOA(3)=RHOA(3)*CFD
      RHOM(1)=RHOM(1)*CFD
      RHOM(2)=RHOM(2)*CFD
      RHOM(3)=RHOM(3)*CFD
      RHOG(1)=RHOG(1)*CFD
      RHOG(2)=RHOG(2)*CFD
      RHOG(3)=RHOG(3)*CFD
      TG(1)=TG(1)*CFT
      TG(2)=TG(2)*CFT
      TG(3)=TG(3)*CFT
      TW(1)=TW(1)*CFT
      TW(2)=TW(2)*CFT
      TW(3)=TW(3)*CFT
      TWW(1)=TWW(1)*CFT
      TWW(2)=TWW(2)*CFT
      TWW(3)=TWW(3)*CFT
      P(1)=P(1)*CFP
      P(2)=P(2)*CFP
      P(3)=P(3)*CFP
      TB(1)=TB(1)*CFT
      TB(2)=TB(2)*CFT
      TB(3)=TB(3)*CFT
      TDEW(1)=TDEW(1)*CFT
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      TDEW(2)=TDEW(2)*CFT
      TDEW(3)=TDEW(3)*CFT
  853 CONTINUE
      WRITE(6,400) FAIO,ISTAGE
  400 FORMAT(1H1,1X,≠**********************  ≠,1X,
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F7.5,1X,≠(ISTAGE= ≠,I2,1X,
     $≠)≠,2X,≠**********************≠)
      PRATIO=P(3)/P(1)
      TRATIO=TG(3)/TG(1)
      GAMMAV=(GAMMAS+GAMMAO)/2.0
      G4=(GAMMAV-1.0)/GAMMAV
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)
      WRITE(6,402) JPERFM
  402 FORMAT(1H0,5X,≠STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT≠,
     $≠(JPERFM=≠,I1,≠)≠)
      WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)
      WRITE(6,4025)
 4025 FORMAT(1H0,12X,≠**STAGE INLET**≠,4X,≠**STAGE OUTLET**≠,
     $4X,≠**STAGE OUTLET**≠)
      WRITE(6,4026)
 4026 FORMAT(1H ,33X,≠(BEFORE INTER-≠,6X,≠(AFTER INTER-≠)
      WRITE(6,4027)
 4027 FORMAT(1H ,34X,≠STAGE ADJUST-≠,7X,≠STAGE ADJUST-≠)
      WRITE(6,4028)
 4028 FORMAT(1H ,34X,≠MENT)≠,15X,≠MENT)≠)
      WRITE(6,405) XV(1), XV(1), XV(3)
  405 FORMAT(1H ,5X,≠XV=≠,3(F15.5,5X))
      WRITE(6,406) XW(1), XW(1) , XW(3)
  406 FORMAT(1H ,5X,≠XW=≠,3(F15.5,5X))
      WRITE(6,4060) XWW(1),XWW(1),XWW(3)
 4060 FORMAT(1H ,5X,≠XWW=≠,3(F15.5,5X))
      WRITE(6,4061) XWT(1),XWT(1),XWT(3)
 4061 FORMAT(1H ,5X,≠XWT=≠,3(F15.5,5X))
      WRITE(6,4062) XAIR(1),XAIR(1),XAIR(3)
 4062 FORMAT(1H ,5X,≠XAIR=≠,3(F15.5,5X))
      WRITE(6,4063) XMETAN(1),XMETAN(1),XMETAN(3)
 4063 FORMAT(1H ,5X,≠XMETAN=≠,3(F15.5,5X))
      WRITE(6,4064) XGAS(1),XGAS(1),XGAS(3)
 4064 FORMAT(1H ,5X,≠XGAS≠,3(F15.5,5X))
      WRITE(6,407) WMASS(1), WMASS(1) , WMASS(3)
  407 FORMAT(1H ,5X,≠WMASS=≠,3(F15.5,5X))
      WRITE(6,4070) WWMASS(1),WWMASS(1),WWMASS(3)
 4070 FORMAT(1H ,5X,≠WWMASS=≠,3(F15.5,5X))
       WRITE(6,4071) WTMASS(1),WTMASS(1),WTMASS(3)
 4071 FORMAT(1H ,5X,≠WTMASS=≠,3(F15.5,5X))
       WRITE(6,4072) AMASS,AMASS,AMASS
 4072 FORMAT(1H ,5X,≠AMASS=≠,3(F15.5,5X))
      WRITE(6,4073) CHMASS.CHMASS,CHMASS
 4073 FORMAT(1H ,5X,≠CHMASS=≠,3(F15.5,5X))
      WRITE(6,408) VMASS(1) , VMASS(1) , VMASS(3)
  408 FORMAT(1H ,5X,≠VMASS=≠,3(F15.5,5X))
      WRITE(6,4080) GMASS(1),GMASS(1),GMASS(3)
 4080 FORMAT(1H ,5X,≠GMASS=≠,3(F15.5,5X))
      WRITE(6,4081) TMASS(1),TMASS(1),TMASS(3)
 4081 FORMAT(1H ,5X,≠TMASS=≠.3(F15.5,5X))
      WRITE(6,409) WS(1) , WS(1) , WS(3)
  409 FORMAT(1H ,5X,≠WS=≠,3(F15.5,5X))
      WRITE(6,410) RHOA(1) , RHOA(2) , RHOA(3)
  410 FORMAT(1H ,5X,≠RHOA=≠,3(F15.5,5X))
      WRITE(6,411) RHOM(1), RHOM(2),RHOM(3)
  411 FORMAT(1H ,5X,≠RHOM=≠,3(F15.5,5X))
      WRITE(6,412) RHOG(1),RHOG(2),RHOG(3)
  412 FORMAT(1H ,5X,≠RHOG=≠.3(F15.5,5X))
      WRITE(6,413) TG(1),TG(2),TG(3)
  413 FORMAT(1H ,5X,≠TG=≠,3(F15.5,5X))
      WRITE(6,414) TW(1).TW(2),TW(3)
  414 FORMAT(1H ,5X,≠TW=≠,3(F15.5.5X))
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      WRITE(6,4140) TWW(1),TWW(2),TWW(3)
 4140 FORMAT(1H ,5X,≠TWW=≠,3(F15.5,5X))
      WRITE(6,415) P(1),P(2),P(3)
  415 FORMAT(1H ,5X,≠P=≠,3(F15.5,5X))
      WRITE(6,416) TB(1),TB(2),TB(3)
  416 FORMAT(1H ,5X,≠TB=≠,3(F15.5,5X))
      WRITE(6,422) TDEW(1),TDEW(2),TDEW(3)
  422 FORMAT(1H ,5X,≠TDEW=≠,3(F15.5,5X))
      IF(IUNIT.NE.2) GO TO 854
      WMASS(1)=WMASS(1)/CFM
      WMASS(3)=WMASS(3)/CFM
      WWMASS(1)=WWMASS(1)/CFM
      WWMASS(3)=WWMASS(3)/CFM
      WTMASS(1)=WTMASS(1)/CFM
      WTMASS(3)=WTMASS(3)/CFM
      AMASS=AMASS/CFM
      CHMASS=CHMASS/CFM
      VMASS(1)=VMASS(1)/CFM
      VMASS(3)=VMASS(3)/CFM
      GMASS(1)=GMASS(1)/CFM
      GMASS(3)=GMASS(3)/CFM
      TMASS(1)=TMASS(1)/CFM
      TMASS(3)=TMASS(3)/CFM
      RHOA(1)=RHOA(1)/CFD
      RHOA(2)=RHOA(2)/CFD
      RHOA(3)=RHOA(3)/CFD
      RHOM(1)=RHOM(1)/CFD
      RHOM(2)=RHOM(2)/CFD
      RHOM(3)=RHOM(3)/CFD
      RHOG(1)=RHOG(1)/CFD
      RHOG(2)=RHOG(2)/CFD
      RHOG(3)=RHOG(3)/CFD
      TG(2)=TG(2)/CFT
      TG(3)=TG(3)/CFT
      TW(1)=TW(1)/CFT
      TW(2)=TW(2)/CFT
      TW(3)=TW(3)/CFT
      TWW(1)=TWW(1)/CFT
      TWW(2)=TWW(2)/CFT
      TWW(3)=TWW(3)/CFT
      P(1)=P(1)/CFP
      P(2)=P(2)/CFP
      P(3)=P(3)/CFP
      TB(1)=TB(1)/CFT
      TB(2)=TB(2)/CFT
      TB(3)=TB(3)/CFT
      TDEW(1)=TDEW(1)/CFT
      TDEW(2)=TDEW(2)/CFT
      TDEW(3)=TDEW(3)/CFT
  854 CONTINUE
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C BOILING                                                              C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(XDIN.GT.0.0) GO TO 460
      GO TO 450
  460 IF(TW(3).LT.TB(3)) GO TO 450
      HV=1115.3272-0.6840905*(TB(3)-460.0)
      DAMY=CPG/HV*(TG(3)-TB(3))
      XE=DAMY/(DAMY+1.0)
      IF(XE.GT.XW(3)) GO TO 451
      XEVAPO=XE
      TW(3)=TB(3)
      TG(3)=TB(3)
      XW(3)=XW(3)-XEVAPO
      XV(3)=XV(3)+XEVAPO
      GO TO 452
  451 XEVAPO=XW(3)
```

```
      TW(3)=0.0                                                          MAIN
      TG(3)=TG(3)-XW(3)/(1.0-XW(3))*HV/CPG                               MAIN
      XW(3)=0.0                                                          MAIN
      XV(3)=XV(3)+XEVAPO                                                 MAIN
  452 WMASS(3)=XW(3)*MMASS                                               MAIN
      VMASS(3)=XV(3)*MMASS                                               MAIN
      GMASS(3)=VMASS(3)+AMASS                                            MAIN
      IF(IPRINT.EQ.2) WRITE(6,453)                                       MAIN
  453 FORMAT(1H0,≠BOILING≠)                                              MAIN
      IF(IPRINT.EQ.2) WRITE(6,454) HV,XEVAPO,TW(3),TG(3),XW(3),XV(3)     MAIN
     $,WMASS(3),GMASS,VMASS(3),MMASS                                     MAIN
  454 FORMAT(1H0,10(F10.5,2X))                                           MAIN
  450 CONTINUE                                                           MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
C                                                                      C  MAIN
C BLEED                                                                C  MAIN
C                                                                      C  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
      AMASS=AMASS*(1.0+XG1BLD(ISTAGE))                                   MAIN
      CHMASS=CHMASS*(1.0+XG3BLD(ISTAGE))                                 MAIN
      VMASS(3)=VMASS(3)*(1.0+XG2BLD(ISTAGE))                             MAIN
      WMASS(3)=WMASS(3)*(1.0+XWBLD(ISTAGE))                              MAIN
      WWMASS(3)=WWMASS(3)*(1.0+XWWBLD(ISTAGE))                           MAIN
      WTMASS(3)=WMASS(3)+WWMASS(3)                                       MAIN
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)                              MAIN
      TMASS(3)=MMASS                                                     MAIN
      GMASS(3)=TMASS(3)-WTMASS(3)                                        MAIN
      XW(3)=WMASS(3)/MMASS                                               MAIN
      XWW(3)=WWMASS(3)/MMASS                                             MAIN
      XWT(3)=WTMASS(3)/MMASS                                             MAIN
      XV(3)=VMASS(3)/MMASS                                               MAIN
      XA=AMASS/MMASS                                                     MAIN
      XCH4=CHMASS/MMASS                                                  MAIN
      XG=XA+XV(3)+XCH4                                                   MAIN
      XAIR(3)=XA                                                         MAIN
      XMETAN(3)=XCH4                                                     MAIN
      XGAS(3)=XG                                                         MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
C                                                                      C  MAIN
C REPEAT                                                               C  MAIN
C                                                                      C  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
      IF(ISTAGE.EQ.NS) GO TO 902                                         MAIN
      GO TO 900                                                          MAIN
  902 OVALPR=P(3)/OP01                                                   MAIN
      OVALTR=TG(3)/OT01G                                                 MAIN
      GAMMAV=(GAMMAI+GAMMAO)/2.0                                         MAIN
      G4=(GAMMAV-1.0)/GAMMAV                                             MAIN
      OVALEF=(OVALPR**G4-1.0)/(OVALTR-1.0)                               MAIN
      ODELTG=TG(3)-OT01G                                                 MAIN
      ODELTW=0.0                                                         MAIN
      DELTWW=0.0                                                         MAIN
      DELMT=0.0                                                          MAIN
      DELMWT=0.0                                                         MAIN
      DELMG=0.0                                                          MAIN
      IF(XDIN.GT.0.0) ODELTW=TW(3)-OT01D                                 MAIN
      IF(XDDIN.GT.0.0) DELTWW=TWW(3)-OT01D                               MAIN
      DELMT=(MMASS-TLMO)/TLMO                                            MAIN
      IF(WTMO.GT.0.0) DELMWT=(WTMASS(3)-WTMO)/WTMO                       MAIN
      DELMG=(GMASS(3)-GMO)/GMO                                           MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
C                                                                      C  MAIN
C OUTPUT (OVERALL PERFORMANCE)                                          C  MAIN
C                                                                      C  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
      CCMASS=CMASS*AAAR1T/AAAIGV                                         MAIN
      C2MASS=CMASS2*AAAR1T/AAAIGV                                        MAIN
```

