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ANALYSIS OF GEOMETRY AND DESIGN POINT PERFORMANCE OF AXIAL FLOW TURBINES

Part II - Computer Program

by M. Platt and A. F. Carter

Prepared by
NORTHERN RESEARCH AND ENGINEERING CORPORATION
Cambridge, Mass.
for Lewis Research Center

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FOREWORD

The research described herein, which was conducted by Northern Research and Engineering, was performed under NASA Contract NAS 3-9418. The work was done under the technical management of Mr. Edward L. Warren, Airbreathing Engines Division, NASA-Lewis Research Center, with Mr. Arthur J. Glassman, Fluid System Components Division, NASA-Lewis Research Center, as technical consultant. Dr. D. M. Dix directed the work for Northern Research and Engineering. The report was originally issued as Northern Research and Engineering Report 1125-2, January 1968.

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ANALYSIS OF GEOMETRY AND DESIGN POINT PERFORMANCE OF AXIAL FLOW TURBINES

II - COMPUTER PROGRAM

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Northern Research and Engineering Corporation

SUMMARY

This volume is the second part of a two-part report on the analysis of the design-point performance and associated geometry of axial flow turbines. It concerns the computer program which has been developed to solve the equations governing flow in an axial turbine. A complete description of the program, an indication of its usage, and sample results obtained from the program are included.

The computer program follows directly from the analysis and the loss coefficient correlation which were developed in the first part of this report (NASA CR-1181). The program can be used to analytically investigate the effects of changes in the design variables. The variables include: number of stages, annulus geometry, work distribution, stage work split, radial distribution of stator exit whirl velocity or flow angle, radial variations of the meridional components of streamline slope and curvature, and blade element loss characteristics when values other than the internally computed total-pressure-loss coefficients are considered necessary for the analysis. The coefficients of the total-pressure-loss coefficient correlations are also input items and, therefore, can be used as analysis variables.

INTRODUCTION

The basic equations which govern the design-point performance of an axial flow turbine were developed in Reference 1. These equations must be solved by numerical methods which can be lengthy and time-consuming. Therefore, it is of considerable importance that they be solved using a digital computer.

Program TD is an integrated computer program which has been developed for the above purpose. It is written in Version 13 of the Fortran IV language for use with the IBM 7090/7094 data processing system. The computer program is capable of analyzing both single and multispool units (a maximum of three spools is allowed), and each spool may have up to eight stages. The absolute and relative flow fields are computed at the first stator inlet, at each interblade row plane, and at the final rotor exit; these axial locations are referred to throughout the report as the design stations of the turbine. The effects of the radial variation of the following quantities are taken into account: inlet conditions, streamline angle of inclination and curvature, loss coefficient or efficiency, whirl velocity or angle, and power output. Further, the effects of coolant flows, interfilament mixing, and a station-to-station variation of the specific heat can be included. As additional features, the program allows for: (1) the internal calculation of losses based on the correlation which has been developed for pressure-loss coefficient, and (2) either subsonic or supersonic solutions for the absolute velocity (except when the whirl velocity is specified and the mass averaged value of the meridional velocity component is supersonic).

Report Arrangement

The volume is, essentially, divided into two sections. The main body of the volume consists of a functional description of the computer program. The functional description is suitable for personnel who require knowledge of the general content of the program and the mechanics of operating the program. The appendices to the volume, on the other hand, contain an operational description of the computer program. The operational description is suitable for personnel who require detailed knowledge of the program.

The main body of the report supplements the Part I report, which presents the analysis on which the computer program is based. The description of the program in the main body provides the following information:

1. Capabilities and limitations of the program
2. Over-all program logic
3. Description and discussion of input data
4. Normal output
5. Error messages
6. Miscellaneous operational information
7. Sample cases

The appendices present the operational description of the computer program. The first appendix contains a step-by-step presentation of the over-all analysis procedure and a discussion of the numerical techniques used. Appendix II contains the CØMMØN Fortran nomenclature. The third appendix describes the main program, and each of the following appendices are devoted to the individual subroutines of the program. The following information is included for each of the subroutines:

1. Function of the subroutine
2. List of calling and called subroutines
3. External inputs and outputs (quantities transmitted by READ and WRITE statements)
4. Internal inputs and outputs (quantities transmitted to and from the calling subroutine through CØMMØN statements and arguments in the SUBRØUTINE statement)
5. Fortran nomenclature
6. Internal structure of the subroutine related to the analysis procedure of Appendix I
7. Fortran listing

Capabilities and Limitations of the Program

The basic assumptions used in the development of the analysis method are:

1. The flow is inviscid and axisymmetric at each of the design stations.
2. The effect on radial equilibrium of any variation of meridional velocity in the meridional direction at the design stations is negligible.
3. The value of specific heat at constant pressure is radially constant at all design stations.
4. The meridional components of streamline slope and curvature vary linearly with radius between values established at the annulus walls, when slopes and curvatures are internally computed, or are directly specified as a function of radius by input data.

The program will compute the standard turbine design parameters at a preselected number of streamlines. These parameters will be consistent with the requirement of radial equilibrium, the definition of blade element performance being used for the analysis, and the input specifications of design requirements and analysis variables when a valid solution of the design problem exists. The general capabilities have been stated earlier. When used for the analysis of a single spool, designs for any number of sets of analysis variables may be computed consecutively.

It is obvious that there are design specifications for which there are no valid solutions of the design problem; the meridional velocity must always be positive and less than the value corresponding to a zero static temperature. In the event that the design specification (including the definition of blade element losses being used in the analysis) produces substantial local gradients of meridional velocity, it is possible that numerical accuracy of the program will preclude a valid solution. Experience with the program has shown that for some arbitrary specifications of the radial variation of stator exit whirl velocities or flow angles and the radial variation of stage power output the program will produce output which is invalid. In general, such outputs will be obtained when no valid solution is possible. These cases are readily identifiable as mechanically unacceptable designs by inspection of the computed flow angles which will reflect the severe gradients of meridional velocity. Where the validity of the solution is in doubt in these border-line cases, inspection of the computed static pressures will indicate the validity of the solution; for valid solutions, the radial variation of static pressure will be consistent with the radial equilibrium requirement whereas invalid solutions will invariably display a discontinuity in the static pressure profile. This point is discussed in greater detail later in the report.

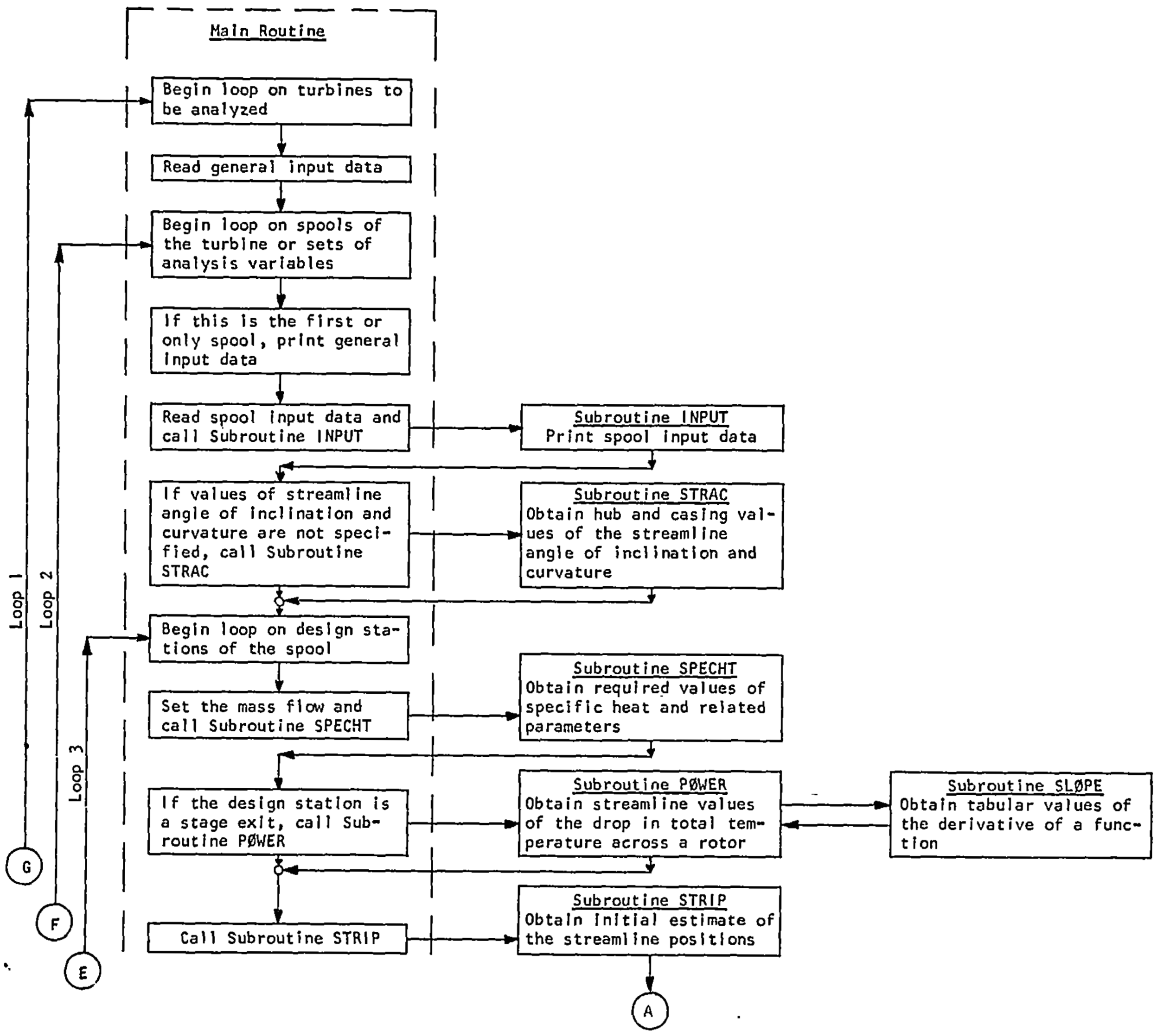
OVER-ALL PROGRAM LOGIC

Program TD is composed of a main routine and nineteen subroutines. Fifteen subroutines can be classified as specialized subroutines; they are INPUT, STRAC, SPECHT, PØWER, STRIP, STRVAL, VMNTL, RADEQL, DERIV, VMSUB, REMAIN, SETUP, ØUTPUT, PLC, and LCNV. The remaining four subroutines are classified as general service subroutines; they are IIAP1, SLØPE, RUNKUT, and SIMEQ. Information is transferred within the computer program through blocks of CØMMØN and as arguments of certain subroutines.

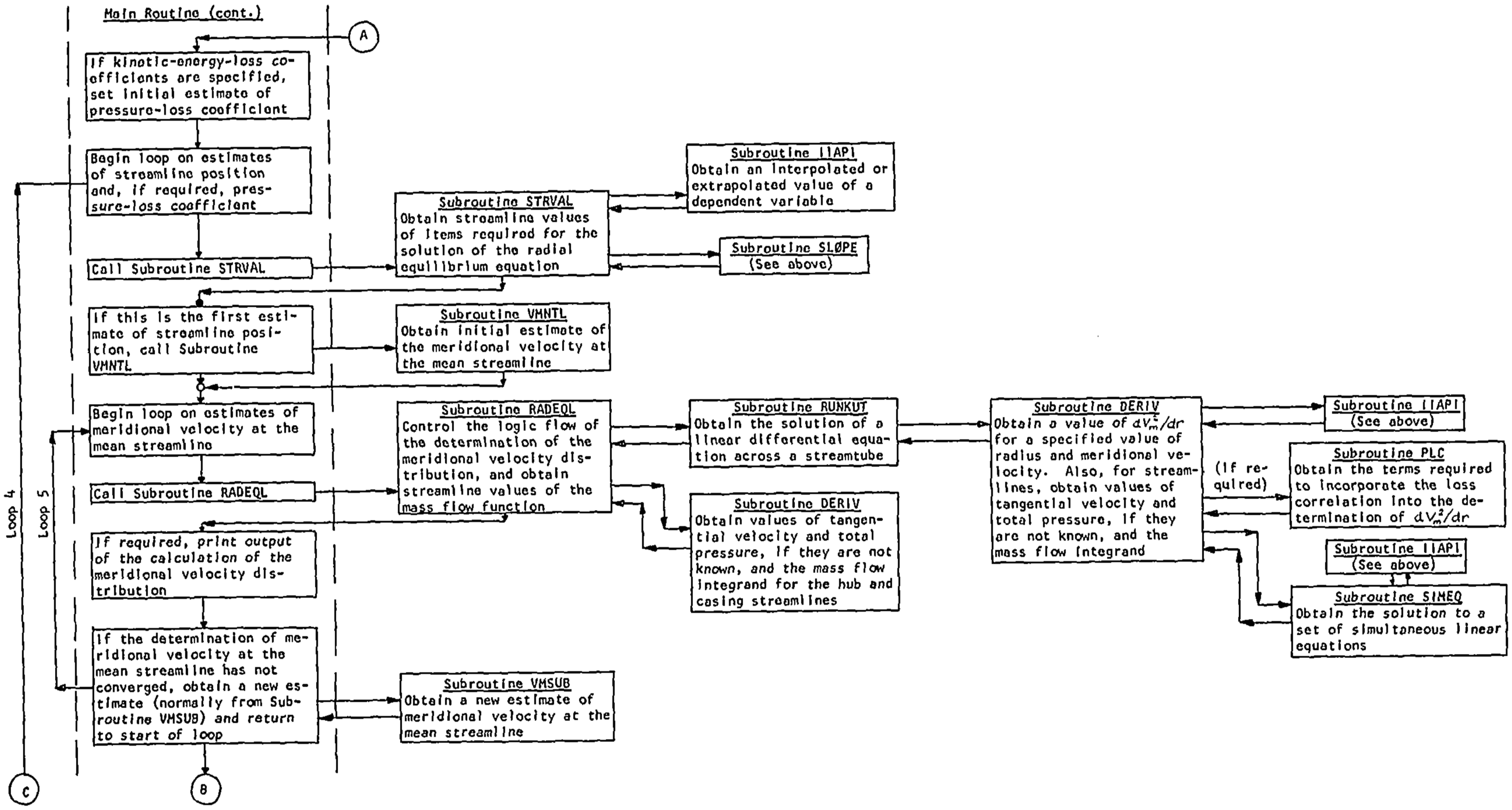
An over-all flow diagram for Program TD is given below. This diagram is intended to illustrate the purpose of each section of the program and the general relationship between the sections. (For a detailed description of CØMMØN, the main routine, and each subroutine, see the appendices to the report.) Certain liberties have been taken with the actual logic flow to avoid confusion in the flow diagram. For example, Subroutines IIAP1 and SLØPE are each called a number of times by Subroutine STRVAL but they are shown only once. Similarly, Subroutines REMAIN and ØUTPUT are called in tandem by the main routine a number of times; again, they are shown only once in tandem. In conjunction with this simplification, the alterations to the logic flow when difficulties have been encountered in obtaining a solution are not shown. Finally, some elementary functions performed by the program are not included.

It can be seen that the over-all control of the calculation procedure is maintained by the main routine while Subroutine RADEQL maintains control over the calculational procedure for the meridional velocity distribution. The logic flow begins at the start of the main routine, and the calculations are performed within five major nested loops. The loops are numbered 1 through 5 in the following flow diagram (pages 9, 10, 11, and 12). The outermost loop (1) is performed, in turn, for each turbine to be analyzed. The next loop (2) within the nest is performed, in turn, for each spool of the turbine or, if there is only one spool, for each set of analysis variables. The next loop (3) is performed, in turn, for each design station of the spool. The iterative determination of streamline positions and, if kinetic-energy-loss coefficients are specified at the design station, pressure-loss coefficients constitutes the next loop (4). The innermost loop (5) shown on the flow diagram is the iterative determination of the meridional velocity at the mean streamline which satisfies continuity. In addition, within this loop at various stages of the calculations are loops performed for each streamline of the design station.