```
      IF(IUNIT.NE.2) GO TO 855
      TOG=TOG*CFT
      PO=PO*CFP
      CMASS=CMASS*CFM
      CCMASS=CCMASS*CFM
      CMASS2=CMASS2*CFM
      C2MASS=C2MASS*CFM
      ODELTG=ODELTG*CFT
  855 CONTINUE
      WRITE(6,421)
  421 FORMAT(1H1,≠********** OVERALL PERFORMANCE *********≠)
      WRITE(6,4220) FAIO
 4220 FORMAT(1H0,1X,≠INITIAL FLOW COEFFICIENT=≠,F7.5)
      WRITE(6,423) CRPM,FNF
  423 FORMAT(1H0,1X,≠CORRECTED SPEED=≠,F7.1,5X,F5.3,1X,
     $≠FRACTION OF DEIGN CORRECTED SPEED≠)
      WRITE(6,424)XDIN,XDDIN,XWTO,RHUMID,XCH4IN
  424 FORMAT(1H0,1X,≠INITIAL WATER CONTENT(SMALL DROPLET)=≠,F5.3,/,
     $2X,≠INITIAL WATER CONTENT(LARGE DROPLET)=≠,F5.3,/,
     $2X,≠INITIAL WATER CONTENT(TOTAL)=≠,F5.3,/,
     $2X,≠INITIAL RELATIVE HUMIDITY=≠,F5.1,1X,≠PER CENT≠,/,
     $2X,≠INITIAL METHANE CONTENT=≠,F5.3)
      WRITE(6,425) TOG
  425 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL TEMPERATURE=≠,F8.2)
      WRITE(6,426) PO
  426 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      CCMASS=CMASS*AAAR1T/AAAIGV
      C2MASS=CMASS2*AAAR1T/AAAIGV
      WRITE(6,427)  CMASS,CCMASS
  427 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE OF MIXTURE=≠,F6.3,
     $≠(≠,F6.3,≠)≠)
      WRITE(6,428)  CMASS2,C2MASS
  428 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE OF GAS PHASE ≠,F6.3,
     $≠(≠,F6.3,≠)≠)
      WRITE(6,429) OVALPR
  429 FORMAT(1H0,1X,≠OVERALL TOTAL PRESSURE RATIO=≠,F6.4)
      WRITE(6,430) OVALTR
  430 FORMAT(1H0,1X,≠OVERALL TOTAL TEMPERATURE RATIO=≠,F6.4)
      WRITE(6,431) OVALEF
  431 FORMAT(1H0,1X,≠OVERALL ADIABATIC EFFICIENCY=≠,F6.4)
      WRITE(6,432) ODELTG
  432 FORMAT(1H0,1X,≠OVERALL TEMPERATURE RISE OF GAS PHASE=≠,F8.3)
      IF(IUNIT.NE.2) GO TO 856
      TOG=TOG/CFT
      PO=PO/CFP
      CMASS=CMASS/CFM
      CCMASS=CCMASS/CFM
      CMASS2=CMASS2/CFM
      C2MASS=C2MASS/CFM
      ODELTG=ODELTG/CFT
  856 CONTINUE
      GO TO 901
  998 STOP
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICSPA                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPA(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAVE, XDIN,ETA,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK3)
      REAL M,MMASS
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
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      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                    WICSPA
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                    WICSPA
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)   WICSPA
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)   WICSPA
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI  WICSPA
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  WICSPA
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    WICSPA
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  WICSPA
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        WICSPA
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)              WICSPA
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   WICSPA
      DIMENSION RHOM(3),ETAA(8)                                          WICSPA
      CPW=1.0                                                            WICSPA
      RHOW=62.3                                                          WICSPA
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)         WICSPA
      RHOG(1)=P(1)/RMIX/TG(1)                                            WICSPA
      BMASS=MMASS                                                        WICSPA
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,           WICSPA
     $RMIX,CPMIX,AREA(ISTAGE))                                           WICSPA
      ASPEED=C                                                           WICSPA
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)                                 WICSPA
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)                     WICSPA
      VZ=BMASS/RHOM(1)/AREA(ISTAGE)                                      WICSPA
      VZZ=VZ                                                             WICSPA
      FAI=VZ/UTIPG(ISTAGE)                                               WICSPA
      IF(IPRINT.EQ.2) WRITE(6,602) ISTAGE                                WICSPA
  602 FORMAT(1H1,1X,≠ROTER INLET  ISTAGE=≠,I2)                           WICSPA
      XG=XA+XV(1)+XCH4                                                   WICSPA
      IF(IPRINT.EQ.2) WRITE(6,601) ASPEED,RHOG(1),RHOM(1),XG,XWT(1),     WICSPA
     $RHOG(1),FAI,VZ,UTIP                                                WICSPA
  601 FORMAT(1H0,9(F12.5,1X))                                            WICSPA
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPA
C VELOCITY TRIANGLE                                                      WICSPA
      CALL WICVT(ISTAGE,ASPEED,ALFA1,VZ,V1,VS1,WS1,BETA1,W1,BETA2,       WICSPA
     $WS2,VS2,ALFA2,W2,V2,ALFA3,V3,AK1,AK3)                              WICSPA
      DELWS=WS1-WS2                                                      WICSPA
      IF(IPRINT.EQ.2) WRITE(6,605)                                       WICSPA
  605 FORMAT(1H0,1X,≠VEL TRI≠)                                           WICSPA
      IF(IPRINT.EQ.2) WRITE(6,606) ALFA1,VZ,V1,VS1,WS1,BETA1,W1,BETA2,   WICSPA
     $WS2,VS2                                                            WICSPA
  606 FORMAT(1H0,10(F12.5,1X))                                           WICSPA
      IF(IPRINT.EQ.2) WRITE(6,607) ALFA2,W2,V2,ALFA3,DELWS,V3            WICSPA
  607 FORMAT(1H ,6(F12.5,1X))                                            WICSPA
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPA
C PERFORMANCE CURVE                                                      WICSPA
      CALL WICSCC(FAI,SAI,ETA,TAU,ISTAGE)                                WICSPA
      ETAA(ISTAGE)=ETA                                                   WICSPA
      IF(SAI.GT.1.0.AND.ETA.GT.0.0) GO TO 203                            WICSPA
      IF(IPRINT.EQ.2) WRITE(6,204) ISTAGE,FAI,SAI,ETA,TAU                WICSPA
  204 FORMAT(1H0,≠FAI IS TOO BIG OR TOO SMALLE AT ISTAGE=≠,              WICSPA
     $I2,2X,4(F6.4,5X))                                                  WICSPA
      GO TO 901                                                          WICSPA
  203 DELT=TAU*TD(ISTAGE)*UOU(ISTAGE)                                    WICSPA
      DELHIN=WICCPA(TG(1))*DELT                                          WICSPA
      DELHM=DELHIN                                                       WICSPA
      DELHG=DELHM*(1.0-XW(1))                                            WICSPA
      DELHW=DELHM*XW(1)                                                  WICSPA
      DELHWW=0.0                                                         WICSPA
      DELTWW=0.0                                                         WICSPA
      CPG=CPMIX                                                          WICSPA
      DELTG=DELHG/CPG/(XV(1)+XA+XCH4)                                    WICSPA
      IF(XDIN.GT.0.0) GO TO 850                                          WICSPA
      DELTW=0.0                                                          WICSPA
      GO TO 851                                                          WICSPA
  850 DELTW=DELHW/CPW/XW(1)                                              WICSPA
  851 PRATIO=(DELTG/TG(1)*ETA+1.0)**G1                                   WICSPA
      P(3)=PRATIO*P(1)                                                   WICSPA
      P(2)=P(3)                                                          WICSPA
      TG(2)=TG(1)+DELTG                                                  WICSPA
      TW(2)=TW(1)+DELTW                                                  WICSPA
```

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      TG(3)=TG(2)                                                       WICSPA    87
      TW(3)=TW(2)                                                       WICSPA    88
      IF(IPRINT.EQ.2) WRITE(6,603)                                      WICSPA    89
  603 FORMAT(1H0,1X,≠PERFORMANCE CURVE≠)                                WICSPA    90
      IF(IPRINT.EQ.2) WRITE(6,604) FAI,SAI,ETA,TAU,DELT,PRATIO,P(3),    WICSPA    91
     $DELHIN                                                            WICSPA    92
  604 FORMAT(1H ,8(F12.5,1X))                                           WICSPA    93
      IF(IPRINT.EQ.2) WRITE(6,650) DELT,DELHM,DELHG,DELHW,DELTG,DELTW   WICSPA    94
  650 FORMAT(1H ,6(F12.5,1X))                                           WICSPA    95
  901 RETURN                                                            WICSPA    96
      END                                                               WICSPA    97
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICSCC     1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSCC     2
C                                                                      C WICSCC     3
C SUBROUTINE WICSCC                                                    C WICSCC     4
C                                                                      C WICSCC     5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSCC     6
      SUBROUTINE WICSCC(FAI,SAI,ETA,TAU,ISTAGE)                         WICSCC     7
      X=FAI                                                             WICSCC     8
      IF(ISTAGE.EQ.1) GO TO 11                                          WICSCC     9
      IF(ISTAGE.EQ.2) GO TO 12                                          WICSCC    10
      IF(ISTAGE.EQ.3) GO TO 13                                          WICSCC    11
      IF(ISTAGE.EQ.4) GO TO 14                                          WICSCC    12
      IF(ISTAGE.EQ.5) GO TO 15                                          WICSCC    13
      IF(ISTAGE.EQ.6) GO TO 16                                          WICSCC    14
   11 A1=26.456                                                         WICSCC    15
      B1=-366.48033                                                     WICSCC    16
      C1=2161.46222                                                     WICSCC    17
      D1=-6670.16668                                                    WICSCC    18
      E1=11405.55557                                                    WICSCC    19
      F1=-10280.00001                                                   WICSCC    20
      G1=3822.22223                                                     WICSCC    21
      A2=-120.02                                                        WICSCC    22
      B2=1599.02                                                        WICSCC    23
      C2=-8730.12223                                                    WICSCC    24
      D2=25068.33336                                                    WICSCC    25
      E2=-39922.22228                                                   WICSCC    26
      F2=33466.66671                                                    WICSCC    27
      G2=-11555.55557                                                   WICSCC    28
      A3=-0.34                                                          WICSCC    29
      B3=0.226                                                          WICSCC    30
      GO TO 200                                                         WICSCC    31
   12 A1=-4.285                                                         WICSCC    32
      B1=65.44567                                                       WICSCC    33
      C1=-332.95889                                                     WICSCC    34
      D1=907.0                                                          WICSCC    35
      E1=-1375.55556                                                    WICSCC    36
      F1=1093.33334                                                     WICSCC    37
      G1=-355.55556                                                     WICSCC    38
      A2=116.32                                                         WICSCC    39
      B2=-1354.73334                                                    WICSCC    40
      C2=6515.80003                                                     WICSCC    41
      D2=-16503.33341                                                   WICSCC    42
      E2=23266.66677                                                    WICSCC    43
      F2=-17333.33341                                                   WICSCC    44
      G2=5333.33336                                                     WICSCC    45
      A3=-0.055                                                         WICSCC    46
      B3=0.095                                                          WICSCC    47
      GO TO 200                                                         WICSCC    48
   13 A1=154.07500                                                      WICSCC    49
      B1=-1761.37834                                                    WICSCC    50
      C1=8374.33337                                                     WICSCC    51
      D1=-21034.16676                                                   WICSCC    52
      E1=29450.00013                                                    WICSCC    53
      F1=-21800.00010                                                   WICSCC    54
      G1=6666.66670                                                     WICSCC    55
      A2=-492.54                                                        WICSCC    56
      B2=5539.88003                                                     WICSCC    57
      C2=-25815.48301                                                   WICSCC    58
      D2=63806.66696                                                    WICSCC    59
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```
      E2=-88155.55596
      F2=64533.33363
      G2=-19555.55565
      A3=-0.1333333
      B3=0.1539999
      GO TO 200
   14 A1=75.43300
      B1=-860.65834
      C1=4090.41113
      D1=-10210.83338
      E1=14147.77784
      F1=-10333.33338
      G1=3111.11113
      A2=-1182.22001
      B2=13501.23673
      C2=-63739.07807
      D2=159216.66740
      E2=-221844.44546
      F2=163466.66741
      G2=-49777.77800
      A3=-0.04
      B3=0.092
      GO TO 200
   15 A1=-105.07400
      B1=1149.70467
      C1=-5143.83224
      D1=12189.83339
      E1=-16138.88897
      F1=11320.00006
      G1=-3288.88891
      A2=352.04
      B2=-3991.84002
      C2=18707.68897
      D2=-46346.66688
      E2=64088.88918
      F2=-46933.33355
      G2=14222.22229
      A3=-0.1066666
      B3=0.12999999
      GO TO 200
   16 A1=-110.32400
      B1=1282.14134
      C1=-6126.79558
      D1=15550.00007
      E1=-22068.88899
      F1=16586.66674
      G1=-5155.55558
      A2=-175.54
      B2=1836.93001
      C2=-7955.44448
      D2=18268.33342
      E2=-23411.11123
      F2=15866.66675
      G2=-4444.44447
      A3=-0.255
      B3=0.21375
  200 SAI=A1+B1*X+C1*X**2+D1*X**3+E1*X**4+F1*X**5+G1*X**6
      ETA=A2+B2*X+C2*X**2+D2*X**3+E2*X**4+F2*X**5+G2*X**6
      TAU=A3*X+B3
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICSPB                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPB(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAV,DELV,WMAS,N,
     $OMEGA1,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK2,
```

```
     $AK3)
      REAL M,MMASS
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      DIMENSION RHOM(3),ETAA(6)
      AJ=778.26
      PAI=3.1415926
      CPW=1.0
      RHOW=62.3
      GC=32.174
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMA1=GAMMA
      RHOG(1)=P(1)/RMIX/TG(1)
      BMASS=MMASS
      AAA2=AREAS(ISTAGE)
      AAA3=AREA(ISTAGE+1)
      IF(ISTAGE.EQ.NS) AAA3=AAA2
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,
     $RMIX,CPMIX,AAA1)
      ASPEED=C
      ASPED1=ASPEED
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)
      VZ1=VZ
      VZZ=VZ
      FAI1=VZ1/UTIPG(ISTAGE)
      ALFA1R = ALFA1 * PAI / 180.0
      V1 = VZ / COS ( ALFA1R )
      VS1 = VZ * TAN ( ALFA1R )
      WS1 = U(ISTAGE)- VS1
      T = WS1 / VZ
      BETA1R = ATAN ( T)
      BETA1 = BETA1R * 180.0 / PAI
      TT = VZ **2 + WS1 **2
      W1 = SQRT ( TT )
      AMACH1 = W1 / ASPEED
      AMAC1=V1/ASPEED
      TS1=TG(1)/(1.0+G2*AMAC1**2)
      PS1=(TG(1)/TS1)**(-G1)*P(1)
      PREL1=(1.0+G2*AMACH1**2)**G1*PS1
      TREL1=(1.0+G2*AMACH1**2)*TS1
      JJJ=1
 2000 VZ2AS=VZ
      CALL WICGSL(OMEGR(ISTAGE),SIGUMR(ISTAGE),BET1SR(ISTAGE),BET2SR(IST
     $AGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),AMACH1,BETA1,DEQ,DEQN,SITACS,
     $SITACN,BET2N,OMEGAN,FMR1(ISTAGE),IDESIN,AK1,AK2,AK3,VZ1,VZ2AS,
     $U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))
      IF(IPRINT.EQ.2) WRITE(6,190) OMEGR(ISTAGE),SIGUMR(ISTAGE),
     $BET1SR(ISTAGE),BET2SR(ISTAGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),
     $AMACH1,BETA1,DEQ,DEQN,SITACS,SITACN,BET2N,OMEGAN
  190 FORMAT(1H0,1X,14(F7.3,2X))
      DEQRR=DEQN
      SITACR=SITACN
      AINCIR=BETA1-BET1MR(ISTAGE)
      ADEVIR=BET2N-BET2MR(ISTAGE)
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      IF(IPRINT.EQ.2) WRITE(6,191) AINCIR,AINCSR(ISTAGE),ADEVIR,          WICSPB
     $ADEVUSR(ISTAGE)                                                     WICSPB
  191 FORMAT(1H0,1X,4(F7.3,2X))                                           WICSPB
      OMEGA1=OMEGAN                                                       WICSPB
      BETA2=BET2N                                                         WICSPB
      BETA2R=BETA2*PAI/180.0                                              WICSPB
      W2=VZ/COS(BETA2R)                                                   WICSPB
      UG=(W1+W2)/2.0                                                      WICSPB
      OMEGAP=0.0                                                          WICSPB
      IF(XW(1).GT.0.0)                                                    WICSPB
     $CALL WICSDL(RC(ISTAGE),SIGUMR(ISTAGE),BETA1,BETA2,UG,RHOG(1),       WICSPB
     $WMAS,AAA1,VZ,IPRINT,OMEGAP)                                         WICSPB
      OMEGA2=OMEGAP                                                       WICSPB
      DELP2=OMEGA2*0.5*RHOG(1)/GC*(W1**2)                                 WICSPB
      OMEGA3=0.0                                                          WICSPB
      DELP3=0.0                                                           WICSPB
      BETA2R = BETA2 * PAI / 180.0                                        WICSPB
      JJ=1                                                                WICSPB
  200 VZAS=VZ                                                             WICSPB
      WS2 = VZ * TAN ( BETA2R )                                           WICSPB
      VS2 = UU2(ISTAGE) - WS2                                             WICSPB
      IF(VS2.LT.0.0) GO TO 999                                            WICSPB
      TTT=VS2/VZ                                                          WICSPB
      ALFA2R = ATAN ( TTT )                                               WICSPB
      ALFA2 = ALFA2R * 180.0 / PAI                                        WICSPB
      TTTT = VZ ** 2 + WS2 ** 2                                           WICSPB
      W2 = SQRT ( TTTT )                                                  WICSPB
      TTTTT = VZ ** 2 + VS2 ** 2                                          WICSPB
      V2 = SQRT ( TTTTT )                                                 WICSPB
      DELH=WKDONE*(UU2(ISTAGE)*VS2-U(ISTAGE)*VS1)/GC/AJ                   WICSPB
      XG=1.0-XWT(1)                                                       WICSPB
      CALL WICIRS(ISTAGE,RRTIP(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,     WICSPB
     $WW2,WW)                                                             WICSPB
      AMIMPR=WW                                                           WICSPB
      IF(AMIMPR.GT.WMAS) AMIMPR=WMAS                                      WICSPB
      PREB=50.0                                                           WICSPB
      AMREBR=AMIMPR*PREB/100.0                                            WICSPB
      AMWAKR=AMIMPR*(1.0-PREB/100.0)                                      WICSPB
      AMNOIR=WMAS-AMIMPR                                                  WICSPB
      XWNOIR=AMNOIR/MMASS                                                 WICSPB
      XWREBR=AMREBR/MMASS                                                 WICSPB
      XWWAKR=AMWAKR/MMASS                                                 WICSPB
      XW1=0.0                                                             WICSPB
      XW2=0.0                                                             WICSPB
      XW3=0.0                                                             WICSPB
      IF(WMAS.GT.0.0) XW1=AMNOIR/WMAS                                     WICSPB
      IF(WMAS.GT.0.0) XW2=AMWAKR/WMAS                                     WICSPB
      IF(WMAS.GT.0.0) XW3=AMREBR/WMAS                                     WICSPB
      DELTG=DELH/CPMIX                                                    WICSPB
      DELTW1=DELH/CPW                                                     WICSPB
      DELTW2=DELH/CPW                                                     WICSPB
      DELTW3=0.0                                                          WICSPB
      DELTW=XW1*DELTW1+XW2*DELTW2+XW3*DELTW3                              WICSPB
      TW(2)=TW(1)+DELTW                                                   WICSPB
      TG(2)=TG(1)+DELTG                                                   WICSPB
      TS2=TG(2)-V2**2/(2.0*CPMIX*GC*AJ)                                   WICSPB
      AG2=(GAMMA*RMIX*TS2*GC)**0.5                                        WICSPB
      ASPEED=WICASD(XWT(1),RHOG(1),AG2)                                   WICSPB
      AMAC2=V2/ASPEED                                                     WICSPB
      AMACH2=W2/ASPEED                                                    WICSPB
      PP1=GAMMA*RMIX*TREL1*GC                                             WICSPB
      PP2=(UU2(ISTAGE)/U(ISTAGE))**2-1.0                                  WICSPB
      PP3=1.0+G2*U(ISTAGE)**2/PP1*PP2                                     WICSPB
      PP=PP3**G1                                                          WICSPB
      PRREL=PP-(OMEGA1+OMEGA2+OMEGA3)*(1.0-PS1/PREL1)                     WICSPB
      PR12=(TG(2)/TG(1))**G1*PRREL/PP                                     WICSPB
      P(2)=PR12*P(1)                                                      WICSPB
      PS2=(1.0+G2*AMAC2**2)**(-G1)*P(2)                                   WICSPB
      RHOG2=PS2/RMIX/TS2                                                  WICSPB
      RHOG(2)=RHOG2                                                       WICSPB
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      RHOM2=1.0/(XG/RHOG2+XWT(1)/RHOW)
      VZ=BMASS/RHOM2/AAA2
      VZ2=VZ
      EPS=1.0E-4
      IF(JJ.EQ.2) GO TO 201
      IF(JJ.GT.2) GO TO 202
      X1=VZAS
      Y1=VZ2
      VZ=VZ2
      JJ=JJ+1
      GO TO 200
  201 X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,203) JJ,VZ
  203 FORMAT(1H ,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  202 IF(ABS((VZAS-VZ2)/VZAS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,204) JJ,VZ
  204 FORMAT(1H0,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      IF(JJ.EQ.20) GO TO 300
      GO TO 200
  300 VZ2CL=VZ
      IF(JJJ.EQ.2) GO TO 2010
      IF(JJJ.GT.2) GO TO 2020
      XX1=VZ2AS
      YY1=VZ2CL
      JJJ=JJJ+1
      GO TO 2000
 2010 XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2030) JJJ,VZ
 2030 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      GO TO 2000
 2020 IF(ABS((VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 3000
      XX1=XX2
      YY1=YY2
      XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2040) JJJ,VZ
 2040 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      IF(JJJ.EQ.20) GO TO 3000
      GO TO 2000
 3000 VZ2=VZ2CL
      FAI2=VZ2/UTIPG(ISTAGE)
      P(2)=(1.0+G2*AMAC2**2)**G1*PS2
      JJJJ=1
 3001 VZ3AS=VZ
      CALL WICGSL(OMEGS(ISTAGE),SIGUMS(ISTAGE),BET1SS(ISTAGE),
     $BET2SS(ISTAGE),AINCSS(ISTAGE),ADEVSS(ISTAGE),AMAC2,ALFA2,DEQS,
     $DEQN,SITACS,SITACN,BET2N,OMEGAN,FMA2(ISTAGE),IDESIN,AK1,AK2,AK3,
     $VZ2,VZ3AS,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))
      ASPED2=ASPEED
      DEQSS=DEQN
      SITACS=SITACN
      AINCIS=ALFA2-BET1MS(ISTAGE)
      ADEVIS=BET2N-BET2MS(ISTAGE)
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      IF(IPRINT.EQ.2) WRITE(6,302) AINCIS,AINCSS(ISTAGE),ADEVIS,                WICSPB
     $ADEVSS(ISTAGE)                                                            WICSPB
  302 FORMAT(1H0,1X,4(F7.3,2X))                                                 WICSPB
      OMEGA4=OMEGAN                                                             WICSPB
      ALFA3=BET2N                                                               WICSPB
      ALFA3R=ALFA3*PAI/180.0                                                    WICSPB
      V3=VZ/COS(ALFA3R)                                                         WICSPB
      UG=(V2+V3)/2.0                                                            WICSPB
      OMEGAP=0.0                                                                WICSPB
      IF(XW(1).GT.0.0)                                                          WICSPB
     $CALL WICSDL(SC(ISTAGE),SIGUMS(ISTAGE),ALFA2,ALFA3,UG,RHOG(2)              WICSPB
     $,WMAS,AAA2,VZ,IPRINT,OMEGAP)                                              WICSPB
      OMEGA5=OMEGAP                                                             WICSPB
      DELP5=OMEGA5*0.5*RHOG(2)/GC*(V2**2)                                       WICSPB
      DELP6=0.0                                                                 WICSPB
      OMEGA6=0.0                                                                WICSPB
      PR23=1.0-(OMEGA4+OMEGA5+OMEGA6)*(1.0-PS2/P(2))                            WICSPB
      PR13I=(TG(2)/TG(1))**G1                                                   WICSPB
      PR13=(TG(2)/TG(1))**G1*PRREL*PR23/PP                                      WICSPB
      P(3)=PR13*P(1)                                                            WICSPB
      TG(3)=TG(2)                                                               WICSPB
      TS3=TG(3)-V3**2/(2.0*CPMIX*GC*AJ)                                         WICSPB
      AG3=(GAMMA*RMIX*TS3*GC)**0.5                                              WICSPB
      ASPEED=WICASD(XWT(1),RHOG(2),AG3)                                         WICSPB
      ASPED3=ASPEED                                                             WICSPB
      AMAC3=V3/ASPEED                                                           WICSPB
      PS3=(1.0+G2*AMAC3**2)**(-G1)*P(3)                                         WICSPB
      RHOG3=PS3/RMIX/TS3                                                        WICSPB
      RHOG(3)=RHOG3                                                             WICSPB
      RHOM3=1.0/(XG/RHOG3+XWT(1)/RHOW)                                          WICSPB
      VZ=BMASS/RHOM3/AAA3                                                       WICSPB
      VZ3CL=VZ                                                                  WICSPB
      IF(JJJJ.EQ.2) GO TO 3010                                                  WICSPB
      IF(JJJJ.GT.2) GO TO 3020                                                  WICSPB
      XXX1=VZ3AS                                                                WICSPB
      YYY1=VZ3CL                                                                WICSPB
      JJJJ=JJJJ+1                                                               WICSPB
      GO TO 3001                                                                WICSPB
 3010 XXX2=VZ3AS                                                                WICSPB
      YYY2=VZ3CL                                                                WICSPB
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)                                            WICSPB
      IF(IPRINT.EQ.2) WRITE(6,3030) JJJJ,VZ                                     WICSPB
 3030 FORMAT(1H ,1X,I2,2X,≠VZ33=≠,F10.5)                                        WICSPB
      JJJJ=JJJJ+1                                                               WICSPB
      GO TO 3001                                                                WICSPB
 3020 IF(ABS((VZ3AS-VZ3CL)/VZ3AS).LT.EPS) GO TO 4000                            WICSPB
      XXX1=XXX2                                                                 WICSPB
      YYY1=YYY2                                                                 WICSPB
      XXX2=VZ3AS                                                                WICSPB
      YYY2=VZ3CL                                                                WICSPB
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)                                            WICSPB
      IF(IPRINT.EQ.2) WRITE(6,3040) JJJJ,VZ                                     WICSPB
 3040 FORMAT(1H ,1X,I2,≠VZ33=≠,F10.5)                                           WICSPB
      JJJJ=JJJJ+1                                                               WICSPB
      IF(JJJJ.EQ.20) GO TO 999                                                  WICSPB
      GO TO 3001                                                                WICSPB
 4000 VZ3=VZ3CL                                                                 WICSPB
      FAI3=VZ3/UTIPG(ISTAGE+1)                                                  WICSPB
      TW(3)=TW(2)                                                               WICSPB
      OMEGTR=OMEGA1+OMEGA2+OMEGA3                                               WICSPB
      OMEGTS=OMEGA4+OMEGA5+OMEGA6                                               WICSPB
      POMEG1=OMEGA1/OMEGTR*100.0                                                WICSPB
      POMEG2=OMEGA2/OMEGTR*100.0                                                WICSPB
      POMEG3=OMEGA3/OMEGTR*100.0                                                WICSPB
      POMEG4=OMEGA4/OMEGTS*100.0                                                WICSPB
      POMEG5=OMEGA5/OMEGTS*100.0                                                WICSPB
      POMEG6=OMEGA6/OMEGTS*100.0                                                WICSPB
      PRATIO=P(3)/P(1)                                                          WICSPB
      TRATIO=TG(3)/TG(1)                                                        WICSPB
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)                WICSPB
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      GAMMA2=GAMMA                                                      WICSPB
      GAMMAV=(GAMMA1+GAMMA2)/2.0                                        WICSPB
      G4=(GAMMAV-1.0)/GAMMAV                                            WICSPB
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)                        WICSPB
      IF(IUNIT.NE.2) GO TO 857                                          WICSPB
      UTIPG(ISTAGE)=UTIPG(ISTAGE)*CFV                                   WICSPB
      P(1)=P(1)*CFP                                                     WICSPB
      P(2)=P(2)*CFP                                                     WICSPB
      P(3)=P(3)*CFP                                                     WICSPB
      PS1=PS1*CFP                                                       WICSPB
      PS2=PS2*CFP                                                       WICSPB
      PS3=PS3*CFP                                                       WICSPB
      TG(1)=TG(1)*CFT                                                   WICSPB
      TG(2)=TG(2)*CFT                                                   WICSPB
      TG(3)=TG(3)*CFT                                                   WICSPB
      TS1=TS1*CFT                                                       WICSPB
      TS2=TS2*CFT                                                       WICSPB
      TS3=TS3*CFT                                                       WICSPB
      RHOG(1)=RHOG(1)*CFD                                               WICSPB
      RHOG2=RHOG2*CFD                                                   WICSPB
      RHOG3=RHOG3*CFD                                                   WICSPB
      RHOM(1)=RHOM(1)*CFD                                               WICSPB
      RHOM2=RHOM2*CFD                                                   WICSPB
      RHOM3=RHOM3*CFD                                                   WICSPB
      VZ1=VZ1*CFV                                                       WICSPB
      VZ2=VZ2*CFV                                                       WICSPB
      VZ3=VZ3*CFV                                                       WICSPB
      V1=V1*CFV                                                         WICSPB
      V2=V2*CFV                                                         WICSPB
      V3=V3*CFV                                                         WICSPB
      W1=W1*CFV                                                         WICSPB
      W2=W2*CFV                                                         WICSPB
      U(ISTAGE)=U(ISTAGE)*CFV                                           WICSPB
      UU2(ISTAGE)=UU2(ISTAGE)*CFV                                       WICSPB
      U(ISTAGE+1)=U(ISTAGE+1)*CFV                                       WICSPB
      VS1=VS1*CFV                                                       WICSPB
      VS2=VS2*CFV                                                       WICSPB
      WS1=WS1*CFV                                                       WICSPB
      WS2=WS2*CFV                                                       WICSPB
      ASPED1=ASPED1*CFV                                                 WICSPB
      ASPED2=ASPED2*CFV                                                 WICSPB
      ASPED3=ASPED3*CFV                                                 WICSPB
      AAA1=AAA1*CFA                                                     WICSPB
      AAA2=AAA2*CFA                                                     WICSPB
      AAA3=AAA3*CFA                                                     WICSPB
  857 CONTINUE                                                          WICSPB
      WRITE(6,404) FAI0,ISTAGE                                          WICSPB
  404 FORMAT(1H1,1X,≠********************  ≠,1X,                        WICSPB
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F7.5,1X,≠(STAGE=≠,I2,1X,           WICSPB
     $≠)≠,2X,≠********************≠)                                    WICSPB
       WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)                          WICSPB
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,              WICSPB
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,                      WICSPB
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)                           WICSPB
       WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)                              WICSPB
  402 FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,                   WICSPB
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,                                      WICSPB
     $6X,≠ROTOR SPEED=≠,F7.2,/)                                         WICSPB
      WRITE(6,403) PR13,PR13I,PRREL,PR23                                WICSPB
  403 FORMAT(1H ,5X,≠STAGE TOTAL PRESSURE RATIO(ACTUAL)=≠,F12.5,/,      WICSPB
     $6X,≠STAGE TOTAL PRESSURE RATIO(IDEAL)=≠,F12.5,/,                  WICSPB
     $6X,≠LOSS FACTOR IN ROTOR=≠,F12.5,/,                               WICSPB
     $6X,≠LOSS FACTOR IN STATOR=≠,F12.5,/)                              WICSPB
      WRITE(6,405)                                                      WICSPB
  405 FORMAT(1H0,24X,≠*ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*≠)    WICSPB
      WRITE(6,406) P(1),P(2),P(3)                                       WICSPB
  406 FORMAT(1H ,1X,≠TOTAL PRESSURE≠,10X,3(F10.2,5X))                   WICSPB
      WRITE(6,407) PS1,PS2,PS3                                          WICSPB
  407 FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,3(F10.2,5X))                   WICSPB
      WRITE(6,408) TG(1),TG(2),TG(3)                                    WICSPB
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408 FORMAT(1H ,1X,≠TOTAL TEMPERATURE(GAS)≠,3X,3(F10.4,5X))
    WRITE(6,409) TS1,TS2,TS3
409 FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,3(F10.4,5X))
    WRITE(6,410) RHOG(1),RHOG2,RHOG3
410 FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,3(F10.4,5X))
    WRITE(6,411) RHOM(1),RHOM2,RHOM3
411 FORMAT(1H ,1X,≠STATIC DENSITY(MIXTURE)≠,1X,3(F10.4,5X))
    WRITE(6,412) VZ1,VZ2,VZ3
412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,3(F10.4,5X))
    WRITE(6,413) V1,V2,V3
413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,3(F10.4,5X))
    WRITE(6,414) W1,W2
414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))
    WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)
415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))
    WRITE(6,416) VS1,VS2
416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))
    WRITE(6,417) WS1,WS2
417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))
    WRITE(6,418) ASPED1,ASPED2,ASPED3
418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,3(F10.4,5X))
    WRITE(6,419) AMAC1,AMAC2,AMAC3
419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,3(F10.4,5X))
    WRITE(6,420) AMACH1,AMACH2
420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))
    WRITE(6,421) FAI1,FAI2,FAI3
421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,3(F10.4,5X))
    WRITE(6,422) AAA1,AAA2,AAA3
422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,3(F10.4,5X))
    WRITE(6,423) ALFA1,ALFA2,ALFA3
423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))
    WRITE(6,424) BETA1,BETA2
424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))
    WRITE(6,425) AINCIR,AINCIS
425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))
    WRITE(6,426) ADEVIR,ADEVIS
426 FORMAT(1H ,1X,≠DEVIATION≠,30X,2(F10.4,5X))
    IF(IUNIT.NE.2) GO TO 858
    UTIPG(ISTAGE)=UTIPG(ISTAGE)/CFV
    P(1)=P(1)/CFP
    P(2)=P(2)/CFP
    P(3)=P(3)/CFP
    PS1=PS1/CFP
    PS2=PS2/CFP
    PS3=PS3/CFP
    TG(1)=TG(1)/CFT
    TG(2)=TG(2)/CFT
    TG(3)=TG(3)/CFT
    TS1=TS1/CFT
    TS2=TS2/CFT
    TS3=TS3/CFT
    RHOG(1)=RHOG(1)/CFD
    RHOG2=RHOG2/CFD
    RHOG3=RHOG3/CFD
    RHOM(1)=RHOM(1)/CFD
    RHOM2=RHOM2/CFD
    RHOM3=RHOM3/CFD
    VZ1=VZ1/CFV
    VZ2=VZ2/CFV
    VZ3=VZ3/CFV
    V1=V1/CFV
    V2=V2/CFV
    V3=V3/CFV
    W1=W1/CFV
    W2=W2/CFV
    U(ISTAGE)=U(ISTAGE)/CFV
    UU2(ISTAGE)=UU2(ISTAGE)/CFV
    U(ISTAGE+1)=U(ISTAGE+1)/CFV
    VS1=VS1/CFV
    VS2=VS2/CFV
```

```
      WS1=WS1/CFV                                                       WICSPB
      WS2=WS2/CFV                                                       WICSPB
      ASPED1=ASPED1/CFV                                                 WICSPB
      ASPED2=ASPED2/CFV                                                 WICSPB
      ASPED3=ASPED3/CFV                                                 WICSPB
      AAA1=AAA1/CFA                                                     WICSPB
      AAA2=AAA2/CFA                                                     WICSPB
      AAA3=AAA3/CFA                                                     WICSPB
  858 CONTINUE                                                          WICSPB
  999 RETURN                                                            WICSPB
      END                                                               WICSPB
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSFC
C                                                                      C WICSPC
C SUBROUTINE WICSPC                                                    C WICSPC
C                                                                      C WICSPC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSPC
      SUBROUTINE WICSPC(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAV,DELV,WMAS,   WICSPC
     $WWMAS,N,                                                          WICSPC
     $OMEGA1,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,                 WICSPC
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,REAVE,      WICSPC
     $DELVU2,DELVL2,AK1,AK2,AK3)                                        WICSPC
      REAL M,MMASS                                                      WICSPC
      COMMON TD(7),IUNIT                                                WICSPC
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                WICSPC
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                   WICSPC
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)   WICSPC
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)  WICSPC
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                          WICSFC
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                   WICSPC
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                   WICSPC
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)  WICSPC
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)  WICSPC
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI WICSPC
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT WICSPC
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                   WICSPC
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                 WICSPC
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)       WICSPC
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)             WICSPC
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)  WICSPC
      DIMENSION RHOM(3),ETAA(6)                                         WICSPC
      IPRINT=1                                                          WICSPC
      CPW=1.0                                                           WICSPC
      RHOW=62.3                                                         WICSPC
      GC=32.174                                                         WICSPC
      AJ=778.26                                                         WICSPC
      PAI=3.1415926                                                     WICSPC
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)        WICSPC
      GAMMA1=GAMMA                                                      WICSPC
      RHOG(1)=P(1)/RMIX/TG(1)                                           WICSPC
      BMASS=MMASS-WMAS-WWMAS                                            WICSPC
      AAA2=AREAS(ISTAGE)                                                WICSPC
      AAA3=AREA(ISTAGE+1)                                               WICSPC
      IF(ISTAGE.EQ.NS) AAA3=AAA2                                        WICSPC
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,          WICSPC
     $RMIX,CPMIX,AAA1)                                                  WICSPC
      ASPEED=C                                                          WICSPC
      ASPED1=ASPEED                                                     WICSPC
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)                                WICSPC
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)                    WICSPC
      VZ1=VZ                                                            WICSPC
      VZZ=VZ                                                            WICSPC
      FAI1=VZ1/UTIPG(ISTAGE)                                            WICSPC
      ALFA1R = ALFA1 * PAI / 180.0                                      WICSPC
      V1 = VZ / COS ( ALFA1R )                                          WICSPC
      VS1 = VZ * TAN ( ALFA1R )                                         WICSPC
      WS1 = U(ISTAGE)- VS1                                              WICSPC
      T = WS1 / VZ                                                      WICSPC
      BETA1R = ATAN ( T)                                                WICSPC
      BETA1 = BETA1R * 180.0 / PAI                                      WICSPC
```

```
      TT = VZ **2 + WS1 **2
      W1 = SQRT ( TT )
      AMACH1 = W1 / ASPEED
      AMAC1=V1/ASPEED
      TS1=TG(1)/(1.0+G2*AMAC1**2)
      PS1=(TG(1)/TS1)**(-G1)*P(1)
      PREL1=(1.0+G2*AMACH1**2)**G1*PS1
      TREL1=(1.0+G2*AMACH1**2)*TS1
      TG(2)=TG(1)
      P(2)=P(1)
      ALFA2=BET1SS(ISTAGE)
      JJJ=1
 2000 VZ2AS=VZ
      CALL WICGSL(OMEGR(ISTAGE),SIGUMR(ISTAGE),BET1SR(ISTAGE),BET2SR(
     $ISTAGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),AMACH1,BETA1,DEQS,DEQN,
     $SITACS,SITACN,BET2N,OMEGAN,FMR1(ISTAGE),IDESIN,AK1,AK2,AK3,VZ1,
     $VZ2AS,U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))
      OMEGA7=OMEGAN
      BETA2=BET2N
      BETA1R=BETA1*PAI/180.0
      BETA2R=BETA2*PAI/180.0
      BETAVE=(BETA1R+BETA2R)/2.0
      TANGT=WICTAN(BETA1R)-WICTAN(BETA2R)
      CSAV=COS(BETAVE)
      CS1=COS(BETA1R)
      CL=2.0/SIGUMR(ISTAGE)*TANGT*CSAV
      CDS=0.018*(CL**2)
      OMEGSE=CDS*SIGUMR(ISTAGE)*(CS1**2)/(CSAV**3)
      H=RRTIP(ISTAGE)-RRHUB(ISTAGE)
      SHR=RC(ISTAGE)/H/SIGUMR(ISTAGE)
      CDA=0.020*SHR
      OMEGAN=CDA*SIGUMR(ISTAGE)*(CS1**2)/(CSAV**3)
      IF(IPRINT.EQ.2) WRITE(6,2001) OMEGA1,OMEGSE,OMEGAN,OMEGA7,CDS,CDA
 2001 FORMAT(1H0,6F10.6)
      OMES1=OMEGSE
      OMEA1=OMEGAN
      AINCIR=BETA1-BET1MR(ISTAGE)
      ADEVIR=BET2N-BET2MR(ISTAGE)
      BETA2R=BETA2*PAI/180.0
      W2=VZ/COS(BETA2R)
      WG=(W1+W2)/2.0
      CALL WICRSL(SIGUMR(ISTAGE),BETA1,BETA2,RC(ISTAGE),DAV,CDR,OMEGAR)
      DELP1=OMEGA1*0.5*RHOG(1)/GC*(W1**2)
      IF(IPRINT.EQ.2) WRITE(6,2002) OMEGA1,DELP1
 2002 FORMAT(1H ,1X,≠OMEGA1=≠,2F10.5)
      XG=1.0-XWT(1)
      CALL WICIRL(ISTAGE,RRTIP(ISTAGE),XWW(1),XG,RHOG(1),BETA1,W1,WW1,WW
     $2,WW)
      BMIMPR=WW
      IF(BMIMPR.GT.WWMAS) BMIMPR=WWMAS
      BMREBR=BMIMPR*PREB/100.0
      BMWAKR=BMIMPR*(1.0-PREB/100.0)
      BMNOIR=WWMAS-BMIMPR
      XWWNOR=BMNOIR/MMASS
      XWWRER=BMREBR/MMASS
      XWWWAR=BMWAKR/MMASS
      IF(IPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR,
     $XWWRER,XWWWAR
 6090 FORMAT(1H ,7(F12.5,1X))
      RST1=RADI1(ISTAGE)**2-AAA1*144.0/2.0/PAI
      RST1=SQRT(RST1)
      RST2=2.0*RADI1(ISTAGE)**2-RST1**2
      RST2=SQRT(RST2)
      DELR=(RST2-RST1)/12.0
      FMASSR=BMWAKR/DELR
      CALL WICFML(W1,W2,FMASSR,RHOG(1),RC(ISTAGE),SIGUMR(ISTAGE),BETA1,
     $BETA2,CDF,OMEGAF)
      OMEGA2=OMEGAF
      DELP2=OMEGA2*0.5*RHOG(1)/GC*(W1**2)
      IF(IPRINT.EQ.2) WRITE(6,6091) OMEGA2,DELP2
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 6091 FORMAT(1H ,1X,≠OMEGA2=≠,2F10.5)
      V2=0.0
      V3=0.0
      ALFA=0.0
      ALFA3=0.0
      CALL WICSTL(ISTAGE,1,DAV,W1,W2,DELV,V2,V3,WWMAS,VZ,N,BETA1,BETA2,
     $ALFA2,ALFA3,BMASS,DELVU2,DELVL2,OMEGRU,OMEGRL,OMEGSU,OMEGSL,
     $DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)
      OMEGA3=OMEGRU+OMEGRL
      DELP3=OMEGA3*0.5*RHOG(1)/GC*(W1**2)
      IF(IPRINT.EQ.2) WRITE(6,6092) OMEGA3,DELP3
 6092 FORMAT(1H ,1X,≠OMEGA3=≠,2F10.5)
      REAVE1=REAVE
      BETA2R = BETA2 * PAI / 180.0
      JJ=1
  200 VZAS=VZ
      WS2 = VZ * TAN ( BETA2R )
      VS2 = UU2(ISTAGE) - WS2
      TTT=VS2/VZ
      ALFA2R = ATAN ( TTT )
      ALFA2 = ALFA2R * 180.0 / PAI
      TTTT = VZ ** 2 + WS2 ** 2
      W2 = SQRT ( TTTT )
      TTTTT = VZ ** 2 + VS2 ** 2
      V2 = SQRT ( TTTTT )
      DELH=WKDONE*(UU2(ISTAGE)*VS2-U(ISTAGE)*VS1)/GC/AJ
      CALL WICIRS(ISTAGE,RRTIP(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,
     $WW2,WW)
      AMIMPR=WW
      IF(AMIMPR.GT.WMAS) AMIMPR=WMAS
      PREB=50.0
      AMREBR=AMIMPR*PREB/100.0
      AMWAKR=AMIMPR*(1.0-PREB/100.0)
      AMNOIR=WMAS-AMIMPR
      XW1=0.0
      XW2=0.0
      XW3=0.0
      IF(WMAS.GT.0.0) XW1=AMNOIR/WMAS
      IF(WMAS.GT.0.0) XW2=AMWAKR/WMAS
      IF(WMAS.GT.0.0) XW3=AMREBR/WMAS
      DELTG=DELH/CPMIX
      DELTW1=DELH/CPW
      DELTW2=DELH/CPW
      DELTW3=0.0
      DELTW=XW1*DELTW1+XW2*DELTW2+XW3*DELTW3
      DETWW1=0.0
      DETWW2=0.0
      DETWW3=0.0
      DELTWW=0.0
      TW(2)=TW(1)+DELTW
      TWW(2)=TWW(1)+DELTWW
      TG(2)=TG(1)+DELTG
      TS2=TG(2)-V2**2/(2.0*CPMIX*GC*AJ)
      AG2=(GAMMA*RMIX*TS2*GC)**0.5
      ASPEED=WICASD(XWT(1),RHOG(1),AG2)
      ASPED2=ASPEED
      AMAC2=V2/ASPEED
      AMACH2=W2/ASPEED
      PP1=GAMMA*RMIX*TREL1*GC
      PP2=(UU2(ISTAGE)/U(ISTAGE))**2-1.0
      PP3=1.0+G2*U(ISTAGE)**2/PP1*PP2
      PP=PP3**G1
      PRREL=PP-(OMEGA7+OMEGA1+OMEGA2+OMEGA3)*(1.0-PS1/PREL1)
      PR12=(TG(2)/TG(1))**G1*PRREL/PP
      P(2)=PR12*P(1)
      PS2=(1.0+G2*AMAC2**2)**(-G1)*P(2)
      RHOG2=PS2/RMIX/TS2
      RHOG(2)=RHOG2
      RHOM2=1.0/(XG/RHOG2+XWT(1)/RHOW)
      VZ=BMASS/RHOG2/AAA2
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      VZ2=VZ
      EPS=1.0E-4
      IF(JJ.EQ.2) GO TO 201
      IF(JJ.GT.2) GO TO 202
      X1=VZAS
      Y1=VZ2
      VZ=VZ2
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  201 X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,203) JJ,VZ
  203 FORMAT(1H ,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  202 IF(ABS((VZAS-VZ2)/VZAS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,204) JJ,VZ
  204 FORMAT(1H0,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      IF(JJ.EQ.20) GO TO 999
      GO TO 200
  300 VZ2CL=VZ
      IF(JJJ.EQ.2) GO TO 2010
      IF(JJJ.GT.2) GO TO 2020
      XX1=VZ2AS
      YY1=VZ2CL
      JJJ=JJJ+1
      GO TO 2000
 2010 XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2030) JJJ,VZ
 2030 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      GO TO 2000
 2020 IF(ABS((VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 3000
      XX1=XX2
      YY1=YY2
      XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2040) JJJ,VZ
 2040 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      IF(JJJ.EQ.20) GO TO 3000
      GO TO 2000
 3000 VZ2=VZ2CL
      FAI2=VZ2/UTIPG(ISTAGE)
      P(2)=(1.0+G2*AMAC2**2)**G1*PS2
      JJJJ=1
 3001 VZ3AS=VZ
      CALL WICGSL(OMEGS(ISTAGE),SIGUMS(ISTAGE),BET1SS(ISTAGE),BET2SS
     $(ISTAGE),AINCSS(ISTAGE),ADEVSS(ISTAGE),AMAC2,ALFA2,DEQS,DEQN,
     $SITACS,SITACN,BET2N,OMEGAN,FMA2(ISTAGE),IDESIN,AK1,AK2,AK3,VZ2,
     $VZ3AS,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))
      OMEGA8=OMEGAN
      ALFA3=BET2N
      ALFA1R=ALFA2*PAI/180.0
      ALFA2R=ALFA3*PAI/180.0
      ALFAAV=(ALFA1R+ALFA2R)/2.0
      TANGT=WICTAN(ALFA1R)-WICTAN(ALFA2R)
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      CSAV=COS(ALFAAV)
      CS1=COS(ALFA1R)
      CL=2.0/SIGUMS(ISTAGE)*TANGT*CSAV
      CDS=0.018*(CL**2)
      OMEGSE=CDS*SIGUMS(ISTAGE)*(CS1**2)/(CSAV**3)
      H=SRTIP(ISTAGE)-SRHUB(ISTAGE)
      SHR=SC(ISTAGE)/H/SIGUMR(ISTAGE)
      CDA=0.020*SHR
      OMEGAN=CDA*SIGUMS(ISTAGE)*(CS1**2)/(CSAV**3)
      IF(IPRINT.EQ.2) WRITE(6,3002)
     $OMEGA4,OMEGSE,OMEGAN,OMEGA8,CDS,CDA
 3002 FORMAT(1H0,6F10.5)
      OMES2=OMEGSE
      OMEA2=OMEGAN
      AINCIS=ALFA2-BET1MS(ISTAGE)
      ADEVIS=BET2N-BET2MS(ISTAGE)
      ALFA3R=ALFA3*PAI/180.0
      V3=VZ/COS(ALFA3R)
      CALL WICRSL(SIGUMS(ISTAGE),ALFA2,ALFA3,SC(ISTAGE),DAV,CDR,OMEGAR)
      DELP4=OMEGA4*0.5*RHOG(2)/GC*(V2**2)
      IF(IPRINT.EQ.2) WRITE(6,3003) OMEGA4,DELP4
 3003 FORMAT(1H ,1X,≠OMEGA4=≠,2F10.5)
      CALL WICISL(ISTAGE,SRTIP(ISTAGE),XWW(2),XG,RHOG(2),ALFA2,V2,WW1
     $,WW2,WW)
      BMIMPS=WW
      IF(BMIMPS.GT.WWMAS) BMIMPS=WWMAS
      BMREBS=BMIMPS*PREB/100.0
      BMWAKS=BMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,6616)
 6616 FORMAT(1H ,1X,≠IMPINS≠)
      IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2),XA,RHOG(2),VZ,WW,BMIMPS,BM
     $REBS,BMWAKS
 6617 FORMAT(1H ,8(F12.5,1X))
      RST1=RADI2(ISTAGE)**2-AAA2*144.0/2.0/PAI
      RST1=SQRT(RST1)
      RST2=2.0*RADI2(ISTAGE)**2-RST1**2
      RST2=SQRT(RST2)
      DELR=(RST2-RST1)/12.0
      FMASSS=BMWAKS/DELR
      CALL WICFML(V2,V3,FMASSS,RHOG2,SC(ISTAGE),SIGUMS(ISTAGE),BETA1,
     $BETA2,CDF,OMEGAF)
      OMEGA5=OMEGAF
      DELP5=OMEGA5*0.5*RHOG(2)/GC*(V2**2)
      IF(IPRINT.EQ.2) WRITE(6,6618) OMEGA5,DELP5
 6618 FORMAT(1H ,1X,≠OMEGA5=≠,2F10.5)
      CALL WICSTL(ISTAGE,2,DAV,W1,W2,DELV,V2,V3,WWMAS,VZ,N,BETA1,BETA2,
     $ALFA2,ALFA3,BMASS,DELVU2,DELVL2,OMEGRU,OMEGRL,OMEGSU,OMEGSL,
     $DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)
      OMEGA6=OMEGSU+OMEGSL
      DELP6=OMEGA6*0.5*RHOG(2)/GC*(V2**2)
      IF(IPRINT.EQ.2) WRITE(6,6619) OMEGA6,DELP6
 6619 FORMAT(1H ,1X,≠OMEGA6=≠,2F10.5)
      REAVE2=REAVE
      REAVE=(REAVE1+REAVE2)*0.5
      PR23=1.0-(OMEGA8+OMEGA4+OMEGA5+OMEGA6)*(1.0-PS2/P(2))
      PR13=(TG(2)/TG(1))**G1*PRREL*PR23/PP
      PR13I=(TG(2)/TG(1))**G1
      P(3)=PR13*P(1)
      TG(3)=TG(2)
      TS3=TG(3)-V3**2/(2.0*CPMIX*GC*AJ)
      AG3=(GAMMA*RMIX*TS3*GC)**0.5
      ASPEED=WICASD(XWT(1),RHOG(2),AG3)
      ASPED3=ASPEED
      AMAC3=V3/ASPEED
      PS3=(1.0+G2*AMAC3**2)**(-G1)*P(3)
      RHOG3=PS3/RMIX/TS3
      RHOG(3)=RHOG3
      RHOM3=1.0/(XG/RHOG3+XWT(1)/RHOW)
      VZ=BMASS/RHOG3/AAA3
      VZ3CL=VZ
```