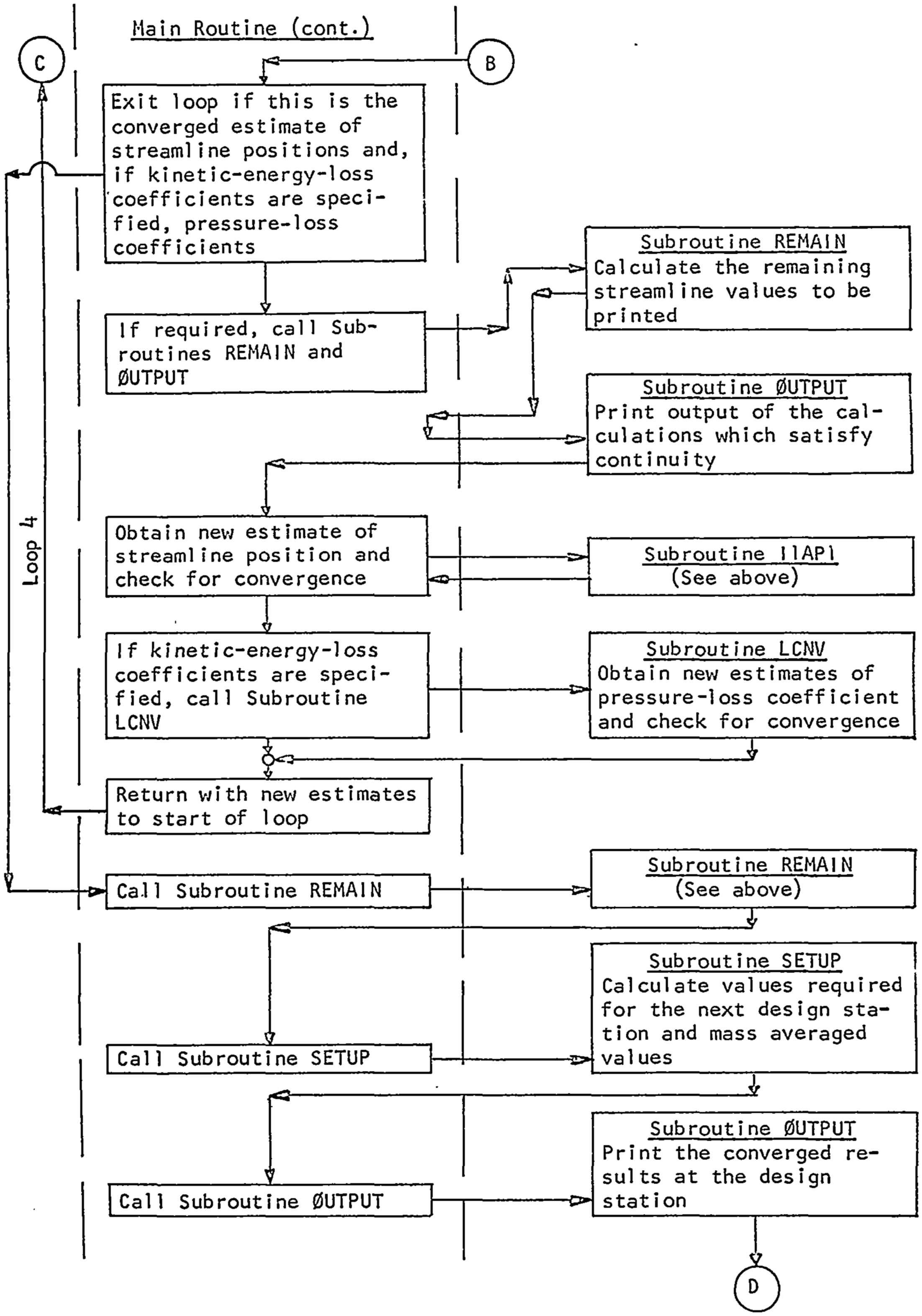
The individual steps of the analysis are detailed in Appendix I which also specifies the location of each step within the over-all flow diagram.



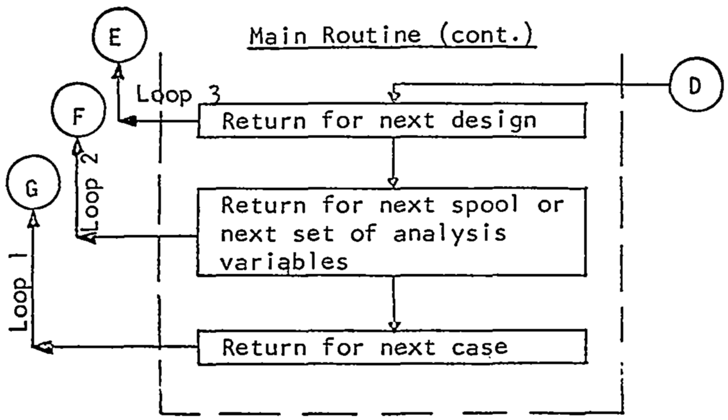
OVER-ALL FLOW DIAGRAM FOR PROGRAM TD



OVER-ALL FLOW DIAGRAM FOR PROGRAM TD (CONTINUED)



OVER-ALL FLOW DIAGRAM FOR PROGRAM TD (CONTINUED)



OVER-ALL FLOW DIAGRAM FOR PROGRAM TD (CONTINUED)

INPUT DATA

Description of Input Data

The physical input data used by Program TD can be divided into three categories: general design requirements, spool design requirements, and spool analysis variables. Input data in the first category are specified for the turbine as a unit. Input data in the latter two categories are specified for each spool of the turbine, if there is more than one spool, or for each set of analysis variables to be considered. In addition, various other input data which are necessary to obtain a solution must be specified.

The general design requirements of the turbine consist of:

1. Number of spools
2. Gas constant of the working fluid
3. Mass flow at the inlet of the turbine
4. Flow conditions at the inlet of the turbine (total temperature, total pressure, and flow angle as a function of radius)

The spool design requirements consist of:

1. Rotative speed
2. Power output

Finally, the spool analysis variables consist of:

1. Number of stages
2. Power output of each stage
3. Specific heat at spool inlet and each blade row exit design station
4. Annulus geometry and axial position of each station (the stations include one upstream of the first stator and one

downstream of the last rotor, as well as the standard design stations), or annulus geometry and streamline geometry (angle of inclination and curvature as a function of radius) at each design station

5. Mass flow and, if desired, total temperature of the coolant added in each blade row if the turbine is cooled
6. Streamline values of the mixing coefficient for each blade row if interfilament mixing is considered
7. Whirl velocity or flow angle as a function of radius at each stator exit
8. Streamline values of the power output distribution at each stage exit if a nonuniform distribution is desired
9. Total-pressure or kinetic-energy-loss coefficient as a function of radius at each stator exit, or additional loss factor, if desired, as a function of radius at each stator exit when total-pressure-loss coefficient is calculated internally
10. Stage efficiency, rotor efficiency, total-pressure-loss coefficient, or kinetic-energy-loss coefficient as a function of radius at each stage exit, or additional loss factor, if desired, as a function of radius at each stage exit when the total-pressure-loss coefficient is calculated internally

Detailed Description of Input Data

The information required to prepare the input data for a typical case is furnished below. This information contains a description of each input item as well as a description of the form in which these items are written on input data sheets. It should be noted that the units of the input items are not consistent but, rather, are those units which have found common usage. The units of each input item are included in the description of the item.

The first group of input items read by Program TD consists of a description of the case and the general input options. These items, which appear in the following table, are read into the program using FØRMAT statements. The case description given on the first card is read as an alphanumeric field; any combination of numbers, capital letters, punctuations, or blanks may be used. The general input options are read as integer fields; *these numbers may never contain a decimal point.*

Line	Location	Fortran Symbol	Description
1	1-72	CØMENT	A statement describing the case to be considered; this may not be omitted but may be left blank
2	6	ICØEF	Indicator: ICØEF=0 if total-pressure-loss coefficients are either specified in the input data or calculated internally from the loss correlation ICØEF=1 if kinetic-energy-loss coefficients are specified in the input data
	12	ISPEC	Indicator: ISPEC=0 if values of a loss parameter as a function of radius are specified at each blade row exit ISPEC=1 if streamline values of total-pressure-loss coefficient are calculated from the internal correlation <u>without</u> an additional loss factor at each blade row exit ISPEC=2 if streamline values of total-pressure-loss coefficient are calculated from the internal

Line	Location	Fortran Symbol	Description
			correlation with an additional loss factor at each blade row exit (this item may be left blank if ICØEF=1)
	18	ILØSS	Indicator: ILØSS=0 if values of loss coefficient as a function of radius are specified at each stage exit ILØSS=1 if values of rotor isentropic efficiency as a function of radius are specified at each stage exit ILØSS=2 if values of stage isentropic efficiency as a function of radius are specified at each stage exit (this item may be left blank if ISPEC=1 or 2)
	24	IWRL	Indicator: IWRL=0 if values of whirl velocity, fps, as a function of radius are specified at each stator exit IWRL=1 if values of flow angle, deg, as a function of radius are specified at each stator exit and only subsonic solutions are desired IWRL=2 if values of flow angle, deg, as a function of radius are specified at each stator exit and a supersonic solution is desired at one or more stator exits
	30	ICØØL	Indicator: ICØØL=0 if a coolant schedule is not specified in the input data ICØØL=1 if a coolant mass flow schedule is specified in the input data ICØØL=2 if a coolant mass flow and total temperature schedule are specified in the input data
	36	IMIX	Indicator: IMIX=0 if a mixing schedule is not specified in the input data

Line	Location	Fortran Symbol	Description
			IMIX=1 if a mixing schedule is specified in the input data
	42	ISTRAC	Indicator: ISTRAC=0 if the streamline angles of inclination and curvatures are calculated internally at each design station ISTRAC=1 if values of streamline angle of inclination and curvature as a function of radius are specified at each design station
	48	IDLETE	Indicator: IDLETE=0 if only the converged results of the iteration loop on streamline position are to be printed at each design station IDLETE=1 if the results of each pass through the iteration loop on streamline position are to be printed at each design station
	54	IEXTRA	Indicator: IEXTRA=0 if the results of the passes through the iteration loop on meridional velocity at the mean streamline are <u>not</u> to be printed IEXTRA=1 if the results of the passes through the iteration loop on meridional velocity at the mean streamline are to be printed when the results of a pass through the iteration loop on streamline position are to be printed

The remaining input items are read into Program TD using NAMELIST statements. Input data referring to a NAMELIST statement begins with a $ in the second location on a new line, immediately followed by the NAMELIST name, immediately followed by one or more blank characters. Any combination of three types of data items may then follow. The data items must be separated by commas. If more than one line is needed for the input data, the last item on each line, except the last line, must be a number followed by a comma. The first location on each line should always be left blank since it is ignored. The end of a group of data items is signaled by a $ anywhere except in the first location of a line. The form that data items may take is:

1. Variable name = constant, where the variable name may be an array element or a simple variable name. Subscripts must be integer constants.
2. Array name = set of constants separated by commas where k* constant may be used to represent k consecutive values of a constant. The number of constants must be equal to the number of elements in the array.
3. Subscripted variable = set of constants separated by commas where, again, k* constant may be used to represent k consecutive values of a constant. This results in the set of constants being placed in consecutive array elements, starting with the element designated by the subscripted variable.

The namelist NAM1 is used to read the input items which include the general design requirements. The items in NAM1 are as follows:

Fortran Symbol	Input Item	Description
NSPØØL	n''	Number of spools of the turbine being considered; 1, 2, or 3 spools are allowed
NAV		Number of sets of analysis variables; any number is allowed if NSPØØL=1, but only one set of analysis variables is allowed if NSPØØL > 1 and NAV need not be specified

Fortran Symbol	Input Item	Description
NLINES	n	Number of streamlines to be used in the calculations (including the hub and casing streamlines); any odd number from 3 to 17 is allowed but 9 is recommended
GASC	R	Gas constant of the working fluid, ft lbf per lbm deg R
FLWM	$(w_T)_{inlet}$	Mass flow rate at the inlet of the turbine, lbm per sec
NLT		Number of radii at which the inlet conditions of the turbine are specified; any number from 1 to 17 is allowed
(RLT(J), J=1,NLT)	r_{inlet}	Radial coordinates at which the inlet conditions of the turbine are specified, in; the values of RLT must be monotonically increasing
(TØLT(J), J=1,NLT)	$(T_o)_{inlet}$	Values of the absolute total temperature at the inlet of the turbine corresponding to the radial coordinates RLT, deg R
(PØLT(J), J=1,NLT)	$(P_o)_{inlet}$	Values of the absolute total pressure at the inlet of the turbine corresponding to the radial coordinates RLT, psi
(BETLT(J), J=1,NLT)	β_{inlet}	Values of the absolute flow angle at the inlet of the turbine corresponding to the radial coordinates RLT, deg

The namelist NAM2 is used to read the input items for a spool, including the spool design requirements and the spool analysis variables. Each spool of the turbine, or each set of analysis variables are specified in separate namelist groups. The items in NAM2 are as follows:

Fortran Symbol	Input Item	Description
RPM	Ω	Rotative speed of the spool, rpm

Fortran Symbol	Input Item	Description
HP	P_T	Power output of the spool, hp
NSTG	$(n'-1)/2$	Number of stages on the spool; any number from 1 to 8 is allowed
(FHP(I), I=1,NSTG)	$P'_{Ti''}$	Power output of each stage of the spool, expressed as a fraction of the total power output of the spool
(CP(I), I=1,NDSTAT)	c_{pi}	Specific heat at constant pressure of the working fluid at each design station of the spool (where NDSTAT=2*NSTG+1), Btu per lbm deg R

If ISTRAC=1, the following three items should be omitted.

Fortran Symbol	Input Item	Description
(XSTAT(I), I=1,NSTAT)	x_i	Axial coordinate of each station of the spool (where NSTAT=2*NSTG+3), in
(RANN(I,1), I=1,NSTAT)	r_{hi}	Radial coordinate of the hub at each station of the spool, in
(RANN(I,2), I=1,NSTAT)	r_{ci}	Radial coordinate of the casing at each station of the spool, in

If ISTRAC=0, the following six items should be omitted.

Fortran Symbol	Input Item	Description
(RANN(I,1), I=1,NDSTAT)	r_{hi}	Radial coordinate of the hub at each design station of the spool, in
(RANN(I,2), I=1,NDSTAT)	r_{ci}	Radial coordinate of the casing at each design station of the spool, in
NSTRAC		Number of radii at which streamline angles of inclination and curvatures are specified at each design station of the spool; any number from 1 to 17 is allowed
((RSTRAC(J,I), J=1,NSTRAC), I=1,NDSTAT)	r_i	Radial coordinates at which streamline angles of inclination and curvatures are specified at each design station of the spool, in;

Fortran Symbol	Input Item	Description
		the values of RSTRAC at each design station must be monotonically increasing
((ASTR(J,I), J=1,NSTRAC), I=1,NDSTAT)	A_i	Values of the streamline angle of inclination at each design station of the spool corresponding to the radial coordinates RSTRAC, deg
((CSTR(J,I), J=1,NSTRAC), I=1,NDSTAT)	$(1/r_m)_i$	Values of the streamline curvature at each design station of the spool corresponding to the radial coordinates RSTRAC, per in
(FLWCN(I), I=1,NBR)	$w'_{ci'}$	Mass flow of the coolant added in each blade row of the spool (where NBR=2*NSTG), expressed as a fraction of the inlet mass flow of the turbine; this item should be omitted if ICØØL=0
(TØC(I), I=1,NBR)	$(T_{oc})_{i'}$	Absolute total temperature of the coolant added in each blade row of the spool, deg R; this item should be omitted if ICØØL=0 or 1
((XMIX(J,I), J=1,NLINES), I=1,NBR)	$(X_{mi'})_j$	Streamline values of the mixing coefficient for each blade row of the spool; this item should be omitted if IMIX=0
NXT		Number of radii at which the exit conditions of each blade row of the spool are specified; any number from 1 to 17 is allowed
(ISØNIC(I), I=1,NSTG)		Indicator: ISØNIC(I)=0 if a subsonic solution is desired at a stator exit of the spool ISØNIC(I)=1 if a supersonic solution is desired at a stator exit of the spool (this item should be omitted if IWRL=0 or 1)

Fortran Symbol	Input Item	Description
((RNXT(J,I), J=1,NXT), I=1,NSTG)	r_i	Radial coordinates at which the exit conditions of each stator of the spool are specified, in; the values of RNXT at each stator exit must be monotonically increasing
((WRL(J,I), J=1,NXT), I=1,NSTG)		Values of the quantity indicated by IWRL at each stator exit of the spool corresponding to the radial coordinates RNXT
(IPØF(I), I=1,NSTG)		Indicator: IPØF(I)=0 if a uniform power output distribution is desired at a stage exit of the spool; IPØF(I)=1 if a nonuniform power output distribution is desired at a stage exit of the spool
((PØF(J,I), J=1,NLINES), I=1,NSTG)	P'_{ij}	Streamline values of the nondimensional power output function at each stage exit of the spool (the value of PØF(1,I) should be 0 and PØF(NLINES,I) should be 1); this item may be omitted for those stages where IPØF(I)=0

If ISPEC=1, the following three items should be omitted.

Fortran Symbol	Input Item	Description
((YØSS(J,2*I-1), J=1,NXT), I=1,NSTG)		Values of the loss coefficient (if ISPEC=0) or an additional loss factor (if ISPEC=2) at each stator exit of the spool corresponding to the radial coordinates RNXT
((RSXT(J,I), J=1,NXT), I=1,NSTG)	r_i	Radial coordinates at which the exit conditions of each stage of the spool are specified; the values of RSXT at each stage exit must be monotonically increasing
((YØSS(J,2*I), J=1,NXT), I=1,NSTG)		Values of the quantity indicated by ILØSS (if ISPEC=0) or an additional loss factor (if ISPEC=2) at each stage exit of the spool corresponding to the radial coordinates RSXT

Fortran Symbol	Input Item	Description
		If ISPEC=0, the following item should be omitted.
(YCØN(I), I=1,9)	a	Value of the nine constants which define the internal loss correlation

This completes the input data for a single spool, one spool of a multispool design, or one set of analysis variables. For each new case the complete input specification from "line 1", the comment card, will be required. For additional spools or sets of analysis variables, the input specification returns to the beginning of the NAM2 namelist. When more than one set of analysis variables is used, any quantity which is not explicitly reset will remain unchanged from the value previously specified.