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      IF(JJJJ.EQ.2) GO TO 3010
      IF(JJJJ.GT.2) GO TO 3020
      XXX1=VZ3AS
      YYY1=VZ3CL
      JJJJ=JJJJ+1
      GO TO 3001
 3010 XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3030) JJJJ,VZ
 3030 FORMAT(1H ,1X,I2,2X,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      GO TO 3001
 3020 IF(ABS((VZ3AS-VZ3CL)/VZ3AS).LT.EPS) GO TO 4000
      XXX1=XXX2
      YYY1=YYY2
      XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3040) JJJJ,VZ
 3040 FORMAT(1H ,1X,I2,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      IF(JJJJ.EQ.20) GO TO 4000
      GO TO 3001
 4000 VZ3=VZ3CL
      FAI3=VZ3/UTIPG(ISTAGE+1)
      TW(3)=TW(2)
      TWW(3)=TW(2)
      OMEGTR=OMEGA1+OMEGA2+OMEGA3+OMEGA7
      OMEGTS=OMEGA4+OMEGA5+OMEGA6+OMEGA8
      POMEG1=OMEGA1/OMEGTR*100.0
      POMEG2=OMEGA2/OMEGTR*100.0
      POMEG3=OMEGA3/OMEGTR*100.0
      POMEG4=OMEGA4/OMEGTS*100.0
      POMEG5=OMEGA5/OMEGTS*100.0
      POMEG6=OMEGA6/OMEGTS*100.0
      POMEG7=OMEGA7/OMEGTR*100.0
      POMEG8=OMEGA8/OMEGTS*100.0
      PRATIO=P(3)/P(1)
      TRATIO=TG(3)/TG(1)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMA2=GAMMA
      GAMMAV=(GAMMA1+GAMMA2)/2.0
      G4=(GAMMAV-1.0)/GAMMAV
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)
      IF(IUNIT.NE.2) GO TO 859
      UTIPG(ISTAGE)=UTIPG(ISTAGE)*CFV
      P(1)=P(1)*CFP
      P(2)=P(2)*CFP
      P(3)=P(3)*CFP
      PS1=PS1*CFP
      PS2=PS2*CFP
      PS3=PS3*CFP
      TG(1)=TG(1)*CFT
      TG(2)=TG(2)*CFT
      TG(3)=TG(3)*CFT
      TS1=TS1*CFT
      TS2=TS2*CFT
      TS3=TS3*CFT
      RHOG(1)=RHOG(1)*CFD
      RHOG2=RHOG2*CFD
      RHOG3=RHOG3*CFD
      RHOM(1)=RHOM(1)*CFD
      RHOM2=RHOM2*CFD
      RHOM3=RHOM3*CFD
      VZ1=VZ1*CFV
      VZ2=VZ2*CFV
      VZ3=VZ3*CFV
      V1=V1*CFV
      V2=V2*CFV
```

```
      V3=V3*CFV
      W1=W1*CFV
      W2=W2*CFV
      U(ISTAGE)=U(ISTAGE)*CFV
      UU2(ISTAGE)=UU2(ISTAGE)*CFV
      U(ISTAGE+1)=U(ISTAGE+1)*CFV
      VS1=VS1*CFV
      VS2=VS2*CFV
      WS1=WS1*CFV
      WS2=WS2*CFV
      ASPED1=ASPED1*CFV
      ASPED2=ASPED2*CFV
      ASPED3=ASPED3*CFV
      AAA1=AAA1*CFA
      AAA2=AAA2*CFA
      AAA3=AAA3*CFA
  859 CONTINUE
      WRITE(6,404) FAIO,ISTAGE
  404 FORMAT(1H1,1X,≠**********************  ≠,1X,
     $≠INITIAL FLOW COEFFICIENT-≠,1X,F7.5,1X,≠(STAGE=≠,I2,1X,
     $≠)≠,2X,≠**********************≠)
       WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)
       WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)
  402 FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,
     $6X,≠ROTOR SPEED=≠,F7.2,/)
      WRITE(6,403) PR13,PR13I,PRREL,PR23
  403 FORMAT(1H ,5X,≠STAGE TOTAL PRESSURE RATIO(ACTUAL)=≠,F12.5,/,
     $6X,≠STAGE TOTAL PRESSURE RATIO(IDEAL)=≠,F12.5,/,
     $6X,≠LOSS FACTOR IN ROTOR=≠,F12.5,/,
     $6X,≠LOSS FACTOR IN STATOR=≠,F12.5,/)
      WRITE(6,405)
  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(F10.2,5X))
      WRITE(6,407) PS1,PS2,PS3
  407 FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,3(F10.2,5X))
      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,TS3
  409 FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,3(F10.4,5X))
      WRITE(6,410) RHOG(1),RHOG2,RHOG3
  410 FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,3(F10.4,5X))
      WRITE(6,411) RHOM(1),RHOM2,RHOM3
  411 FORMAT(1H ,1X,≠STATIC DENSITY(MIXTURE)≠,1X,3(F10.4,5X))
      WRITE(6,412) VZ1,VZ2,VZ3
  412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,3(F10.4,5X))
      WRITE(6,413) V1,V2,V3
  413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,3(F10.4,5X))
      WRITE(6,414) W1,W2
  414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))
      WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)
  415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))
      WRITE(6,416) VS1,VS2
  416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))
      WRITE(6,417) WS1,WS2
  417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))
      WRITE(6,418) ASPED1,ASPED2,ASPED3
  418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,3(F10.4,5X))
      WRITE(6,419) AMAC1,AMAC2,AMAC3
  419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,3(F10.4,5X))
      WRITE(6,420) AMACH1,AMACH2
  420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))
      WRITE(6,421) FAI1,FAI2,FAI3
  421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,3(F10.4,5X))
      WRITE(6,422) AAA1,AAA2,AAA3
  422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,3(F10.4,5X))
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      WRITE(6,423) ALFA1,ALFA2,ALFA3
  423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))
      WRITE(6,424) BETA1,BETA2
  424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))
      WRITE(6,425) AINCIR,AINCIS
  425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))
      WRITE(6,426) ADEVIR,ADEVIS
  426 FORMAT(1H ,1X,≠DEVIATION≠,30X,2(F10.4,5X))
      IF(IUNIT.NE.2) GO TO 860
      UTIPG(ISTAGE)=UTIPG(ISTAGE)/CFV
      P(1)=P(1)/CFP
      P(2)=P(2)/CFP
      P(3)=P(3)/CFP
      PS1=PS1/CFP
      PS2=PS2/CFP
      PS3=PS3/CFP
      TG(1)=TG(1)/CFT
      TG(2)=TG(2)/CFT
      TG(3)=TG(3)/CFT
      TS1=TS1/CFT
      TS2=TS2/CFT
      TS3=TS3/CFT
      RHOG(1)=RHOG(1)/CFD
      RHOG2=RHOG2/CFD
      RHOG3=RHOG3/CFD
      RHOM(1)=RHOM(1)/CFD
      RHOM2=RHOM2/CFD
      RHOM3=RHOM3/CFD
      VZ1=VZ1/CFV
      VZ2=VZ2/CFV
      VZ3=VZ3/CFV
      V1=V1/CFV
      V2=V2/CFV
      V3=V3/CFV
      W1=W1/CFV
      W2=W2/CFV
      U(ISTAGE)=U(ISTAGE)/CFV
      UU2(ISTAGE)=UU2(ISTAGE)/CFV
      U(ISTAGE+1)=U(ISTAGE+1)/CFV
      VS1=VS1/CFV
      VS2=VS2/CFV
      WS1=WS1/CFV
      WS2=WS2/CFV
      ASPED1=ASPED1/CFV
      ASPED2=ASPED2/CFV
      ASPED3=ASPED3/CFV
      AAA1=AAA1/CFA
      AAA2=AAA2/CFA
      AAA3=AAA3/CFA
  860 CONTINUE
  999 RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C SUBROUTINE WICMAC                                                   C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICMAC(ISTAGE,AMASSM,T01G,PRES,M,VZ,C,XW1,ALFA,
     $RMIX,CPMIX,AREA1)
      REAL M ,MA1,MC1,MA2,MC2,MANEW,MCNEW
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PRED,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
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      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      GAMMA=1.0/(1.0-RMIX/CPMIX/778.0)
      G2=(GAMMA-1.0)/2.0
      G3=-1.0/(GAMMA-1.0)
      MA1=0.5
      RHOG1=PRES/RMIX/T01G
      RHOGS=(1.0+G2*MA1**2)**G3*RHOG1
      RHOW=62.4
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)
      TS=T01G/(1.0+G2*MA1**2)
      A=SQRT(GAMMA*RMIX*TS*32.174)
      C=WICASD(XW1,RHOGS,A)
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI
      ALFAR=ALFA*3.1415927/180.0
      MC1=VZ/C/COS(ALFAR)
      MA2=0.6
      RHOGS=(1.0+G2*MA2**2)**G3*RHOG1
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)
      TS=T01G/(1.0+G2*MA2**2)
      A=SQRT(GAMMA*RMIX*TS*32.174)
      C=WICASD(XW1,RHOGS,A)
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI
      MC2=VZ/C/COS(ALFAR)
      J=1
  300 MANEW=WICNEW(MA1,MC1,MA2,MC2)
      RHOGS=(1.0+G2*MANEW**2)**G3*RHOG1
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)
      TS=T01G/(1.0+G2*MANEW**2)
      A=SQRT(GAMMA*RMIX*TS*32.174)
      C=WICASD(XW1,RHOGS,A)
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI
      MCNEW=VZ/C/COS(ALFAR)
      ERROR=ABS(MANEW-MCNEW)
      ERROR=ERROR/MANEW
      EPS=1.0E-6
      IF(ERROR.LT.EPS) GO TO 200
      MA1=MA2
      MC1=MC2
      MA2=MANEW
      MC2=MCNEW
      J=J+1
      IF(J.LT.50) GO TO 300
      WRITE(6,403) ISTAGE
  403 FORMAT(1H0,≠MZ DOES NOT CONVERGE AT STAGE=≠,I1)
      GO TO 998
  200 M=MANEW
      IF(AMASSM.LT.0.001) ISTAGE=0
  998 RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICASD                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICASD ( XW , RHOG , CG )
      RHOW=62.2567
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```
      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/ SQRT ( A4 )
      RETURN
      END
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                  C
C SUBROUTINE WICBOA                                                C
C                                                                  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICBOA(OMEGAS,SIGUMA,BET1S,BET2S,AINCIS,ADEVIS,AMACH1,
     1BET1,DEQS,DEQN,SITACS,SITACN,BET2N,X,AK1,AK3,VZ1,VZ2,UR1,R1,R2)
      CALL WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,OMEGAS,
     $DEQS,SITACS)
      AINCI=BET1+AINCIS-BET1S
      BET2A=BET2S
      X1=BET2A
      DELDEQ=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X1,SIGUMA,AINCIS,AINCI)
     $-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      Y1=BET2C
      N=1
   12 IF(N.GT.1) GO TO 10
      BET2A=BET2S*1.1
   10 X2=BET2A
      DEQN=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X2,SIGUMA,AINCIS,AINCI)
      DELDEQ=DEQN-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      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
   11 BET2N=X2
      GO TO 15
   13 WRITE(6,201)
  201 FORMAT(1H0,≠DO NOT CONVERGE≠)
   15 RETURN
      END
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                  C
C SUBROUTINE WICEDD                                                C
C                                                                  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,
     $OMEGAS,DEQS,SITACS)
      C1=180.0/3.1415926
      BET1SR=BET1S/C1
      BET2SR=BET2S/C1
      CSB1=COS(BET1SR)
      CSB2=COS(BET2SR)
      CSCS=CSB2/CSB1*(VZ1/VZ2)
      CSCSS=CSB2/CSB1
      TNB1=WICTAN(BET1SR)
      TNB2=WICTAN(BET2SR)*(VZ2/VZ1)*(R2/R1)
```

```
      TNTN=TNB1-TNB2-(UR1/VZ1)*(1.0-(R2/R1)**2)                         WICEDD      18
      DEQS=1.12*CSCS+0.61*(CSB1**2)/SIGUMA*TNTN*CSCS                    WICEDD      19
      DEQS=AK3*DEQS                                                     WICEDD      20
      SITACS=OMEGAS*CSB2/2.0/SIGUMA*(CSCSS**2)                          WICEDD      21
      RETURN                                                            WICEDD      22
      END                                                               WICEDD      23
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICED        1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICED        2
C                                                                      C WICED        3
C FUNCTION WICED                                                       C WICED        4
C                                                                      C WICED        5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICED        6
      FUNCTION WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,BET2,SIGUMA,AINCIS,     WICED        7
     $AINCI)                                                            WICED        8
      C1=180.0/3.1415926                                                WICED        9
      BET1R=BET1/C1                                                     WICED       10
      BET2R=BET2/C1                                                     WICED       11
      CSB1=COS(BET1R)                                                   WICED       12
      CSB2=COS(BET2R)                                                   WICED       13
      CSCS=CSB2/CSB1*(VZ1/VZ2)                                          WICED       14
      TNB1=WICTAN(BET1R)                                                WICED       15
      TNB2=WICTAN(BET2R)*(VZ2/VZ1)*(R2/R1)                              WICED       16
      TNTN=TNB1-TNB2-(UR1/VZ1)*(1.0-(R2/R1)**2)                         WICED       17
      DEQ1=1.12*CSCS                                                    WICED       18
      AAA=ABS(AINCI-AINCIS)                                             WICED       19
      DEQ2=0.0117*(AAA**1.43)*CSCS                                      WICED       20
      DEQ3=0.61*(CSB1**2)/SIGUMA*TNTN*CSCS                              WICED       21
      WICED=DEQ1+DEQ2+DEQ3                                              WICED       22
      WICED=AK3*WICED                                                   WICED       23
      RETURN                                                            WICED       24
      END                                                               WICED       25
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICMTK       1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTK       2
C                                                                      C WICMTK       3
C FUNCTION WICMTK                                                      C WICMTK       4
C                                                                      C WICMTK       5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTK       6
      FUNCTION WICMTK(SITACS,AMACH1,DELDEQ,AK2)                         WICMTK       7
      IF(DELDEQ.LT.0.0) GO TO 10                                        WICMTK       8
      A1=0.827*AMACH1                                                   WICMTK       9
      A2=2.692*(AMACH1**2)                                              WICMTK      10
      A3=2.675*(AMACH1**3)                                              WICMTK      11
      A=A1-A2+A3                                                        WICMTK      12
      WICMTK=SITACS+A*(DELDEQ**2)*AK2                                   WICMTK      13
      GO TO 11                                                          WICMTK      14
   10 B1=2.80*AMACH1                                                    WICMTK      15
      B2=8.71*(AMACH1**2)                                               WICMTK      16
      B3=9.36*(AMACH1**3)                                               WICMTK      17
      B=B1-B2+B3                                                        WICMTK      18
      WICMTK=SITACS+B*(DELDEQ**2)*AK2                                   WICMTK      19
   11 RETURN                                                            WICMTK      20
      END                                                               WICMTK      21
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICLOS       1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICLOS       2
C                                                                      C WICLOS       3
C FUNCTION WICLOS                                                      C WICLOS       4
C                                                                      C WICLOS       5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICLOS       6
      FUNCTION WICLOS(BET1,BET2,SIGUMA,SITA)                            WICLOS       7
      C1=180.0/3.1415926                                                WICLOS       8
      BET1R=BET1/C1                                                     WICLOS       9
      BET2R=BET2/C1                                                     WICLOS      10
      CSB1=COS(BET1R)                                                   WICLOS      11
      CSB2=COS(BET2R)                                                   WICLOS      12
      CSCS=CSB1/CSB2                                                    WICLOS      13
      WICLOS=SITA*2.0*SIGUMA/CSB2*(CSCS**2)                             WICLOS      14
      RETURN                                                            WICLOS      15
      END                                                               WICLOS      16
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICIRS       1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRS       2
```

```
C                                                                      C WICIRS
C SUBROUTINE WICIRS                                                     C WICIRS
C                                                                      C WICIRS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRS
      SUBROUTINE WICIRS(ISTAGE,R,XW1,XG,RHOG1,BETA1,W1,                  WICIRS
     1WW1 , WW2 , WW )                                                   WICIRS
      REAL LWC                                                           WICIRS
      COMMON TD(7),IUNIT                                                 WICIRS
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                 WICIRS
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                    WICIRS
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)    WICIRS
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)   WICIRS
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                           WICIRS
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                    WICIRS
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                    WICIRS
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)   WICIRS
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)   WICIRS
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI  WICIRS
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  WICIRS
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    WICIRS
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  WICIRS
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        WICIRS
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)              WICIRS
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   WICIRS
      N = ISTAGE                                                         WICIRS
      PAI = 3.1415926                                                    WICIRS
      B1 = 1.0                                                           WICIRS
      B2R = ( 90.0 - BETA1 + STAGER ( N )) * PAI / 180.0                 WICIRS
      B2 = COS ( B2R )                                                   WICIRS
      LWC=XW1/XG*RHOG1                                                   WICIRS
      DS1=0.07*RC(N)                                                     WICIRS
      BETA1R = BETA1* PAI / 180.0                                        WICIRS
      DS2 = 2.0 * PAI * R / RBLADE(N) * COS (BETA1R) /                   WICIRS
     $COS(B2R)                                                           WICIRS
      IF(DS2.GE.RC(N)) DS2=RC(N)                                         WICIRS
      H=(AAA1*144.0)/(2.0*PAI*R)                                         WICIRS
      A1=DS1*H*RBLADE(N)/144.0                                           WICIRS
      A2=DS2*H*RBLADE(N)/144.0                                           WICIRS
      WW1 = LWC * W1 * B1 * A1                                           WICIRS
      WW2 = LWC * W1 * B2 * A2                                           WICIRS
      WW = WW1 + WW2                                                     WICIRS
      RETURN                                                             WICIRS
      END                                                                WICIRS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICISS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISS
C                                                                      C WICISS
C SUBROUTINE WICISS                                                     C WICISS
C                                                                      C WICISS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISS
      SUBROUTINE WICISS( ISTAGE ,R ,XW1, XG , RHOGAS ,ALFA2,V1 ,         WICISS
     $WW1,WW2,WW)                                                        WICISS
      REAL LWC                                                           WICISS
      COMMON TD(7),IUNIT                                                 WICISS
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                 WICISS
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                    WICISS
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)    WICISS
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)   WICISS
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                           WICISS
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                    WICISS
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                    WICISS
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)   WICISS
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)   WICISS
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI  WICISS
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  WICISS
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    WICISS
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  WICISS
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        WICISS
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)              WICISS
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   WICISS
      LWC = XW1/ XG * RHOGAS                                             WICISS
```

```
      DS1=( 0.06 * SC ( ISTAGE ) ) / 12.0                                WICISS   28
      PAI=3.1415926                                                      WICISS   29
      B1=1.0                                                             WICISS   30
      B2R=(90.0-ALFA2+STAGES(ISTAGE))*PAI/180.0                          WICISS   31
      B2=COS(B2R)                                                        WICISS   32
      ALFA2R=ALFA2*PAI/180.0                                             WICISS   33
      DS2=2.0*PAI*R/SBLADE(ISTAGE)*COS(ALFA2R)/COS(B2R)                  WICISS   34
      IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE)                               WICISS   35
      H=(AAA2*144.0)/(2.0*PAI*R)                                         WICISS   36
      A1=DS1*H*SBLADE(ISTAGE)/144.0                                      WICISS   37
      A2=DS2*H*SBLADE(ISTAGE)/144.0                                      WICISS   38
      WW1=LWC*V1*B1*A1                                                   WICISS   39
      WW2=LWC*V1*B2*A2                                                   WICISS   40
      WW=WW1+WW2                                                         WICISS   41
      RETURN                                                             WICISS   42
      END                                                                WICISS   43
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICIRL    1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRL    2
C                                                                      C WICIRL    3
C SUBROUTINE WICISL                                                    C WICIRL    4
C                                                                      C WICIRL    5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRL    6
      SUBROUTINE WICISL(ISTAGE,R,XW1,XG,RHOG1,ALFA2,W1,WW1,WW2,WW)       WICIRL    7
      REAL LWC                                                           WICIRL    8
      COMMON TD(7),IUNIT                                                 WICIRL    9
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                 WICIRL   10
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                    WICIRL   11
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)    WICIRL   12
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)   WICIRL   13
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                           WICIRL   14
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                    WICIRL   15
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                    WICIRL   16
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)   WICIRL   17
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)   WICIRL   18
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI  WICIRL   19
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  WICIRL   20
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    WICIRL   21
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  WICIRL   22
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        WICIRL   23
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)              WICIRL   24
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   WICIRL   25
      PAI=3.1415926                                                      WICIRL   26
      LWC = XW1/ XG * RHOG1                                              WICIRL   27
      ALFA=(90.0-ALFA2)/2.0*PAI/180.0                                    WICIRL   28
      BETA=(90.0+ALFA2)/2.0*PAI/180.0                                    WICIRL   29
      B1=SIN(ALFA)                                                       WICIRL   30
      B2=SIN(BETA)                                                       WICIRL   31
      V1=W1*COS(ALFA)                                                    WICIRL   32
      V2=W1*COS(BETA)                                                    WICIRL   33
      S=2.0*PAI*SRTIP(ISTAGE)/SBLADE(ISTAGE)/2.0                         WICIRL   34
      GSI=ALFA2+(90.0-ALFA2)/2.0                                         WICIRL   35
      GSIR=GSI*PAI/180.0                                                 WICIRL   36
      STAGR=STAGES(ISTAGE)*PAI/180.0                                     WICIRL   37
      Y2=GAPS(ISTAGE)/2.0*(WICTAN(STAGR)-WICTAN(GSIR))+S                 WICIRL   38
      DAMY1=(90.0-GSI)*PAI/180.0                                         WICIRL   39
      Y1=Y2*SIN(DAMY1)                                                   WICIRL   40
      DAMY2=(GSI-STAGES(ISTAGE))*PAI/180.0                               WICIRL   41
      DS1=Y1/SIN(DAMY2)                                                  WICIRL   42
      IF(DS1.GT.SC(ISTAGE)) DS1=SC(ISTAGE)                               WICIRL   43
      DAMY3=(90.-(90.0+ALFA2)/2.0)*PAI/180.0                             WICIRL   44
      DAMY4=STAGES(ISTAGE)*PAI/180.0                                     WICIRL   45
      DAMY5=ALFA2*PAI/180.0                                              WICIRL   46
      DAMY6=S-GAPS(ISTAGE)/2.0*(WICTAN(DAMY5)-WICTAN(DAMY3))             WICIRL   47
      DAMY7=COS(DAMY4)*WICTAN(DAMY3)+SIN(DAMY4)                          WICIRL   48
      DS2=DAMY6/DAMY7                                                    WICIRL   49
      IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE)                               WICIRL   50
      H=(AAA2*144.0)/(2.0*PAI*R)                                         WICIRL   51
      A1=DS1*H*SBLADE(ISTAGE)/144.0                                      WICIRL   52
      A2=DS2*H*SBLADE(ISTAGE)/144.0                                      WICIRL   53
      WW1=LWC*V1*B1*A1                                                   WICIRL   54
```

```
      WW2=LWC*V2*B2*A2
      WW=WW1+WW2
      RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICWAK                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICWAK ( RHOG , V , DWAKE , DWAKEM )
      VISCOF=1.20E-3
      SIGUMA = 4.6534E-3
      GC = 32.174
      WE=21.0
      DWAKE1 = ( WE * SIGUMA * GC ) / RHOG / V ** 2
      SN=VISCOF**2/(RHOG*SIGUMA*DWAKE1*GC)
      WELIMT=12.0*(1.0+SN**0.36)
      D1=WELIMT*SIGUMA*GC/(RHOG*V**2)
      WE=22.0
      DWAKE2=(WE*SIGUMA*GC)/RHOG/V**2
      SN=VISCOF**2/(RHOG*SIGUMA*DWAKE2*GC)
      WELIMT=12.0*(1.0+SN**0.36)
      D2=WELIMT*SIGUMA*GC/(RHOG*V**2)
      XXXX=WICNEW(DWAKE1,D1,DWAKE2,D2)
      SN=VISCOF**2/(RHOG*SIGUMA*XXXX*GC)
      WELIMT=12.0*(1.0+SN**0.36)
      DWAKE=WELIMT*SIGUMA*GC/(RHOG*V**2)
      DWAKEM = DWAKE / 3.2802 * 1.0E6
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICHET                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICHET(TG1,TG3,TW1,TW3,DAVEN2,DAVEN,
     $DELZI,VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH,DELTWH,RE)
      DIMENSION DELHET(51)
      REAL ND , KA , NV , MMASS,NU
      DELTGH=0.0
      DELTWH=0.0
      IF(WMASS1.LT.1.0E-6) GO TO 11
      PAI = 3.1415927
      DAVEAV=(DAVEN2+DAVEN)/2.0*1.0E-6*3.2802
      IF(DAVEAV.LT.1.0E-6) GO TO 11
      RHOW = 62.54
      ND = WMASS1     / ( RHOW * 4.0 / 3.0 * PAI * ( DAVEAV / 2.0 ) ** 3)
      KA = 0.015 / 3600.0
      PR=0.7
      NU=2.0+0.6*SQRT(RE)*PR**0.33
      HCONVE = KA / DAVEAV * NU
      J = 1
   10 DELT=((TG1-TW1)+(TG3-TW3))/2.0
      DELHH = HCONVE * 4.0 * PAI * ( DAVEAV / 2.0 ) **2*DELT *
     $ND*DELZI/VZ
      GMASS1=VMASS1+AMASS+CHMASS
      DELTGH=DELHH/(GMASS1*CPG)
      DELTWH=DELHH/(WMASS1*CPW)
      TG3=TG3-DELTGH
      TW3=TW3+DELTWH
      DELHET(J)=DELHH
      J=J+1
      IF(J.EQ.2) GO TO 10
      EROR=ABS(DELHET(J-1)-DELHET(J-2))
      EPS=0.0001
      IF(J.GT.50) GO TO 11
      IF(EROR.GT.EPS) GO TO 10
   11 RETURN
```