Discussion of Input Data

The following point-by-point discussion of the input data contains suggestions for the most efficient use of Program TD. The items are discussed in the same order as they appear in the Detailed Description of Input Data. In several instances, reference is made to a preliminary design calculation. These calculations should be performed before the preparation of any input data for a new design. Four typical input data sheets are shown later in the report in the section devoted to sample cases.

Case Description and General Input Options

1. ICØEF - The specification of kinetic-energy-loss coefficients requires the computer program to determine the comparable total-pressure-loss coefficients iteratively. Hence, ICØEF=1 should only be used for those cases in which it

would be much more difficult to specify the total-pressure-loss coefficients.

2. ISPEC - A valid comparison of alternative designs requires consistency between the computed flow parameters and the anticipated level of loss. Hence, the use of the option to internally compute total-pressure-loss coefficients from the flow parameters and a loss correlation defined by the coefficients of the loss correlation is recommended. However, it should be noted that the use of the internal loss correlation can increase the difficulty of obtaining a solution in some cases. These cases occur when either stator exit whirl distributions are specified that require a large gradient of meridional velocity to maintain radial equilibrium, or when an element of rotor blading is close to its limiting loading. (This point is further discussed later in the report.) The additional loss factor should be used to increase the over-all loss level when excessive losses due to tip clearance, trailing edge thickness, low aspect ratio, and so forth, are expected. Specified loss parameters, on the other hand, can be used for the preliminary assessment of a design, the assessment of loss level variations, and the assessment of test data from an existing design.

3. ILØSS - In most cases, ILØSS should be equal to 0. ILØSS=1 or 2 can be used for the assessment of test data from an existing design.

4. IWRL - The specification of flow angle is usually preferred since it provides greater control of the stator geometry.

The preliminary design calculation should determine whether supersonic solutions will be required at one or more stator exits.

5. ICØØL - The preliminary design calculation should also be used to determine if the use of a coolant is required. The gross effects of the coolant mass flow and the temperature of the coolant are included in the analysis to increase the validity of the solution.

6. IMIX - The specification of a mixing schedule will reduce the adverse effects experienced when the total-pressure profile degenerates after a number of blade rows. Experimental data are required in this area.

7. ISTRAC - Streamline angles of inclination and curvature should be calculated internally to reduce the input data requirements unless better information is available or simple radial equilibrium is to be considered.

8. IDLETE - In the initial phases of a design, IDLETE=1 should be used to obtain as much information as possible. As a design is refined, IDLETE=0 will usually provide sufficient information.*

9. IEXTRA - In almost all cases, IEXTRA should have the same value as IDLETE.*

General Input Data

10. NSPØØL - The initial phases of a design should probably

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* Additional output is described in the following chapter.

consider the turbine as a unit. However, as noted previously, NSPØØL=1 is required if a number of sets of analysis variables is to be investigated.

11. NLINES - Since the accuracy of the calculations should improve as the number of streamlines is increased, a large number of streamlines should be used if substantial radial gradients are specified in the input data and a small number of streamlines should be used if minimal radial gradients are specified.

12. NLT - Set NLT=1 if the turbine inlet conditions do not vary with radius. If the inlet conditions are the output of a previous run, NLT should be set equal to number of streamlines used in that output. Otherwise, NLT should increase as the magnitude of the radial gradients increases.

13. RLT - If NLT=1, any value for RLT will suffice. If the inlet conditions are the output of a previous run, RLT should be specified to be the streamline radial coordinates (proceeding from the hub to the casing) of that output. Otherwise, the first value of RLT should be the hub radius, the last value should be the casing radius, and approximately evenly spaced values should be specified for the interior points.

14. TØLT, PØLT, BETLT - Design requirements corresponding to the radial positions RLT. It should be noted that only the subsonic solution for the values of BETLT can be obtained.

Spool Input Data

15. NSTG, FHP - The number of stages of a spool should be

selected on the basis of mean stage loading factor. A first approximation to the power split among the stages should be based on rotor root loading factors.

16. CP - The design station values of specific heat should be based upon the static temperatures obtained from the preliminary design calculation. These values can be refined if necessary on subsequent runs.

17. XSTAT - The axial spacing between design stations should be selected to be representative of the anticipated final design standard in terms of annulus angles of inclination and curvatures.

18. RANN - Hub and casing radii should be selected to insure that:

    a. The Mach number at the inlet and exit of the spool are reasonable.

    b. The hub-tip ratios are mechanically acceptable.

    c. In conjunction with the values of XSTAT, that the geometry of the annulus walls is satisfactory.

19. NSTRAC - The same general comments concerning NLT apply to the number of radial positions at which streamline angles of inclination and curvatures are specified at each design station.

20. RSTRAC - Again, the same general comments concerning RLT apply to RSTRAC.

21. ASTR, CSTR - The values of ASTR and CSTR should be set equal to zero if simple radial equilibrium is to be considered.

22. FLWCN, TØC - The amount of coolant added in each blade row and the coolant temperature should be specified with sufficient accuracy to insure a valid analysis. The coolant temperature should be that at the source of the coolant.

23. XMIX - The values of XMIX for a blade row should be set equal to zero if no mixing is to be considered or equal to 1 if complete mixing of the absolute total pressure and temperature is desired. Complete mixing in the stator rows of a multistage spool can be used to prevent degeneracy of the meridional velocity distribution.

24. NXT - The same general comments concerning NLT apply to the number of radial positions at which blade exit conditions are specified.

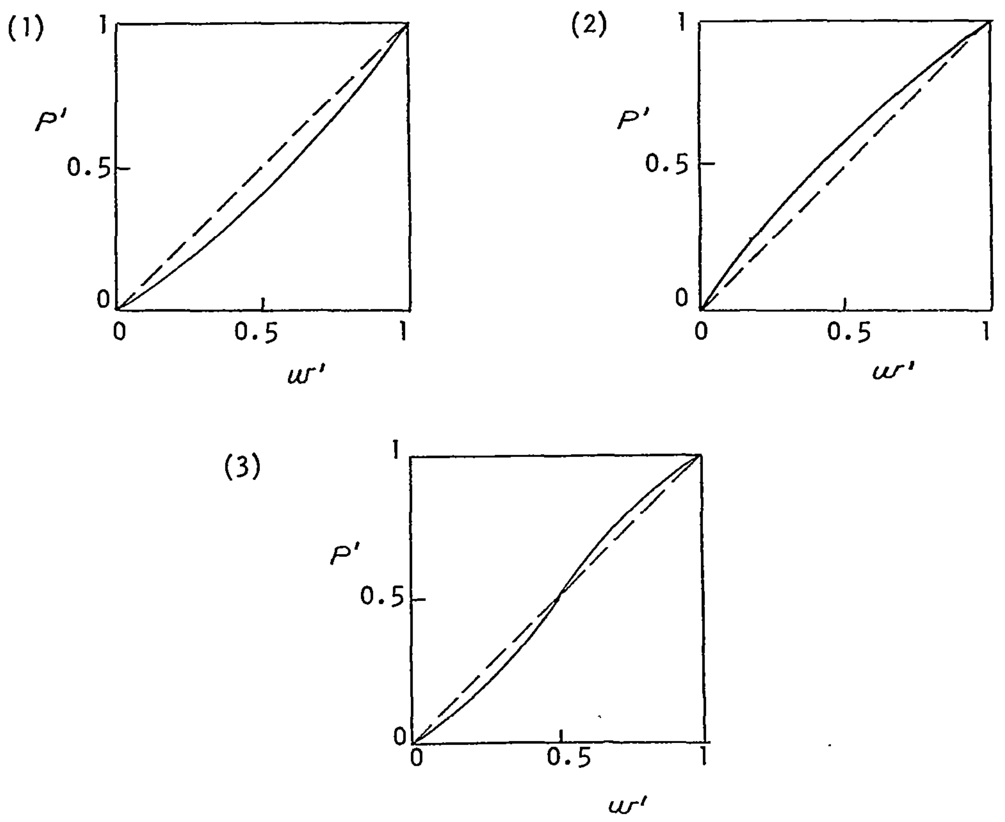
25. ISØNIC - As stated previously, the preliminary design calculation should determine which stator exits require a supersonic solution.

26. RNXT - The same general comments concerning RLT apply to RNXT.

27. WRL - Since there are distributions of whirl velocity and angle for which no solution will exist, for initial analysis it is recommended that free-vortex whirl velocity distributions or constant stator angles be specified. These distributions are most likely to provide solutions of the flow field and hence provide a basis for further modifications.

28. IPØF - Again, it can be rather difficult in certain cases to specify a power output distribution for which a solution exists. It is recommended that IPØF(I)=0 should be specified initially to obtain a uniform distribution.

29. PØF - The nondimensional power output function is specified with respect to a nondimensional mass flow function. The mass flow function increases in value from zero at the hub to 1 at the casing in equal increments across each streamtube. Similarly, the power output function increases from zero at the hub to 1 at the casing. When IPØF(I)=0, the increase occurs in equal increments across each streamtube. On the other hand, when IPØF(I)=1 the increase across each streamtube can be varied. The following diagrams illustrate three possible variations of the power output function. (The IPØF(I)=0 case is shown as a dotted line in each diagram for reference.)



Possible Variations of the Nondimensional Power Output Function

In the first variation, the work output increases monotonically from the hub to the casing. Just the opposite is true in the second variation, where the work output decreases monotonically from the hub to the casing. In the final variation, the work output increases from the hub to the mean streamline and then decreases from the mean streamline to the casing. (In each case, the amount of variation illustrated has been exaggerated from suggested practice.)

30. YØSS - For the preliminary assessment of a design or the assessment of loss level variations, a constant value for a blade exit is recommended. Otherwise, test data should be used to obtain the loss parameter variation.

31. RSXT - The same general comments concerning RLT apply to RSXT.

32. YCØN - The correlation developed in Reference 1 relates the total-pressure-loss coefficient for any element of blading to its inlet and exit relative flow angles and its reaction defined as the ratio of inlet-to-exit velocity (V_{i-1}/V_i). The nine coefficients a_1 to a_9 (which are input quantities when ISPEC=1 or 2) are used in the following correlation:

$$Y = \frac{f_L \,|\tan\beta_{i-1} - \tan\beta_i|\,[a_1 + a_2\{(V_{i-1}/V_i) - a_3\}]}{a_4 + a_5\cos\beta_i} \qquad \text{if } V_{i-1}/V_i \geq a_3$$

$$Y = \frac{f_L \,|\tan\beta_{i-1} - \tan\beta_i|\,\{a_6 + a_7(V_{i-1}/V_i)^{a_8}\}}{a_4 + a_5\cos\beta_i} \qquad \text{if } V_{i-1}/V_i < a_3$$

$$Y \leq a_9$$

where f_L is the additional loss factor.

In the absence of total-pressure-loss coefficient data which could be considered more relevant to a particular design analysis, it is recommended that the following values of the nine coefficients should be used:

$$a_1 = 0.055$$

$$a_2 = 0.15$$

$$a_3 = 0.6$$

$$a_4 = 0.6$$

$$a_5 = 0.8$$

$$a_6 = 0.03$$

$$a_7 = 0.157255$$

$$a_8 = 3.6$$

$$a_9 = 1.0$$

DESCRIPTION OF NORMAL OUTPUT

The output of Program TD consists entirely of printed data. Reference to the section containing the computer output from the sample cases will show that all the quantities listed are fully described. The information included in the normal output can be divided into the following categories:

1. General input data
2. Spool input data
3. Values of selected flow and performance parameters obtained from each pass through the iteration loop to satisfy continuity at a design station (if IEXTRA=1)
4. Tabulated streamline values of flow and performance parameters which satisfy continuity obtained from each pass through the iteration loop on streamline position at a design station (if IDLETE=1)
5. Tabulated streamline values of the flow parameters obtained from the converged pass at a design station
6. Tabulated streamline values of the mixed and/or cooled flow parameters for a blade row (if IMIX=1 or ICØØL=2)
7. Tabulated streamline values of the performance parameters of the stator and rotor blade rows
8. Mass averaged performance parameters for a stage
9. Tabulated mass averaged performance parameters for each stage of a spool (if NSTG > 1)
10. Mass averaged performance parameters for a spool
11. Mass averaged performance parameters for the turbine (if NSPØØL > 1)

A description of the items in each category is given below. The sample cases which are referred to are presented later in the report.

The normal output of a typical case begins with the statement describing the case, immediately followed by the items in category 1 - general input data. (If there is more than one set of analysis variables, the output for each set of analysis variables is treated as if it were a new case.) The general input data consists of:

1. Number of spools
2. Number of sets of analysis variables (if NSPØØL=1)
3. Number of streamlines
4. Gas constant, lbf ft per lbm deg R
5. Mass flow at the turbine inlet, lbm per sec
6. Tabulated values of absolute total temperature, deg R, absolute total pressure, psi, and absolute flow angle, deg, versus radial position, in, at the turbine inlet

Each item above is shown on the first page of output of Sample Cases 1, 3, and 4. (Each item above is also shown at the start of the output for the second set of analysis variables in Sample Case 1.) Each item above except item 2 is shown on the first page of output of Sample Case 2.

The normal output of a typical case continues with the items in category 2 - spool input data. The spool input data consists of:

1. Rotative speed, rpm
2. Power output, hp
3. Number of stages
4. Tabulated power output split among the stages of the spool, expressed as fractions of the power output of the spool

5. Tabulated design station values of the specific heat at constant pressure, Btu per lbm deg R

6. Tabulated station values of axial position, in, hub radius, in, and casing radius, in (if ISTRAC=0)

7. Tabulated design station values of hub radius, in, and casing radius, in (if ISTRAC=1)

8. Tabulated values of streamline angle of inclination, deg, and curvature, per in, versus radial position, in, at each design station of the spool (if ISTRAC=1)

9. Tabulated blade row values of coolant mass flow, expressed as fractions of the mass flow at the turbine inlet (if ICØØL= 1 or 2) and coolant total temperature, deg R (if ICØØL=2)

10. Tabulated streamline values of the mixing coefficient for each blade row of the spool (if IMIX=1)

11. Tabulated values of the exit conditions for each blade row of the spool. For stators, one exit condition is values of either whirl velocity, fps (if IWRL=0) or flow angle, deg (if IWRL=1 or 2) versus radial position, in. For rotors, one exit condition is streamline values of the nondimensional power output function, expressed as fractions of the stage power output. If ISPEC=1, there are no other exit conditions. If ISPEC=2, the other exit condition for both stators and rotors is values of additional loss factor versus radial position, in. If ISPEC=0, the other exit condition for stators is values of either pressure-loss coefficient (if ICØEF=0) or kinetic-energy-loss coefficient (if ICØEF=1). If ISPEC=0, the other exit condition for rotors is values of

either pressure-loss coefficient (if ILØSS=0 and ICØEF=0), kinetic-energy-loss coefficient (if ILØSS=0 and ICØEF=1), rotor isentropic efficiency (if ILØSS=1), or stage isentropic efficiency (if ILØSS=2) versus radial position.

12. If the total-pressure-loss coefficients are internally computed (ISPEC=1 or 2) the loss correlation is defined with the input values of the nine correlation coefficients appropriately inserted.

Each of the first ten items and item 12 are shown in the output of at least one sample case. Most of the variations of item 11 are also shown in the output of at least one sample case.

The results of the spool calculations appear next in the normal output for a typical case, beginning with the first design station of the spool. (If the spool is not the first spool of the turbine, the results shown for the first design station are taken from the converged results at the exit of the previous spool.) If IDLETE=1, results are shown for each pass through the iteration loop on streamline position whereas if IDLETE=0, results are shown for only the converged values of streamline position. In either case, if IEXTRA=1, the results begin with the items in category 3 - selected flow and performance parameters - for each pass through the iteration loop to satisfy continuity. The selected flow and performance parameters consist of:

1. Meridional velocity at the mean streamline, fps
2. Calculated value of the mass flow, lbm per sec
3. Tabulated streamline values of meridional velocity, fps, tangential velocity, fps, absolute total pressure, psi, and, if the design station is a blade row exit and ISPEC=1

or 2, pressure-loss coefficient

Each item above is shown in the output of Sample Case 3.

The items in category 4 - flow and performance parameters which satisfy continuity - complete the output for each pass through the iteration loop on streamline position. These flow and performance parameters consist of:

1. Tabulated streamline values of radial position, in, mass flow function, lbm per sec, meridional velocity, fps, axial velocity, fps, tangential velocity, fps, absolute velocity, fps, absolute Mach number, absolute total pressure, psi, absolute total temperature, deg R, absolute flow angle, deg, static pressure, psi, and static temperature, deg R, for the design station
2. Tabulated streamline values of streamline angle of inclination, deg, and curvature, per in, if the design station is the turbine inlet
3. Tabulated streamline values of pressure-loss coefficient, blade row efficiency, blade velocity, fps, relative velocity, fps, relative Mach number, relative total pressure, psi, relative total temperature, deg R, and relative flow angle, deg, if the design station is a blade row exit

Again, each item above is shown in the output of Sample Case 3.

The items in category 5 - flow parameters - complete the output of the converged pass at a design station. These flow parameters consist of the same items as in category 4 with the exception that streamline angle of inclination, deg, and curvature, per in, replace pressure-loss coefficient and blade row efficiency in item 3. Each item above is shown in the output of all the sample cases.

If either IMIX=1 or ICØØL=2, the items in category 6 - mixed and/or cooled flow parameters - follow the output of each design station except the spool exit. The mixed and/or cooled flow parameters consist of:

1. Tabulated streamline values of mixed and/or cooled absolute total pressure, psi, and absolute total temperature, deg R, in the blade row
2. Tabulated streamline values of mixed and/or cooled relative total pressure, psi, and relative total temperature, deg R, if the blade row is a stator

Each item above is shown in the output of Sample Case 2.

If the design station is a stage exit, the design station output of a typical case continues with the items in category 7 - stage performance parameters. The stage performance parameters consist of tabulated streamline values of: stator reaction, rotor reaction, stator pressure-loss coefficient, rotor pressure-loss coefficient, stator blade row efficiency, rotor blade row efficiency, rotor isentropic efficiency, and stage isentropic efficiency. Again, each item above is shown in the output of all the sample cases.

The stage performance output continues with the items in category 8 - mass averaged stage performance parameters. The mass averaged performance parameters consist of:

1. Stator blade row efficiency
2. Rotor blade row efficiency
3. Stage work output, Btu per lbm
4. Stage total efficiency

5. Stage static efficiency

6. Stage blade-to-jet speed ratio

Once again, each item above is shown in the output of all the sample cases.

If the design station is the spool exit, the normal output of a typical case continues with spool performance summary. If the spool has more than one stage, the spool performance summary begins with the items in category 9 - tabulated stage values of the mass averaged performance parameters. These tabulated values consist of the same items as in category 8 and are shown in the output of Sample Case 2.

The spool performance summary continues with the items in category 10 - mass averaged spool performance parameters. These mass averaged performance parameters consist of:

1. Spool work output, Btu per lbm
2. Spool power output, hp
3. Spool total-to-total pressure ratio
4. Spool total-to-static pressure ratio
5. Spool total efficiency
6. Spool static efficiency
7. Spool blade-to-jet speed ratio

Again, each item above is shown in the output of all sample cases.

If the design station is the turbine exit and there is more than one spool, the normal output of a typical case concludes with the items in category 11 - mass averaged turbine performance parameters. These mass averaged performance parameters consist of:

1. Over-all work output, Btu per lbm
2. Over-all total-to-total pressure ratio
3. Over-all total-to-static pressure ratio

4. Over-all total efficiency

5. Over-all static efficiency

6. Over-all blade-to-jet speed ratio

Each item above is shown in the output of Sample Case 2.

ERROR MESSAGES

Description of Messages

In addition to the normal output, various messages may appear in the output. These messages occur when difficulty has been encountered in the calculation. Each of the eight messages are considered in turn. All except the last are outputs from the main program.

1. A MEAN LINE MERIDIØNAL VELØCITY ØF _____ FPS HAS FAILED TØ PRØDUCE A VALID SØLUTION WHEN ILLØØP=_____.

This message indicates that radial equilibrium could not be satisfied at some radial position within the annulus. There are three possible reasons for this message:

a. The determinant of the three simultaneous equations which are solved for slope of the square of the meridional velocity has passed through zero or has become identically zero.

b. A computed value of meridional velocity is less than 1.0 ft per sec.

c. The maximum possible value of velocity (which is 1.0 ft per sec less than that corresponding to a zero static temperature) is less than 1.0 ft per sec at some point in the calculation.

The first of these will occur at step 42 of the analysis procedure* and the second and third at step 33. Since the problem which produces the message can occur in an intermediate loop of the convergence to satisfy flow continuity, the message only appears in the output when the additional output has been specified (IEXTRA=2). The program automatically

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* Steps of the analysis procedure are listed in Appendix I.

adjusts the convergence procedure when any value of meridional velocity has caused a failure to satisfy the conditions imposed by a and b above. A higher value of mean streamline meridional velocity is chosen for the following continuity loop and no value of the meridional velocity lower than any one which produces an unrealistic meridional velocity distribution is used in later loops.

The condition imposed in c is extremely improbable and would only occur when there are errors in the input data.

2. CALCULATIØN ABANDØNED BECAUSE ØF DIFFICULTY ØN ØR AFTER THE THIRTIETH PASS.

If the program experiences difficulties in obtaining a satisfactory meridional velocity distribution (as assessed by a, b, and c above), it is extremely unlikely that a converged solution will be obtained and the calculation is aborted in step 49 of the over-all procedure. The message will be proceeded by the design station output for a value of mass flow which is the closest approximation to the design specification. This output will indicate which radial portion of the design is responsible for the basic problem. It will be necessary to review the specifications of the analysis variables and/or the design specification before attempting any further design investigations.

3. CALCULATIØN ABANDØNED BECAUSE ØF DIFFICULTY ØN ØR AFTER 30 PASSES WITHØUT EVER ØBTAINING A SUCCESSFUL PASS.

It is possible that none of thirty estimates of the mean line meridional velocity will produce a valid solution of the flow field. Step 49 will again abort the calculation but no design station output will be available. If message 3 rather than message 2 occurs, it is unlikely that a successful design will be obtained unless the design and analysis requirements are substantially altered; the message will occur after the program has investigated a wide range of mean line meridional velocities, and hence mass flows, and none have satisfied the radial equilibrium requirement.

4. CALCULATIØN ABANDØNED ØN PASS_____ BECAUSE ØF TWØ REPETITIØNS ØF A MEAN LINE MERIDIØNAL VELØCITY WITHØUT MASS FLØW CØNVERGENCE.

This message is initiated by step 28 of the analysis procedure. It will appear when the convergence on mass flow is not proceeding to the design specification and three successive mean line meridional velocity estimates are almost identical. If the successive meridional velocities differ by less than 0.0001 per cent, the calculation is aborted after the best available result is computed for the design station. This situation will arise when the program cannot satisfy the mass flow continuity requirement due to a failure to satisfy radial equilibrium at a lower value of mass flow. The error message and program stop avoids unnecessary continuity iteration loops. The basic problem indicated is the same as that indicated by messages 1 and 2. Hence, the remedial action must be a revision of the input specifications.

5. CALCULATIØN ABANDØNED ØN PASS_____ BECAUSE ØF INSTABILITY IN MEAN LINE MERIDIØNAL VELØCITY ITERATIØN DUE TØ CHØKED CØNDITIØNS.

This message is associated with step 54 of the procedure. As the program attempts to find a mean line meridional velocity which will satisfy the specified mass flow, the behavior of the computed mass flow with the variation of mean line velocity is assessed by Subroutine VMSUB.

If the slope of the flow versus velocity characteristic changes sign more than four times the calculations are aborted. The normal indication of these sign changes is that the required mass flow exceeds the critical value; that is that the design mass flow exceeds the choked value. The program will print out the conditions for the highest flow which will pass through the design station. Thus, an estimate of the changes necessary can be made from the output; the change could be either an increase in the annulus areas, a reduction in the mean stator flow angle which will also change the stage reaction, or an appropriate combination of both. In addition for multistage designs, a redistribution of stage power outputs may be useful as a means of avoiding choking at one of the design stations.

Because of possible inaccuracies in the calculation of meridional velocity distributions very close to a point where radial equilibrium cannot be satisfied, it is possible that the program will sense a minimum or maximum in the flow versus mean line meridional velocity distribution which is not that corresponding to a choked flow condition. However, the message together with the output can be used to differentiate between true choking and numerical accuracy problems. In the latter case, a check on the meridional velocity distribution and/or static pressures can be made to establish the presence of numerical inaccuracies.

6. ITERATIØN FØR THE MERIDIØNAL VELØCITY AT THE MEAN STREAMLINE HAS NØT CØNVERGED WHEN ILØØP=_____.

A limit of thirty-five iterations is placed on the continuity loop by step 58 in the analysis procedure. If the mass flow has not converged to the required value within the preset tolerance, the results from the thirty-fifth loop are printed and the case is aborted. The convergence procedure is such that if any design station has not converged within thirty-five loops, the probability of the design being aerodynamically acceptable is remote. The results of the last pass will provide an indication of the changes to be made in subsequent analyses.

7. ITERATIØN FØR STREAMLINE PØSITIØNS ØR PRESSURE LØSS CØEFFICIENTS, WHEN THEY ARE NØT KNØWN, HAS NØT CØNVERGED.

The number of loops on streamline position (and total-pressure-loss coefficient when kinetic-energy-loss coefficients are specified) is controlled by step 79. The number of loops is limited to twenty-five and if the streamline positions have not converged to within the preset tolerance at this pass, the results are printed. The program is, however, allowed to proceed to the next design station if one exists. For designs in which the meridional velocity distributions are not extreme, it is extremely unlikely that the streamline positions will fail to converge. However, the error message is provided to guard against the possibility that streamline positions are oscillating about the converged value but just outside the tolerance. A check on the distribution of mass flow between the stream filaments is recommended in cases where error message 7 appears; in all probability, the distribution of mass flow will be acceptable.

8. A UNIQUE SØLUTIØN TØ THE RADIAL EQUILIBRIUM EQUATIØN CØULD NØT BE ØBTAINED AT R=_____ WHEN ILØØP=_____ AND ILLØØP=_____.

This diagnostic is written by Subroutine DERIV when Subroutine SIMEQ is unable to obtain a valid solution of the equations which are solved to obtain the gradient dV_m^2/dr. Step 44 of the analysis procedure controls this error message. The probability of this message ever appearing in an output is extremely remote since a check on the determinant of the three equations solved by Subroutine SIMEQ is made before this subroutine is entered. The more probable error message would be message 2.

Discussion of Remedies

With the exception of error messages 3 and 8, some output data will be provided with the message. This output can be used as a basis for the modification of the input specification. In general, errors in input data will be immediately obvious if a preliminary design calculation has been performed as recommended before the input was prepared. The correction of any input errors and the adjustments of the input data for the choked flow condition when correctly indicated by message 5 present no great problem. However, when the design analysis has been aborted by a failure to satisfy radial equilibrium at the design value of flow, some experience in turbine design or the use of the program as a design tool is necessary in order to make suitable changes in the input specifications.

If the failure occurs at a stator exit design station and whirl velocities have been specified, it is recommended that subsequent design analyses should use the option to specify stator exit flow angles. It has been found from experience that the range of distributions of whirl velocity with radius for which radial equilibrium can be satisfied is quite limited when the design specifications require absolute flow angles in excess of 70 degrees. If the failure occurs at a rotor exit plane, the most probable cause of the failure is that the specifications imply that one or more sections of the blade were required to work beyond its limiting loading. That is, as the level of local meridional velocity is changed to satisfy the local work output requirement, the resultant change in local static pressure is such that the pressure is limited to a value which is less than that required to maintain radial equilibrium. To obtain a solution in subsequent design attempts, it will be necessary to reduce the required temperature drop of those streamlines which show a large drop in meridional velocity from an adjacent streamline value. Hence, the radial variation of the power output function should be adjusted to reduce the total temperature drop of those stream filaments which are near to or beyond a limiting loading value. If the redistribution of power output function merely transfers the limiting loading condition from one section to another, more drastic changes will be necessary. Assuming the total power output of the stage cannot be off loaded to some other stage, it will be necessary to revise the annulus specifications so that an improvement in the efficiency level of the stage will result.

In cases where there are limiting loading problems but no data on which to base any revision (for example when message 3 appears), it is recommended that an assessment of the problem be obtained by performing one analysis using the option to specify blade row loss coefficients or stage efficiency variations.

MISCELLANEOUS OPERATIONAL INFORMATION

Program TD occupies approximately 15,000 storage locations on an IBM 7094 computer. Thus, with an average monitor system storage of approximately 9000 locations, the total required machine capacity is well within the capacity of a machine having 32,000 storage locations.

Typical running time for the program using a standard IBM 7094 computer is 0.015 hours per single stage. A single stage with full output will require approximately 0.02 hours, but a multistage analysis with standard output will require approximately 0.01 hours per stage. Using an IBM 7044/94 directly coupled system, the running time for a multistage analysis with standard output is reduced to approximately 0.003 hours per stage.

For designs in which the input specifications will produce meridional velocity distributions which are devoid of large changes in the radial gradient of the distribution, the accuracy of the solution is more than adequate for turbine design or analysis. The Runge-Kutta method of forward stepping ensures sufficient accuracy with as few as five streamlines for a relatively conventional design at a moderate value of hub-to-tip radius ratio. However, a nine streamline analysis is generally recommended. If the accuracy of the solution is in question at any time, it is recommended that a larger number of streamlines be specified to check over-all accuracy.

The accuracy of the solutions which have rapid local changes of meridional velocity can be poor as a result of the forward-stepping procedure which is an integral part of the method. This, however, is not a serious drawback, since the probability of accepting the resultant design as mechanically feasible is remote. Where the output indicates a significant change in meridional velocity between adjacent streamlines (say of the order 100 ft per sec in a stage where the mean velocity level is 400 ft per sec), the static pressure distribution should be inspected to see whether or not it indicates a discontinuity. As a general rule, an inaccurate solution will only be obtained when a more accurate solution would have indicated that radial equilibrium could not have been satisfied.

The convergence procedures for satisfying the design mass flow and the location of the streamlines to define a stream filament of equal flow have been found to be adequate with the maximum number of loops specified within the program. The convergence on the design mass flow, or the lowest mass flow for which radial equilibrium can be satisfied simultaneously with the definition of loss being used, can be investigated for any particular case by specifying the additional output. In the case of a design in which the specifications correspond very closely to a choked flow condition, the number of iteration loops tends towards the maximum permitted. The number of designs in this category which have been investigated is rather limited to date. It may be necessary, at some future date, to either increase the number of iterations in the continuity loop or to relax the preset tolerance on mass flow if experience shows that this is necessary (cards 0053 and 0054 of TD).

The specifications of input for the program should be prepared after preliminary hand calculations have been completed. The calculation need not be complex or time consuming. The solution of stator exit conditions, where the absolute flow angles are relatively large, is extremely sensitive to the specified whirl velocity distribution. Relatively small changes in whirl specification can produce large changes in meridional velocity distribution and the range of whirl distribution for which a radial equilibrium solution can be obtained is not great for low hub-to-tip diameter ratio stages. Hence, the specification of flow angles is to be preferred to the specification of whirl velocities. The basic problem encountered at stage exit design planes is that of the occurrence of a limiting loading. When realistic correlations of loss are used, it is to be expected that element efficiencies will decrease towards the hub section. Hence, for many designs it will be necessary to reduce the power output requirements of the stream filaments near the hub. To obtain a first estimate of the amount of variation of power output with radius that may be necessary, the program can be used with loss coefficient or stage efficiency specified together with a uniform distribution of power output. From the output of such an analysis a check can be made on the compatibility of the total-pressure-loss coefficients computed by the program and values which might be expected from the blading geometry. If the program computed loss at any section is significantly less than would be expected in practice, it is quite probable that a limiting loading condition would exist and preclude a solution which satisfies radial equilibrium if the internal computation of loss coefficients were used. Any redistribution of the power output between the stream filaments, however, should be carefully selected to avoid a transfer of the limiting loading situation from one part of the annulus to another. A review of the data presented in the following section provides a useful guide to the selection of analysis variables.

SAMPLE CASES

The sample cases which are presented in the following pages have been selected to illustrate most of the major options available to the program user. For each of the four cases the input data sheets and computer output are presented. The designs illustrated do not necessarily represent final designs. Each is briefly discussed below.

Sample Case I

This first case is based on a single stage selected by NASA for the part of the over-all program concerned with the application of the computer program. It illustrates the use of the program for the investigation of two sets of analysis variables. In both cases stator exit flow angles and internally computed total-pressure-loss coefficients are specified. The output is the standard output and illustrates the changes in the design parameters produced by changes in the radial variations of stator exit angle and power output.

Sample Case II

This case provides an example of the analysis of a two-spool turbine. The turbine has a two-stage hp spool and a three-stage lp spool. In this example stator exit whirl distributions are specified together with internally computed total-pressure-loss coefficients. In addition, the analysis uses the options to specify the addition of coolant to the mainstream and interfilament mixing. This mixing is assumed to occur within the stator rows so that the analysis of each stage is based on the assumption that total temperature and total pressure profiles are modified within the stator blade rows. Again, the output is of the standard form. One of the features illustrated by the output is the occurrence of a limiting loading near the hub of the final rotor (stage 1 of the lp spool). The meridional velocity drops from 344 ft per sec at streamline 3 to 317 and 80.8 ft per sec at streamlines 2 and 1, respectively. Accompanying this meridional velocity distribution, the computed relative flow angles are 66.29, 67.38, and 83.63 at these three streamlines. Although the printout represents a converged solution, the result of the calculation of static pressures clearly indicates that a limiting loading condition has occurred between streamline 2 and the hub; the calculated hub static pressure is 55.81 psi which is approximately 1 psi less than that required for radial equilibrium. The third stage of the lp spool is used for the third sample case to illustrate one possible approach to a limiting loading situation.