```
      END
I
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICMAS                                                     C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE  WICMAS( HW1 , TW1 , TW2 , PP1 , PP2 , TG1 , TG2 , DZ ,
     1 PWB1 , PWB2 , PW1 , PW2 , VZ , DDAVE1 , DDAVE2 , HW2 , VMASS1 ,
     1 VMASS2 , WMASS1 , WMASS2 , DMDTAV , AMASS ,RE)
      PWB1 = WICPWB(TW1)*144.0
      PWB2 = WICPWB( TW2 )*144.0
      PW1 = ( HW1 * PP1 ) / ( HW1 + 0.6219 )
      DMDT1 = WICMTR( TG1 , TW1 , PP1 , DDAVE1 , VZ , DZ , WMASS1 ,
     1PW1 ,RE)
      PW2AS1 = PW1
      DMDT2 = WICMTR( TG 2 , TW 2 , PP2 , DDAVE2 , VZ , DZ , WMASS1 ,
     1PW2AS1 ,RE)
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0
      VMASS2 = VMASS1 + DMDTAV
      WMASS2 = WMASS1 - DMDTAV
      HW2=VMASS2/AMASS
      PW2CL1 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )
      PW2AS2 = PW1 * 1.05
      DMDT2 = WICMTR( TG2 , TW2 , PP2 , DDAVE2 , VZ , DZ , WMASS2 ,
     1PW2AS2 ,RE)
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0
      VMASS2 = VMASS1 + DMDTAV
      WMASS2 = WMASS1 - DMDTAV
      HW2 = VMASS2 / AMASS
      PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )
    2 PW2ASN = WICNEW ( PW2AS1 , PW2CL1 , PW2AS2 , PW2CL2 )
      PW2AS1 = PW2AS2
      PW2CL1 = PW2CL2
      PW2AS2 = PW2ASN
      DMDT2 = WICMTR( TG2 , TW2 , PP2 , DDAVE2 , VZ , DZ , WMASS2 , PW
     12AS2 ,RE)
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0
      VMASS2 = VMASS1 + DMDTAV
      WMASS2 = WMASS1 - DMDTAV
      HW2 = VMASS2 / 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
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICMTR                                                       C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICMTR(TTG,TTW,PPP,DAVE,VZ,DZ,MMASS,PW,RE)
      REAL KG , ND , MMASS
      IF(DAVE.LT.1.0E-6) WICMTR=0.0
      IF(DAVE.LT.1.0E-6) GO TO 10
      DD=DAVE*1.0E-6*3.2802
      T = ( TTG + TTW ) / 2.0
      PAI = 3.1415926
      RHOW = 62.2567
      RR = DD / 2.0
      TT = T * 5.0 / 9.0
      PP = PPP * 47.880258
      DV=4.24028E-3*(TT**1.5)/PP
      SCT=0.60
      SH=2.0+0.60*SQRT(RE)*SCT**0.33
      KG = DV / DD * SH
```

```
      HV=1115.3279-0.6840909*(TTW-460.0)
      PWBB=PW+29.0/18.0*0.45/HV*PPP*(TTG-TTW)
      R = 85.78
      ND = MMASS / ( RHOW * 4.0 / 3.0 * PAI * RR ** 3 )
      WICMTR = KG * 4.0 * PAI * RR ** 2 * ( PWBB / TTW - PW / TTG ) / R
     1 * ND * DZ / VZ
   10 RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICPWB                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICPWB(TWB)
      TSTAG=TWB
      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
   42 AA=A-B/(TSTAGC+273.0)
      PS=10.0**AA
      PS=PS/4.88247E-4
      WICPWB=PS/144.0
      RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICNEW                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      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
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICBPT                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      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
   22 PS=PSTAG*4.88247E-4
      TBOILK=B/(A-ALOG10(PS))
      WICBPT=TBOILK*1.8
      RETURN
```

```
      END                                                               WICBPT    23
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICSH      1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSH      2
C                                                                    C  WICSH      3
C FUNCTION WICSH                                                     C  WICSH      4
C                                                                    C  WICSH      5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSH      6
      FUNCTION WICSH(TSTAG,PSTAG)                                       WICSH      7
      TSTAGC=(TSTAG-492.0)/1.8                                          WICSH      8
      IF(TSTAGC.LT.100.0) GO TO 40                                      WICSH      9
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 41                  WICSH     10
      A=5.45142                                                         WICSH     11
      B=2010.8                                                          WICSH     12
      GO TO 42                                                          WICSH     13
   40 A=5.9778                                                          WICSH     14
      B=2224.4                                                          WICSH     15
      GO TO 42                                                          WICSH     16
   41 A=5.6485                                                          WICSH     17
      B=2101.1                                                          WICSH     18
   42 AA=A-B/(TSTAGC+273.0)                                             WICSH     19
      PS=10.0**AA                                                       WICSH     20
      PS=PS/4.88247E-4                                                  WICSH     21
      WICSH=0.6218847*PS/(PSTAG-PS)                                     WICSH     22
      RETURN                                                            WICSH     23
      END                                                               WICSH     24
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICTAN     1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICTAN     2
C                                                                    C  WICTAN     3
C FUNCTION WICTAN                                                    C  WICTAN     4
C                                                                    C  WICTAN     5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICTAN     6
      FUNCTION WICTAN(X)                                                WICTAN     7
      A=COS(X)                                                          WICTAN     8
      B=SIN(X)                                                          WICTAN     9
      WICTAN=B/A                                                        WICTAN    10
      RETURN                                                            WICTAN    11
      END                                                               WICTAN    12
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICCEN     1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCEN     2
C                                                                    C  WICCEN     3
C SUBROUTINE WICCEN                                                  C  WICCEN     4
C                                                                    C  WICCEN     5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCEN     6
      SUBROUTINE WICCEN(RZERO,UZERO,DD,VZ,DELZZ,ALFAAV,FN,IRS,RHOGAS,   WICCEN     7
     1RHUB,R2,U2,ITIP,VZTIME,XG,XA,XVV,XCH4,RTIPIN)                     WICCEN     8
      REAL N                                                            WICCEN     9
      PAI=3.1415926                                                     WICCEN    10
      ALFAAR=ALFAAV*PAI/180.0                                           WICCEN    11
      IF(DD.LT.1.0E-6) GO TO 12                                         WICCEN    12
      D=DD*1.0E-6*3.2802                                                WICCEN    13
      RHOA=RHOGAS                                                       WICCEN    14
      RHOD=62.37                                                        WICCEN    15
      XXAA=XA/XG                                                        WICCEN    16
      XXVV=XVV/XG                                                       WICCEN    17
      XXCC=XCH4/XG                                                      WICCEN    18
      VISCO=(XXAA*0.05715+XXVV*0.03293+XXCC*0.035)/3600.0               WICCEN    19
      ENDTIM=DELZZ/VZ                                                   WICCEN    20
      JJ=10                                                             WICCEN    21
      DELTIM=ENDTIM/FLOAT(JJ)                                           WICCEN    22
      R1=RZERO                                                          WICCEN    23
      U1=UZERO                                                          WICCEN    24
      TIME=0.0                                                          WICCEN    25
      JJJ=1                                                             WICCEN    26
   11 RE=D*U1/VISCO                                                     WICCEN    27
      B1=0.44                                                           WICCEN    28
      N=0.0                                                             WICCEN    29
      IF(RE.LT.1.9) B1=24.0                                             WICCEN    30
      IF(RE.LT.1.9) N=1.0                                               WICCEN    31
      IF(RE.GT.1.9.AND.RE.LT.500.0) B1=18.5                             WICCEN    32
      IF(RE.GT.1.9.AND.RE.LT.500.0) N=0.6                               WICCEN    33
```

```
      B=((VISCO**N)*B1*PAI*(RHOA**(1.0-N))*6.0)/(8.0*RHOD*PAI)
      C=B/(D**(1.0+N))
      VW1=R1/12.0*2.0*PAI*FN/60.0
      IF(R1.GT.RTIPIN) VW1=RTIPIN/12.0*2.0*PAI*FN/60.0
      VW2=VZ*WICTAN(ALFAAR)
      IF(ALFAAV.LT.1.0) VW=VW1
      IF(ALFAAV.GT.1.0) VW=VW1/2.0
      A=VW*VW*(1.0-RHOA/RHOD)
      DELU=(A/R1*12.0-C*U1**(2.0-N))*DELTIM
      U2=U1+DELU
      UAVE=U1+DELU/2.0
      DELR=UAVE*DELTIM*12.0
      R2=R1+DELR
      TIME=TIME+DELTIM
      IPRINT=1
      IF(IPRINT.EQ.2)
     $WRITE(6,101) R1,VW,A,U1,DELU,U2,UAVE,DELR,R2,TIME
  101 FORMAT(1H ,7(F11.4,2X),E10.4,2X,F10.4,2X,E10.4)
      U1=U2
      R1=R2
      JJJ=JJJ+1
      VZTIME=VZ*TIME*12.0
      IF(TIME.GT.ENDTIM) GO TO 12
      IF(JJJ.EQ.JJ) GO TO 12
      GO TO 11
   12 RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICDMS                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICDMS(IPRINT,IRAD,AMASW1,AMASWT,AMASW,R1,R2,STAREA,
     $RSTAVE,RTIP,DMIN,DMOUT,AMASW2,DELMAS)
      PAI=3.1415926
      RST1=RSTAVE
      A1=STAREA
      A2=PAI*(R2**2-R1**2)/144.0
      A2=A2*0.5
      DMCENT=A2/A1*AMASW
  120 IF(DMCENT.LT.0.0) DMCENT=0.0
      IF(DMCENT.GT.AMASWT) DMCENT=AMASWT
      IF(R1.GT.RST1) GO TO 110
      DMIN=DMCENT
      DMOUT=DMCENT
      GO TO 100
  110 CONTINUE
      DMIN=0.0
      DMOUT=DMCENT
  100 IF(IRAD.EQ.1) DMOUT=0.0
      IF(IRAD.EQ.3) DMIN=0.0
      AMASW2=AMASW1+DMIN-DMOUT
      IF(AMASW2.LT.0.0) AMASW2=0.0
      IF(AMASW2.GT.AMASWT) AMASW2=AMASWT
      DELMAS=AMASW2-AMASW1
      IF(IPRINT.EQ.2) WRITE(6,200) AMASW2,AMASW1,DMIN,DMOUT,DMCENT,
     $AMASWT,AMASW,DELMAS
  200 FORMAT(1H0,8(F10.5,3X))
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICDML                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICDML(IPRINT,IRAD,AMASW1,AMASWT,AMASW,R1,R2,STAREA,
     $RSTAVE,RTIP,DMIN,DMOUT,AMASW2,DELMAS)
      PAI=3.1415926
```

```
      RST1=RSTAVE                                                       WICDML
      A1=STAREA                                                         WICDML
      A2=PAI*(R2**2-R1**2)/144.0                                        WICDML
      A2=A2*0.5                                                         WICDML
      DMCENT=A2/A1*AMASW                                                WICDML
  120 IF(DMCENT.LT.0.0) DMCENT=0.0                                      WICDML
      IF(DMCENT.GT.AMASWT) DMCENT=AMASWT                                WICDML
      IF(R1.GT.RST1) GO TO 110                                          WICDML
      DMIN=DMCENT                                                       WICDML
      DMOUT=DMCENT                                                      WICDML
      GO TO 100                                                         WICDML
  110 CONTINUE                                                          WICDML
      DMIN=0.0                                                          WICDML
      DMOUT=DMCENT                                                      WICDML
  100 IF(IRAD.EQ.1) DMOUT=0.0                                           WICDML
      IF(IRAD.EQ.3) DMIN=0.0                                            WICDML
      AMASW2=AMASW1+DMIN-DMOUT                                          WICDML
      IF(AMASW2.LT.0.0) AMASW2=0.0                                      WICDML
      IF(AMASW2.GT.AMASWT) AMASW2=AMASWT                                WICDML
      DELMAS=AMASW2-AMASW1                                              WICDML
      IF(IPRINT.EQ.2) WRITE(6,200) AMASW2,AMASW1,DMIN,DMOUT,DMCENT,     WICDML
     $AMASWT,AMASW,DELMAS                                               WICDML
  200 FORMAT(1H0,8(F10.5,3X))                                           WICDML
      RETURN                                                            WICDML
      END                                                               WICDML
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICDRG
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDRG
C                                                                      C WICDRG
C SUBROUTINE WICDRG                                                     C WICDRG
C                                                                      C WICDRG
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDRG
      SUBROUTINE WICDRG(D,DELV1,RHGAS1,RHGAS2,CD2,DELV2,DRAG1,RE)         WICDRG
      REAL N,N1                                                         WICDRG
      GC=32.174                                                         WICDRG
      IPRINT=1                                                          WICDRG
      VISCOG=12.0E-6                                                    WICDRG
      PAI=3.1415927                                                     WICDRG
      IF(D.GT.0.0) GO TO 300                                            WICDRG
      CD2=0.0                                                           WICDRG
      DELV2=0.0                                                         WICDRG
      DRAG1=0.0                                                         WICDRG
      RE=0.0                                                            WICDRG
      GO TO 301                                                         WICDRG
  300 RE1=(RHGAS1*D*DELV1)/VISCOG                                       WICDRG
      RE=RE1                                                            WICDRG
      B11=0.44                                                          WICDRG
      N1=0.0                                                            WICDRG
      IF(RE.LT.1.9) B11=24.0                                            WICDRG
      IF(RE.LT.1.9) N1=1.0                                              WICDRG
      IF(RE.GT.1.9.AND.RE.LT.500.0) B11=18.5                            WICDRG
      IF(RE.GT.1.9.AND.RE.LT.500.0) N1=0.6                              WICDRG
      CD1=B11/(RE1**N1)                                                 WICDRG
      DRAG1=0.5*RHGAS1*(DELV1**2)*(PAI*D**2)*CD1                        WICDRG
     $/GC                                                               WICDRG
      DAMY=DRAG1*GC/(CD1*0.5*RHGAS2*(PAI*D**2))                         WICDRG
      IF(IPRINT.EQ.2) WRITE(6,200) D,DELV1,RHGAS1,RHGAS2,RE1,B11,N1,    WICDRG
     $CD1,DRAG1,DAMY                                                    WICDRG
  200 FORMAT(1H0,10(F10.5,2X))                                          WICDRG
      DELV2=SQRT(DAMY)                                                  WICDRG
      RE2=RHGAS2*D*DELV2/VISCOG                                         WICDRG
      B1=0.44                                                           WICDRG
      N=0.0                                                             WICDRG
      IF(RE2.LT.1.9) B1=24.0                                            WICDRG
      IF(RE2.LT.1.9) N=1.0                                              WICDRG
      IF(RE2.GT.1.9.AND.RE2.LT.500.0) B1=18.5                           WICDRG
      IF(RE2.GT.1.9.AND.RE2.LT.500.0) N=0.6                             WICDRG
      CD2=B1/(RE2**N)                                                   WICDRG
      IF(IPRINT.EQ.2) WRITE(6,101) RE1,B11,N1,CD1,DELV1,RE2,B1,N,CD2,   WICDRG
     $DELV2                                                             WICDRG
  101 FORMAT(1H0,2X,10(F10.5,2X))                                       WICDRG
```

```
      RE=(RE1+RE2)/2.0                                                   WICDRG
  301 RETURN                                                             WICDRG
      END                                                                WICDRG
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICSIZ
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSIZ
C                                                                      C WICSIZ
C SUBROUTINE WICSIZ                                                    C WICSIZ
C                                                                      C WICSIZ
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSIZ
      SUBROUTINE WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DL,DS,D1,D2,  WICSIZ
     $D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)                                   WICSIZ
      TMASS1=WMASSL+WMASSS+AMING1+AMING2+AMING3                          WICSIZ
      AML=0.0                                                            WICSIZ
      AMS=0.0                                                            WICSIZ
      IF(DL.GT.DLIMIT) AML=AML+WMASSL                                    WICSIZ
      IF(DL.LT.DLIMIT) AMS=AMS+WMASSL                                    WICSIZ
      IF(DS.GT.DLIMIT) AML=AML+WMASSS                                    WICSIZ
      IF(DS.LT.DLIMIT) AMS=AMS+WMASSS                                    WICSIZ
      IF(D1.GT.DLIMIT) AML=AML+AMING1                                    WICSIZ
      IF(D1.LT.DLIMIT) AMS=AMS+AMING1                                    WICSIZ
      IF(D2.GT.DLIMIT) AML=AML+AMING2                                    WICSIZ
      IF(D2.LT.DLIMIT) AMS=AMS+AMING2                                    WICSIZ
      IF(D3.GT.DLIMIT) AML=AML+AMING3                                    WICSIZ
      IF(D3.LT.DLIMIT) AMS=AMS+AMING3                                    WICSIZ
      TMASS2=AML+AMS                                                     WICSIZ
      ERROR=ABS(TMASS1-TMASS2)                                           WICSIZ
      IF(ERROR.LT.1.0E-6) GO TO 100                                      WICSIZ
      IF(TMASS2.LT.1.0E-6) GO TO 100                                     WICSIZ
      TT=TMASS1/TMASS2                                                   WICSIZ
      IF(TT.LT.1.0) AML=AML/TT                                           WICSIZ
      IF(TT.LT.1.0) AMS=AMS/TT                                           WICSIZ
      IF(TT.GT.1.0) AML=AML*TT                                           WICSIZ
      IF(TT.GT.1.0) AMS=AMS*TT                                           WICSIZ
  100 AMLGE=AML                                                          WICSIZ
      AMSLL=AMS                                                          WICSIZ
      ADL=0.0                                                            WICSIZ
      ADS=0.0                                                            WICSIZ
      IF(DL.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+DL*(WMASSL/AML)            WICSIZ
      IF(DL.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+DL*(WMASSL/AMS)            WICSIZ
      IF(DS.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+DS*(WMASSS/AML)            WICSIZ
      IF(DS.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+DS*(WMASSS/AMS)            WICSIZ
      IF(D1.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D1*(AMING1/AML)            WICSIZ
      IF(D1.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D1*(AMING1/AMS)            WICSIZ
      IF(D2.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D2*(AMING2/AML)            WICSIZ
      IF(D2.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D2*(AMING2/AMS)            WICSIZ
      IF(D3.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D3*(AMING3/AML)            WICSIZ
      IF(D3.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D3*(AMING3/AMS)            WICSIZ
      DLGE=ADL                                                           WICSIZ
      DSLL=ADS                                                           WICSIZ
      IF(DL.GT.0.0.AND.DLGE.GT.DL) DLGE=DL                               WICSIZ
      IF(DS.GT.0.0.AND.DSLL.GT.DS) DSLL=DS                               WICSIZ
      RETURN                                                             WICSIZ
      END                                                                WICSIZ
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICPRP
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICPRP
C                                                                      C WICPRP
C SUBROUTINE WICPRP                                                    C WICPRP
C                                                                      C WICPRP
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICPRP
      SUBROUTINE WICPRP(XAIR,XH2O,XCH4,T,RMIX,CPMIX,GAMMA,G1,G2,G3)      WICPRP
C T IN R                                                                 WICPRP
C CPMIX IN BTU/LBM-R                                                     WICPRP
C RMIX IN LBF-FT/LBM-R                                                   WICPRP
      RAIR=1545.3/28.964                                                 WICPRP
      RH2O=1545.3/18.016                                                 WICPRP
      RCH4=1545.3/16.043                                                 WICPRP
      XXAIR=XAIR/(XAIR+XH2O+XCH4)                                        WICPRP
      XXH2O=XH2O/(XAIR+XH2O+XCH4)                                        WICPRP
      XXCH4=XCH4/(XAIR+XH2O+XCH4)                                        WICPRP
      RMIX=XXAIR*RAIR+XXH2O*RH2O+XXCH4*RCH4                              WICPRP
```

```
      CPMIX=XXAIR*WICCPA(T)+XXH2O*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 +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICCPA                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICCPA(T)
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
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICCPH                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WILCPH(T)
C T IN R
C CPH2O 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
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICCPC                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICCPC(T)
C T IN R
C 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
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
```