Sample Case III

The input to this case is based on the output from Sample Case II. The inlet conditions are obtained from the second stage exit conditions and the annulus wall slopes and curvatures are those previously computed. The row performances are specified by means of stator row total-pressure-loss coefficients and the radial variation of stage efficiency; both sets of data are obtained from the previous example with the exception of the hub value of stage efficiency. The output format specified is that which gives the intermediate loop data on the convergence of the flow and streamline locations. This sample illustrates the form of the output when the indicators IDELETE and IEXTRA are both specified as 1. The stator inlet and stator exit conditions compare well with the values computed at these stations in Sample Case II. At the rotor exit, the meridional velocity still decreases rapidly towards the hub even with the radial variation of stage efficiency specified. From this output it can be concluded that it would be necessary to reduce the power output of the hub stream filament. The rotor hub total-pressure-loss coefficient, implied by the specified stator loss coefficient and stage efficiency, is less than that which would be expected from the computed row reaction and flow angles. Thus, to obtain a satisfactory solution of the flow field at rotor exit, it will be necessary to raise the stage exit total pressure at the hub by reducing the total temperature drop in the vicinity of the hub.

Sample Case IV

This sample case illustrates the specification of a supersonic solution at a stator exit when the flow angle is also specified. The example is based on the turbine of Reference 2 which is a small single-stage fuel-pump turbine having a total-to-static pressure ratio in excess of 4:1. A point to note is that the total-pressure-loss coefficient is internally computed but an additional loss factor of 3.4 was specified for the stator (so that the stator row exit flow conditions would closely approximate those given in Reference 2). This loss factor is approximately equal to the square of the ratio of mean streamline stator exit Mach number to a reference Mach number of 0.8. Three sets of analysis variables have been specified with the second and third sets differing from the first in the distribution of power output with radius only. The standard output is specified.

The first set of analysis variables includes a uniform distribution of work output and the calculation is abandoned on the third pass. The lowest value of mass flow for which a radial equilibrium solution could be obtained was 7.37 lbm per sec compared with a design value of 6.808. The output obtained at this higher flow indicates the hub loading is the basic problem; the meridional velocity is 229 ft per sec at the hub compared to a 384 ft per sec at the adjacent streamline. The second set of analysis variables has a parabolic distribution of the power output function which reduces the hub total temperature by 1.3 per cent. With this distribution a solution could be obtained at the design flow but the distribution of meridional velocity and rotor relative exit flow angles cannot be considered satisfactory. With the third set of analysis variables in which the hub section is still further unloaded an acceptable design is produced. In this design the meridional velocity monotonically increases from outer to inner radius. This sample case illustrates that relatively small changes in the power output distribution are required to produce an acceptable design. However, the particular turbine has a relatively high hub-to-tip diameter radius of 0.87. Thus, it is to be expected that stages of lower hub-to-tip ratio will require greater variations of power output function to avoid local limiting loading condition when the stage is highly loaded.

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL PROJECT: AXIAL TURBINE DESIGN PROJECT NO: 1125

TITLE: SAMPLE CASE I SHEET: 1 OF 1

LOCATION

1 6	7 12	13 18	19 24	25 30	31 36	37 42	43 48	49 54	55 60	61 66	67 72

```
NASA SINGLE STAGE TURBINE
     0     1     0     1     0     0     0     0     0
$NAM1
NSPOOL=1,NAV=2,NLINES=9,GASC=53.35,FLWM=45.51,NLT=1,
RLT(1)=16.0,TOLT(1)=518.7,POLT(1)=14.696,BETLT(1)=0.0 $
$NAM2
RPM=4660.0,HP=1287.5,NSTG=1,FHP(1)=1.0,CP(1)=3*0.24,
XSTAT(1)=0.0,1.0,2.0,3.0,4.0,
RANN(1,1)=5*14.465,RANN(1,2)=5*18.0,
NXT=5,RNXT(1,1)=14.465,15.34875,16.2325,17.11625,18.00000,
WRL(1,1)=69.000,67.842,66.700,65.575,64.475,
YCON(1)=.05,.2,.6,.6,.8,.02818182,.36223185,5.5,2.0,      *
IPOF(1)=0 $
$NAM2
WRL(1,1)=5*66.700,IPOF(1)=1,
POF(1,1)=0.0,.12219551,.24519230,.36899038,.49358974,.61899038,
.74519230,.87219551,1.0000000 $
```

* The coefficients of the loss correlation differ from those recommended. This particular set was selected during an investigation of the effect of the loss assumption on predicted velocity diagrams.

** PROGRAM TD - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

NASA SINGLE STAGE TURBINE

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 2
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 45.51000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
16.0000	518.70	14.6960	0.

*** SPCOL INPLT DATA ***

** DESIGN REQUIREMENTS **

RCTATIVE SPEED = 466C.0 RPM
POWER OLTPLT = 1287.5C HP

** SET 1 OF ANALYSIS VARIABLES **

NUMPER OF STAGES = 1

* POWER-OUTPLT SPLIT *

STAGE NUMBER	FRACTICN OF SPOOL PCWER OLTPUT
1	1.CCCOC

* SPECIFIC-HEAT SPECIFICATICN *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	C.24C00
2	C.24CCC
3	C.24C0C

* ANNULUS SPECIFICATION *

STATICN NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	C.	14.465C	18.0000
2	1.0000	14.465C	18.0CCC
3	2.0C00	14.465C	18.CC00
4	3.0000	14.4650	18.0000
5	4.0000	14.465C	18.0000

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	WHIRL ANGLE (DEG)
14.4650	69.00C
15.3487	67.842
16.2325	66.7CC
17.1163	65.575
18.00C0	64.475

ROTOR 1

STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTION
1	C.
2	C.125CC
3	C.25000
4	0.375C0
5	0.50000
6	0.625CC
7	C.7500C
8	0.875C0
9	1.C0000

* BASIC INTERNAL LOSS CORRELATION *

```
    TAN(INLET ANGLE) + TAN(EXIT ANGLE)                (0.C2818181 + 0.36223185 * (V RATIO)** 5.50)  IF (V RATIO) .LT. 0.60000000 &
Y = ------------------------------------------ *TIMES*
    0.60000000 + 0.80000000 * COS(EXIT ANGLE)         (C.C500CCCC + 0.2C000C0C *((V RATIO)-0.600))  IF (V RATIO) .GT. 0.60000000
```

THE PRESSURE-LOSS CCEFFICIENT COMPUTED IN THIS MANNER MAY NCT EXCEED A LIMIT OF 2.0000000C

*** OUTPUT OF SPOOL DESIGN ANALYSIS (SET 1 OF ANALYSIS VARIABLES) ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4650	0.	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
2	14.9526	5.68875	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
3	15.4247	11.37750	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
4	15.8831	17.06625	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
5	16.3284	22.75500	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
6	16.7620	28.44375	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
7	17.1845	34.13250	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
8	17.5970	39.82125	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
9	18.0000	45.51000	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	14.2127	513.77	0.	0.
2	14.2127	513.77	0.	0.
3	14.2127	513.77	0.	0.
4	14.2127	513.77	0.	0.
5	14.2127	513.77	0.	0.
6	14.2127	513.77	0.	0.
7	14.2127	513.77	0.	0.
8	14.2127	513.77	0.	0.
9	14.2127	513.77	0.	0.

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4650	0.	320.336	320.336	834.504	893.875	0.85751	14.2418	518.70	69.000

2	[illegible]	5.64859	321.158	321.158	807.781	869.283	0.83061	14.2799	518.70	68.318
3	15.4740	11.37710	321.906	321.906	784.075	847.583	0.80713	14.3120	518.70	67.679
4	[illegible]	17.06590	322.592	322.592	762.807	828.210	0.78638	14.3394	518.70	67.076
5	[illegible]	22.75441	323.226	323.226	743.551	810.767	0.76784	14.3631	518.70	66.505
6	[illegible]	28.44303	323.812	323.812	725.953	794.897	0.75109	14.3838	518.70	65.961
7	17.2213	34.13166	324.341	324.341	709.826	780.417	0.73591	14.4020	518.70	65.443
8	17.6171	39.82029	324.812	324.812	694.529	767.091	0.72203	14.4181	518.70	64.948
9	18.0000	45.50893	325.236	325.236	681.107	754.775	0.70926	14.4325	518.70	64.475

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	[illegible]	452.21	0.	0.	588.236	404.058	0.38762	9.7728	465.80	37.552
2	9.0817	455.87	0.	0.	609.336	377.522	0.36073	9.9383	467.68	31.712
3	9.3227	458.92	0.	0.	629.269	357.195	0.34015	10.0998	469.54	25.683
4	9.5344	461.62	0.	0.	648.211	342.340	0.32505	10.2584	471.37	19.556
5	9.7236	464.00	0.	0.	666.299	332.329	0.31473	10.4146	473.19	13.442
6	9.8941	466.12	0.	0.	683.641	326.565	0.30857	10.5695	475.00	7.445
7	10.0487	468.02	0.	0.	700.324	324.480	0.30598	10.7228	476.78	1.678
8	10.1897	469.74	0.	0.	716.421	325.522	0.30640	10.8751	478.55	-3.785
9	10.3183	471.30	0.	0.	731.591	329.193	0.30934	11.0268	480.31	-8.892

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4600	0.	391.204	391.204	-16.547	391.553	0.38855	7.5059	435.39	-2.422
2	14.9798	5.68875	404.160	404.160	-13.803	404.396	0.40170	7.5595	435.39	-1.956
3	15.4641	11.37750	412.193	412.193	-11.488	412.353	0.40986	7.5938	435.39	-1.596
4	15.9257	17.06624	417.826	417.826	-9.514	417.934	0.41560	7.6184	435.39	-1.304
5	16.3686	22.75499	422.105	422.105	-7.798	422.177	0.41997	7.6373	435.39	-1.058
6	16.7958	28.44373	425.533	425.533	-6.336	425.580	0.42347	7.6525	435.39	-0.853
7	17.2051	34.13247	428.378	428.378	-5.016	428.407	0.42639	7.6653	435.39	-0.671
8	17.6101	39.82121	430.801	430.801	-3.850	430.818	0.42888	7.6762	435.39	-0.512
9	18.0000	45.50996	432.897	432.897	-2.806	432.906	0.43103	7.6856	435.39	-0.371

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	6.7638	427.63	0.	0.	588.236	720.279	0.71475	9.5073	465.80	-57.103
2	6.7647	421.78	0.	0.	609.171	742.591	0.73763	9.7100	467.66	-57.026
3	6.7645	471.24	0.	0.	628.867	761.550	0.75695	9.8886	469.50	-57.231

4	6.7646	420.85	0.	0.	647.636	778.733	0.77438	10.0556	471.31	-57.551
5	6.7647	420.55	0.	0.	665.649	794.798	0.79064	10.2165	473.12	-57.921
6	6.7647	420.31	0.	0.	683.019	810.116	0.80611	10.3743	474.92	-58.313
7	6.7646	420.11	0.	0.	699.827	824.810	0.82092	10.5299	476.72	-58.710
8	6.7645	419.94	0.	0.	716.135	839.027	0.83525	10.6846	478.52	-59.106
9	6.7643	419.79	0.	0.	731.991	852.834	0.84914	10.8388	480.31	-59.496

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.27233	0.56097	0.08363	0.09678	0.94275	0.92874	0.96065	0.91975
2	0.28004	0.50838	0.08008	0.07706	0.94408	0.94297	0.96676	0.92867
3	0.28721	0.46904	0.07697	0.06659	0.94531	0.95079	0.96994	0.93446
4	0.29393	0.43961	0.07422	0.06018	0.94647	0.95572	0.97179	0.93864
5	0.30025	0.41813	0.07176	0.05580	0.94755	0.95916	0.97294	0.94186
6	0.30624	0.40311	0.06955	0.05256	0.94857	0.96178	0.97373	0.94449
7	0.31193	0.39340	0.06754	0.05001	0.94952	0.96388	0.97429	0.94668
8	0.31734	0.38798	0.06573	0.04790	0.95041	0.96563	0.97471	0.94856
9	0.32252	0.38600	0.06406	0.04612	0.95124	0.96714	0.97504	0.95020

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.94736

ROTOR BLADE-ROW EFFICIENCY = 0.95598

STAGE WORK = 19.996 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.93974
STAGE STATIC EFFICIENCY = 0.80796
STAGE BLADE- TO JET-SPEED RATIO = 0.59648

```
*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***


                          SPOOL WORK =    19.996 BTU PER LBM
                         SPOOL POWER =   1287.50 HP
 SPOOL TCTAL- TO TCTAL-PRESSURE RATIO =   1.92739
SPOOL TOTAL- TO STATIC-PRESSURE RATIO =   2.17253
              SPOOL TOTAL EFFICIENCY =   C.93974
             SPOOL STATIC EFFICIENCY =   0.80796
     SPCCL BLADE- TO JET-SPEED RATIO =   0.59648
```

** PROGRAM TD - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

NASA SINGLE STAGE TURBINE

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 2
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 45.51000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
16.0000	518.70	14.6960	0.

*** SPCOL INPUT DATA ***

** DESIGN REQUIRFMENTS **

RCTATIVE SPEED =   4660.0 RPM
POWER OUTPUT =   1287.5C HP

** SET 2 OF ANALYSIS VARIABLES **

NUMBER OF STAGES = 1

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTICN OF SPOOL PCWER OUTPUT
1	1.CCCCC

* SPECIFIC-HEAT SPECIFICATICN *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	0.24C00
2	C.24C0C
3	0.24CCC

* ANNULUS SPECIFICATICN *

STATICN NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	0.	14.465C	18.0000
2	1.0000	14.465C	18.0C00
3	2.0000	14.4650	18.0000
4	3.0000	14.465C	18.0000
5	4.0000	14.4650	18.0000

* BLADE-ROW EXIT CONDITIONS *

STATCR 1	RADIAL POSITION (IN)	WHIRL ANGLE (DEG)
	14.465C	66.70C
	15.3487	66.7CC
	16.2325	66.70C
	17.1163	66.70C
	18.COCO	66.7CC

ROTOR 1	STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTICN
	1	C.
	2	C.1222C
	3	C.24519
	4	C.36859
	5	0.49359
	6	C.61899
	7	C.74519
	8	0.87220
	9	1.C00CC

* BASIC INTERNAL LOSS CCRRELATION *

```
       TAN(INLET ANGLE) + TAN(EXIT ANGLE)              (0.02818181 + C.36223185 * (V RATIO)** 5.50)  IF (V RATIO) .LT. 0.60000000 &
Y = ------------------------------------------ *TIMES*
    0.60000000 + 0.80000000 * COS(EXIT ANGLE)          (C.0500COCC + 0.2C000CCC *((V RATIO)-0.600))  IF (V RATIO) .GT. 0.60000000
```

THE PRESSURE-LOSS CCEFFICIENT CCMPUTED IN THIS MANNER MAY NCT EXCEED A LIMIT CF 2.00000COC

*** OUTPUT OF SPOOL DESIGN ANALYSIS (SET 2 OF ANALYSIS VARIABLES) ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4650	0.	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
2	14.9526	5.68875	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
3	15.4249	11.37750	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
4	15.8831	17.06625	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
5	16.3284	22.75500	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
6	16.7620	28.44375	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
7	17.1846	34.13250	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
8	17.5970	39.82125	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.
9	18.0000	45.51000	243.432	243.432	0.	243.432	0.21909	14.6960	518.70	0.

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	14.2127	513.77	0.	0.
2	14.2127	513.77	0.	0.
3	14.2127	513.77	0.	0.
4	14.2127	513.77	0.	0.
5	14.2127	513.77	0.	0.
6	14.2127	513.77	0.	0.
7	14.2127	513.77	0.	0.
8	14.2127	513.77	0.	0.
9	14.2127	513.77	0.	0.

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4650	0.	356.488	356.488	827.756	901.256	0.86564	14.2975	518.70	66.700

2	14.9405	5.68854	347.277	347.277	806.369	877.970	0.84007	14.3136	518.70	66.700
3	15.4042	11.37710	338.799	338.799	786.684	858.537	0.81679	14.3283	518.70	66.700
4	15.8574	17.06569	330.954	330.954	768.465	836.701	0.79545	14.3417	518.70	66.700
5	16.3013	22.75427	323.658	373.658	751.525	818.257	0.77578	14.3541	518.70	66.700
6	16.7368	28.44288	316.846	316.846	735.708	801.035	0.75756	14.3656	518.70	66.700
7	17.1647	34.13151	310.462	310.462	720.884	784.895	0.74060	14.3762	518.70	66.700
8	17.5855	39.82015	304.459	304.459	706.947	769.720	0.72476	14.3860	518.70	66.700
9	18.0000	45.50880	298.799	298.799	693.804	755.410	0.70991	14.3952	518.70	66.700

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	8.7701	451.11	0.	0.	588.236	429.480	0.41251	9.8599	466.46	33.897
2	9.0171	454.56	0.	0.	607.571	400.152	0.38288	9.9768	467.88	29.789
3	9.2432	457.65	0.	0.	626.428	374.789	0.35740	10.0964	469.34	25.315
4	9.4512	460.45	0.	0.	644.860	353.283	0.33587	10.2187	470.83	20.480
5	9.6433	462.99	0.	0.	662.912	335.569	0.31815	10.3440	472.36	15.312
6	9.8214	465.31	0.	0.	680.622	321.599	0.30414	10.4721	473.91	9.863
7	9.9870	467.44	0.	0.	698.021	311.303	0.29373	10.6033	475.50	4.212
8	10.1416	469.40	0.	0.	715.136	304.570	0.28678	10.7375	477.12	-1.541
9	10.2861	471.22	0.	0.	731.991	301.229	0.28309	10.8748	478.77	-7.283

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4650	0.	432.497	432.497	-1.473	432.499	0.42952	7.6746	437.52	-0.195
2	14.9383	5.68875	433.456	433.456	-1.753	433.459	0.43078	7.6803	436.99	-0.232
3	15.3971	11.37751	431.236	431.236	-2.236	431.242	0.42877	7.6713	436.45	-0.297
4	15.8456	17.06626	427.203	427.203	-2.881	427.213	0.42489	7.6541	435.92	-0.386
5	16.2862	22.75502	422.030	422.030	-3.659	422.046	0.41983	7.6320	435.39	-0.497
6	16.7207	28.44377	416.066	416.066	-4.542	416.091	0.41397	7.6068	434.85	-0.625
7	17.1504	34.13253	409.498	409.498	-5.512	409.535	0.40749	7.5794	434.32	-0.771
8	17.5765	39.82128	402.421	402.421	-6.551	402.474	0.40049	7.5505	433.78	-0.933
9	18.0000	45.51003	394.874	394.874	-7.646	394.948	0.39301	7.5204	433.25	-1.109

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	6.7606	421.96	0.	0.	588.236	731.307	0.72627	9.6034	466.46	-53.743
2	6.7607	421.35	0.	0.	607.482	747.696	0.74308	9.7545	467.87	-54.569
3	6.7606	420.98	0.	0.	626.142	762.118	0.75775	9.8905	469.31	-55.539

4	6.7606	420.73	0.	0.	644.381	775.533	0.77131	10.0198	470.78	-56.575	*
5	6.7605	420.56	0.	0.	662.298	788.421	0.78429	10.1468	472.29	-57.637	
6	6.7605	420.44	0.	0.	679.566	801.038	0.79695	10.2740	473.84	-58.707	*
7	6.7505	420.36	0.	0.	697.441	813.530	0.80946	10.4028	475.43	-59.778	*
8	6.7606	420.30	0.	0.	714.769	825.981	0.82190	10.5342	477.07	-60.843	*
9	6.7608	420.27	0.	0.	731.991	838.444	0.83434	10.6689	478.77	-61.903	*

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.27010	0.58728	0.07209	0.09023	0.95039	0.93359	0.96114	0.92398
2	0.27727	0.53518	0.07220	0.07403	0.94951	0.94523	0.96692	0.93103
3	0.28420	0.49177	0.07231	0.06507	0.94871	0.95187	0.97011	0.93558
4	0.29094	0.45554	0.07244	0.05985	0.94795	0.95587	0.97189	0.93870
5	0.29750	0.42562	0.07257	0.05670	0.94725	0.95839	0.97285	0.94096
6	0.30390	0.40148	0.07272	0.05477	0.94658	0.96003	0.97331	0.94267
7	0.31015	0.38266	0.07287	0.05360	0.94595	0.96114	0.97346	0.94398
8	0.31626	0.36874	0.07304	0.05295	0.94535	0.96188	0.97338	0.94501
9	0.32225	0.35927	0.07321	0.05268	0.94477	0.96235	0.97314	0.94579

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.94736

ROTOR BLADE-ROW EFFICIENCY = 0.95530

STAGE WORK = 19.996 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.93517
STAGE STATIC EFFICIENCY = 0.80743
STAGE BLADE- TO JET-SPEED RATIO = 0.59428

```
*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***


                                   SPOOL WORK =    19.996 BTU PER LBM
                                  SPOOL POWER =   1287.50 HP
     SPOOL TOTAL- TO TOTAL-PRESSURE RATIO =   1.92823
    SPOOL TOTAL- TO STATIC-PRESSURE RATIO =   2.17377
                      SPOOL TOTAL EFFICIENCY =   0.93917
                     SPOOL STATIC EFFICIENCY =   0.80743
          SPOOL BLADE- TO JET-SPEED RATIO =   0.59428
```

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL PROJECT: AXIAL TURBINE DESIGN PROJECT NO: 1125

TITLE: SAMPLE CASE II SHEET: 1 OF 3

LOCATION

```
1    6|7   12|13  18|19  24|25  30|31  36|37  42|43  48|49  54|55  60|61  66|67  72
NASA MULTISTAGE TWINSPOOL TURBINE
     0     1     0     0     2     1     0     0     0
$NAM1
NSPOOL=2,NLINES=9,GASC=53.35,FLWM=111.9,NLT=1,
RLT(1)=14.5,TOLT(1)=2410.,POLT(1)=342.4,BETLT(1)=0.0 $
$NAM2
RPM=10800.,HP=24530.,NSTG=2,FHP(1)=.49,.51,CP(1)=2*.288,2*.282,.275,
XSTAT(1)=0.0,1.5,3.0,4.5,6.0,7.5,9.0,
RANN(1,1)=13.975,14.0,14.025,14.05,14.075,14.1,14.14,
RANN(1,2)=14.85,15.1,15.35,15.60,15.85,16.1,16.65,
FLWCN(1)=2*.01698,.01609,0.0,TOC(1)=4*1400.,
XMIX(1,1)=9*1.0,
XMIX(1,2)=9*0.0
XMIX(1,3)=9*1.0,
XMIX(1,4)=9*0.0,
NXT=5,RNXT(1,1)=14.025,14.35625,14.6875,15.01875,15.35,
RNXT(1,2)=14.075,14.51875,14.9625,15.40625,15.85,
WRL(1,1)=1425.43,1397.32,1370.7,1345.48,1321.55,
WRL(1,2)=1483.60,1438.26,1395.6,1355.4,1317.46,
YCON(1)=.043,.0936,.5,1.0,0.0,.03,.157255,3.6,2.0,
```

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL PROJECT: AXIAL TURBINE DESIGN PROJECT NO: 1125

TITLE: SAMPLE CASE II SHEET: 2 OF 3

LOCATION

1 6 | 7 12 | 13 18 | 19 24 | 25 30 | 31 36 | 37 42 | 43 48 | 49 54 | 55 60 | 61 66 | 67 72

```
IPOF(1)=0,0 $
$NAM2
RPM=4646.,HP=11209.3,NSTG=3,FHP(1)=.3091,.3330,.3579,
CP(1)=2*.275,2*.273,2*.271,.268,
XSTAT(1)=7.5,9.0,10.5,12.0,13.5,15.0,16.5,18.0,19.5,
RANN(1,1)=14.075,14.1,14.14,14.18,14.22,14.26,14.30,14.34,14.38,
RANN(1,2)=15.85,16.1,16.65,17.20,17.75,18.30,18.85,19.40,19.95,
FLWCN(1)=6*0.0,TOC(1)=6*0.0,
XMIX(1,1)=9*1.0,
XMIX(1,2)=9*0.0,
XMIX(1,3)=9*1.0,
XMIX(1,4)=9*0.0,
XMIX(1,5)=9*1.0,
XMIX(1,6)=9*0.0,
NXT=5,RNXT(1,1)=14.14,14.7675,15.395,16.0225,16.65,
RNXT(1,2)=14.22,15.1025,15.985,16.8675,17.75,
RNXT(1,3)=14.3,15.4375,16.575,17.7125,18.85,
WRL(1,1)=793.16,759.46,728.5,699.97,673.59,
WRL(1,2)=845.01,798.70,757.90,721.73,689.50,
WRL(1,3)=900.00,837.50,784.20,738.32,698.51,
```

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL PROJECT: AXIAL TURBINE DESIGN PROJECT NO: 1125

TITLE: SAMPLE CASE II SHEET: 3 OF 3

LOCATION

1 6	7 12	13 18	19 24	25 30	31 36	37 42	43 48	49 54	55 60	61 66	67 72
IPOF(1)=3*0		$									

** PROGRAM TD - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

NASA MULTISTAGE TWINSPOOL TURBINE

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 2
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.3500C LBF FT/LBM DEG R
INLET MASS FLOW = 111.9C00C LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.5000	2410.00	342.4CCC	0.

*** INPUT DATA FOR SPOOL 1 ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 10800.0 RPM
POWER OUTPUT = 2453C.CO HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 2

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	C.49COC
2	0.51COC

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	C.28800
2	C.288CC
3	C.28200
4	0.28200
5	0.2750C

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	0.	13.9750	14.8500
2	1.5000	14.CCOC	15.1C00
3	3.0000	14.C25C	15.3500
4	4.5000	14.C5CC	15.6C00

5	6.0000	14.075C	15.8500
6	7.5000	14.100C	16.1000
7	9.0000	14.140C	16.6500

* COOLANT SCHEDULE *

BLADE ROW NUMBER	FRACTION OF INLET MASS FLOW	TOTAL TEMPERATURE (DEG R)
1	0.01698	1400.00
2	C.01698	1400.C0
3	0.01609	1400.00
4	0.	1400.CC

* MIXING COEFFICIENTS *

STREAMLINE NUMBER	BLADE ROW 1	BLADE ROW 2	BLADE ROW 3	BLADE ROW 4
1	1.00000	0.	1.00000	0.
2	1.CC000	0.	1.0C0C0	0.
3	1.C0000	0.	1.CCCCC	0.
4	1.00000	C.	1.00000	0.
5	1.000C0	0.	1.0C0C0	0.
6	1.CC000	0.	1.00000	0.
7	1.00000	0.	1.CCCC0	0.
8	1.00000	0.	1.00000	0.
9	1.000C0	0.	1.0C0C0	0.

* BLADE-ROW EXIT CONDITIONS *

STATOR 1	RADIAL POSITION (IN)	WHIRL VELOCITY (FPS)
	14.0250	1425.43C
	14.3563	1397.32C
	14.6875	1370.70C
	15.0187	1345.48C
	15.3500	1321.550

ROTOR 1	STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTION
	1	C.
	2	C.125C0
	3	0.250C0
	4	C.375CC
	5	C.500C0

```
                 6            C.625C0
                 7            C.75000
                 8            C.875C0
                 9            1.00000

                RADIAL        WHIRL
 STATOR 2      POSITION      VELOCITY
                 (IN)          (FPS)

               14.0750       1483.6CC
               14.5187       1438.26C
               14.9625       1395.60C
               15.4063       1355.400
               15.8500       1317.460

                            NONDIMENSIONAL
              STREAMLINE     POWER OUTPUT
 ROTOR 2        NUMBER         FUNCTION

                 1            C.
                 2            0.12500
                 3            C.250C0
                 4            0.375CC
                 5            C.50000
                 6            0.62500
                 7            C.750C0
                 8            C.87500
                 9            1.C00C0


                 * BASIC INTERNAL LOSS CORRELATICN *

      TAN(INLET ANGLE) + TAN(EXIT ANGLE)               (0.02995999 + 0.15725499 * (V RATIO)** 3.60)  IF (V RATIO) .LT. 0.50000000 *
Y = ---------------------------------------- *TIMES*
    1.00000000 + 0.          * COS(EXIT ANGLE)          (0.0430CC00 + 0.09360000 *((V RATIO)-0.500))  IF (V RATIO) .GT. 0.50000000

        THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF   2.00000000
```

*** OUTPUT OF DESIGN ANALYSIS FOR SPOOL 1 ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0000	0.	427.145	427.086	0.	427.145	0.18380	342.4000	2410.00	0.
2	14.1415	13.98749	427.145	426.872	0.	427.145	0.18380	342.4000	2410.00	0.
3	14.2817	27.97499	427.145	426.507	0.	427.145	0.18380	342.4000	2410.00	0.
4	14.4207	41.96248	427.145	425.994	0.	427.145	0.18380	342.4000	2410.00	0.
5	14.5585	55.94998	427.145	425.337	0.	427.145	0.18380	342.4000	2410.00	0.
6	14.6953	69.93748	427.145	424.539	0.	427.145	0.18380	342.4000	2410.00	0.
7	14.8311	83.92498	427.145	423.604	0.	427.145	0.18380	342.4000	2410.00	0.
8	14.9660	97.91249	427.145	422.535	0.	427.145	0.18380	342.4000	2410.00	0.
9	15.1000	111.90000	427.145	421.334	0.	427.145	0.18380	342.4000	2410.00	0.

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	334.9122	2397.35	0.955	0.
2	334.9122	2397.35	2.049	0.00000
3	334.9122	2397.35	3.134	0.00000
4	334.9122	2397.35	4.208	0.00000
5	334.9122	2397.35	5.274	0.00000
6	334.9122	2397.35	6.332	0.00000
7	334.9122	2397.35	7.383	0.00000
8	334.9122	2397.35	8.426	0.00000
9	334.9122	2397.35	9.462	0.00000

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	342.4000	2393.14
2	342.4000	2393.14

3	342.4000	2393.14
4	342.4000	2393.14
5	342.4000	2393.14
6	342.4000	2393.14
7	342.4000	2393.14
8	342.4000	2393.14
9	342.4000	2393.14

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0250	0.	456.759	456.695	1425.430	1496.823	0.66666	334.2682	2393.14	72.235
2	14.1918	14.22500	452.388	452.105	1411.088	1481.831	0.65953	334.3947	2393.14	72.235
3	14.3577	28.44999	447.652	447.000	1397.202	1467.162	0.65256	334.5062	2393.14	72.259
4	14.5223	42.67497	442.478	441.317	1383.753	1452.777	0.64575	334.6023	2393.14	72.311
5	14.6877	56.89993	436.863	435.058	1370.681	1438.616	0.63905	334.6836	2393.14	72.390
6	14.8525	71.12488	430.766	428.191	1357.960	1424.646	0.63245	334.7500	2393.14	72.499
7	15.0176	85.34991	424.114	420.650	1345.566	1410.822	0.62594	334.8006	2393.14	72.640
8	15.1833	99.57498	416.889	412.425	1333.432	1397.082	0.61947	334.8355	2393.14	72.813
9	15.3500	113.80004	408.959	403.394	1321.550	1383.380	0.61304	334.8523	2393.14	73.026

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	252.1378	2237.77	0.955	-0.	1321.825	468.362	0.20860	259.4163	2252.99	12.782
2	253.7027	2240.87	2.026	-0.00000	1337.547	458.326	0.20399	260.7028	2255.44	9.239
3	255.2175	2243.87	3.091	-0.00000	1353.179	449.811	0.20007	261.9884	2257.90	5.625
4	256.6857	2246.78	4.152	-0.00000	1368.750	442.732	0.19679	263.2723	2260.38	1.947
5	258.1138	2249.62	5.210	-0.00000	1384.286	437.075	0.19415	264.5590	2262.87	-1.791
6	259.5049	2252.40	6.268	-0.00000	1399.817	432.795	0.19213	265.8494	2265.38	-5.583
7	260.8622	2255.11	7.328	-0.00000	1415.374	429.821	0.19070	267.1442	2267.92	-9.423
8	262.1921	2257.79	8.392	-0.00000	1430.991	428.152	0.18985	268.4492	2270.50	-13.309
9	263.4964	2260.43	9.462	-0.00000	1446.703	427.680	0.18953	269.7633	2273.11	-17.236

** ROTOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)

1	334.2682	2376.83	258.9514	2236.68
2	334.3947	2376.83	260.2444	2239.13
3	334.5062	2376.83	261.5364	2241.59
4	334.6023	2376.83	262.8269	2244.07
5	334.6836	2376.83	264.1203	2246.56
6	334.7500	2376.83	265.4176	2249.08
7	334.8006	2376.83	266.7194	2251.62
8	334.8355	2376.83	268.0315	2254.19
9	334.8523	2376.83	269.3530	2256.81

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0500	0.	449.597	449.535	34.608	450.927	0.20639	202.8664	2119.19	4.402
2	14.2550	14.46256	453.854	453.555	36.512	455.321	0.20842	202.9714	2119.19	4.602
3	14.4556	28.92508	456.977	456.273	38.404	458.588	0.20993	203.0531	2119.19	4.811
4	14.6526	43.38754	459.146	457.876	40.313	460.912	0.21100	203.1145	2119.19	5.031
5	14.8464	57.84998	460.497	458.509	42.218	462.428	0.21170	203.1579	2119.19	5.261
6	15.0376	72.31242	461.126	458.274	44.138	463.233	0.21207	203.1851	2119.19	5.501
7	15.2267	86.77492	461.091	457.237	46.086	463.389	0.21214	203.1968	2119.19	5.756
8	15.4141	101.23749	460.449	455.460	48.039	462.548	0.21194	203.1943	2119.19	6.021
9	15.6000	115.70012	459.227	452.978	50.024	461.543	0.21147	203.1774	2119.19	6.302