```
C SUBROUTINE WICGSL                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICGSL(OMEGAS,SIGUMA,BET1S,BET2S,AINCIS,ADEVIS,AMACH1,
     1BET1,DEQS,DEQN,SITACS,SITACN,BET2N,OMEGAN,X,IDESIN,AK1,AK2,AK3
     2,VZ1,VZ2,UR1,R1,R2)
      CALL WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,OMEGAS,
     $DEQS,SITACS)
      AINCI=BET1-BET1S+AINCIS
      BET2A=BET2S
      X1=BET2A
      DELDEQ=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X1,SIGUMA,AINCIS,AINCI)
     $-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      Y1=BET2C
      N=1
   12 IF(N.GT.1) GO TO 10
      BET2A=BET2S*1.1
   10 X2=BET2A
      DEQN=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X2,SIGUMA,AINCIS,AINCI)
      DELDEQ=DEQN-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      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
   11 BET2N=X2
      GO TO 14
   13 WRITE(6,201)
  201 FORMAT(1H0,≠DO NOT CONVERGE≠)
      GO TO 15
   14 SITACN=WICMTK(SITACS,AMACH1,DELDEQ,AK2)
      OMEGAN=WICLOS(BET1,BET2N,SIGUMA,SITACN)
      SSS=SITACN-SITACS
   15 RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICSDL                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSDL(CHORD,SIGUMA,BETA1,BETA2,UG,RHOG,
     $AMASSW,AREA,VZ,IPRINT,OMEGAP)
      PAI=3.1415926
      RHOG0=RHOG
      RHOP0=AMASSW/AREA/VZ
      RR=RHOP0/RHOG0
      VISCOG=0.128E-4
      C=CHORD/12.0
      RE=UG*C*RHOG0/VISCOG
      DELC=0.37/(RE**0.2)/(1.0+1.442*RR)**0.8
      DELP=0.1402*DELC
      BETA1R=BETA1*PAI/180.0
      BETA2R=BETA2*PAI/180.0
      OMEGAP=DELP*2.0*SIGUMA/COS(BETA2R)*(COS(BETA1R)/COS(BETA2R))**2
      RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
C                                                                          C
C SUBROUTINE WICSTL                                                        C
C                                                                          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSTL(ISTAGE,IROTOR,DAV,W1,W2,DELV,V2,V3,WMASS,VZ,N
     $,BETA1,BETA2,ALFA2,ALFA3,MMASS,DELVU2,DELVL2,
     $OMEGRU,OMEGRL,OMEGSU,OMEGSL,DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)
      REAL M,MMASS
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
      COMMON SRHUB(7) , SC(7) , SBLADE(7),STAGES(7)
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON VR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      PAI=3.1415927
      GC=32.174
      RHOW=62.3
      IF(IROTOR.EQ.2) GO TO 100
C DROPLET DRAG IN ROTOR
      DD=DAV*1.0E-6*3.28
      VG1=W1
      VP1=VG1-DELV
      A1=WMASS*RC(ISTAGE)/12.0/VZ
      A2=RHOW*4.0/3.0*PAI*(DD/2.0)**3
      TN=0.0
      IF(WMASS.GT.0.0) GO TO 2000
      GO TO 2001
 2000 TN=A1/A2
 2001 VAVE=(W1+W2)/2.0
      GMU1=(90.0-BETA1)/2.0*PAI/180.0
      DELVU1=VG1-VP1*COS(GMU1)
      IF(N.GT.2) DELVU1=DELVU2
      TNU=TN*(180.0-BETA1-BETA2)/360.0
      XWW(2)=XWW(1)
      XWT(2)=XWT(1)
      CALL WICPRP(XA,XV(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)
      IF(IPRINT.EQ.2) WRITE(6,4000)
 4000 FORMAT(1H0,≠DROPLET DRAG IN ROTOR (UPPER PART)≠)
      CALL WICDRG(DD,DELVU1,RHOG(1),RHOG(2),CD2,DELV2,DRAG1,RE)
      DELVU2=DELV2
      CDRU=CD2
      RERUP=RE
      DRAGRU=DRAG1*TNU
      AREA1=PAI*(RRTIP(ISTAGE)**2-RRHUB(ISTAGE)**2)/144.0/10.0
      DELPRU=DRAGRU/AREA1
      OMEGRU=DELPRU/(0.5*RHOG(1)/GC*W1**2)
      CDRUU=CDRU*DELVU2**2*PAI/4.0*DD**2*TNU/VAVE**2/RC(ISTAGE)*12.0
      GML1=(90.0+BETA1)/2.0*PAI/180.0
      DELVL1=VG1-VP1*COS(GML1)
      IF(N.GT.2) DELVL1=DELVL2
      TNL=TN*(180.0+BETA1+BETA2)/360.0
      IF(IPRINT.EQ.2) WRITE(6,4001)
 4001 FORMAT(1H0,≠DROPLET DRAG IN ROTOR (LOWER PART)≠)
      CALL WICDRG(DD,DELVL1,RHOG(1),RHOG(2),CD2,DELV2,DRAG1,RE)
      DELVL2=DELV2
      CDRL=CD2
      RERLOW=RE
      DRAGRL=DRAG1*TNU
      DELPRL=DRAGRL/AREA1
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      OMEGRL=DELPRL/(0.5*RHOG(1)/GC*W1**2)                              WICSTL
      CDRLL=CDRL*DELVL2**2*PAI/4.0*DD**2*TNL/VAVE**2/RC(ISTAGE)*12.0    WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2002)                                     WICSTL
 2002 FORMAT(1H0,≠DROPLET DRAG SUMMARY≠)                                WICSTL
      IF(IPRINT.EQ.2) WRITE(6,720)DELVU1,DELVU2,DELVL1,DELVL2,CDRU,CD   WICSTL
     $RUU,CDRL,CDRLL                                                    WICSTL
     $,DRAGRU,DRAGRL                                                    WICSTL
  720 FORMAT(1H0,10(F10.5,2X))                                          WICSTL
      RUP1=(90.0-BETA1)/180.0                                           WICSTL
      RLOW1=(90.0+BETA1)/180.0                                          WICSTL
      RUP2=(90.0-BETA2)/180.0                                           WICSTL
      RLOW2=(90.0+BETA2)/180.0                                          WICSTL
      REAVE=RERUP*(RUP1+RUP2)*0.5+RERLOW*(RLOW1+RLOW2)*0.5              WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2010) RUP1,RUP2,RLOW1,RLOW2               WICSTL
 2010 FORMAT(1H0,4(F10.5,2X))                                           WICSTL
      GO TO 200                                                         WICSTL
C DROPLET DRAG IN STATOR                                                WICSTL
  100 DD=DAV*1.0E-6*3.28                                                WICSTL
      VG1=W1                                                            WICSTL
      VP1=VG1-DELV                                                      WICSTL
      A1=WMASS*SC(ISTAGE)/12.0/VZ                                       WICSTL
      A2=RHOW*4.0/3.0*PAI*(DD/2.0)**3                                   WICSTL
      TN=0.0                                                            WICSTL
      IF(WMASS.GT.0.0) GO TO 5002                                       WICSTL
      GO TO 5003                                                        WICSTL
 5002 TN=A1/A2                                                          WICSTL
 5003 VAVE=(V3+V2)/2.0                                                  WICSTL
      DELVU1=DELVU2                                                     WICSTL
      TNU=TN*(180.0-ALFA2-ALFA3)/360.0                                  WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2005)                                     WICSTL
 2005 FORMAT(1H0,≠DROPLET DRAG IN STATOR (UPPER PART)≠)                 WICSTL
      CALL WICDRG(DD,DELVU1,RHOG(2),RHOG(2),CD2,DELV2,DRAG1,RE)         WICSTL
      DELVU2=DELV2                                                      WICSTL
      CDSU=CD2                                                          WICSTL
      RESUP=RE                                                          WICSTL
      DRAGSU=DRAG1*TNU                                                  WICSTL
      AREA2=PAI*(SRTIP(ISTAGE)**2-SRHUB(ISTAGE)**2)/144.0/10.0          WICSTL
      DELPSU=DRAGSU/AREA2                                               WICSTL
      OMEGSU=DELPSU/(0.5*RHOG(2)/GC*V2**2)                              WICSTL
      CDSUU=CDSU*DELVU2**2*PAI/4.0*DD**2*TNU/VAVE**2/SC(ISTAGE)*12.0    WICSTL
      DELVL1=DELVL2                                                     WICSTL
      TNL=TN*(180.0+ALFA2+ALFA3)/360.0                                  WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2006)                                     WICSTL
 2006 FORMAT(1H0,≠DROPLET DRAG IN STATOR (LOWER PART)≠)                 WICSTL
      CALL WICDRG(DD,DELVL1,RHOG(2),RHOG(2),CD2,DELV2,DRAG1,RE)         WICSTL
      DELVL2=DELV2                                                      WICSTL
      CDSL=CD2                                                          WICSTL
      RESLOW=RE                                                         WICSTL
      DRAGSL=DRAG1*TNL                                                  WICSTL
      DELPSL=DRAGSL/AREA2                                               WICSTL
      OMEGSL=DELPSL/(0.5*RHOG(2)/GC*V2**2)                              WICSTL
      CDSLL=CDSL*DELVL2**2*PAI/4.0*DD**2*TNL/VAVE**2/SC(ISTAGE)*12.0    WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2007)                                     WICSTL
 2007 FORMAT(1H0,≠DROPLET DRAG IN STATOR (SUMMARY)≠)                    WICSTL
      IF(IPRINT.EQ.2)WRITE(6,721) DELVU1,DELVU2,DELVL1,DELVL2,CDSU,CD   WICSTL
     $SUU,CDSL,CDSLL                                                    WICSTL
     ^,DRAGSU,DRAGSL                                                    WICSTL
  721 FORMAT(1H0,10(F10.5,2X))                                          WICSTL
      SUP1=(90.0-ALFA2)/180.0                                           WICSTL
      SLOW1=(90.0+ALFA2)/180.0                                          WICSTL
      SUP2=(90.0-ALFA3)/180.0                                           WICSTL
      SLOW2=(90.0+ALFA3)/180.0                                          WICSTL
      REAVE=RESUP*(SUP1+SUP2)*0.5+RESLOW*(SLOW1+SLOW2)*0.5              WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2011) SUP1,SUP2,SLOW1,SLOW2               WICSTL
 2011 FORMAT(1H0,4(F10.5,2X))                                           WICSTL
  200 RETURN                                                            WICSTL
      END                                                               WICSTL
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICFML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICFML
C                                                                     C WICFML
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C SUBROUTINE WICFML                                                     C  WICFML     4
C                                                                       C  WICFML     5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICFML     6
      SUBROUTINE WICFML(WG1,WG2,FMASS,RHOG1,CHORD,SIGUMA,BETA1,BETA2,      WICFML     7
     $CDF,OMEGAF)                                                          WICFML     8
      PAI=3.1415926                                                        WICFML     9
      VISCOG=0.128E-4                                                      WICFML    10
      VISCOL=6.500E-4                                                      WICFML    11
      C=CHORD/12.0                                                         WICFML    12
      WCAVE=0.5*(WG1+WG2)                                                  WICFML    13
      VFILM=0.5*WCAVE*VISCOG/VISCOL                                        WICFML    14
      CDF=FMASS*VFILM/(0.5*RHOG1*WG1*WC1*C)                                WICFML    15
      BETA1R=BETA1*PAI/180.0                                               WICFML    16
      BETA2R=BETA2*PAI/180.0                                               WICFML    17
      BETA3R=0.5*(BETA1R+BETA2R)                                           WICFML    18
      CS1=COS(BETA1R)**2                                                   WICFML    19
      CS2=COS(BETA3R)**3                                                   WICFML    20
      OMEGAF=CDF*SIGUMA*CS1/CS2                                            WICFML    21
      RETURN                                                               WICFML    22
      END                                                                  WICFML    23
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICRSL     1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICRSL     2
C                                                                       C  WICRSL     3
C SUBROUTINE WICRSL                                                     C  WICRSL     4
C                                                                       C  WICRSL     5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICRSL     6
      SUBROUTINE WICRSL(SIGUMA,BETA1,BETA2,CHORD,DL,CDR,OMEGAR)            WICRSL     7
      PAI=3.1415926                                                        WICRSL     8
      IF(DL.LT.1.0E-6) CDR=0.0                                             WICRSL     9
      IF(DL.LT.1.0E-6) OMEGAR=0.0                                          WICRSL    10
      IF(DL.LT.1.0E-6) GO TO 10                                            WICRSL    11
      BETA1R=BETA1*PAI/180.0                                               WICRSL    12
      BETA2R=BETA2*PAI/180.0                                               WICRSL    13
      BETA3R=0.5*(BETA1R+BETA2R)                                           WICRSL    14
      CS1=COS(BETA1R)**2                                                   WICRSL    15
      CS2=COS(BETA3R)**3                                                   WICRSL    16
      C=CHORD*2.54*0.01*1.0E6                                              WICRSL    17
      A=C/DL                                                               WICRSL    18
      IF(A.LT.1000  ) A=1000                                               WICRSL    19
      CDR=1.89+1.62*ALOG10(A)                                              WICRSL    20
      CDR=1.0/CDR**2.5                                                     WICRSL    21
      OMEGAR=CDR*SIGUMA*CS1/CS2                                            WICRSL    22
   10 RETURN                                                               WICRSL    23
      END                                                                  WICRSL    24
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICUT      1
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICUT      2
C                                                                       C  WICUT      3
C SUBROUTINE WICUT                                                      C  WICUT      4
C                                                                       C  WICUT      5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICUT      6
      SUBROUTINE WICUT(ISTAGE,ASPEED,ALFA1,VZ,V1,                          WICUT      7
     1VS1 , WS1 , BETA1, W1 , BETA2 , WS2 , VS2 , ALFA2 , W2 , V2 ,        WICUT      8
     1ALFA3 ,V3,AK1,AK3)                                                   WICUT      9
      COMMON TD(7),IUNIT                                                   WICUT     10
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                   WICUT     11
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                      WICUT     12
      COMMON FREE,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)      WICUT     13
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)     WICUT     14
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                             WICUT     15
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                      WICUT     16
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                      WICUT     17
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)     WICUT     18
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)     WICUT     19
      COMMON UTIPC(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI    WICUT     20
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IFRINT    WICUT     21
      COMMON ICENT,IICENT,FMA1(6),FMA2(6),IDESIN,FAID                      WICUT     22
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                    WICUT     23
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)          WICUT     24
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                WICUT     25
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)     WICUT     26
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      PAI = 3.1415927                                                    WICUT
      ALFA1R = ALFA1 * PAI / 180.0                                       WICUT
      V1 = VZ / COS ( ALFA1R )                                           WICUT
      VS1 = VZ * TAN ( ALFA1R )                                          WICUT
      WS1 = U(ISTAGE)- VS1                                               WICUT
      T = WS1 / VZ                                                       WICUT
      BETA1R = ATAN ( T)                                                 WICUT
      BETA1 = BETA1R * 180.0 / PAI                                       WICUT
      TT = VZ **2 + WS1 **2                                              WICUT
      W1 = SQRT ( TT )                                                   WICUT
      AMACH1 = W1 / ASPEED                                               WICUT
      CALL WICBOA (OMEGR(ISTAGE), SIGUMR ( ISTAGE ) , BET1SR ( ISTAGE    WICUT
     1),BET2SR(ISTAGE),                                                  WICUT
     1  AINCSR ( ISTAGE ) , ADEVSR ( ISTAGE ) ,                          WICUT
     1AMACH1 , BETA1 , DEOS,DEQN,SITACS,SITACN,BET2N ,FMR1(ISTAGE),      WICUT
     1AK1,AK3,VZ,VZ,U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))               WICUT
      BETA2 = BET2N                                                      WICUT
      BETA2R = BETA2 * PAI / 180.0                                       WICUT
      WS2 = VZ * TAN ( BETA2R )                                          WICUT
      VS2 = U(ISTAGE) - WS2                                              WICUT
      TTT=VS2/VZ                                                         WICUT
      ALFA2R = ATAN ( TTT )                                              WICUT
      ALFA2 = ALFA2R * 180.0 / PAI                                       WICUT
      TTTT = VZ ** 2 + WS2 ** 2                                          WICUT
      W2 = SQRT ( TTTT )                                                 WICUT
      TTTTT = VZ ** 2 + VS2 ** 2                                         WICUT
      V2 = SQRT ( TTTTT )                                                WICUT
      AMACH2 = V2 / ASPEED                                               WICUT
      CALL WICBOA (OMEGS(ISTAGE), SIGUMS(ISTAGE)  , BET1SS(ISTAGE) ,     WICUT
     1BET2SS ( ISTAGE ) , AINCSS ( ISTAGE ) , ADEVSS ( ISTAGE ),         WICUT
     1AMACH2 , ALFA2 , DEOS,DEQN,SITACS,SITACN,BET2N,FMA2(ISTAGE),       WICUT
     1AK1,AK3,VZ,VZ,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))                   WICUT
      ALFA3 = BET2N                                                      WICUT
      ALFA3R=ALFA3*PAI/180.0                                             WICUT
      V3=VZ/COS(ALFA3R)                                                  WICUT
      RETURN                                                             WICUT
      END                                                                WICUT
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSPD
C                                                                     C  WICSPD
C SUBROUTINE WICSPD                                                   C  WICSPD
C                                                                     C  WICSPD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSPD
      SUBROUTINE WICSPD(AMASS,ISTAGE)                                    WICSPD
      REAL M,MIN,M1,M2,M1REL,M2REL                                       WICSPD
      COMMON TD(7),IUNIT                                                 WICSPD
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                 WICSPD
      COMMON JPERFM,RHUG(3),RERUP,RERLOW,RESUP,RESLOW                    WICSPD
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)    WICSPD
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)   WICSPD
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                           WICSPD
      COMMON RRHUB(6),RC(6),RBLADE(6),STAGER(6)                          WICSPD
      COMMON SRHUB(7),SC(7),SBLADE(7),STAGES(7)                          WICSPD
      COMMON SIGUMR(6),BET1SR(6),BET2SR(6),AINCSR(6),ADEVSR(6)           WICSPD
      COMMON SIGUMS(7),BET1SS(7),BET2SS(7),AINCSS(7),ADEVSS(7)           WICSPD
      COMMON UTIPC(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI  WICSPD
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  WICSPD
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    WICSPD
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  WICSPD
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        WICSPD
      COMMON DR(6),DS(6),DEOR(6),DEQS(6),BLOCK(6),BLOCKS(7)              WICSPD
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   WICSPD
      AJ=778.26                                                          WICSPD
      PAI=3.1415926                                                      WICSPD
      GC=32.174                                                          WICSPD
      TREF=518.70                                                        WICSPD
      PREF=14.7*144.0                                                    WICSPD
      AAAR1T=PAI*(RRTIP(1)**2-RRHUB(1)**2)/144.0*BLOCK(1)                WICSPD
      CMASS=AMASS*SQRT(TG(1)/TREF)/(P(1)/PREF)*AAAR1T/SAREA(1)           WICSPD
C IGV INLET                                                              WICSPD
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```
      ISTAGE=NS1
      CALL WICPRP(1.0,0.0,0.0,0.0,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      CALL WICMAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,0.0,0.0,RMIX,CPMIX,ARE
     $AS(NS1))
      VZIN=VZ
      AIN=C
      MIN=M
      TOIN=TG(1)
      POIN=P(1)
      PSIN=P(1)/(1.0+G2*M**2)**G1
      TSIN=TG(1)/(1.0+G2*M**2)
      RHOGIN=PSIN/RMIX/TSIN
      FAIIN=VZIN/UTIPG(1)
      FAID=FAIIN
      GAMAIN=GAMMA
      TOIN=TG(1)
      POIN=P(1)
C IGV INLET PRINTOUT
      IF(IUNIT.NE.2) GO TO 861
      TOIN=TOIN*CFT
      POIN=POIN*CFP
      TSIN=TSIN*CFT
      PSIN=PSIN*CFP
      RHOGIN=RHOGIN*CFD
      AIN=AIN*CFV
      VZIN=VZIN*CFV
      AREAS(NS1)=AREAS(NS1)*CFA
  861 CONTINUE
      WRITE(6,1000)
 1000 FORMAT(1H1,≠***************** DESIGN POINT INFORMATION ************
     $****≠)
      WRITE(6,1010)
 1010 FORMAT(1H0,1X,≠****** COMPRESSOR INLET ******≠)
      WRITE(6,1020) TOIN,POIN,TSIN,PSIN,RHOGIN
 1020 FORMAT(1H0,1X,≠TOTAL TEMPERATURE AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠TOTAL PRESSURE AT COMPRESSOR INLET=≠,F10.2,/,
     $2X,≠STATIC TEMPERATURE AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠STATIC PRESSURE AT COMPRESSOR INLET=≠,F10.2,/,
     $2X,≠STATIC DENSITY AT COMPRESSOR INLET=≠,F10.5)
      WRITE(6,1030) AIN,VZIN,MIN,AREAS(NS1),FAIIN
 1030 FORMAT(1H0,1X,≠ACOUSTIC SPEED AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠AXIAL 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.NE.2) GO TO 862
      TOIN=TOIN/CFT
      POIN=POIN/CFP
      TSIN=TSIN/CFT
      PSIN=PSIN/CFP
      RHOGIN=RHOGIN/CFD
      AIN=AIN/CFV
      VZIN=VZIN/CFV
      AREAS(NS1)=AREAS(NS1)/CFA
  862 CONTINUE
C ROTOR INLET
      ISTAGE=1
  100 I=ISTAGE-1
      IF(I.EQ.0) I=NS1
      ALFA1=BET2SS(I)
      ADEVSS(I)=ALFA1-BET2MS(I)
      CALL WICMAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,0.0,ALFA1,RMIX,
     $CPMIX,AREA(ISTAGE))
      CPMIX1=CPMIX
      GAMMA1=GAMMA
      VZ1=VZ
      A1=C
      M1=M
      PS1=P(1)/(1.0+G2*M1**2)**G1
      TS1=TG(1)/(1.0+G2*M1**2)
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      RHOGS1=PS1/RMIX/TS1                                               WICSPD     104
      FAIRIN=VZ1/UTIPG(ISTAGE)                                          WICSPD     105
      ALFA1R=ALFA1*PAI/180.0                                            WICSPD     106
      V1=VZ1/COS(ALFA1R)                                                WICSPD     107
      VS1=VZ1*WICTAN(ALFA1R)                                            WICSPD     108
      WS1=U(ISTAGE)-VS1                                                 WICSPD     109
      WV=WS1/VZ1                                                        WICSPD     110
      BETA1R=ATAN(WV)                                                   WICSPD     111
      BETA1=BETA1R*180.0/PAI                                            WICSPD     112
      BET1SR(ISTAGE)=BETA1                                              WICSPD     113
      AINCSR(ISTAGE)=BETA1-BET1MR(ISTAGE)                               WICSPD     114
      W1=VZ1/COS(BETA1R)                                                WICSPD     115
      M1REL=W1/A1                                                       WICSPD     116
      TREL1=(1.0+G2*M1REL**2)*TS1                                       WICSPD     117
      PREL1=(1.0+G2*M1REL**2)**G1*PS1                                   WICSPD     118
      IF(ISTAGE.GE.2) DS(ISTAGE-1)=1.0-V1/V2+ABS(VS2-VS1)/2.0/          WICSPD     119
     $SIGUMS(ISTAGE-1)/V2                                               WICSPD     120
      IF(ISTAGE.GE.2) DEQS(ISTAGE-1)=COS(ALFA1R)/COS(ALFA2R)*           WICSPD     121
     $(1.12+0.61*COS(ALFA2R)**2/SIGUMS(ISTAGE-1)*(WICTAN(ALFA2R)-       WICSPD     122
     $WICTAN(ALFA1R)))                                                  WICSPD     123
      IF(ISTAGE.GT.NS) GO TO 101                                        WICSPD     124
C ROTOR OUTLET                                                          WICSPD     125
      P(2)=PR12D(ISTAGE)*P(1)                                           WICSPD     126
      TR12=(PR12D(ISTAGE)**(1.0/G1)-1.0)/ETARD(ISTAGE)+1.0              WICSPD     127
      TG(2)=TR12*TG(1)                                                  WICSPD     128
      CALL WICPRP(1.0,0.0,0.0,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)          WICSPD     129
      GAMMA2=GAMMA                                                      WICSPD     130
      CPMIX2=CPMIX                                                      WICSPD     131
      GAMMAV=(GAMMA1+GAMMA2)/2.0                                        WICSPD     132
      CPMIXV=(CPMIX1+CPMIX2)/2.0                                        WICSPD     133
      G1AV=GAMMAV/(GAMMAV-1.0)                                          WICSPD     134
      G2AV=(GAMMAV-1.0)/2.0                                             WICSPD     135
      PR13I=(TG(2)/TG(1))**G1AV                                         WICSPD     136
      DELT=TG(2)-TG(1)                                                  WICSPD     137
      VS2=(U(ISTAGE)*VS1+DELT*CPMIXV*GC*AJ)/UU2(ISTAGE)                 WICSPD     138
      JJ=1                                                              WICSPD     139
      VZ2AS=VZ1                                                         WICSPD     140
  200 VS2VZ2=VS2/VZ2AS                                                  WICSPD     141
      ALFA2R=ATAN(VS2VZ2)                                               WICSPD     142
      ALFA2=ALFA2R*180.0/PAI                                            WICSPD     143
      BET1SS(ISTAGE)=ALFA2                                              WICSPD     144
      AINCSS(ISTAGE)=ALFA2-BET1MS(ISTAGE)                               WICSPD     145
      WS2=UU2(ISTAGE)-VS2                                               WICSPD     146
      WS2VZ2=WS2/VZ2AS                                                  WICSPD     147
      BETA2R=ATAN(WS2VZ2)                                               WICSPD     148
      BETA2=BETA2R*180.0/PAI                                            WICSPD     149
      BET2SR(ISTAGE)=BETA2                                              WICSPD     150
      ADEVSR(ISTAGE)=BETA2-BET2MR(ISTAGE)                               WICSPD     151
      V2=VZ2AS/COS(ALFA2R)                                              WICSPD     152
      W2=VZ2AS/COS(BETA2R)                                              WICSPD     153
      TS2=TG(2)-V2**2/(2.0*CPMIX2*GC*AJ)                                WICSPD     154
      A2=SQRT(GAMMA2*RMIX*TS2*GC)                                       WICSPD     155
      M2=V2/A2                                                          WICSPD     156
      PS2=P(2)/(1.0+G2*M2**2)**G1                                       WICSPD     157
      RHOGS2=PS2/RMIX/TS2                                               WICSPD     158
      M2REL=W2/A2                                                       WICSPD     159
      TREL2=(1.0+G2*M2REL**2)*TS2                                       WICSPD     160
      PREL2=(1.0+M2REL**2)**G1*PS2                                      WICSPD     161
      VZ2CL=FMASS/(RHOGS2*AREAS(ISTAGE))                                WICSPD     162
      EPS=1.0E-6                                                        WICSPD     163
      IF(JJ.EQ.2) GO TO 201                                             WICSPD     164
      IF(JJ.GT.2) GO TO 202                                             WICSPD     165
      X1=VZ2AS                                                          WICSPD     166
      Y1=VZ2CL                                                          WICSPD     167
      VZ2AS=VZ2CL                                                       WICSPD     168
      JJ=JJ+1                                                           WICSPD     169
      GO TO 200                                                         WICSPD     170
  201 X2=VZ2AS                                                          WICSPD     171
      Y2=VZ2CL                                                          WICSPD     172
      VZ2AS=WICNEW(X1,Y1,X2,Y2)                                         WICSPD     173
```

```
      JJ=JJ+1
      GO TO 200
  202 IF((ABS(VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZ2AS
      Y2=VZ2CL
      VZ2AS=WICNEW(X1,Y1,X2,Y2)
      JJ=JJ+1
      GO TO 200
  300 VZ2=VZ2CL
      FAIOUT=VZ2/UTIPG(ISTAGE)
      DR(ISTAGE)=1.0-W2/W1+ABS(WS1-WS2)/2.0/SIGUMR(ISTAGE)/W1
      DEQR(ISTAGE)=COS(BETA2R)/COS(BETA1R)*
     $(1.12+0.61*COS(BETA1R)**2/SIGUMR(ISTAGE)*
     $(WICTAN(BETA1R)-WICTAN(BETA2R)))
      PRRELI=(1.0+C2AV*U(ISTAGE)**2/(GAMMAV*RMIX*TREL1*GC)
     $*((UU2(ISTAGE)/U(ISTAGE))**2-1.0))**G1AV
      PLOSSR=PR12D(ISTAGE)/(TG(2)/TG(1))**G1AV*PRRELI
      IF(PRRELI.LT.PLOSSR) PRRELI=1.0
      OMEGR(ISTAGE)=(PRRELI-PLOSSR)/(1.0-PS1/PREL1)
C STATOR OUTLET
      PLOSSS=PR13D(ISTAGE)/PR12D(ISTAGE)
      PR13=(TG(2)/TG(1))**G1AV*PLOSSR*PLOSSS/PRRELI
      OMEGS(ISTAGE)=(1.0-PLOSSS)/(1.0-PS2/P(2))
      ETASG=(PR13**(1.0/G1AV)-1.0)/(TR12-1.0)
      P(3)=PR13*P(1)
      TG(3)=TG(2)
      TD(ISTAGE)=TG(1)
C PRINTOUT OF STAGE PERFORMANCE
      IF(IUNIT.NE.2) GO TO 863
      TG(1)=TG(1)*CFT
      TG(2)=TG(2)*CFT
      P(1)=P(1)*CFP
      P(2)=P(2)*CFP
      TS1=TS1*CFT
      TS2=TS2*CFT
      PS1=PS1*CFP
      PS2=PS2*CFP
      RHOGS1=RHOGS1*CFD
      RHOGS2=RHOGS2*CFD
      VZ1=VZ1*CFV
      VZ2=VZ2*CFV
      V1=V1*CFV
      V2=V2*CFV
      W1=W1*CFV
      W2=W2*CFV
      VS1=VS1*CFV
      VS2=VS2*CFV
      WS1=WS1*CFV
      WS2=WS2*CFV
      U(ISTAGE)=U(ISTAGE)*CFV
      UU2(ISTAGE)=UU2(ISTAGE)*CFV
      TREL1=TREL1*CFT
      PREL1=PREL1*CFP
      TREL2=TREL2*CFT
      PREL2=PREL2*CFP
      AREA(ISTAGE)=AREA(ISTAGE)*CFA
      AREAS(ISTAGE)=AREAS(ISTAGE)*CFA
      RADI1(ISTAGE)=RADI1(ISTAGE)*CFL
      RADI2(ISTAGE)=RADI2(ISTAGE)*CFL
  863 CONTINUE
      WRITE(6,1000)
      WRITE(6,1100) ISTAGE
 1100 FORMAT(1H0,1X,≠*****  STAGE=≠,I2,≠ ******≠)
      WRITE(6,1101)
 1101 FORMAT(1H0,16X,≠TOTAL≠,8X,≠TOTAL≠,7X,≠STATIC≠,7X,≠STATIC≠,7X,
     $≠STATIC≠,/,17X,≠TEMP≠,7X,≠PRESSURE≠,7X,≠TEMP≠,7X,≠PRESSURE≠,6X,
     $≠DENSITY≠)
      WRITE(6,1110) TG(1),P(1),TS1,PS1,RHOGS1
```

```
 1110 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.3,3X))
      WRITE(6,1120) TG(2),P(2),TS2,PS2,RHOGS2
 1120 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.3,3X))
      WRITE(6,1111)
 1111 FORMAT(1H0,16X,≠AXIAL≠,6X,≠ABSOLUTE≠,5X,≠RELATIVE≠,5X,≠TAN COMP≠,
     $5X,≠TAN COMP≠,/,15X,≠VELOCITY≠,5X,≠VELOCITY≠,5X,≠VELOCITY≠,4X,
     $≠OF ABS VEL≠,3X,≠OF REL VEL≠)
      WRITE(6,1130) VZ1,V1,W1,VS1,WS1
 1130 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.5,3X))
      WRITE(6,1140) VZ2,V2,W2,VS2,WS2
 1140 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.5,3X))
      WRITE(6,1141)
 1141 FORMAT(1H0,15X,≠ROTOR≠,7X,≠ABS MACH≠,5X,≠REL MACH≠,5X,≠REL TOTAL≠,
     $4X,≠REL TOTAL≠,/,16X,≠SPEED≠,8X,≠NUMBER≠,7X,≠NUMBER≠,7X,≠TEMP≠,8X,
     $≠PRESSURE≠)
      WRITE(6,1150) U(ISTAGE),M1,M1REL,TREL1,PREL1
 1150 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.3,3X))
      WRITE(6,1160) UU2(ISTAGE),M2,M2REL,TREL2,PREL2
 1160 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.3,3X))
      I=ISTAGE
      IF(ISTAGE.EQ.1) I=8
      WRITE(6,1161)
 1161 FORMAT(1H0,14X,≠ABS FLOW≠,5X,≠REL FLOW≠,4X,≠STREAMTUBE≠,18X,
     $≠FLOW≠,/,16X,≠ANGLE≠,8X,≠ANGLE≠,8X,≠AREA≠,9X,≠RADIUS≠,5X,
     $≠COEFFICIENT≠)
      WRITE(6,1170) BET2SS(I-1),BET1SR(ISTAGE),AREA(ISTAGE),
     $RADI1(ISTAGE),FAIRIN
 1170 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.5,3X))
      WRITE(6,1180) BET1SS(ISTAGE),BET2SR(ISTAGE),AREAS(ISTAGE),
     $RADI2(ISTAGE),FAIOUT
 1180 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.5,3X))
      WRITE(6,1190) PR13,ETASG,PR12D(ISTAGE),ETARD(ISTAGE),TR12
 1190 FORMAT(1H0,1X,≠STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=≠,F10.5,
     $/,2X,≠STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=≠,F10.5,/,2X,
     $≠ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=≠,F10.5,/,2X,
     $≠ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=≠,F10.5,/,2X,
     $≠ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=≠,F10.5)
      IF(IUNIT.NE.2) GO TO 864
      TG(1)=TG(1)/CFT
      TG(2)=TG(2)/CFT
      P(1)=P(1)/CFP
      P(2)=P(2)/CFP
      TS1=TS1/CFT
      TS2=TS2/CFT
      PS1=PS1/CFP
      PS2=PS2/CFP
      RHOGS1=RHOGS1/CFD
      RHOGS2=RHOGS2/CFD
      VZ1=VZ1/CFV
      VZ2=VZ2/CFV
      V1=V1/CFV
      V2=V2/CFV
      W1=W1/CFV
      W2=W2/CFV
      VS1=VS1/CFV
      VS2=VS2/CFV
      WS1=WS1/CFV
      WS2=WS2/CFV
      U(ISTAGE)=U(ISTAGE)/CFV
      UU2(ISTAGE)=UU2(ISTAGE)/CFV
      TREL1=TREL1/CFT
      PREL1=PREL1/CFP
      TREL2=TREL2/CFT
      PREL2=PREL2/CFP
      AREA(ISTAGE)=AREA(ISTAGE)/CFA
      AREAS(ISTAGE)=AREAS(ISTAGE)/CFA
      RADI2(ISTAGE)=RADI2(ISTAGE)/CFL
  864 CONTINUE
C REPEAT
      TG(1)=TG(3)
```

```
      P(1)=P(3)
      IF(ISTAGE.EQ.NS) ADEVSS(NS)=BET2SS(NS)-BET2MS(NS)
      ISTAGE=ISTAGE+1
      IF(ISTAGE.EQ.NS1) GO TO 101
      GO TO 100
C OVERALL PERFORMANCE AT DESIGN POINT
  101 OVALPR=P(3)/POIN
      OVALTR=TC(3)/TOIN
      GAMMAV=(GAMAIN+GAMMA)/2.0
      G1AV=GAMMAV/(GAMMAV-1.0)
      OVALEF=(OVALPR**(1.0/G1AV)-1.0)/(OVALTR-1.0)
      OVALDT=TC(3)-TOIN
C PRINTOUT OF OVERALL PERFORMANCE AT DESIGN POINT
      IF(IUNIT.NE.2) GO TO 865
      TOIN=TOIN*CFT
      POIN=POIN*CFP
      CMASS=CMASS*CFM
      OVALDT=OVALDT*CFT
      DO 422 I=1,NS
      TD(I)=TD(I)*CFT
  422 CONTINUE
  865 CONTINUE
      WRITE(6,1000)
      WRITE(6,421)
  421 FORMAT(1H0,≠*********** OVERALL PERFORMANCE AT DESIGN POINT ****
     $*******≠)
      WRITE(6,425) TOIN
  425 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL TEMPERATURE=≠,F8.2)
      WRITE(6,426) POIN
  426 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      WRITE(6,427) CMASS
  427 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE=≠,F6.3)
      WRITE(6,429) OVALPR
  429 FORMAT(1H0,1X,≠OVERALL TOTAL PRESSURE RATIO=≠,F6.4)
      WRITE(6,430) OVALTR
  430 FORMAT(1H0,1X,≠OVERALL TOTAL TEMPERATURE RATIO=≠,F6.4)
      WRITE(6,431) OVALEF
  431 FORMAT(1H0,1X,≠OVERALL ADIABATIC EFFICIENCY=≠,F6.4)
      WRITE(6,432) OVALDT
  432 FORMAT(1H0,1X,≠OVERALL TEMPERATURE RISE=≠,F8.3)
      WRITE(6,1621)
 1621 FORMAT(1H0,14X,≠1≠,5X,≠2≠,5X,≠3≠,5X,≠4≠,5X,≠5≠,5X,≠6≠,4X,≠IGV≠)
      WRITE(6,1710) (BET1SR(I),I=1,NS)
 1710 FORMAT(1H ,1X,≠BET1SR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1720) (BET2SR(I),I=1,NS)
 1720 FORMAT(1H ,1X,≠BET2SR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1730) (AINCSR(I),I=1,NS)
 1730 FORMAT(1H ,1X,≠AINCSR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1740) (ADEVSR(I),I=1,NS)
 1740 FORMAT(1H ,1X,≠ADEVSR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1760) (BET1SS(I),I=1,NS)
 1760 FORMAT(1H ,1X,≠BET1SS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1770) (BET2SS(I),I=1,NS1)
 1770 FORMAT(1H ,1X,≠BET2SS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1780) (AINCSS(I),I=1,NS)
 1780 FORMAT(1H ,1X,≠AINCSS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1790) (ADEVSS(I),I=1,NS)
 1790 FORMAT(1H ,1X,≠ADEVSS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1791) (TD(I),I=1,NS)
 1791 FORMAT(1H ,1X,≠TD(I)≠,6X,6(F5.1,1X))
      WRITE(6,1793) (OMEGS(I),I=1,NS)
 1793 FORMAT(1H ,1X,≠OMEGS(I)≠,3X,6(F5.3,1X))
      WRITE(6,1794) (OMEGR(I),I=1,NS)
 1794 FORMAT(1H ,1X,≠OMEGR(I)≠,3X,6(F5.3,1X))
      IF(IUNIT.NE.2) GO TO 866
      TOIN=TOIN/CFT
      POIN=POIN/CFP
      CMASS=CMASS/CFM
      OVALDT=OVALDT/CFT
      DO 423 I=1,NS
```

```
      TD(I)=TD(I)*CFT                                                   WICSPD     384
  423 CONTINUE                                                          WICSPD     385
  868 CONTINUE                                                          WICSPD     386
      RETURN                                                            WICSPD     387
      END                                                               WICSPD     388
```

APPENDIX 5

PRINTOUT OF TEST CASE

A.5.1 Test Case Part I

```
      *************************** INPUT DATA **************************************

NS(NUMBER OF STAGE)= 6
UNIT=ENGLISH UNIT
IPERFM=2
PERFORMANCE AT MEAN

                 1     2     3     4     5     6    IGV
RRHUB(I)      .770 1.035 1.232 1.378 1.489 1.572
RC(I)         .605  .554  .534  .510  .483  .456
RBLADE(I)    16.00 20.00 20.00 25.00 28.00 32.00
STAGER(I)    34.25 29.96 27.37 28.30 29.17 29.75
STAGES(I)    23.67 25.62 26.94 28.41 29.82 38.99
SRHUB(I)      .923 1.145 1.311 1.445 1.538 1.580  .774
SC(I)         .442  .412  .412  .412  .412  .412
SBLADE(I)    14.00 26.00 28.00 32.00 36.00 30.00
SIGUMR(I)    1.052 1.120 1.037 1.182 1.211 1.283
SIGUMS(I)     .640 1.061 1.093 1.199 1.311 1.087
GAPR(I)       .125  .125  .125  .125  .125  .125
GAPS(I)       .125  .125  .125  .125  .125  .125
RRTIP(I)      2.16  2.16  2.16  2.16  2.16  2.16
SRTIP(I)      2.16  2.16  2.16  2.16  2.16  2.16  2.16
RT(I)        2.149 2.151 2.148 2.149 2.149 2.147
RM(I)        1.426 1.575 1.642 1.722 1.789 1.836
RH(I)         .781 1.056 1.252 1.411 1.533 1.621
ST(I)        2.147 2.138 2.127 2.123 2.118 2.100
SM(I)        1.502 1.573 1.637 1.712 1.766 1.784
SH(I)         .934 1.152 1.318 1.453 1.548 1.592
BLOCK(I)      .983  .976  .967  .949  .923  .902
BLOCKS(I)     .978  .966  .945  .928  .908  .863
BET1MR(I)    42.72 42.74 41.62 42.85 44.00 45.07
BET2MR(I)    25.79 17.17 13.12 13.76 14.33 14.43
BET1MS(I)    35.15 40.11 43.35 45.00 46.31 48.71     0
BET2MS(I)    12.19 11.13 10.51 11.81 13.32 29.28 21.99
PR12D(I)     1.154 1.165 1.221 1.237 1.230 1.215
PR13D(I)     1.152 1.159 1.213 1.228 1.221 1.208
ETARD(I)      .966  .966  .968  .965  .962  .954
```

```
****************************** INPUT DATA ******************************
FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=    0
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=    0
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=   2116.80

DIN(INITIIL 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)=      .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

CORRECTED ROTOR SPEED= 51120.0 RPM(  100.0PER 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= 496.28109
 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 *****

               TOTAL        TOTAL       STATIC       STATIC       STATIC
               TEMP       PRESSURE       TEMP       PRESSURE      DENSITY

ROTOR INLET    518.700     2116.800      492.637     1767.579         .067
ROTOR OUTLET   541.148     2442.787      508.269     1961.576         .072

               AXIAL      ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
             VELOCITY     VELOCITY     VELOCITY    OF ABS VEL   OF REL VEL

ROTOR INLET  538.76531    559.39838    725.32398    150.52734    485.62003
ROTOR OUTLET 525.97105    628.55682    618.75550    344.14838    325.90306

              ROTOR       ABS MACH     REL MACH     REL TOTAL    REL TOTAL
              SPEED        NUMBER       NUMBER       TEMP        PRESSURE