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	197.2561	2104.79	0.955	0.00000	1324.181	1365.700	0.62510	253.3708	2236.88	-70.782
2	197.2494	2104.51	2.080	0.00000	1343.504	1383.550	0.63331	254.9938	2240.07	-70.862
3	197.2473	2104.30	3.181	0.00000	1362.411	1400.651	0.64117	256.5801	2243.23	-70.985
4	197.2485	2104.14	4.262	0.00000	1380.971	1417.103	0.64872	258.1346	2246.36	-71.143
5	197.2525	2104.05	5.326	0.00000	1399.239	1433.025	0.65603	259.6656	2249.48	-71.331
6	197.2585	2103.99	6.376	0.00000	1417.263	1448.485	0.66311	261.1765	2252.58	-71.544
7	197.2660	2103.98	7.413	0.00000	1435.084	1463.530	0.67000	262.6696	2255.67	-71.779
8	197.2747	2104.01	8.442	0.00000	1452.740	1478.242	0.67673	264.1514	2258.76	-72.035
9	197.2837	2104.08	9.462	0.00000	1470.265	1492.640	0.68331	265.6213	2261.86	-72.310

** STAGE 1 PERFORMANCE **

STATOR PRESSURE	ROTOR PRESSURE	STATOR	ROTOR	ROTOR	STAGE

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	LOSS COEFFICIENT	LOSS COEFFICIENT	BLADE ROW EFFICIENCY	BLADE ROW EFFICIENCY	ISENTROPIC EFFICIENCY	ISENTROPIC EFFICIENCY
1	0.28537	0.34295	0.09901	0.10320	0.92406	0.93062	0.95105	0.90358
2	0.28826	0.33127	0.09921	0.10030	0.92366	0.93260	0.95129	0.90442
3	0.29114	0.32114	0.09956	0.09791	0.92316	0.93421	0.95142	0.90507
4	0.29402	0.31242	0.10008	0.09593	0.92254	0.93554	0.95145	0.90556
5	0.29691	0.30500	0.10078	0.09426	0.92181	0.93665	0.95139	0.90591
6	0.29983	0.29879	0.10167	0.09285	0.92094	0.93758	0.95128	0.90613
7	0.30276	0.29369	0.10278	0.09164	0.91991	0.93836	0.95111	0.90622
8	0.30574	0.28964	0.10413	0.09060	0.91871	0.93902	0.95090	0.90620
9	0.30877	0.28653	0.10577	0.08969	0.91731	0.93960	0.95066	0.90607

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.92143

ROTOR BLADE-ROW EFFICIENCY = 0.93613

STAGE WORK = 73.427 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.91865
STAGE STATIC EFFICIENCY = 0.87293
STAGE BLADE- TO JET-SPEED RATIO = 0.67313

** STATOR 2 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	203.1119	2108.17
2	203.1119	2108.17
3	203.1119	2108.17
4	203.1119	2108.17
5	203.1119	2108.17
6	203.1119	2108.17
7	203.1119	2108.17
8	203.1119	2108.17
9	203.1119	2108.17

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE	RADIAL	MASS-FLOW	MERIDIONAL	AXIAL	WHIRL	ABSOLUTE	ABSOLUTE MACH	ABSOLUTE TOTAL	ABSOLUTE TOTAL	ABSOLUTE * FLOW *

NUMBER	POSITION (IN)	FUNCTION (LBM/SEC)	VELOCITY (FPS)	VELOCITY (FPS)	VELOCITY (FPS)	VELOCITY (FPS)	NUMBER	PRESSURE (PSI)	TEMPERATURE (DEG R)	ANGLE (DEG)
1	14.0750	0.	476.872	476.806	1483.600	1558.357	0.74368	197.4819	2108.17	72.183
2	14.3271	14.68757	488.292	487.944	1457.514	1537.132	0.73268	197.8119	2108.17	71.491
3	14.5677	29.37514	497.831	496.997	1433.421	1517.409	0.72248	198.0904	2108.17	70.878
4	14.7988	44.06272	505.920	504.413	1411.054	1499.009	0.71300	198.3302	2108.17	70.329
5	15.0217	58.75029	512.943	510.589	1390.099	1481.717	0.70412	198.5413	2108.17	69.832
6	15.2374	73.43786	519.137	515.773	1370.426	1465.459	0.69579	198.7293	2108.17	69.376
7	15.4470	88.12544	524.690	520.164	1351.822	1450.077	0.68792	198.8995	2108.17	68.954
8	15.6510	102.81301	529.714	523.884	1334.196	1435.505	0.68049	199.0547	2108.17	68.562
9	15.8500	117.50059	534.223	526.954	1317.460	1421.652	0.67345	199.1970	2108.17	68.200

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	139.1586	1936.19	0.955	-0.00000	1326.537	502.072	0.23960	144.5123	1954.04	18.232
2	140.7741	1940.84	2.163	-0.00000	1350.296	499.925	0.23829	146.1300	1958.54	12.393
3	142.2514	1945.11	3.316	-0.00000	1372.975	501.487	0.23877	147.6857	1962.92	6.934
4	143.6112	1949.04	4.424	-0.00000	1394.751	506.183	0.24076	149.1908	1967.18	1.851
5	144.8746	1952.69	5.492	-0.00000	1415.757	513.585	0.24406	150.6606	1971.37	-2.877
6	146.0512	1956.08	6.526	-0.00000	1436.095	523.274	0.24845	152.0991	1975.47	-7.256
7	147.1550	1959.26	7.531	-0.00000	1455.844	534.502	0.25376	153.5163	1979.52	-11.309
8	148.1926	1962.23	8.508	-0.00000	1475.070	548.126	0.25984	154.9145	1983.51	-15.051
9	149.1718	1965.04	9.462	-0.00000	1493.827	562.582	0.26650	156.2958	1987.45	-18.505

** ROTOR 2 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	197.4819	2108.17	144.5123	1954.04
2	197.8119	2108.17	146.1301	1958.54
3	198.0904	2108.17	147.6858	1962.92
4	198.3302	2108.17	149.1908	1967.18
5	198.5413	2108.17	150.6606	1971.37
6	198.7293	2108.17	152.0991	1975.47
7	198.8995	2108.17	153.5164	1979.52
8	199.0547	2108.17	154.9145	1983.51
9	199.1970	2108.17	156.2959	1987.45

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.	508.827	508.707	63.205	512.737	0.25142	110.4820	1837.96	7.083
2	14.3905	14.68755	526.513	525.677	61.948	530.145	0.26005	110.7208	1837.96	6.721
3	14.6668	29.37511	543.332	541.163	60.763	546.719	0.26828	110.9159	1837.96	6.406
4	14.9307	44.06267	560.063	555.975	59.702	563.236	0.27649	111.0816	1837.96	6.129
5	15.1835	58.75024	577.229	570.651	58.689	580.204	0.28493	111.2276	1837.96	5.872
6	15.4262	73.43781	595.118	585.493	57.779	597.917	0.29375	111.3600	1837.96	5.636
7	15.6595	88.12538	613.905	600.677	56.906	616.537	0.30303	111.4835	1837.96	5.412
8	15.8838	102.81296	633.678	616.294	56.095	636.156	0.31283	111.6009	1837.96	5.201
9	16.1000	117.50055	654.467	632.369	55.358	656.805	0.32316	111.7143	1837.96	5.003

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	105.9501	1818.87	1.241	0.00666	1328.893	1364.137	0.66891	141.2367	1954.01	-68.104
2	105.8707	1817.55	3.230	0.02317	1356.276	1397.320	0.68543	143.0988	1959.35	-67.896
3	105.7542	1816.26	5.121	0.03886	1382.315	1428.884	0.70117	144.8778	1964.53	-67.731
4	105.6011	1814.92	6.978	0.05385	1407.187	1459.242	0.71633	146.5918	1969.56	-67.579
5	105.4110	1813.57	8.658	0.06821	1431.013	1488.779	0.73111	148.2592	1974.48	-67.421
6	105.1833	1812.00	10.319	0.08200	1453.882	1517.652	0.74560	149.8850	1979.27	-67.248
7	104.9177	1810.36	11.915	0.09525	1475.863	1546.066	0.75990	151.4793	1983.95	-67.056
8	104.6134	1808.57	13.452	0.10800	1497.015	1574.103	0.77407	153.0441	1988.51	-66.843
9	104.2701	1806.63	14.931	0.12028	1517.389	1601.830	0.78812	154.5814	1992.97	-66.610

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.28936	0.36805	0.09653	0.09665	0.92878	0.94030	0.96707	0.91766
2	0.29621	0.35777	0.09292	0.09088	0.93082	0.94413	0.96282	0.91996
3	0.30222	0.35096	0.08993	0.08621	0.93251	0.94722	0.96337	0.92188
4	0.30748	0.34688	0.08739	0.08227	0.93394	0.94986	0.96380	0.92356
5	0.31209	0.34497	0.08517	0.07866	0.93519	0.95222	0.96419	0.92513
6	0.31610	0.34479	0.08319	0.07540	0.93631	0.95441	0.96457	0.92664
7	0.31956	0.34598	0.08141	0.07232	0.93733	0.95649	0.96496	0.92814
8	0.32250	0.34821	0.07977	0.06937	0.93826	0.95850	0.96538	0.92967
9	0.32493	0.35121	0.07826	0.06651	0.93914	0.96046	0.96585	0.93125

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY =	0.93479
ROTOR BLADE-ROW EFFICIENCY =	0.95165
STAGE WORK =	75.253 BTU PER LBM
STAGE TOTAL EFFICIENCY =	0.93931
STAGE STATIC EFFICIENCY =	0.86727
STAGE BLADE- TO JET-SPEED RATIO =	0.67653

*** SPOOL 1 PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	0.92143	0.93613	73.427	0.91865	0.87293	0.67313
2	0.93479	0.95165	75.253	0.93931	0.86727	0.67693

SPOOL WORK = 148.679 BTU PER LBM
SPOOL POWER = 24530.00 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.07952
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 3.25142
SPOOL TOTAL EFFICIENCY = 0.93514
SPOOL STATIC EFFICIENCY = 0.89770
SPOOL BLADE- TO JET-SPEED RATIO = 0.48293

*** INPUT DATA FOR SPOOL 2 ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 11209.30 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 3

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	C.3C91C
2	0.333CC
3	C.3579C

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	C.275CC
2	C.27500
3	0.27300
4	0.27300
5	C.27100
6	C.27100
7	C.26800

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	7.5000	14.075C	15.8500
2	9.0000	14.1C00	16.1000

3	10.5000	14.1400	16.6500
4	12.0000	14.1800	17.2000
5	13.5000	14.2200	17.7500
6	15.0000	14.2600	18.3000
7	16.5000	14.3000	18.8500
8	18.0000	14.3400	19.4000
9	19.5000	14.3800	19.9500

• COOLANT SCHEDULE •

BLADE ROW NUMBER	FRACTION OF INLET MASS FLOW	TOTAL TEMPERATURE (DEG R)
1	0.	0.
2	0.	0.
3	0.	0.
4	0.	0.
5	0.	0.
6	0.	0.

• MIXING COEFFICIENTS •

STREAMLINE NUMBER	BLADE ROW 1	BLADE ROW 2	BLADE ROW 3	BLADE ROW 4	BLADE ROW 5	BLADE ROW 6
1	1.00000	0.	1.00000	0.	1.00000	0.
2	1.00000	0.	1.00000	0.	1.00000	0.
3	1.00000	0.	1.00000	0.	1.00000	0.
4	1.00000	0.	1.00000	0.	1.00000	0.
5	1.00000	0.	1.00000	0.	1.00000	0.
6	1.00000	0.	1.00000	0.	1.00000	0.
7	1.00000	0.	1.00000	0.	1.00000	0.
8	1.00000	0.	1.00000	0.	1.00000	0.
9	1.00000	0.	1.00000	0.	1.00000	0.

• BLADE-ROW EXIT CONDITIONS •

STATOR 1	RADIAL POSITION (IN)	WHIRL VELOCITY (FPS)
	14.1400	753.160
	14.7675	759.460
	15.3950	728.500
	16.0225	659.970
	16.6500	673.590

STREAMLINE	NONDIMENSIONAL POWER OUTPUT

ROTOR 1	NUMBER	FLNCTICN
	1	C.
	2	C.125CC
	3	C.250CC
	4	C.375C0
	5	C.500C0
	6	C.625C0
	7	C.750CC
	8	C.87500
	9	1.C0000

STATOR 2	RACIAL PCSITION (IN)	WHIRL VELCCITY (FPS)
	14.22CC	845.010
	15.1025	798.70C
	15.9850	757.900
	16.8675	721.73C
	17.7500	689.500

ROTCR 2	STREAMLINE NUMBER	NONDIMENSICNAL POWER CUTPUT FUNCTICN
	1	C.
	2	C.12500
	3	C.250C0
	4	0.375CC
	5	C.5C0C0
	6	C.625CC
	7	0.750C0
	8	C.875CC
	9	1.CC000

STATOR 3	RADIAL PCSITION (IN)	WHIRL VELCCITY (FPS)
	14.30C0	9C0.00C
	15.4375	837.5CC
	16.5750	784.20C
	17.7125	738.320
	18.85CC	698.51C