ROTOR INLET    636.147         .514         .667      536.454     2381.210
ROTOR OUTLET   670.051         .569         .560      540.141     5091.790

             ABS FLOW     REL FLOW    STREAMTUBE                  FLOW
              ANGLE        ANGLE        AREA         RADIUS     COEFFICIENT

ROTOR INLET   15.61000     42.03015       .01036      1.42600       .55886
ROTOR OUTLET  33.19714     31.78325       .00987      1.50200       .54559

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15200
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .95383
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15400
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.04329
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**************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 2 *****

               TOTAL        TOTAL       STATIC       STATIC       STATIC
               TEMP        PRESSURE      TEMP       PRESSURE      DENSITY

 ROTOR INLET   541.148     2438.554     511.984     2008.852         .074
 ROTOR OUTLET  566.141     2840.915     522.316     2142.394         .077

               AXIAL      ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
             VELOCITY     VELOCITY     VELOCITY    OF ABS VEL   OF REL VEL

 ROTOR INLET  549.21299    591.88727    730.68951    220.67086    481.94632
 ROTOR OUTLET 581.16447    725.94045    639.44211    435.01464    266.71034

              ROTOR       ABS MACH     REL MACH     REL TOTAL    REL TOTAL
              SPEED        NUMBER       NUMBER       TEMP        PRESSURE

 ROTOR INLET   702.617         .534         .659     556.431     2688.136
 ROTOR OUTLET  701.725         .648         .571     556.331     5751.007

             ABS FLOW     REL FLOW    STREAMTUBE                  FLOW
              ANGLE        ANGLE        AREA        RADIUS     COEFFICIENT

 ROTOR INLET  21.89000     41.26765       .00930     1.57500       .56970
 ROTOR OUTLET 36.81569     24.65154       .00841     1.57300       .60285

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15900
 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
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**************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 3 *****

                 TOTAL       TOTAL       STATIC      STATIC      STATIC
                 TEMP       PRESSURE      TEMP      PRESSURE     DENSITY

 ROTOR INLET     566.141     2826.284     535.362    2323.868        .081
 ROTOR OUTLET    600.462     3450.892     549.786    2533.049        .086

                 AXIAL      ABSOLUTE    RELATIVE    TAN COMP    TAN COMP
                VELOCITY    VELOCITY    VELOCITY   OF ABS VEL  OF REL VEL

 ROTOR INLET    574.81563   608.26663   784.29006   198.93541   533.57089
 ROTOR OUTLET   614.43880   781.11343   662.59507   482.28950   247.98627

                 ROTOR      ABS MACH    REL MACH    REL TOTAL   REL TOTAL
                 SPEED       NUMBER      NUMBER      TEMP       PRESSURE

 ROTOR INLET      732.506        .536        .692     586.533    3199.070
 ROTOR OUTLET     730.276        .680        .577     586.263    6929.751

                ABS FLOW    REL FLOW   STREAMTUBE                FLOW
                 ANGLE       ANGLE       AREA        RADIUS    COEFFICIENT

 ROTOR INLET     19.09000    42.86892      .00803     1.64200      .59626
 ROTOR OUTLET    38.12932    21.97990      .00708     1.63700      .63736

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

 ***** STAGE= 4 *****
                    TOTAL        TOTAL        STATIC       STATIC       STATIC
                    TEMP         PRESSURE     TEMP         PRESSURE     DENSITY

 ROTOR INLET        600.462      3428.282     569.069      2839.989       .094
 ROTOR OUTLET       639.381      4240.785     585.841      3118.959       .100

                    AXIAL        ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
                  VELOCITY       VELOCITY     VELOCITY    OF ABS VEL   OF REL VEL

 ROTOR INLET  580.04590    614.69778    809.54747    203.47020    564.72459
 ROTOR OUTLET 619.63965    803.61317    668.93304    511.70446    252.02926

                   ROTOR        ABS MACH     REL MACH     REL TOTAL    REL TOTAL
                   SPEED        NUMBER       NUMBER       TEMP         PRESSURE

 ROTOR INLET        768.195         .526         .692      623.519     3912.431
 ROTOR OUTLET       763.734         .678         .564      622.951     8231.914

                  ABS FLOW     REL FLOW     STREAMTUBE                  FLOW
                   ANGLE        ANGLE        AREA         RADIUS     COEFFICIENT

 ROTOR INLET    19.33000     44.23321       .00692      1.72200       .60169
 ROTOR OUTLET   39.55025     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=   1.06481
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*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 5 *****

                 TOTAL       TOTAL       STATIC      STATIC       STATIC
                 TEMP       PRESSURE      TEMP      PRESSURE      DENSITY

ROTOR INLET     639.381     4209.930     606.962     3506.755        .108
ROTOR OUTLET    679.732     5178.214     625.197     3857.244        .116

                 AXIAL      ABSOLUTE    RELATIVE     TAN COMP     TAN COMP
                VELOCITY    VELOCITY    VELOCITY    OF ABS VEL   OF REL VEL

ROTOR INLET   586.84149    625.22167   826.78513    215.68308    582.40082
ROTOR OUTLET  617.08868    811.98444   669.65381    527.75042    260.07304

                 ROTOR      ABS MACH    REL MACH     REL TOTAL    REL TOTAL
                 SPEED       NUMBER      NUMBER       TEMP        PRESSURE

ROTOR INLET     798.084         .518        .685      663.653     4798.526
ROTOR OUTLET    787.823         .663        .547      662.302     9691.778

                ABS FLOW    REL FLOW    STREAMTUBE                  FLOW
                 ANGLE       ANGLE        AREA        RADIUS     COEFFICIENT

ROTOR INLET    20.18000     44.78240      .00591      1.78300       .60873
ROTOR OUTLET   40.53794     22.85308      .00526      1.76600       .64011

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .92580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.06311
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 6 *****

                  TOTAL       TOTAL       STATIC      STATIC      STATIC
                  TEMP       PRESSURE      TEMP      PRESSURE     DENSITY

 ROTOR INLET     679.732     5140.325    646.933    4318.954       .125
 ROTOR OUTLET    720.259     6245.495    665.989    4736.291       .133

                  AXIAL     ABSOLUTE    RELATIVE    TAN COMP    TAN COMP
                VELOCITY    VELOCITY    VELOCITY   OF ABS VEL  OF REL VEL

 ROTOR INLET  587.19574   629.60666   833.74045   227.16890   591.88199
 ROTOR OUTLET 603.39773   811.09676   654.61329   542.02320   253.83017

                 ROTOR      ABS MACH    REL MACH   REL TOTAL   REL TOTAL
                 SPEED       NUMBER      NUMBER      TEMP      PRESSURE

 ROTOR INLET     819.051        .506        .669     704.449    5829.034
 ROTOR OUTLET    795.853        .642        .518     701.350   10970.182

                ABS FLOW    REL FLOW   STREAMTUBE                 FLOW
                 ANGLE       ANGLE       AREA       RADIUS     COEFFICIENT

 ROTOR INLET    21.15000    45.22772     .00511     1.83600      .60910
 ROTOR OUTLET   41.93288    22.81494     .00467     1.78400      .62591

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=    1.20800
 STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=     .92365
 ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=    1.21500
 ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=     .93400
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=    1.05962
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**************** 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=1.3886

 OVERALL ADIABATIC EFFICIENCY= .9223

 OVERALL TEMPERATURE RISE= 201.559

                 1      2      3      4      5      6     IGV
 BET1SR(I)   42.03  41.27  42.87  44.23  44.78  45.23
 BET2SR(I)   31.78  24.65  21.98  22.13  22.85  22.81
 AINCSR(I)    -.69  -1.47   1.25   1.38    .78    .16
 ADEVSR(I)    5.99   7.48   8.86   8.37   8.52   8.38
 BET1SS(I)   33.20  36.82  38.13  39.55  40.54  41.93
 BET2SS(I)   21.89  19.09  19.33  20.18  21.15  34.86  15.61
 AINCSS(I)   -1.95  -3.29  -5.23  -5.45  -5.77  -6.78
 ADEVSS(I)    9.70   7.96   8.82   8.37   7.83   5.58
 TD(I)       518.7  541.1  566.1  600.5  639.4  679.7
 OMEGS(I)     .009   .021   .025   .028   .029   .024
 OMEGR(I)     .020   .021   .024   .028   .030   .036
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********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 1 )  *******************

    STAGE TOTAL PRESSURE RATIO=      1.18052
    STAGE TOTAL TEMPERATURE RATIO=     1.05118
    STAGE ADIABATIC EFFICIENCY=      .94929

    STAGE FLOW COEFFICIENT= .500
    AXIAL VELOCITY= 482.12
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.18052
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.19072
    LOSS FACTOR IN ROTOR=     1.01779
    LOSS FACTOR IN STATOR=      .99767

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2116.80        2504.78         2498.93
STATIC PRESSURE            1833.16        2064.66         2151.05
TOTAL TEMPERATURE(GAS)     518.7000       545.2462        545.2462
STATIC TEMPERATURE(GAS)   497.7954       515.9463        522.3760
STATIC DENSITY(GAS)          .0690          .0750           .0772
STATIC DENSITY(MIXTURE)      .0690          .0750           .0772

AXIAL VELOCITY            482.1211       465.8891        480.6390
ABSOLUTE VELOCITY         500.9898       593.2170        524.1017
RELATIVE VELOCITY         694.5426       555.6590
BLADE SPEED               636.1474       670.0514        702.6172
TANG. COMP. OF ABS. VEL.  136.1987       367.2243
TANG. COMP. OF REL. VEL.  499.9486       302.8271
ACOUSTIC SPEED           1093.9243      1120.9182       1120.6073
ABSOLUTE MACH NUMBER         .4580          .5327           .4677
RELATIVE MACH NUMBER         .6349          .4989

FLOW COEFFICIENT             .5001          .4833           .4986
FLOW AREA                    .0104          .0099           .0093

ABSOLUTE FLOW ANGLE        15.7749        38.2460         23.5019
RELATIVE FLOW ANGLE       46.0400        33.0238
INCIDENCE                   3.3200         3.0960
DEVIATION                                 7.2338         11.3119
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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  1 )  ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.18052
    STAGE TOTAL TEMPERATURE RATIO=     1.05118
    STAGE ADIABATIC EFFICIENCY=      .94929

           **STAGE INLET**   **STAGE OUTLET**    **STAGE OUTLET**
                               (BEFORE INTER-      (AFTER INTER-
                                STAGE ADJUST-       STAGE ADJUST-
                                MENT)               MENT)
    XV=         .00000              .00000              .00000
    XW=              0                   0                   0
    XWW=              0                   0                   0
    XWT=              0                   0                   0
    XAIR=        1.00000             1.00000             1.00000
    XMETAN=              0                   0                   0
    XGAS=       1.00000             1.00000             1.00000
    WMASS=              0                   0                   0
    WWMASS=              0                   0                   0
    WTMASS=              0                   0                   0
    AMASS=         .34491              .34491              .34491
    CHMASS=              0                   0                   0
    VMASS=         .00000              .00000              .00000
    GMASS=         .34491              .34491              .34491
    TMASS=         .34491              .34491              .34491
    WS=         .00000              .00000              .00000
    RHOA=         .07649              .07500              .07718
    RHOM=         .06904              .07500              .07718
    RHOG=         .06902              .07500              .07718
    TG=      518.70000           545.24617           545.24617
    TW=      513.70000           513.70000           513.70000
    TWW=      513.70000                   0           513.70000
    P=     2116.80000          2504.77696          2498.92898
    TB=      671.40656                   0           679.62039
    TDEW=        271.99506           273.35228           273.35228
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********************  INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 2 )  *******************

    STAGE TOTAL PRESSURE RATIO=      1.18150
    STAGE TOTAL TEMPERATURE RATIO=      1.05273
    STAGE ADIABATIC EFFICIENCY=       .92538

    STAGE FLOW COEFFICIENT= .499
    AXIAL VELOCITY= 480.65
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.18150
    STAGE TOTAL PRESSURE RATIO(IDEAL)=      1.19700
    LOSS FACTOR IN ROTOR=       .99305
    LOSS FACTOR IN STATOR=       .99331

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE              2498.93        2972.36        2952.48
STATIC PRESSURE             2151.02        2334.66        2553.83
TOTAL TEMPERATURE(GAS)      545.2462       573.9966       573.9966
STATIC TEMPERATURE(GAS)   522.3793       535.7319       550.6973
STATIC DENSITY(GAS)          .0772          .0817          .0869
STATIC DENSITY(MIXTURE)      .0772          .0817          .0869

AXIAL VELOCITY            480.6495       502.3934       494.1596
ABSOLUTE VELOCITY         524.1276       678.1185       529.1491
RELATIVE VELOCITY         688.9633       559.5039
BLADE SPEED               702.6172       701.7250       732.5063
TANG. COMP. OF ABS. VEL.  209.0116       455.4619
TANG. COMP. OF REL. VEL.  493.6056       246.2631
ACOUSTIC SPEED           1120.4811      1150.2843      1150.4507
ABSOLUTE MACH NUMBER         .4678          .5976          .4599
RELATIVE MACH NUMBER         .6149          .4931

FLOW COEFFICIENT             .4986          .5211          .5126
FLOW AREA                    .0093          .0084          .0080

ABSOLUTE FLOW ANGLE        23.5019        42.1950        20.9539
RELATIVE FLOW ANGLE        45.7619        26.1132
INCIDENCE                    3.0219         2.0850
DEVIATION                                  8.9432         9.8239
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```
********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  2 )  ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.18150
    STAGE TOTAL TEMPERATURE RATIO=     1.05273
    STAGE ADIABATIC EFFICIENCY=      .92538

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00000              .00000              .00000
    XW=              0                   0                   0
    XWW=              0                   0                   0
    XWT=              0                   0                   0
    XAIR=        1.00000             1.00000             1.00000
    XMETAN=              0                   0                   0
    XGAS        1.00000             1.00000             1.00000
    WMASS=              0                   0                   0
    WWMASS=              0                   0                   0
    WTMASS=              0                   0                   0
    AMASS=         .34491              .34491              .34491
    CHMASS=              0                   0                   0
    VMASS=         .00000              .00000              .00000
    GMASS=         .34491              .34491              .34491
    TMASS=         .34491              .34491              .34491
    WS=         .00000              .00000              .00000
    RHOA=         .08590              .08168              .08692
    RHOM=         .06904              .08168              .08692
    RHOG=         .07718              .08168              .08692
    TG=      545.24617           573.99661           573.99661
    TW=      513.70000           513.70000           513.70000
    TWW=      513.70000                   0           513.70000
    P=     2498.92898          2972.35955          2952.48188
    TB=      679.62039                   0           688.08016
    TDEW=      273.35228           274.74655           274.74655
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 3 )  ******************

    STAGE TOTAL PRESSURE RATIO=    1.22966
    STAGE TOTAL TEMPERATURE RATIO=    1.06596
    STAGE ADIABATIC EFFICIENCY=      .92118

    STAGE FLOW COEFFICIENT= .513
    AXIAL VELOCITY= 494.17
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.22966
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.25071
    LOSS FACTOR IN ROTOR=      .99061
    LOSS FACTOR IN STATOR=     .99091


                      *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE            2952.48       3663.87       3630.55
STATIC PRESSURE           2553.80       2827.58       3166.80
TOTAL TEMPERATURE(GAS)    573.9966      611.8566      611.8566
STATIC TEMPERATURE(GAS)  550.7079      568.2392      588.4487
STATIC DENSITY(GAS)         .0869         .0933         .1009
STATIC DENSITY(MIXTURE)     .0869         .0933         .1009

AXIAL VELOCITY           494.1744      522.5140      494.0333
ABSOLUTE VELOCITY        529.1692      724.3096      530.6107
RELATIVE VELOCITY        734.4023      570.3622
BLADE SPEED              732.5063      730.2758      768.1948
TANG. COMP. OF ABS. VEL. 189.2399      501.6010
TANG. COMP. OF REL. VEL. 543.2664      228.6748
ACOUSTIC SPEED          1150.2627     1188.4867     1189.0241
ABSOLUTE MACH NUMBER        .4600         .6199         .4463
RELATIVE MACH NUMBER        .6385         .4881

FLOW COEFFICIENT            .5126         .5420         .5125
FLOW AREA                   .0080         .0071         .0069

ABSOLUTE FLOW ANGLE       20.9539       43.8301       21.4115
RELATIVE FLOW ANGLE       47.7092       23.6363
INCIDENCE                   6.0892         .4701
DEVIATION                               10.5163       10.9015
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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  3 )  ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.22966
    STAGE TOTAL TEMPERATURE RATIO=     1.06596
    STAGE ADIABATIC EFFICIENCY=      .92118

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                MENT)               MENT)
    XU=         .00000              .00000              .00000
    XW=              0                   0                   0
    XWW=              0                   0                  0
    XWT=              0                   0                   0
    XAIR=        1.00000             1.00000            1.00000
    XMETAN=              0                   0                  0
    XGAS        1.00000             1.00000            1.00000
    WMASS=              0                   0                  0
    WWMASS=              0                   0                  0
    WTMASS=              0                   0                  0
    AMASS=         .34491              .34491             .34491
    CHMASS=              0                   0                  0
    VMASS=         .00000              .00000             .00000
    GMASS=         .34491              .34491             .34491
    TMASS=         .34491              .34491             .34491
    WS=         .00000              .00000             .00000
    RHOA=         .09641              .09326             .10086
    RHOM=         .06904              .09326             .10086
    RHOG=         .08692              .09326             .10086
    TG=      573.99661          611.85659           611.85659
    TW=      513.70000          513.70000           513.70000
    TWW=      513.70000                  0           513.70000
    P=     2952.48188         3663.87348          3630.55342
    TB=      688.08016                  0           698.86348
    TDEW=      274.74655          276.46988           276.46988
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********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 4 )  ********************

    STAGE TOTAL PRESSURE RATIO=      1.24218
    STAGE TOTAL TEMPERATURE RATIO=     1.06978
    STAGE ADIABATIC EFFICIENCY=      .91298

    STAGE FLOW COEFFICIENT= .513
    AXIAL VELOCITY= 494.07
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.24218
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.26694
    LOSS FACTOR IN ROTOR=      .98759
    LOSS FACTOR IN STATOR=      .98968

                        *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE              3630.55        4556.82        4509.80
STATIC PRESSURE             3166.66        3525.69        3957.68
TOTAL TEMPERATURE(GAS)     611.8566       654.5529       654.5529
STATIC TEMPERATURE(GAS)   588.4681       608.4010       630.6384
STATIC DENSITY(GAS)          .1009          .1086          .1176
STATIC DENSITY(MIXTURE)      .1009          .1086          .1176

AXIAL VELOCITY            494.0715       522.8404       496.2018
ABSOLUTE VELOCITY         530.6990       745.6155       536.7235
RELATIVE VELOCITY         757.6978       572.0630
BLADE SPEED               768.1948       763.7337       798.0839
TANG. COMP. OF ABS. VEL.  193.7390       531.5829
TANG. COMP. OF REL. VEL.  574.4558       232.1508
ACOUSTIC SPEED           1188.6880      1230.0789      1230.5425
ABSOLUTE MACH NUMBER         .4465          .6169          .4362
RELATIVE MACH NUMBER         .6374          .4733

FLOW COEFFICIENT             .5125          .5423          .5147
FLOW AREA                    .0069          .0061          .0059

ABSOLUTE FLOW ANGLE        21.4115        45.4750        22.4163
RELATIVE FLOW ANGLE        49.3022        23.9421
INCIDENCE                   6.4522          .4750
DEVIATION                               10.1821        10.6063
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********************  INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  4 )  ********************
    STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

    STAGE TOTAL PRESSURE RATIO=     1.24218
    STAGE TOTAL TEMPERATURE RATIO=     1.06978
    STAGE ADIABATIC EFFICIENCY=       .91298

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                               (BEFORE INTER-      (AFTER INTER-
                                STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XU=         .00000              .00000              .00000
    XW=              0                   0                   0
    XWW=              0                   0                   0
    XWT=              0                   0                   0
    XAIR=        1.00000             1.00000             1.00000
    XMETAN=              0                   0                   0
    XGAS        1.00000             1.00000             1.00000
    WMASS=              0                   0                   0
    WWMASS=              0                   0                   0
    WTMASS=              0                   0                   0
    AMASS=         .34491              .34491              .34491
    CHMASS=              0                   0                   0
    VMASS=         .00000              .00000              .00000
    GMASS=         .34491              .34491              .34491
    TMASS=         .34491              .34491              .34491
    WS=         .00000              .00000              .00000
    RHOA=         .11122              .10860              .11762
    RHOM=         .06904              .10860              .11762
    RHOG=         .10086              .10860              .11762
    TG=      611.85659           654.55293           654.55293
    TW=      513.70000           513.70000           513.70000
    TWW=      513.70000                   0           513.70000
    P=     3630.55342          4556.82036          4509.79574
    TB=      698.86348                   0           710.54436
    TDEW=      276.46988           278.29004           278.29004
```

```
********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 5 )  ********************

    STAGE TOTAL PRESSURE RATIO=     1.23414
    STAGE TOTAL TEMPERATURE RATIO=     1.06793
    STAGE ADIABATIC EFFICIENCY=      .90663

    STAGE FLOW COEFFICIENT= .515
    AXIAL VELOCITY= 496.25
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.23414
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.25990
    LOSS FACTOR IN ROTOR=      .98308
    LOSS FACTOR IN STATOR=      .98949

                        *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             4509.80        5624.85        5565.72
STATIC PRESSURE            3957.52        4401.30        4921.73
TOTAL TEMPERATURE(GAS)     654.5529       699.0183       699.0183
STATIC TEMPERATURE(GAS)   630.6739       651.9165       674.9958
STATIC DENSITY(GAS)          .1176          .1265          .1367
STATIC DENSITY(MIXTURE)      .1176          .1265          .1367

AXIAL VELOCITY            496.2499       517.9326       493.7867
ABSOLUTE VELOCITY         536.8130       754.0599       538.5133
RELATIVE VELOCITY         773.5389       570.7437
BLADE SPEED               798.0839       787.8235       819.0509
TANG. COMP. OF ABS. VEL.  204.7050       548.0439
TANG. COMP. OF REL. VEL.  593.3789       239.7796
ACOUSTIC SPEED           1230.0502      1272.1584      1272.5386
ABSOLUTE MACH NUMBER         .4364          .6030          .4232
RELATIVE MACH NUMBER         .6289          .4564

FLOW COEFFICIENT             .5148          .5373          .5122
FLOW AREA                    .0059          .0053          .0051

ABSOLUTE FLOW ANGLE        22.4163        46.6180        23.5232
RELATIVE FLOW ANGLE        50.0939        24.8420
INCIDENCE                    6.0939          .3080
DEVIATION                                 10.5120        10.2032
```

```
********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  5 )  ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.23414
    STAGE TOTAL TEMPERATURE RATIO=     1.06793
    STAGE ADIABATIC EFFICIENCY=      .90663

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XU=         .00000              .00000              .00000
    XW=              0                   0                   0
    XWW=              0                   0                   0
    XWT=              0                   0                   0
    XAIR=        1.00000             1.00000             1.00000
    XMETAN=              0                   0                   0
    XGAS        1.00000             1.00000             1.00000
    WMASS=              0                   0                   0
    WWMASS=              0                   0                   0
    WTMASS=              0                   0                   0
    AMASS=         .34491              .34491              .34491
    CHMASS=              0                   0                   0
    VMASS=         .00000              .00000              .00000
    GMASS=         .34491              .34491              .34491
    TMASS=         .34491              .34491              .34491
    WS=         .00000              .00000              .00000
    RHOA=         .12914              .12651              .13665
    RHOM=         .06904              .12651              .13665
    RHOG=         .11762              .12651              .13665
    TG=      654.55293           699.01831           699.01831
    TW=      513.70000           513.70000           513.70000
    TWW=      513.70000                   0           513.70000
    P=     4509.79574          5624.84868          5565.71763
    TB=      710.54436                  0           725.30379
    TDEW=      278.29004           270.78298           270.78298
```

```
********************  INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 6 )  ********************

    STAGE TOTAL PRESSURE RATIO=      1.21895
    STAGE TOTAL TEMPERATURE RATIO=     1.06377
    STAGE ADIABATIC EFFICIENCY=       .90463

    STAGE FLOW COEFFICIENT= .512
    AXIAL VELOCITY= 493.84
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.21895
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.24345
    LOSS FACTOR IN ROTOR=       .97403
    LOSS FACTOR IN STATOR=       .99138

                              *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE                  5565.72        6843.38        6784.36
STATIC PRESSURE                 4921.56        5436.20        5876.36
TOTAL TEMPERATURE(GAS)          699.0183       743.5938       743.5938
STATIC TEMPERATURE(GAS)        675.0454       696.5955       713.9007
STATIC DENSITY(GAS)               .1367          .1463          .1543
STATIC DENSITY(MIXTURE)           .1367          .1463          .1543

AXIAL VELOCITY                 493.8405       505.0266       478.8044
ABSOLUTE VELOCITY              538.5989       754.2557       599.5224
RELATIVE VELOCITY              780.2545       557.2913
BLADE SPEED                    819.0509       795.8534          .5000
TANG. COMP. OF ABS. VEL.       214.9659       560.2230
TANG. COMP. OF REL. VEL.       604.0850       235.6304
ACOUSTIC SPEED                1271.8989      1307.3852      1307.9918
ABSOLUTE MACH NUMBER              .4235          .5838          .4584
RELATIVE MACH NUMBER              .6135          .4313

FLOW COEFFICIENT                  .5123          .5239          .4994
FLOW AREA                         .0051          .0047          .0047

ABSOLUTE FLOW ANGLE             23.5232        47.9662        37.0059
RELATIVE FLOW ANGLE             50.7339        25.0124
INCIDENCE                        5.6639         -.7438
DEVIATION                                      10.5824         7.7259
```

```
********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  6 ) *******************

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

    STAGE TOTAL PRESSURE RATIO=     1.21895
    STAGE TOTAL TEMPERATURE RATIO=     1.06377
    STAGE ADIABATIC EFFICIENCY=      .90463

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00000              .00000              .00000
    XW=              0                   0                   0
    XWW=              0                   0                   0
    XWT=              0                   0                   0
    XAIR=        1.00000             1.00000             1.00000
    XMETAN=              0                   0                   0
    XGAS        1.00000             1.00000             1.00000
    WMASS=              0                   0                   0
    WWMASS=              0                   0                   0
    WTMASS=              0                   0                   0
    AMASS=         .34491              .34491              .34491
    CHMASS=              0                   0                   0
    VMASS=         .00000              .00000              .00000
    GMASS=         .34491              .34491              .34491
    TMASS=         .34491              .34491              .34491
    WS=         .00000              .00000              .00000
    RHOA=         .14924              .14623              .15426
    RHOM=         .06904              .14623              .15426
    RHOG=         .13665              .14623              .15426
    TG=      699.01831           743.59381           743.59381
    TW=      513.70000           513.70000           513.70000
    TWW=      513.70000                   0           513.70000
    P=     5565.71763          6843.37717          6784.35886
    TB=      725.30379                  0           737.46504
    TDEW=      270.78298           272.44415           272.44415
```

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

 INITIAL FLOW COEFFICIENT= .50000

 CORRECTED SPEED=51120.0     1.000 FRACTION OF DEIGN CORRECTED SPEED

 INITIAL WATER CONTENT(SMALL DROPLET)=    0
 INITIAL WATER CONTENT(LARGE DROPLET)=    0
 INITIAL WATER CONTENT(TOTAL)=    0
 INITIAL RELATIVE HUMIDITY=   .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=  .345( 2.910)

 CORRECTED MASS FLOW RATE OF GAS PHASE   .345( 2.910)

 OVERALL TOTAL PRESSURE RATIO=3.2050

 OVERALL TOTAL TEMPERATURE RATIO=1.4336

 OVERALL ADIABATIC EFFICIENCY= .9057

 OVERALL TEMPERATURE RISE OF GAS PHASE= 224.894
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AD-A114 850   PURDUE UNIV LAFAYETTE IN SCHOOL OF MECHANICAL ENGINEERING   F/G 21/5
EFFECT OF WATER ON AXIAL FLOW COMPRESSORS. PART I. ANALYSIS AND--ETC(U)
JUN 81   T TSUCHIYA, S N MURTHY   F33615-78-C-2401
UNCLASSIFIED   AFWAL-TR-80-2090-PT-1   NL

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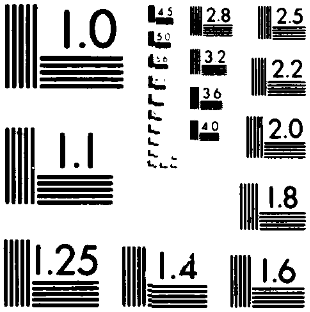

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A.5.2 Test Case Part II

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***************************** INPUT DATA ***********************************

NS(NUMBER OF STAGE)= 6
UNIT=ENGLISH UNIT
IPERFM=2
PERFORMANCE AT MEAN

            1     2     3     4     5     6    IGV
RRHUB(I)   .770 1.035 1.232 1.378 1.489 1.572
RC(I)      .605  .554  .534  .510  .483  .456
RBLADE(I) 16.00 20.00 20.00 25.00 28.00 32.00
STAGER(I) 34.25 29.96 27.37 28.30 29.17 29.75
STAGES(I) 23.67 25.62 26.94 28.41 29.82 38.99
SRHUB(I)   .923 1.145 1.311 1.445 1.538 1.580  .774
SC(I)      .442  .412  .412  .412  .412  .412
SBLADE(I) 14.00 26.00 28.00 32.00 36.00 30.00
SIGUMR(I) 1.052 1.120 1.037 1.182 1.211 1.283
SIGUMS(I)  .640 1.061 1.093 1.199 1.311 1.087
GAPR(I)    .125  .125  .125  .125  .125  .125
GAPS(I)    .125  .125  .125  .125  .125  .125
RRTIP(I)   2.16  2.16  2.16  2.16  2.16  2.16
SRTIP(I)   2.16  2.16  2.16  2.16  2.16  2.16  2.16
RT(I)     2.149 2.151 2.148 2.149 2.149 2.147
RM(I)     1.426 1.575 1.642 1.722 1.789 1.836
RH(I)      .781 1.056 1.252 1.411 1.533 1.621
ST(I)     2.147 2.138 2.127 2.123 2.118 2.100
SM(I)     1.502 1.573 1.637 1.712 1.766 1.784
SH(I)      .934 1.152 1.318 1.453 1.548 1.592
BLOCK(I)   .983  .976  .967  .949  .923  .902
BLOCKS(I)  .978  .966  .945  .928  .908  .863
BET1MR(I) 42.72 42.74 41.62 42.85 44.00 45.07
BET2MR(I) 25.79 17.17 13.12 13.76 14.33 14.43
BET1MS(I) 35.15 40.11 43.36 45.00 46.31 48.71     0
BET2MS(I) 12.19 11.13 10.51 11.81 13.32 29.28 21.99
PR12D(I)  1.154 1.165 1.221 1.237 1.230 1.215
PR13D(I)  1.152 1.159 1.213 1.228 1.221 1.208
ETARD(I)   .966  .966  .968  .965  .962  .954
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****************************** INPUT DATA ******************************

FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)= .040
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=    0
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=   2116.80

DIN(INITIIL 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)=      .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

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

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

 TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
 TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
 STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
 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
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 1 *****

                TOTAL        TOTAL       STATIC       STATIC       STATIC
                TEMP       PRESSURE       TEMP       PRESSURE      DENSITY

 ROTOR INLET    518.700     2116.800       492.637     1767.579         .067
 ROTOR OUTLET   541.148     2442.787       508.269     1961.576         .072

                AXIAL      ABSOLUTE     RELATIVE     TAN COMP      TAN COMP
              VELOCITY     VELOCITY     VELOCITY    OF ABS VEL    OF REL VEL

 ROTOR INLET  538.76531    559.39838     725.32398    150.52734    485.62003
 ROTOR OUTLET 525.97105    628.55682     618.75550    344.14838    325.90306

               ROTOR       ABS MACH     REL MACH     REL TOTAL     REL TOTAL
               SPEED        NUMBER       NUMBER        TEMP        PRESSURE

 ROTOR INLET    636.147         .514          .667      536.454     2381.210
 ROTOR OUTLET   670.051         .569          .560      540.141     5091.790

              ABS FLOW     REL FLOW    STREAMTUBE                  FLOW
               ANGLE        ANGLE        AREA          RADIUS     COEFFICIENT

 ROTOR INLET   15.61000     42.03015        .01036      1.42600       .55886
 ROTOR OUTLET  33.19714     31.78325        .00987      1.50200       .54559

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15200
 STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .95383
 ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15400
 ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .96600
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.04328
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 2 *****

                   TOTAL         TOTAL          STATIC        STATIC        STATIC
                   TEMP        PRESSURE          TEMP        PRESSURE       DENSITY

 ROTOR INLET      541.148      2438.554        511.984       2008.852          .074
 ROTOR OUTLET     566.141      2840.915        522.316       2142.394          .077

                   AXIAL       ABSOLUTE       RELATIVE       TAN COMP      TAN COMP
                 VELOCITY      VELOCITY       VELOCITY     OF ABS VEL    OF REL VEL

 ROTOR INLET  549.21299      591.88727      730.68951      220.67086     481.94632
 ROTOR OUTLET 581.16447      725.94045      639.44211      435.01464     266.71034

                  ROTOR        ABS MACH       REL MACH      REL TOTAL     REL TOTAL
                  SPEED         NUMBER         NUMBER        TEMP         PRESSURE

 ROTOR INLET      702.617          .534           .659        556.431      2688.136
 ROTOR OUTLET     701.725          .648           .571        556.331      5751.007

                 ABS FLOW      REL FLOW      STREAMTUBE                      FLOW
                  ANGLE         ANGLE          AREA          RADIUS      COEFFICIENT

 ROTOR INLET      21.89000      41.26765        .00930        1.57500         .56970
 ROTOR OUTLET     36.81569      24.65154        .00841        1.57300         .60285

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15900
 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
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 3 *****

                TOTAL        TOTAL      STATIC       STATIC       STATIC
                TEMP      PRESSURE       TEMP       PRESSURE      DENSITY

 ROTOR INLET    566.141     2826.284      535.362     2323.868         .081
 ROTOR OUTLET   600.462     3450.892      549.786     2533.049         .086

                AXIAL     ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
              VELOCITY    VELOCITY     VELOCITY    OF ABS VEL   OF REL VEL

 ROTOR INLET  574.81563    608.26663    784.29006    198.93541    533.57089
 ROTOR OUTLET 614.43880    781.11343    662.59507    482.28950    247.98627

               ROTOR      ABS MACH     REL MACH     REL TOTAL    REL TOTAL
               SPEED       NUMBER       NUMBER       TEMP        PRESSURE

 ROTOR INLET    732.506         .536         .692      586.533     3199.070
 ROTOR OUTLET   730.276         .680         .577      586.263     6929.751

              ABS FLOW    REL FLOW    STREAMTUBE                  FLOW
               ANGLE       ANGLE        AREA         RADIUS     COEFFICIENT

 ROTOR INLET   19.09000     42.86892       .00803      1.64200       .59626
 ROTOR OUTLET  38.12932     21.97890       .00708      1.63700       .63736

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

 ***** STAGE= 4 *****

                 TOTAL       TOTAL       STATIC      STATIC      STATIC
                 TEMP       PRESSURE      TEMP      PRESSURE     DENSITY

 ROTOR INLET     600.462     3428.282     569.069     2839.988        .094
 ROTOR OUTLET    639.381     4240.785     585.841     3118.959        .100

                 AXIAL      ABSOLUTE    RELATIVE     TAN COMP    TAN COMP
                VELOCITY    VELOCITY    VELOCITY   OF ABS VEL   OF REL VEL

 ROTOR INLET  580.04590   614.69778   809.54747   203.47020   564.72459
 ROTOR OUTLET 619.63965   803.61317   668.93304   511.70446   252.02926

                ROTOR      ABS MACH    REL MACH    REL TOTAL   REL TOTAL
                SPEED       NUMBER      NUMBER       TEMP      PRESSURE

 ROTOR INLET     768.195        .526        .692     623.519    3912.431
 ROTOR OUTLET    763.734        .678        .564     622.951    8231.914

               ABS FLOW    REL FLOW   STREAMTUBE                 FLOW
                ANGLE       ANGLE        AREA        RADIUS    COEFFICIENT

 ROTOR INLET    19.33000    44.23321      .00692     1.72200      .60169
 ROTOR OUTLET   39.55025    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=    .96500
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.06481
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 5 *****

                TOTAL        TOTAL       STATIC       STATIC       STATIC
                TEMP       PRESSURE      TEMP        PRESSURE      DENSITY

ROTOR INLET     639.381     4209.930     606.962     3506.755        .108
ROTOR OUTLET    679.732     5178.214     625.197     3857.244        .116

                AXIAL      ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
               VELOCITY    VELOCITY     VELOCITY    OF ABS VEL   OF REL VEL

ROTOR INLET   586.84149   625.22167    826.78513    215.68308    582.40082
ROTOR OUTLET  617.08868   811.98444    669.65381    527.75042    260.07304

                ROTOR      ABS MACH     REL MACH    REL TOTAL    REL TOTAL
                SPEED       NUMBER       NUMBER      TEMP        PRESSURE

ROTOR INLET     798.084        .518         .685     663.653     4798.526
ROTOR OUTLET    787.823        .663         .547     662.302     9691.778

               ABS FLOW     REL FLOW    STREAMTUBE                   FLOW
                ANGLE        ANGLE         AREA        RADIUS     COEFFICIENT

ROTOR INLET     20.18000     44.78240      .00591     1.78900        .60873
ROTOR OUTLET    40.53794     22.85308      .00526     1.76600        .64011

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .92580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.06311
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**************** DESIGN POINT INFORMATION ************* ***

 ***** STAGE= 6 *****

                 TOTAL       TOTAL       STATIC      STATIC      STATIC
                 TEMP       PRESSURE      TEMP      PRESSURE     DENSITY

 ROTOR INLET    679.732     5140.325     646.933    4318.954       .125
 ROTOR OUTLET   720.259     6245.495     665.989    4736.291       .133

                 AXIAL      ABSOLUTE    RELATIVE    TAN COMP    TAN COMP
               VELOCITY     VELOCITY    VELOCITY   OF ABS VEL  OF REL VEL

 ROTOR INLET  587.19574    629.60666   833.74045   227.16890   591.88199
 ROTOR OUTLET 603.39773    811.09676   654.61329   542.02320   253.83017

                ROTOR       ABS MACH    REL MACH    REL TOTAL   REL TOTAL
                SPEED        NUMBER      NUMBER      TEMP       PRESSURE

 ROTOR INLET    819.051         .506        .669     704.449    5829.034
 ROTOR OUTLET   795.853         .642        .518     701.350   10970.182

               ABS FLOW     REL FLOW   STREAMTUBE                 FLOW
                ANGLE        ANGLE        AREA        RADIUS    COEFFICIENT

 ROTOR INLET   21.15000     45.22772      .00511     1.83600      .60910
 ROTOR OUTLET  41.93288     22.81494      .00467     1.78400      .62591

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.20800
 STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .92365
 ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.21500
 ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .95400
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.05962
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*************** 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=1.3886

 OVERALL ADIABATIC EFFICIENCY= .9223

 OVERALL TEMPERATURE RISE= 201.559

                 1      2      3      4      5      6     IGV
 BET1SR(I)   42.03  41.27  42.87  44.23  44.78  45.23
 BET2SR(I)   31.78  24.65  21.98  22.13  22.85  22.81
 AINCSR(I)    -.69  -1.47   1.25   1.38    .78    .16
 ADEVSR(I)    5.99   7.48   8.86   8.37   8.52   8.38
 BET1SS(I)   33.20  36.82  38.13  39.55  40.54  41.93
 BET2SS(I)   21.89  19.09  19.33  20.18  21.15  34.86  15.61
 AINCSS(I)   -1.95  -3.29  -5.23  -5.45  -5.77  -6.78
 ADEVSS(I)    9.70   7.96   8.82   8.37   7.83   5.58
 TD(I)       518.7  541.1  566.1  600.5  639.4  679.7
 OMEGS(I)     .009   .021   .025   .028   .029   .024
 OMEGR(I)     .020   .021   .024   .028   .030   .036
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 1 )  ************

    STAGE TOTAL PRESSURE RATIO=     1.17523
    STAGE TOTAL TEMPERATURE RATIO=     1.05076
    STAGE ADIABATIC EFFICIENCY=      .93056

    STAGE FLOW COEFFICIENT= .500
    AXIAL VELOCITY= 482.13
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.17523
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.18907
    LOSS FACTOR IN ROTOR=     1.01550
    LOSS FACTOR IN STATOR=      .99678

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2116.80        2495.77        2487.73
STATIC PRESSURE            1821.98        2038.83        2123.98
TOTAL TEMPERATURE(GAS)     518.7000       545.0303       545.0303
STATIC TEMPERATURE(GAS)   496.9259       515.5746       521.8709
STATIC DENSITY(GAS)          .0687          .0741          .0763
STATIC DENSITY(MIXTURE)      .0716          .0772          .0795

AXIAL VELOCITY            482.1269       469.4052       484.1839
ABSOLUTE VELOCITY         500.9958       594.7932       527.4057
RELATIVE VELOCITY         694.5454       559.6606
BLADE SPEED               636.1474       670.0514       702.6172
TANG. COMP. OF ABS. VEL.  136.2004       365.2913
TANG. COMP. OF REL. VEL.  499.9470       304.7602
ACOUSTIC SPEED           1070.9353      1097.8191      1097.4899
ABSOLUTE MACH NUMBER         .4678          .5453          .4806
RELATIVE MACH NUMBER         .6485          .5131

FLOW COEFFICIENT             .5001          .4869          .5022
FLOW AREA                    .0104          .0099          .0093

ABSOLUTE FLOW ANGLE        15.7749        37.8901        23.3618
RELATIVE FLOW ANGLE        46.0395        32.9935
INCIDENCE                     3.3195         2.7401
DEVIATION                                  7.2035        11.1718
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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  1 )  ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.17523
    STAGE TOTAL TEMPERATURE RATIO=     1.05076
    STAGE ADIABATIC EFFICIENCY=      .93059

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00000              .00000              .00003
    XW=         .04000              .04000              .03997
    XWW=              0                   0                   0
    XWT=         .04000              .04000              .03997
    XAIR=         .96000              .96000              .96000
    XMETAN=           0                   0                   0
    XGAS         .96000              .96000              .96003
    WMASS=         .01431              .01431              .01430
    WWMASS=           0                   0                   0
    WTMASS=         .01431              .01431              .01430
    AMASS=         .34340              .34340              .34340
    CHMASS=           0                   0                   0
    VMASS=         .00000              .00000              .00001
    GMASS=         .34340              .34340              .34341
    TMASS=         .35771              .35771              .35771
    WS=         .00000              .00000              .00004
    RHOA=         .07649              .07432              .06829
    RHOM=         .07160              .07741              .07961
    RHOG=         .06872              .07432              .07643
    TG=      518.70000           545.03032           545.02935
    TW=      513.70000           519.12521           519.13056
    TWW=      513.70000                   0           513.70000
    P=     2116.80000          2495.76975          2487.72825
    TB=      671.40656                   0           679.39541
    TDEW=      271.99506           273.32309           395.40315
```

```
********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 2 )  *******************

    STAGE TOTAL PRESSURE RATIO=      1.17581
    STAGE TOTAL TEMPERATURE RATIO=      1.05225
    STAGE ADIABATIC EFFICIENCY=      .90620

    STAGE FLOW COEFFICIENT= .501
    AXIAL VELOCITY= 483.25
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.17581
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.19510
    LOSS FACTOR IN ROTOR=      .99123
    LOSS FACTOR IN STATOR=      .99193

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2487.73        2948.91        2925.11
STATIC PRESSURE            2124.70        2286.71        2506.57
TOTAL TEMPERATURE(GAS)     545.0293       573.5085       573.5085
STATIC TEMPERATURE(GAS)   521.0067       534.8122       549.7050
STATIC DENSITY(GAS)          .0764          .0801          .0855
STATIC DENSITY(MIXTURE)      .0796          .0835          .0890

AXIAL VELOCITY            483.2456       509.8557       500.4203
ABSOLUTE VELOCITY         526.4003       681.9413       534.8508
RELATIVE VELOCITY         690.9735       567.3462
BLADE SPEED               702.6172       701.7250       732.5063
TANG. COMP. OF ABS. VEL.  208.7366       452.8698
TANG. COMP. OF REL. VEL.  493.8806       248.8552
ACOUSTIC SPEED           1096.4867      1126.0773      1126.2833
ABSOLUTE MACH NUMBER         .4801          .6139          .4749
RELATIVE MACH NUMBER         .6302          .5107

FLOW COEFFICIENT             .5013          .5289          .5191
FLOW AREA                    .0093          .0084          .0080

ABSOLUTE FLOW ANGLE        23.3618        41.6125        20.6723
RELATIVE FLOW ANGLE        45.6236        26.0165
INCIDENCE                    2.8836         1.5025
DEVIATION                                  8.8465         9.5423
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  2 )  ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.17581
    STAGE TOTAL TEMPERATURE RATIO=     1.05225
    STAGE ADIABATIC EFFICIENCY=      .90625

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XU=         .00003              .00003              .00011
    XW=         .03997              .03997              .03989
    XWW=              0                   0                   0
    XWT=         .03997              .03997              .03989
    XAIR=         .96000              .96000              .96000
    XMETAN=              0                   0                   0
    XGAS         .96003              .96003              .96011
    WMASS=         .01430              .01430              .01427
    WWMASS=              0                   0                   0
    WTMASS=         .01430              .01430              .01427
    AMASS=         .34340              .34340              .34340
    CHMASS=              0                   0                   0
    VMASS=         .00001              .00001              .00004
    GMASS=         .34341              .34341              .34344
    TMASS=         .35771              .35771              .35771
    WS=         .00004              .00004              .00011
    RHOA=         .08555              .08043              .07670
    RHOM=         .07160              .08377              .08918
    RHOG=         .07643              .08043              .08563
    TG=      545.02935           573.50850           573.50651
    TW=      519.13056           524.60917           524.62018
    TWW=      513.70000                   0           513.70000
    P=     2487.72825          2948.91283          2925.10631
    TB=      679.39541                   0           687.60211
    TDEW=      395.40315           398.30836           418.76408
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 3 )   ************

    STAGE TOTAL PRESSURE RATIO=     1.22461
    STAGE TOTAL TEMPERATURE RATIO=     1.06555
    STAGE ADIABATIC EFFICIENCY=      .90795

    STAGE FLOW COEFFICIENT= .518
    AXIAL VELOCITY= 499.52
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.22461
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.24902
    LOSS FACTOR IN ROTOR=      .98903
    LOSS FACTOR IN STATOR=      .98975


                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2925.11        3619.23        3582.11
STATIC PRESSURE            2507.36        2750.82        3093.78
TOTAL TEMPERATURE(GAS)     573.5065       611.0987       611.0987
STATIC TEMPERATURE(GAS)   548.8198       566.7669       587.0191
STATIC DENSITY(GAS)          .0856          .0910          .0988
STATIC DENSITY(MIXTURE)      .0892          .0947          .1029

AXIAL VELOCITY            499.5199       533.4818       502.3745
ABSOLUTE VELOCITY         533.8950       730.2472       538.1919
RELATIVE VELOCITY         738.5713       581.5931
BLADE SPEED               732.5063       730.2758       768.1948
TANG. COMP. OF ABS. VEL.  188.4774       498.6562
TANG. COMP. OF REL. VEL.  544.0289       231.6196
ACOUSTIC SPEED           1125.2535      1163.7666      1163.7592
ABSOLUTE MACH NUMBER         .4745          .6386          .4625
RELATIVE MACH NUMBER         .6564          .5086

FLOW COEFFICIENT             .5182          .5534          .5211
FLOW AREA                    .0080          .0071          .0069

ABSOLUTE FLOW ANGLE        20.6723        43.0675        21.0210
RELATIVE FLOW ANGLE        47.4423        23.4688
INCIDENCE                    5.8223         -.2925
DEVIATION                                 10.3488        10.5110
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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  3 )  ********************

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

STAGE TOTAL PRESSURE RATIO=      1.22461
STAGE TOTAL TEMPERATURE RATIO=      1.06554
STAGE ADIABATIC EFFICIENCY=       .90801

       **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                            (BEFORE INTER-      (AFTER INTER-
                             STAGE ADJUST-       STAGE ADJUST-
                             MENT)               MENT)
XV=         .00011               .00011              .00023
XW=         .03989               .03989              .03977
XWW=              0                   0                   0
XWT=         .03989               .03989              .03977
XAIR=         .96000               .96000              .96000
XMETAN=              0                    0                   0
XGAS         .96011               .96011              .96023
WMASS=         .01427               .01427              .01422
WWMASS=              0                    0                   0
WTMASS=         .01427               .01427              .01422
AMASS=         .34340               .34340              .34340
CHMASS=              0                    0                   0
VMASS=         .00004               .00004              .00008
GMASS=         .34344               .34344              .34348
TMASS=         .35771               .35771              .35771
WS=         .00011               .00011              .00024
RHOA=         .09560               .09133              .08912
RHOM=         .07160               .09511              .10303
RHOG=         .08563               .09132              .09894
TG=      573.50651            611.09874           611.09555
TW=      524.62018            531.47995           531.49766
TWW=      513.70000                   0             513.70000
P=     2925.10631           3619.22732           3582.11448
TB=      687.60211                  0            698.15264
TDEW=       418.76408            422.85381            437.94261
```

```
********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 4 )   *******************

    STAGE TOTAL PRESSURE RATIO=     1.23734
    STAGE TOTAL TEMPERATURE RATIO=     1.06937
    STAGE ADIABATIC EFFICIENCY=      .90133

    STAGE FLOW COEFFICIENT= .520
    AXIAL VELOCITY= 501.59
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.23734
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.26524
    LOSS FACTOR IN ROTOR=      .98600
    LOSS FACTOR IN STATOR=      .98874

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             3582.11        4482.78        4432.28
STATIC PRESSURE            3094.58        3413.81        3849.29
TOTAL TEMPERATURE(GAS)     611.0955       653.4876       653.4876
STATIC TEMPERATURE(GAS)   586.1317       606.4676       628.7251
STATIC DENSITY(GAS)          .0989          .1055          .1147
STATIC DENSITY(MIXTURE)      .1030          .1099          .1195

AXIAL VELOCITY            501.5901       536.1439       506.6302
ABSOLUTE VELOCITY         537.3515       752.6615       546.2044
RELATIVE VELOCITY         763.3644       585.5788
BLADE SPEED               768.1948       763.7337       798.0839
TANG. COMP. OF ABS. VEL.  192.7537       528.2509
TANG. COMP. OF REL. VEL.  575.4411       235.4829
ACOUSTIC SPEED           1162.6546      1204.1692      1204.1634
ABSOLUTE MACH NUMBER         .4622          .6364          .4536
RELATIVE MACH NUMBER         .6566          .4951

FLOW COEFFICIENT             .5203          .5561          .5255
FLOW AREA                    .0069          .0061          .0059

ABSOLUTE FLOW ANGLE        21.0210        44.5751        21.9444
RELATIVE FLOW ANGLE        48.9226        23.7118
INCIDENCE                   6.0726         -.4249
DEVIATION                                  9.9518        10.1344
```

```
******************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  4 )  ******************
    STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

    STAGE TOTAL PRESSURE RATIO=  1.23734
    STAGE TOTAL TEMPERATURE RATIO=  1.06936
    STAGE ADIABATIC EFFICIENCY=   .90140

          **STAGE INLET**   **STAGE OUTLET**  **STAGE OUTLET**
                             (BEFORE INTER-     (AFTER INTER-
                              STAGE ADJUST-      STAGE ADJUST-
                              MENT)              MENT)
    XU=        .00023            .00023             .00043
    XW=        .03977            .03977             .03957
    XWW=            0                 0                  0
    XWT=        .03977            .03977             .03957
    XAIR=        .96000            .96000             .96000
    XMETAN=            0                 0                  0
    XGAS        .96023            .96023             .96043
    WMASS=        .01422            .01422            .01416
    WWMASS=            0                 0                  0
    WTMASS=        .01422            .01422            .01416
    AMASS=        .34340            .34340            .34340
    CHMASS=            0                 0                  0
    VMASS=        .00008            .00008            .00015
    GMASS=        .34348            .34348            .34355
    TMASS=        .35771            .35771            .35771
    WS=        .00024            .00024             .00044
    RHOA=        .10987            .10590             .10390
    RHOM=        .07160            .11027             .11964
    RHOG=        .09894            .10589             .11491
    TG=    611.09555         653.48757          653.48292
    TW=    531.49766         538.61927          538.64525
    TWW=     513.70000                 0          513.70000
    P=    3582.11448        4482.77596         4432.28162
    TB=    698.15264                  0         709.59620
    TDEW=     437.94261         442.65883         455.51405
```

```
********************  INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 5 )  ********************

    STAGE TOTAL PRESSURE RATIO=     1.22960
    STAGE TOTAL TEMPERATURE RATIO=     1.06748
    STAGE ADIABATIC EFFICIENCY=       .89617

    STAGE FLOW COEFFICIENT= .525
    AXIAL VELOCITY= 505.96
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.22960
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.25805
    LOSS FACTOR IN ROTOR=      .98167
    LOSS FACTOR IN STATOR=      .98872

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             4432.28        5512.15        5449.96
STATIC PRESSURE            3850.09        4245.77        4768.53
TOTAL TEMPERATURE(GAS)    653.4829       697.5827       697.5827
STATIC TEMPERATURE(GAS)  627.8227       649.5072       672.5710
STATIC DENSITY(GAS)          .1149          .1225          .1329
STATIC DENSITY(MIXTURE)      .1196          .1275          .1383

AXIAL VELOCITY            505.9606       532.9952       505.9950
ABSOLUTE VELOCITY         545.4824       761.9382       549.5787
RELATIVE VELOCITY         780.4550       585.9152
BLADE SPEED               798.0839       787.8235       819.0509
TANG. COMP. OF ABS. VEL.  203.8501       544.4869
TANG. COMP. OF REL. VEL.  594.2338       243.3366
ACOUSTIC SPEED           1202.9772      1244.6349      1245.1170
ABSOLUTE MACH NUMBER         .4534          .6227          .4414
RELATIVE MACH NUMBER         .6488          .4789

FLOW COEFFICIENT             .5248          .5529          .5249
FLOW AREA                    .0059          .0053          .0051

ABSOLUTE FLOW ANGLE        21.9444        45.6111        22.9819
RELATIVE FLOW ANGLE        49.5873        24.5389
INCIDENCE                   5.5873         -.6989
DEVIATION                               10.2089         9.6619
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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  5 )   ********************

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

    STAGE TOTAL PRESSURE RATIO=     1.22960
    STAGE TOTAL TEMPERATURE RATIO=     1.06747
    STAGE ADIABATIC EFFICIENCY=      .89626

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00043              .00043              .00069
    XW=         .03957              .03957              .03931
    XWW=              0                 0                     0
    XWT=         .03957              .03957              .03931
    XAIR=         .96000              .96000              .96000
    XMETAN=              0                   0                   0
    XGAS         .96043              .96043              .96069
    WMASS=         .01416              .01416              .01406
    WWMASS=              0                   0                   0
    WTMASS=         .01416              .01416              .01406
    AMASS=         .34340              .34340              .34340
    CHMASS=              0                   0                   0
    VMASS=         .00015              .00015              .00025
    GMASS=         .34355              .34355              .34365
    TMASS=         .35771              .35771              .35771
    WS=         .00044              .00044              .00072
    RHOA=         .12713              .12295              .12090
    RHOM=         .07160              .12797              .13846
    RHOG=         .11491              .12291              .13303
    TG=      653.48292           697.58272           697.57655
    TW=      538.64525           545.85731           545.89207
    TWW=      513.70000                0             513.70000
    P=     4432.28162          5512.15360          5449.95512
    TB=      709.59620                   0           724.03629
    TDEW=     455.51405            452.07093           463.59244
```

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******************* INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 6 ) *****************

    STAGE TOTAL PRESSURE RATIO=      1.21465
    STAGE TOTAL TEMPERATURE RATIO=     1.06335
    STAGE ADIABATIC EFFICIENCY=       .89377

    STAGE FLOW COEFFICIENT= .524
    AXIAL VELOCITY= 505.48
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.21465
    STAGE TOTAL PRESSURE RATIO(IDEAL)=      1.24176
    LOSS FACTOR IN ROTOR=       .97277
    LOSS FACTOR IN STATOR=       .99051

                           *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE                5449.96        6683.24        6619.79
STATIC PRESSURE               4769.14        5228.99        5656.21
TOTAL TEMPERATURE(GAS)        697.5765       741.7702       741.7702
STATIC TEMPERATURE(GAS)      671.6630       693.7308       710.6187
STATIC DENSITY(GAS)             .1330          .1412          .1491
STATIC DENSITY(MIXTURE)         .1385          .1470          .1552

AXIAL VELOCITY               505.4755       521.2389       493.6021
ABSOLUTE VELOCITY            549.0550       762.7687       614.2333
RELATIVE VELOCITY            788.1246       573.4053
BLADE SPEED                  819.0509       795.8534          .5000
TANG. COMP. OF ABS. VEL.     214.3734       556.8897
TANG. COMP. OF REL. VEL.     604.6775       238.9637
ACOUSTIC SPEED              1243.8832      1279.4619      1279.4537
ABSOLUTE MACH NUMBER            .4414          .6034          .4801
RELATIVE MACH NUMBER            .6336          .4536

FLOW COEFFICIENT                .5243          .5407          .5149
FLOW AREA                       .0051          .0047          .0047

ABSOLUTE FLOW ANGLE           22.9819        46.8939        36.5240
RELATIVE FLOW ANGLE           50.1063        24.6292
INCIDENCE                      5.0363        -1.8161
DEVIATION                                    10.1992         7.2440
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  6 )  *********************

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

    STAGE TOTAL PRESSURE RATIO=     1.21465
    STAGE TOTAL TEMPERATURE RATIO=     1.06334
    STAGE ADIABATIC EFFICIENCY=      .89388

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00069              .00069              .00105
    XW=         .03931              .03931              .03895
    XWW=              0                   0                   0
    XWT=         .03931              .03931              .03895
    XAIR=         .96000              .96000              .96000
    XMETAN=              0                   0                   0
    XGAS         .96069              .96069              .96105
    WMASS=         .01406              .01406              .01393
    WWMASS=              0                   0                   0
    WTMASS=         .01406              .01406              .01393
    AMASS=         .34340              .34340              .34340
    CHMASS=              0                   0                   0
    VMASS=         .00025              .00025              .00038
    GMASS=         .34365              .34365              .34377
    TMASS=         .35771              .35771              .35771
    WS=         .00072              .00072              .00110
    RHOA=         .14644              .14172              .13343
    RHOM=         .07160              .14744              .15538
    RHOG=         .13303              .14165              .14935
    TG=     697.57655            741.77019           741.76245
    TW=     545.89207            552.83791           552.88194
    TWW=      513.70000                   0           513.70000
    P=     5449.95512          6683.24452          6619.79326
    TB=      724.03629                    0,         735.93466
    TDEW=     463.59244            468.68226           479.11464
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```
********** OVERALL PERFORMANCE *********

 INITIAL FLOW COEFFICIENT= .50000

 CORRECTED SPEED=51120.0     1.000 FRACTION OF DEIGN CORRECTED SPEED

 INITIAL WATER CONTENT(SMALL DROPLET)= .040
 INITIAL WATER CONTENT(LARGE DROPLET)=    0
 INITIAL WATER CONTENT(TOTAL)= .040
 INITIAL RELATIVE HUMIDITY=   .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=  .358( 3.018)

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

 OVERALL TOTAL PRESSURE RATIO=3.1273

 OVERALL TOTAL TEMPERATURE RATIO=1.4300

 OVERALL ADIABATIC EFFICIENCY= .8905

 OVERALL TEMPERATURE RISE OF GAS PHASE= 223.062
```

A.5.3 Test Case Part III

```
            **************************** INPUT DATA *************************************
NS(NUMBER OF STAGE)= 6
UNIT=ENGLISH UNIT
IPERFM=2
PERFORMANCE AT MEAN

               1     2     3     4     5     6    IGV
RRHUB(I)     .770 1.035 1.232 1.378 1.489 1.572
RC(I)        .605  .554  .534  .510  .483  .456
RBLADE(I)   16.00 20.00 20.00 25.00 28.00 32.00
STAGER(I)   34.25 29.96 27.37 28.30 29.17 29.75
STAGES(I)   23.67 25.62 26.94 28.41 29.82 38.99
SRHUB(I)     .923 1.145 1.311 1.445 1.538 1.580  .774
SC(I)        .442  .412  .412  .412  .412  .412
SBLADE(I)   14.00 26.00 28.00 32.00 36.00 30.00
SIGUMR(I)   1.052 1.120 1.037 1.182 1.211 1.283
SIGUMS(I)    .640 1.061 1.093 1.199 1.311 1.087
GAPR(I)      .125  .125  .125  .125  .125  .125
GAPS(I)      .125  .125  .125  .125  .125  .125
RRTIP(I)     2.16  2.16  2.16  2.16  2.16  2.16
SRTIP(I)     2.16  2.16  2.16  2.16  2.16  2.16  2.16
RT(I)       2.149 2.151 2.148 2.149 2.149 2.147
RM(I)       1.426 1.575 1.642 1.722 1.789 1.836
RH(I)        .781 1.056 1.252 1.411 1.533 1.621
ST(I)       2.147 2.138 2.127 2.123 2.118 2.100
SM(I)       1.502 1.573 1.637 1.712 1.766 1.784
SH(I)        .934 1.152 1.318 1.453 1.548 1.592
BLUCK(I)     .983  .976  .967  .949  .923  .902
BLOCKS(I)    .978  .966  .945  .928  .908  .863
BET1MR(I)   42.72 42.74 41.62 42.85 44.00 45.07
BET2MR(I)   25.79 17.17 13.12 13.76 14.33 14.43
BET1MS(I)   35.15 40.11 43.36 45.00 46.31 48.71     0
BET2MS(I)   12.19 11.13 10.51 11.81 13.32 29.28 21.99
PR12D(I)    1.154 1.165 1.221 1.237 1.230 1.215
PR13D(I)    1.152 1.159 1.213 1.228 1.221 1.208
ETARD(I)     .966  .966  .968  .965  .962  .954
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    ***************************** INPUT DATA *****************************

FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=    0
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)= .040
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=   2116.80

DIN(INITIIL 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)=     .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

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

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

 TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
 TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
 STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
 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
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 1 *****

               TOTAL        TOTAL       STATIC       STATIC       STATIC
               TEMP       PRESSURE       TEMP       PRESSURE      DENSITY

 ROTOR INLET   518.700     2116.800     492.637     1767.579         .067
 ROTOR OUTLET  541.148     2442.787     508.269     1961.576         .072

               AXIAL      ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
             VELOCITY     VELOCITY     VELOCITY    OF ABS VEL   OF REL VEL

 ROTOR INLET 538.76531    559.39838    725.32398    150.52734    485.62003
 ROTOR OUTLET 525.97105   628.55682    618.75550    344.14838    325.90306

              ROTOR       ABS MACH     REL MACH     REL TOTAL    REL TOTAL
              SPEED        NUMBER       NUMBER        TEMP       PRESSURE

 ROTOR INLET   636.147         .514         .667     536.454     2381.210
 ROTOR OUTLET  670.051         .569         .560     540.141     5091.790

             ABS FLOW     REL FLOW    STREAMTUBE                   FLOW
              ANGLE        ANGLE         AREA        RADIUS     COEFFICIENT

 ROTOR INLET  15.61000     42.03015       .01036     1.42600       .55886
 ROTOR OUTLET 33.19714     31.78325       .00987     1.50200       .54559

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15200
 STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .95383
 ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15400
 ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .96600
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.04328
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**************** DESIGN POINT INFORMATION ************* ***

 ***** STAGE= 2 *****

                  TOTAL        TOTAL       STATIC      STATIC       STATIC
                  TEMP       PRESSURE       TEMP      PRESSURE      DENSITY

 ROTOR INLET      541.148      2438.554     511.984     2008.852         .074
 ROTOR OUTLET     566.141      2840.915     522.316     2142.394         .077

                  AXIAL      ABSOLUTE     RELATIVE     TAN COMP     TAN COMP
                VELOCITY     VELOCITY     VELOCITY   OF ABS VEL   OF REL VEL

 ROTOR INLET    549.21299    591.88727    730.68951    220.67086    481.94632
 ROTOR OUTLET   581.16447    725.94045    639.44211    435.01464    266.71034

                 ROTOR       ABS MACH     REL MACH     REL TOTAL    REL TOTAL
                 SPEED        NUMBER       NUMBER       TEMP        PRESSURE

 ROTOR INLET      702.617         .534         .659      556.431     2688.136
 ROTOR OUTLET     701.725         .648         .571      556.331     5751.007

                ABS FLOW     REL FLOW    STREAMTUBE                   FLOW
                 ANGLE        ANGLE         AREA         RADIUS     COEFFICIENT

 ROTOR INLET     21.89000     41.26765       .00930      1.57500       .56970
 ROTOR OUTLET    36.81569     24.65154       .00841      1.57300       .60285

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.15900
 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
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 3 *****
                TOTAL       TOTAL       STATIC       STATIC       STATIC
                TEMP       PRESSURE      TEMP       PRESSURE      DENSITY

 ROTOR INLET    566.141     2826.284     535.362     2323.868         .081
 ROTOR OUTLET   600.462     3450.892     549.786     2533.049         .086

                AXIAL      ABSOLUTE    RELATIVE     TAN COMP     TAN COMP
              VELOCITY     VELOCITY    VELOCITY    OF ABS VEL   OF REL VEL

 ROTOR INLET  574.81563    608.26663   784.29006    198.93541    533.57089
 ROTOR OUTLET 614.43880    781.11343   662.59507    482.28950    247.98627

               ROTOR       ABS MACH    REL MACH     REL TOTAL    REL TOTAL
               SPEED        NUMBER      NUMBER       TEMP        PRESSURE

 ROTOR INLET    732.506         .536        .692       586.533     3199.070
 ROTOR OUTLET   730.276         .680        .577       586.263     6929.751

              ABS FLOW     REL FLOW    STREAMTUBE                  FLOW
               ANGLE        ANGLE       AREA         RADIUS     COEFFICIENT

 ROTOR INLET   19.09000     42.86892      .00803      1.64200       .59626
 ROTOR OUTLET  38.12932     21.97890      .00708      1.63700       .63736

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

***** STAGE= 4 *****

                 TOTAL       TOTAL       STATIC      STATIC      STATIC
                 TEMP       PRESSURE      TEMP      PRESSURE     DENSITY

ROTOR INLET     600.462     3428.282     569.069     2839.988        .094
ROTOR OUTLET    639.381     4240.785     585.841     3118.959        .100

                 AXIAL      ABSOLUTE    RELATIVE     TAN COMP    TAN COMP
               VELOCITY     VELOCITY    VELOCITY    OF ABS VEL  OF REL VEL

ROTOR INLET    580.04590    614.69778   809.54747    203.47020   564.72459
ROTOR OUTLET   619.63965    803.61317   668.93304    511.70446   252.02926

                ROTOR       ABS MACH    REL MACH    REL TOTAL   REL TOTAL
                SPEED        NUMBER      NUMBER       TEMP      PRESSURE

ROTOR INLET     768.195         .526        .692     623.519    3912.431
ROTOR OUTLET    763.734         .678        .564     622.951    8231.914

               ABS FLOW     REL FLOW    STREAMTUBE                FLOW
                ANGLE        ANGLE        AREA        RADIUS    COEFFICIENT

ROTOR INLET     19.33000     44.23321      .00692     1.72200      .60169
ROTOR OUTLET    39.55025     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
OTOR ADIABATIC EFFICIENCY AT DESIGN POINT=     .96500
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.06481
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 5 *****

               TOTAL        TOTAL       STATIC       STATIC       STATIC
               TEMP        PRESSURE      TEMP       PRESSURE      DENSITY

 ROTOR INLET   639.381     4209.930     606.962     3506.755         .108
 ROTOR OUTLET  679.732     5178.214     625.197     3857.244         .116

               AXIAL       ABSOLUTE    RELATIVE     TAN COMP     TAN COMP
             VELOCITY     VELOCITY    VELOCITY   OF ABS VEL   OF REL VEL

 ROTOR INLET  586.84149   625.22167   826.78513    215.68308    592.40082
 ROTOR OUTLET 617.08868   811.98444   669.65381    527.75042    260.07304

              ROTOR       ABS MACH    REL MACH    REL TOTAL    REL TOTAL
              SPEED        NUMBER      NUMBER      TEMP        PRESSURE

 ROTOR INLET    798.084        .518        .685      663.653     4798.526
 ROTOR OUTLET   787.823        .663        .547      662.302     9691.778

             ABS FLOW     REL FLOW    STREAMTUBE                  FLOW
              ANGLE        ANGLE        AREA        RADIUS     COEFFICIENT

 ROTOR INLET   20.18000    44.78240      .00591      1.78900       .60873
 ROTOR OUTLET  40.53794    22.85308      .00526      1.76600       .64011

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.22100
 STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .92580
 ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.23000
 ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .96200
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.06311
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*************** DESIGN POINT INFORMATION ************ ***

 ***** STAGE= 6 *****

                    TOTAL        TOTAL        STATIC       STATIC       STATIC
                    TEMP        PRESSURE       TEMP       PRESSURE      DENSITY

 ROTOR INLET       679.732      5140.325      646.933      4318.954         .125
 ROTOR OUTLET      720.259      6245.495      665.989      4736.291         .133

                  AXIAL       ABSOLUTE     RELATIVE      TAN COMP     TAN COMP
                 VELOCITY     VELOCITY     VELOCITY     OF ABS VEL   OF REL VEL

 ROTOR INLET     587.19574    629.60666    833.74045    227.16890    591.88199
 ROTOR OUTLET    603.39773    811.09676    654.61329    542.02320    253.83017

                   ROTOR      ABS MACH      REL MACH     REL TOTAL    REL TOTAL
                   SPEED       NUMBER        NUMBER        TEMP       PRESSURE

 ROTOR INLET      819.051         .506          .669      704.449     5829.034
 ROTOR OUTLET     795.853         .642          .518      701.350    10970.182

                  ABS FLOW     REL FLOW    STREAMTUBE                   FLOW
                   ANGLE        ANGLE         AREA        RADIUS     COEFFICIENT

 ROTOR INLET     21.15000     45.22772        .00511      1.83600       .60910
 ROTOR OUTLET    41.93288     22.81494        .00467      1.78400       .62591

 STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=   1.20800
 STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=    .92365
 ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=   1.21500
 ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=    .95400
 ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=   1.05962
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***************** 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=1.3886

 OVERALL ADIABATIC EFFICIENCY= .9223

 OVERALL TEMPERATURE RISE= 201.559

                1      2      3      4      5      6     IGV
 BET1SR(I)  42.03  41.27  42.97  44.23  44.78  45.23
 BET2SR(I)  31.78  24.65  21.98  22.13  22.85  22.81
 AINCSR(I)   -.69  -1.47   1.25   1.38    .78    .16
 ADEVSR(I)   5.99   7.48   8.86   8.37   8.52   8.38
 BET1SS(I)  33.20  36.82  38.13  39.55  40.54  41.93
 BET2SS(I)  21.89  19.09  19.33  20.18  21.15  34.86  15.61
 AINCSS(I)  -1.95  -3.29  -5.23  -5.45  -5.77  -6.78
 ADEVSS(I)   9.70   7.96   8.82   8.37   7.83   5.58
 TD(I)      518.7  541.1  566.1  600.5  639.4  679.7
 OMEGS(I)    .009   .021   .025   .028   .029   .024
 OMEGR(I)    .020   .021   .024   .028   .030   .036
```

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*******************   INITIAL FLOW COEFFICIENT-  .50000 (STAGE= 1 )  ********************

    STAGE TOTAL PRESSURE RATIO=     1.16790
    STAGE TOTAL TEMPERATURE RATIO=     1.05044
    STAGE ADIABATIC EFFICIENCY=     .89932

    STAGE FLOW COEFFICIENT= .500
    AXIAL VELOCITY= 482.10
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.16790
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.18781
    LOSS FACTOR IN ROTOR=     1.01167
    LOSS FACTOR IN STATOR=      .99536

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2116.80        2483.73        2472.21
STATIC PRESSURE            1822.02        2027.51        2105.98
TOTAL TEMPERATURE(GAS)     518.7000       544.8657       544.8657
STATIC TEMPERATURE(GAS)   496.9285       515.3151       521.3902
STATIC DENSITY(GAS)          .0687          .0737          .0757
STATIC DENSITY(MIXTURE)      .0716          .0768          .0789

AXIAL VELOCITY            482.0985       471.7651       487.8474
ABSOLUTE VELOCITY         500.9664       595.7508       530.9922
RELATIVE VELOCITY         694.5315       562.4474
BLADE SPEED               636.1474       670.0514       702.6172
TANG. COMP. OF ABS. VEL.  136.1924       363.8085
TANG. COMP. OF REL. VEL.  499.9550       306.2429
ACOUSTIC SPEED           1070.9380      1090.5707      1096.9841
ABSOLUTE MACH NUMBER         .4678          .5463          .4840
RELATIVE MACH NUMBER         .6485          .5157

FLOW COEFFICIENT             .5001          .4894          .5060
FLOW AREA                    .0104          .0099          .0093

ABSOLUTE FLOW ANGLE        15.7749        37.6381        23.2615
RELATIVE FLOW ANGLE        46.0417        32.9893
INCIDENCE                   3.3217         2.4881
DEVIATION                                  7.1993        11.0715
```

```
******************** INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  1 )  ****************

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

    STAGE TOTAL PRESSURE RATIO=      1.16790
    STAGE TOTAL TEMPERATURE RATIO=     1.05044
    STAGE ADIABATIC EFFICIENCY=       .89932

          **STAGE INLET**   **STAGE OUTLET**   **STAGE OUTLET**
                              (BEFORE INTER-     (AFTER INTER-
                               STAGE ADJUST-      STAGE ADJUST-
                               MENT)              MENT)
    XU=        .00000             .00000             .00000
    XW=             0                  0             .01801
    XWW=        .04000             .04000             .02199
    XWT=        .04000             .04000             .04000
    XAIR=        .96000             .96000             .96000
    XMETAN=             0                 0                  0
    XGAS        .96000             .96000             .96000
    WMASS=             0                  0             .00644
    WWMASS=         .01431            .01431             .00786
    WTMASS=         .01431            .01431             .01431
    AMASS=        .34340             .34340             .34340
    CHMASS=             0                 0                  0
    VMASS=        .00000             .00000             .00000
    GMASS=        .34340             .34340             .34340
    TMASS=        .35771             .35771             .35771
    WS=        .00000             .00000             .00000
    RHOA=        .07649             .07395             .06767
    RHOM=        .07160             .07702             .07902
    RHOG=        .06872             .07395             .07586
    TG=     518.70000          544.86572          544.86571
    TW=     513.70000          513.70000          513.70000
    TWW=     513.70000          513.70000          513.70012
    P=    2116.80000         2483.73050         2472.21005
    TB=     671.40656                  0          679.08227
    TDEW=     271.99506          273.28391          339.24784
```

```
********************  INITIAL FLOW COEFFICIENT-  .50000 (STAGE= 2 )  ********************

    STAGE TOTAL PRESSURE RATIO=     1.16781
    STAGE TOTAL TEMPERATURE RATIO=     1.05175
    STAGE ADIABATIC EFFICIENCY=      .87555

    STAGE FLOW COEFFICIENT= .505
    AXIAL VELOCITY= 486.86
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.16781
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.19311
    LOSS FACTOR IN ROTOR=      .98822
    LOSS FACTOR IN STATOR=      .98982

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2472.21        2916.76        2887.07
STATIC PRESSURE            2106.74        2255.26        2462.37
TOTAL TEMPERATURE(GAS)     544.8657       573.0631       573.0631
STATIC TEMPERATURE(GAS)   520.5178       533.9732       548.5689
STATIC DENSITY(GAS)          .0759          .0792          .0841
STATIC DENSITY(MIXTURE)      .0790          .0825          .0876

AXIAL VELOCITY            486.8556       516.0982       508.2930
ABSOLUTE VELOCITY         529.9329       685.3880       542.5448
RELATIVE VELOCITY         693.1121       573.7782
BLADE SPEED               702.6172       701.7250       732.5063
TANG. COMP. OF ABS. VEL.  209.2856       450.9981
TANG. COMP. OF REL. VEL.  493.3315       250.7269
ACOUSTIC SPEED           1095.9433      1110.0181      1125.0890
ABSOLUTE MACH NUMBER         .4835          .6175          .4822
RELATIVE MACH NUMBER         .6324          .5169

FLOW COEFFICIENT             .5050          .5354          .5273
FLOW AREA                    .0093          .0084          .0080

ABSOLUTE FLOW ANGLE        23.2615        41.1489        20.4692
RELATIVE FLOW ANGLE        45.3785        25.9111
INCIDENCE                   2.6385         1.0389
DEVIATION                                  8.7411         9.3392
```

```
********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  2 )  ******************
    STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

    STAGE TOTAL PRESSURE RATIO=      1.16781
    STAGE TOTAL TEMPERATURE RATIO=      1.05175
    STAGE ADIABATIC EFFICIENCY=      .87561

          **STAGE INLET**      **STAGE OUTLET**     **STAGE OUTLET**
                                (BEFORE INTER-       (AFTER INTER-
                                 STAGE ADJUST-        STAGE ADJUST-
                                 MENT)                MENT)
    XU=         .00000              .00000               .00012
    XW=         .01801              .01801               .02726
    XWW=         .02199              .02199               .01262
    XWT=        .04000               .04000               .03988
    XAIR=        .96000               .96000               .96000
    XMETAN=             0                   0                    0
    XGAS        .96000              .96000               .96012
    WMASS=         .00644              .00644               .00975
    WWMASS=         .00786              .00786               .00452
    WTMASS=         .01431              .01431               .01427
    AMASS=         .34340              .34340               .34340
    CHMASS=             0                   0                    0
    VMASS=         .00000              .00000               .00004
    GMASS=         .34340              .34340               .34344
    TMASS=         .35771              .35771               .35771
    WS=         .00000              .00000               .00012
    RHOA=         .08504              .07945               .07525
    RHOM=         .07160              .08276               .08779
    RHOG=         .07586              .07945               .08429
    TG=       544.86571          573.06306            573.06071
    TW=       513.70000          519.14631            519.16899
    TWW=        513.70012          513.70012            513.70036
    P=     2472.21005         2916.76359           2887.07247
    TB=       679.08227                  0            686.93158
    TDEW=        339.24784           341.32476            419.65418
```

```
*******************   INITIAL FLOW COEFFICIENT-  .50000 (STAGE= 3 )  *******************

    STAGE TOTAL PRESSURE RATIO=      1.21691
    STAGE TOTAL TEMPERATURE RATIO=      1.06493
    STAGE ADIABATIC EFFICIENCY=       .88732

    STAGE FLOW COEFFICIENT= .526
    AXIAL VELOCITY= 507.38
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.21691
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.24647
    LOSS FACTOR IN ROTOR=      .98667
    LOSS FACTOR IN STATOR=      .98789

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             2887.07        3556.35        3513.29
STATIC PRESSURE            2463.17        2688.47        3014.69
TOTAL TEMPERATURE(GAS)     573.0607       610.2670       610.2670
STATIC TEMPERATURE(GAS)   547.6584       565.1550       585.1747
STATIC DENSITY(GAS)          .0843          .0892          .0966
STATIC DENSITY(MIXTURE)      .0878          .0929          .1006

AXIAL VELOCITY            507.3826       544.2751       513.9069
ABSOLUTE VELOCITY         541.5777       736.6414       549.3895
RELATIVE VELOCITY         743.2430       592.3993
BLADE SPEED               732.5063       730.2758       768.1948
TANG. COMP. OF ABS. VEL.  189.3921       496.3922
TANG. COMP. OF REL. VEL.  543.1142       233.8835
ACOUSTIC SPEED           1124.0705      1141.8852      1161.9377
ABSOLUTE MACH NUMBER         .4818          .6451          .4728
RELATIVE MACH NUMBER         .6612          .5188

FLOW COEFFICIENT             .5263          .5646          .5331
FLOW AREA                    .0080          .0071          .0069

ABSOLUTE FLOW ANGLE        20.4692        42.3656        20.7047
RELATIVE FLOW ANGLE        46.9481        23.2540
INCIDENCE                   5.3281         -.9944
DEVIATION                                 10.1340        10.1947
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  3 )  *****************

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

    STAGE TOTAL PRESSURE RATIO=      1.21691
    STAGE TOTAL TEMPERATURE RATIO=      1.06490
    STAGE ADIABATIC EFFICIENCY=       .88760

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER- .   (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00012              .00012              .00077
    XW=         .02726              .02726              .03181
    XWW=         .01262              .01262              .00743
    XWT=         .03988              .03988              .03923
    XAIR=         .96000              .96000              .96000
    XMETAN=              0                   0                   0
    XGAS         .96012              .96012              .96077
    WMASS=         .00975              .00975              .01138
    WWMASS=         .00452              .00452              .00266
    WTMASS=         .01427              .01427              .01403
    AMASS=         .34340              .34340              .34340
    CHMASS=              0                   0                   0
    VMASS=         .00004              .00004              .00027
    GMASS=         .34344              .34344              .34367
    TMASS=         .35771              .35771              .35771
    WS=         .00012              .00012              .00080
    RHOA=         .09443              .08952              .08667
    RHOM=         .07160              .09323              .10063
    RHOG=         .08429              .08951              .09668
    TG=      573.06071          610.26699           610.25190
    TW=      519.16899          526.02007           526.13187
    TWW=      513.70036           513.70036           513.70075
    P=     2887.07247          3556.34709          3513.29461
    TB=      686.93158                   0          697.12854
    TDEW=     419.65418            423.67496           463.62629
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```
********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 4 )  ******************

    STAGE TOTAL PRESSURE RATIO=      1.23667
    STAGE TOTAL TEMPERATURE RATIO=      1.06871
    STAGE ADIABATIC EFFICIENCY=      .90751

    STAGE FLOW COEFFICIENT= .533
    AXIAL VELOCITY= 513.61
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.23667
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.26254
    LOSS FACTOR IN ROTOR=      .98671
    LOSS FACTOR IN STATOR=      .98960

                           *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE                3513.29        4390.45        4344.80
STATIC PRESSURE               3014.95        3322.28        3749.71
TOTAL TEMPERATURE(GAS)        610.2519       652.1841       652.1841
STATIC TEMPERATURE(GAS)      584.2131       604.1817       626.3816
STATIC DENSITY(GAS)             .0967          .1030          .1121
STATIC DENSITY(MIXTURE)         .1006          .1072          .1167

AXIAL VELOCITY               513.6087       549.3247       518.6059
ABSOLUTE VELOCITY            549.0705       760.6511       557.6792
RELATIVE VELOCITY            770.2922       598.5017
BLADE SPEED                  768.1948       763.7337       798.0839
TANG. COMP. OF ABS. VEL.     194.1249       526.1487
TANG. COMP. OF REL. VEL.     574.0699       237.5850
ACOUSTIC SPEED              1161.2398      1202.4310      1202.4238
ABSOLUTE MACH NUMBER            .4728          .6441          .4638
RELATIVE MACH NUMBER            .6633          .5068

FLOW COEFFICIENT                .5328          .5698          .5380
FLOW AREA                       .0069          .0061          .0059

ABSOLUTE FLOW ANGLE           20.7047        43.7655        21.5751
RELATIVE FLOW ANGLE           48.1816        23.3887
INCIDENCE                      5.3316        -1.2345
DEVIATION                                     9.6287         9.7651
```

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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  4 )  *****************

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

   STAGE TOTAL PRESSURE RATIO=     1.23667
   STAGE TOTAL TEMPERATURE RATIO=     1.06864
   STAGE ADIABATIC EFFICIENCY=      .90822

          **STAGE INLET**       **STAGE OUTLET**      **STAGE OUTLET**
                                 (BEFORE INTER-         (AFTER INTER-
                                  STAGE ADJUST-          STAGE ADJUST-
                                  MENT)                  MENT)
   XV=            .00077              .00077                .00248
   XW=            .03181              .03181                .03307
   XWW=            .00743              .00743                .00445
   XWT=            .03923              .03923                .03752
   XAIR=            .96000              .96000                .96000
   XMETAN=               0                    0                    0
   XGAS             .96077              .96077                .96248
   WMASS=             .01138              .01138                .01183
   WWMASS=             .00266              .00266                .00159
   WTMASS=             .01403              .01403                .01342
   AMASS=             .34340              .34340                .34340
   CHMASS=               0                    0                    0
   VMASS=             .00027              .00027                .00089
   GMASS=             .34367              .34367                .34429
   TMASS=             .35771              .35771                .35771
   WS=            .00080              .00080                .00259
   RHOA=            .10791              .10346                .10094
   RHOM=            .07160              .10763                .11655
   RHOG=            .09668              .10341                .11218
   TG=          610.25190          652.18409             652.14134
   TW=          526.13187          533.30984             533.59527
   TWW=          513.70075          513.70036             513.70137
   P=          3513.29461        4390.44609           4344.79698
   TB=          697.12854                0            708.50906
   TDEW=          463.62629          468.88156             498.37453
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********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 5 )  ********************

    STAGE TOTAL PRESSURE RATIO=     1.22899
    STAGE TOTAL TEMPERATURE RATIO=     1.06675
    STAGE ADIABATIC EFFICIENCY=      .90336

    STAGE FLOW COEFFICIENT= .539
    AXIAL VELOCITY= 519.37
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=     1.22899
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.25515
    LOSS FACTOR IN ROTOR=       .98250
    LOSS FACTOR IN STATOR=       .98967

                       *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE             4344.80        5395.45        5339.72
STATIC PRESSURE            3748.75        4131.68        4643.21
TOTAL TEMPERATURE(GAS)     652.1413       695.6709       695.6709
STATIC TEMPERATURE(GAS)   625.3469       646.6178       669.5503
STATIC DENSITY(GAS)          .1122          .1196          .1298
STATIC DENSITY(MIXTURE)      .1165          .1242          .1348

AXIAL VELOCITY            519.3675       547.1502       519.0957
ABSOLUTE VELOCITY         558.4980       770.3315       562.1291
RELATIVE VELOCITY         788.0677       599.7321
BLADE SPEED               798.0839       787.8235       819.0509
TANG. COMP. OF ABS. VEL.  205.3714       542.2521
TANG. COMP. OF REL. VEL.  592.7125       245.5713
ACOUSTIC SPEED           1202.5460      1243.7812      1244.3279
ABSOLUTE MACH NUMBER         .4644          .6300          .4518
RELATIVE MACH NUMBER         .6553          .4904

FLOW COEFFICIENT             .5387          .5676          .5385
FLOW AREA                    .0059          .0053          .0051

ABSOLUTE FLOW ANGLE        21.5751        44.7424        22.5764
RELATIVE FLOW ANGLE        48.7734        24.1714
INCIDENCE                    4.7734        -1.5676
DEVIATION                                  9.8414         9.2564
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********************  INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  5 )  ****************
    STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

    STAGE TOTAL PRESSURE RATIO=     1.22899
    STAGE TOTAL TEMPERATURE RATIO=     1.06664
    STAGE ADIABATIC EFFICIENCY=      .90448

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                                (BEFORE INTER-     (AFTER INTER-
                                 STAGE ADJUST-      STAGE ADJUST-
                                 MENT)              MENT)
    XV=         .00248              .00248              .00559
    XW=         .03307              .03307              .03080
    XWW=         .00445              .00445                   0
    XWT=         .03752              .03752              .03080
    XAIR=         .96000              .96000              .96360
    XMETAN=              0                   0                   0
    XGAS         .96248              .96248              .96920
    WMASS=         .01183              .01183              .01098
    WWMASS=         .00159              .00159                   0
    WTMASS=         .01342              .01342              .01098
    AMASS=         .34340              .34340              .34340
    CHMASS=              0                   0                   0
    VMASS=         .00089              .00089              .00199
    GMASS=         .34429              .34429              .34539
    TMASS=         .35771              .35771              .35637
    WS=         .00259              .00259              .00580
    RHOA=         .12487              .12017              .11734
    RHOM=         .07160              .12465              .13382
    RHOG=         .11218              .11998              .12971
    TG=      652.14134           695.67091           695.59860
    TW=      533.59527           540.88803           541.37489
    TWW=      513.70137           513.70036           513.70155
    P=     4344.79698          5395.45042          5339.72029
    TB=      708.50906                   0           722.80827
    TDEW=      498.37453           496.93587           520.46557
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*********************   INITIAL FLOW COEFFICIENT=  .50000 (STAGE= 6 )  ********************

    STAGE TOTAL PRESSURE RATIO=      1.21378
    STAGE TOTAL TEMPERATURE RATIO=     1.06246
    STAGE ADIABATIC EFFICIENCY=       .90205

    STAGE FLOW COEFFICIENT= .540
    AXIAL VELOCITY= 521.03
    ROTOR SPEED= 964.04

    STAGE TOTAL PRESSURE RATIO(ACTUAL)=      1.21378
    STAGE TOTAL PRESSURE RATIO(IDEAL)=     1.23841
    LOSS FACTOR IN ROTOR=       .97381
    LOSS FACTOR IN STATOR=       .99141

                        *ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*
TOTAL PRESSURE              5339.72        6537.40        6481.27
STATIC PRESSURE             4643.05        5093.62        5499.02
TOTAL TEMPERATURE(GAS)      695.5986       739.0448       739.0448
STATIC TEMPERATURE(GAS)    668.5834       690.0533       706.4154
STATIC DENSITY(GAS)           .1297          .1379          .1454
STATIC DENSITY(MIXTURE)       .1338          .1422          .1500

AXIAL VELOCITY             521.0291       536.5871       508.8163
ABSOLUTE VELOCITY          564.2700       771.9356       629.9781
RELATIVE VELOCITY          796.4797       588.1877
BLADE SPEED                819.0509       795.8534          .5000
TANG. COMP. OF ABS. VEL.  216.6319       554.9404
TANG. COMP. OF REL. VEL.  602.4190       240.9130
ACOUSTIC SPEED            1248.0901      1282.9307      1282.9214
ABSOLUTE MACH NUMBER          .4521          .6088          .4910
RELATIVE MACH NUMBER          .6382          .4639

FLOW COEFFICIENT              .5405          .5566          .5307
FLOW AREA                     .0051          .0047          .0047

ABSOLUTE FLOW ANGLE         22.5764        45.9633        36.1308
RELATIVE FLOW ANGLE         49.1436        24.1788
INCIDENCE                     4.0736        -2.7467
DEVIATION                                   9.7488         6.8508
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********************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  6 )  *****************

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

    STAGE TOTAL PRESSURE RATIO=     1.21378
    STAGE TOTAL TEMPERATURE RATIO=     1.06219
    STAGE ADIABATIC EFFICIENCY=         .90445

           **STAGE INLET**    **STAGE OUTLET**    **STAGE OUTLET**
                               (BEFORE INTER-      (AFTER INTER-
                                 STAGE ADJUST-       STAGE ADJUST-
                                 MENT)               MENT)
    XV=         .00559              .00559              .01742
    XW=         .03080              .03080              .01898
    XWW=              0                   0                   0
    XWT=         .03080              .03080              .01898
    XAIR=         .96360              .96360              .96360
    XMETAN=              0                   0                  0
    XGAS         .96920              .96920              .98102
    WMASS=         .01098              .01098              .00676
    WWMASS=              0                   0                  0
    WTMASS=         .01098              .01098              .00676
    AMASS=         .34340              .34340              .34340
    CHMASS=              0                   0                  0
    VMASS=         .00199              .00199              .00621
    GMASS=         .34539              .34539              .34961
    TMASS=         .35637              .35637              .35637
    WS=         .00580              .00580              .01807
    RHOA=        .14388              .13869              .12770
    RHOM=        .07160              .14259              .14690
    RHOG=        .12971              .13821              .14412
    TG=      695.59860           739.04479          738.85892
    TW=      541.37489           548.44179          549.82046
    TWW=      513.70155           513.70036          513.70155
    P=     5339.72029          6537.39986         6481.26579
    TB=      722.80827                   0          734.62173
    TDEW=      520.46557           526.83752          564.70213
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********** OVERALL PERFORMANCE *********

 INITIAL FLOW COEFFICIENT= .50000

 CORRECTED SPEED=51120.0     1.000 FRACTION OF DEIGN CORRECTED SPEED

 INITIAL WATER CONTENT(SMALL DROPLET)=    0
 INITIAL WATER CONTENT(LARGE DROPLET)= .040
 INITIAL WATER CONTENT(TOTAL)= .040
 INITIAL RELATIVE HUMIDITY=   .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=  .358( 3.018)

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

 OVERALL TOTAL PRESSURE RATIO=3.0618

 OVERALL TOTAL TEMPERATURE RATIO=1.4244

 OVERALL ADIABATIC EFFICIENCY= .8805

 OVERALL TEMPERATURE RISE OF GAS PHASE= 220.159
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