ROTOR 3	STREAMLINE NUMBER	NONDIMENSIONAL POWER CUTPUT FUNCTICN
	1	C.
	2	C.125CC
	3	C.25000
	4	C.375C0
	5	C.500CC
	6	C.625C0
	7	C.750C0
	8	0.875C0

```
                                          9           1.COOCC

                              *.BASIC INTERNAL LOSS CORRELATICN *.

        TAN(INLET ANGLE) + TAN(EXIT ANGLE)                (0.02999999 + 0.15725499 * (V RATIO)** 3.60)  IF (V RATIO) .LT. 0.50000000 *
Y = ------------------------------------------ *TIMES*
     1.00000000 + 0.          * COS(EXIT ANGLE)           (0.0430C000 + 0.09360C0C *((V RATIO)-0.500))  IF (V RATIO) .GT. 0.5000CC00

          THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF   2.00000C00
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*** OUTPUT OF DESIGN ANALYSIS FOR SPOOL 2 ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.	508.827	508.707	63.205	512.737	0.25142	110.4820	1837.96	7.083
2	14.3905	14.68755	526.513	525.677	61.948	530.145	0.26005	110.7208	1837.96	6.721
3	14.6668	29.37511	543.332	541.163	60.763	546.719	0.26828	110.9159	1837.96	6.406
4	14.9307	44.06267	560.063	555.975	59.702	563.236	0.27649	111.0816	1837.96	6.129
5	15.1835	58.75024	577.229	570.651	58.689	580.204	0.28493	111.2276	1837.96	5.872
6	15.4262	73.43781	595.118	585.493	57.779	597.917	0.29375	111.3600	1837.96	5.636
7	15.6594	88.12538	613.905	600.677	56.906	616.537	0.30303	111.4835	1837.96	5.412
8	15.8838	102.81296	633.678	616.294	56.095	636.196	0.31283	111.6009	1837.96	5.201
9	16.1000	117.50055	654.467	632.369	55.358	656.805	0.32316	111.7143	1837.96	5.009

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	105.9501	1818.87	1.241	0.00666
2	105.8707	1817.55	3.230	0.02317
3	105.7542	1816.26	5.121	0.03886
4	105.6011	1814.92	6.928	0.05385
5	105.4110	1813.52	8.658	0.06821
6	105.1833	1812.00	10.319	0.08200
7	104.9177	1810.36	11.915	0.09525
8	104.6134	1808.57	13.452	0.10800
9	104.2701	1806.63	14.931	0.12028

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	111.1861	1837.96

2	111.1861	1837.96
3	111.1861	1837.96
4	111.1861	1837.96
5	111.1861	1837.96
6	111.1861	1837.96
7	111.1861	1837.96
8	111.1861	1837.96
9	111.1861	1837.96

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1400	0.	488.076	487.903	793.160	931.301	0.46228	110.1556	1837.96	58.403
2	14.4711	14.68755	487.429	486.252	775.036	915.570	0.45420	110.1505	1837.96	57.896
3	14.7951	29.37510	486.760	483.742	758.041	900.867	0.44667	110.1453	1837.96	57.456
4	15.1131	44.06267	485.912	480.267	742.107	887.037	0.43959	110.1378	1837.96	57.090
5	15.4262	58.75022	484.809	475.798	727.022	873.842	0.43284	110.1271	1837.96	56.797
6	15.7355	73.43779	483.397	470.322	712.750	861.212	0.42640	110.1126	1837.96	56.580
7	16.0420	88.12538	481.651	463.844	699.119	848.973	0.42016	110.0940	1837.96	56.437
8	16.3465	102.81299	479.535	456.359	686.082	837.056	0.41409	110.0712	1837.96	56.369
9	16.6500	117.50062	476.960	447.806	673.590	825.357	0.40814	110.0437	1837.96	56.384

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	95.7771	1774.98	1.528	-0.	573.292	535.313	0.26572	100.3614	1795.79	24.258
2	96.7301	1777.09	3.982	-0.00000	586.716	522.543	0.25923	100.6101	1796.92	21.171
3	96.6475	1779.03	6.384	-0.00000	599.852	511.820	0.25377	100.8602	1798.05	18.108
4	97.0328	1780.82	8.742	-0.00000	612.746	502.837	0.24919	101.1087	1799.18	15.075
5	97.3927	1782.51	11.064	-0.00000	625.442	495.336	0.24536	101.3569	1800.33	12.051
6	97.7290	1784.10	13.357	-0.00000	637.982	489.145	0.24218	101.6032	1801.48	9.033
7	98.0469	1785.62	15.628	-0.00000	650.405	484.108	0.23959	101.8496	1802.64	5.995
8	98.3401	1787.08	17.886	-0.00000	662.751	480.102	0.23751	102.0958	1803.82	2.927
9	98.6358	1788.49	20.136	-0.00000	675.057	476.962	0.23586	102.3416	1805.01	-0.188

** ROTOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE	ABSOLUTE TOTAL TEMPERATURE	RELATIVE TOTAL PRESSURE	RELATIVE TOTAL TEMPERATURE

	(PSI)	(DEG R)	(PSI)	(DEG R)
1	110.1556	1837.96	100.3614	1795.79
2	110.1505	1837.96	100.6101	1796.92
3	110.1453	1837.96	100.8602	1798.05
4	110.1378	1837.96	101.1087	1799.18
5	110.1271	1837.96	101.3569	1800.33
6	110.1126	1837.96	101.6032	1801.48
7	110.0940	1837.96	101.8496	1802.64
8	110.0712	1837.96	102.0958	1803.82
9	110.0437	1837.96	102.3416	1805.01

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1800	0.	416.072	415.924	-116.691	432.126	0.21587	91.8863	1761.90	-15.672
2	14.5877	14.68755	419.676	418.633	-113.406	434.728	0.21718	91.9189	1761.90	-15.157
3	14.9826	29.37511	422.402	419.709	-110.440	436.601	0.21812	91.9430	1761.90	-14.742
4	15.3670	44.06266	424.271	419.229	-107.660	437.717	0.21869	91.9581	1761.90	-14.403
5	15.7432	58.75022	425.288	417.247	-105.109	438.085	0.21887	91.9639	1761.90	-14.139
6	16.1129	73.43777	425.477	413.829	-102.679	437.691	0.21867	91.9605	1761.90	-13.935
7	16.4774	88.12535	424.858	409.033	-100.420	436.564	0.21811	91.9478	1761.90	-13.794
8	16.8398	102.81296	423.433	402.899	-98.276	434.688	0.21716	91.9258	1761.90	-13.708
9	17.2000	117.50060	421.179	395.435	-96.203	432.027	0.21582	91.8944	1761.90	-13.674

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	89.0822	1748.24	1.528	0.00000	574.914	807.114	0.40320	99.1315	1795.89	-58.970
2	89.0802	1748.07	4.040	0.00000	591.445	820.331	0.40982	99.4967	1797.30	-59.293
3	89.0794	1747.95	6.473	0.00000	607.456	832.944	0.41613	99.8333	1798.71	-59.680
4	89.0796	1747.88	8.842	0.00000	623.041	844.943	0.42214	100.1598	1800.11	-60.156
5	89.0804	1747.86	11.160	0.00000	638.291	856.454	0.42789	100.4787	1801.52	-60.696
6	89.0822	1747.88	13.438	-0.00000	653.281	867.471	0.43339	100.7895	1802.93	-61.303
7	89.0845	1747.96	15.687	-0.00000	668.080	878.121	0.43870	101.0947	1804.36	-61.976
8	89.0875	1748.08	17.917	-0.00000	682.751	888.425	0.44384	101.3946	1805.82	-62.713
9	89.0913	1748.24	20.136	-0.00000	697.397	898.404	0.44880	101.6896	1807.29	-63.513

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.55056	0.66324	0.07167	0.12317	0.93867	0.90112	0.93292	0.91828
2	0.57903	0.63699	0.07439	0.11561	0.93631	0.90683	0.93494	0.90958
3	0.60688	0.61447	0.07711	0.10944	0.93398	0.91154	0.93651	0.90249
4	0.63496	0.59511	0.07999	0.10444	0.93152	0.91538	0.93769	0.89629
5	0.66397	0.57836	0.08315	0.10043	0.92885	0.91849	0.93851	0.89054
6	0.69427	0.56388	0.08668	0.09726	0.92591	0.92095	0.93899	0.88496
7	0.72621	0.55130	0.09064	0.09483	0.92265	0.92284	0.93914	0.87937
8	0.75999	0.54040	0.09510	0.09308	0.91901	0.92421	0.93898	0.87366
9	0.79578	0.53090	0.10014	0.09195	0.91495	0.92510	0.93851	0.86773

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.92813

ROTOR BLADE-ROW EFFICIENCY = 0.91667

STAGE WORK = 20.842 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.89098
STAGE STATIC EFFICIENCY = 0.76712
STAGE BLADE- TO JET-SPEED RATIO = 0.54124

** STATOR 2 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	91.9385	1761.90
2	91.9385	1761.90
3	91.9385	1761.90
4	91.9385	1761.90
5	91.9385	1761.90
6	91.9385	1761.90
7	91.9385	1761.90
8	91.9385	1761.90
9	91.9385	1761.90

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2200	0.	384.098	383.961	845.010	928.210	0.47038	90.7218	1761.90	65.564
2	14.7045	14.68758	385.259	384.282	818.904	905.002	0.45820	90.7816	1761.90	64.861
3	15.1713	29.37515	385.814	383.302	795.321	883.962	0.44719	90.8301	1761.90	64.268
4	15.6238	44.06274	385.683	381.010	774.038	864.804	0.43718	90.8690	1761.90	63.792
5	16.0648	58.75032	385.234	377.828	754.438	847.102	0.42795	90.9039	1761.90	63.398
6	16.4963	73.43789	384.557	373.891	736.463	830.821	0.41948	90.9350	1761.90	63.084
7	16.9200	88.12546	383.730	369.303	719.701	815.609	0.41158	90.9632	1761.90	62.836
8	17.3375	102.81302	382.772	364.117	704.076	801.397	0.40421	90.9890	1761.90	62.654
9	17.7500	117.50059	381.529	358.209	689.500	788.020	0.39728	91.0123	1761.90	62.547

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	78.4722	1698.87	1.528	-0.00000	576.535	468.625	0.23748	81.4690	1714.94	34.962
2	79.0983	1701.98	4.082	-0.00000	596.179	445.007	0.22531	81.8134	1716.47	30.096
3	79.6516	1704.74	6.542	-0.00000	615.105	425.829	0.21542	82.1484	1718.00	25.181
4	80.1428	1707.19	8.928	-0.00000	633.453	410.507	0.20752	82.4721	1719.52	20.253
5	80.5890	1709.40	11.253	-0.00000	651.332	398.793	0.20147	82.7953	1721.04	15.264
6	80.9925	1711.40	13.527	0.00000	668.826	390.462	0.19715	83.1147	1722.56	10.254
7	81.3636	1713.24	15.761	0.00000	686.005	385.206	0.19439	83.4358	1724.09	5.213
8	81.7051	1714.92	17.962	0.00000	702.930	382.774	0.19307	83.7575	1725.63	0.180
9	82.0216	1716.47	20.136	0.00000	719.656	382.719	0.19295	84.0795	1727.19	-4.812

** ROTOR 2 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	90.7218	1761.90	81.4690	1714.94
2	90.7816	1761.90	81.8134	1716.47
3	90.8301	1761.90	82.1484	1718.00
4	90.8690	1761.90	82.4722	1719.52
5	90.9039	1761.90	82.7953	1721.04
6	90.9350	1761.90	83.1148	1722.56
7	90.9632	1761.90	83.4358	1724.09
8	90.9890	1761.90	83.7575	1725.63
9	91.0123	1761.90	84.0795	1727.19

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2600	0.	303.167	303.059	-129.667	329.732	0.16826	73.8404	1679.35	-23.164
2	14.8849	14.68752	329.030	328.058	-122.508	351.097	0.17922	74.0085	1679.35	-20.477
3	15.4492	29.37503	346.112	343.529	-116.448	365.177	0.18645	74.1311	1679.35	-18.726
4	15.9740	44.06254	358.242	353.409	-110.508	375.018	0.19150	74.2241	1679.35	-17.423
5	16.4711	58.75008	366.697	359.062	-105.954	381.697	0.19493	74.2915	1679.35	-16.441
6	16.9481	73.43766	372.774	361.843	-101.260	386.282	0.19729	74.3405	1679.35	-15.634
7	17.4097	88.12529	377.214	362.537	-96.942	389.471	0.19893	74.3763	1679.35	-14.971
8	17.8594	102.81297	380.463	361.622	-92.847	391.628	0.20004	74.4021	1679.35	-14.400
9	18.3000	117.50070	382.796	359.398	-88.878	392.978	0.20073	74.4198	1679.35	-13.890

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	72.4576	1671.34	1.528	0.	578.157	770.016	0.39293	80.2393	1715.03	-66.822
2	72.4387	1670.27	4.406	0.	603.493	797.082	0.40687	80.8034	1717.09	-65.683
3	72.4311	1669.52	7.005	0.	626.371	819.496	0.41840	81.2969	1719.01	-65.181
4	72.4298	1668.99	9.422	0.	647.649	838.897	0.42838	81.7427	1720.85	-65.019
5	72.4317	1668.61	11.712	0.	667.805	856.253	0.43729	82.1549	1722.64	-65.106
6	72.4349	1668.35	13.909	0.	687.142	872.088	0.44541	82.5411	1724.40	-65.347
7	72.4385	1668.17	16.035	0.	705.857	887.004	0.45305	82.9129	1726.15	-65.696
8	72.4423	1668.05	18.107	0.	724.093	901.190	0.46032	83.2736	1727.90	-66.123
9	72.4462	1667.97	20.136	0.	741.955	914.776	0.46727	83.6255	1729.64	-66.608

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.46555	0.60859	0.09933	0.16134	0.91741	0.87347	0.92643	0.87378
2	0.48036	0.55830	0.09902	0.13532	0.91727	0.89232	0.93356	0.88131
3	0.49391	0.51962	0.09916	0.11803	0.91684	0.90526	0.93858	0.88685
4	0.50615	0.48934	0.09972	0.10565	0.91612	0.91472	0.94232	0.89124
5	0.51716	0.46574	0.10030	0.09722	0.91540	0.92125	0.94470	0.89467
6	0.52682	0.44773	0.10093	0.09136	0.91467	0.92584	0.94615	0.89752
7	0.53526	0.43428	0.10160	0.08717	0.91394	0.92914	0.94693	0.90008
8	0.54241	0.42474	0.10228	0.08418	0.91321	0.93152	0.94722	0.90250
9	0.54824	0.41837	0.10302	0.08203	0.91244	0.93323	0.94714	0.90492

*** MASS-AVERAGED QUANTITIES ***

STATOR BLADE-ROW EFFICIENCY = 0.91529

ROTOR BLADE-ROW EFFICIENCY = 0.91542

STAGE WORK = 22.453 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.89286
STAGE STATIC EFFICIENCY = 0.80336
STAGE BLADE- TO JET-SPEED RATIO = 0.55602

**** STATOR 3 MIXED AND/OR COOLED QUANTITIES ****

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	74.2380	1679.35
2	74.2380	1679.35
3	74.2380	1679.35
4	74.2380	1679.35
5	74.2380	1679.35
6	74.2380	1679.35
7	74.2380	1679.35
8	74.2380	1679.35
9	74.2380	1679.35

**** STATOR EXIT - ROTOR INLET 3 ****

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.	338.191	338.071	900.000	961.443	0.49968	73.1010	1679.35	69.412
2	14.9481	14.68757	342.570	341.659	863.262	928.749	0.48201	73.1948	1679.35	68.407
3	15.5602	29.37515	344.756	342.414	831.309	899.962	0.46651	73.2623	1679.35	67.613
4	16.1456	44.06273	345.055	340.735	803.446	874.408	0.45279	73.3119	1679.35	67.019
5	16.7111	58.75032	344.301	337.522	778.319	851.072	0.44031	73.3514	1679.35	66.556
6	17.2611	73.43789	342.852	333.185	755.799	829.928	0.42902	73.3830	1679.35	66.210
7	17.7991	88.12546	340.921	327.978	735.075	810.285	0.41856	73.4090	1679.35	65.954
8	18.3279	102.81303	338.600	322.027	716.030	792.054	0.40888	73.4302	1679.35	65.785
9	18.8500	117.50059	335.566	315.055	698.510	774.933	0.39980	73.4462	1679.35	65.723

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	62.0637	1611.23	1.528	0.	579.779	465.741	0.24205	64.5334	1627.21	43.447
2	62.8405	1615.78	4.178	0.00000	606.056	428.379	0.22232	64.9453	1629.31	36.973
3	63.4975	1619.66	6.681	0.00000	630.872	398.788	0.20672	65.3331	1631.38	30.343
4	64.0603	1623.00	9.076	0.00000	654.609	375.786	0.19459	65.6993	1633.41	23.596
5	64.5592	1625.97	11.389	0.00000	677.535	358.748	0.18560	66.0606	1635.46	16.626
6	64.9993	1628.59	13.638	0.00000	699.835	347.389	0.17958	66.4136	1637.48	9.535
7	65.3978	1630.97	15.838	0.00000	721.647	341.185	0.17624	66.7680	1639.54	2.344
8	65.7586	1633.12	18.001	0.00000	743.084	339.680	0.17535	67.1224	1641.62	-4.802
9	66.0883	1635.10	20.136	0.00000	764.254	341.946	0.17641	67.4757	1643.71	-11.787

** ROTOR 3 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	73.1010	1679.35	64.5334	1627.21
2	73.1948	1679.35	64.9453	1629.31
3	73.2623	1679.35	65.3331	1631.38
4	73.3119	1679.35	65.6993	1633.41
5	73.3514	1679.35	66.0606	1635.46
6	73.3830	1679.35	66.4136	1637.48
7	73.4090	1679.35	66.7680	1639.54
8	73.4302	1679.35	67.1224	1641.62
9	73.4462	1679.35	67.4757	1643.71

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.	80.791	80.763	-141.691	163.106	0.08523	56.0865	1589.81	-60.317
2	15.4927	14.68781	317.106	315.501	-128.946	342.320	0.17926	58.0640	1589.81	-22.230
3	16.1594	29.37330	344.765	341.224	-121.696	365.612	0.19153	58.2419	1589.81	-19.629
4	16.7647	44.06086	360.205	354.237	-115.104	378.149	0.19814	58.3493	1589.81	-18.001
5	17.3327	58.74867	370.005	361.188	-109.347	385.824	0.20219	58.4209	1589.81	-16.843
6	17.8747	73.43661	376.745	364.701	-103.829	390.790	0.20481	58.4707	1589.81	-15.891
7	18.3972	88.12464	381.566	365.951	-98.828	394.157	0.20659	58.5063	1589.81	-15.113
8	18.9046	102.81274	385.075	365.570	-94.080	396.402	0.20777	58.5318	1589.81	-14.432
9	19.4000	117.50092	387.657	363.962	-89.430	397.839	0.20853	58.5494	1589.81	-13.805

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPFRATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	55.8136	1587.82	1.528	-C.	581.401	727.591	0.3802C	61.4332	1627.27	-83.627
2	56.8272	1581.07	5.767	-0.00C00	628.134	82C.808	0.42982	64.2133	1631.28	-67.377
3	56.8281	1579.85	8.219	-0.00C00	655.167	849.928	0.44524	64.7808	1633.68	-66.287
4	56.8353	1579.15	10.445	-0.00C00	679.707	872.624	0.45723	65.2455	1635.89	-65.978
5	56.8435	1578.71	12.533	-C.00000	702.735	892.402	0.46766	65.6640	1638.06	-66.022
6	56.8515	1578.43	14.527	-0.00000	724.710	91C.171	0.47701	66.0499	1640.16	-66.242
7	56.8584	1578.23	16.448	-0.00C00	745.895	926.904	0.48581	66.4205	1642.25	-66.577
8	56.8646	1578.10	18.314	-C.CCC00	766.468	942.776	0.49415	66.7789	1644.33	-66.984
9	56.8597	1578.01	20.136	-C.00000	786.553	957.927	0.50211	67.1269	1646.39	-67.438

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.34296	0.64011	0.10301	0.55556	C.91560	0.66802	0.81805	0.78912
2	0.37803	0.52190	0.10075	0.14202	C.91673	0.89034	0.93200	0.89078
3	0.40577	0.46920	0.09992	0.11539	0.91686	C.90995	0.94043	0.89580
4	0.42888	0.43064	0.10010	0.10C77	0.91631	0.92103	0.94510	0.89793
5	0.44849	0.40200	C.10086	C.09147	C.91538	0.92811	0.94787	0.89908
6	0.46544	0.38167	0.10198	0.08516	C.91417	0.93295	0.94958	0.89978
7	0.48066	0.36809	0.10349	0.08C59	0.91271	0.93646	0.95062	0.90025
8	0.49445	0.36030	0.10531	0.07715	0.91104	0.93910	0.95121	0.90057
9	0.50711	C.35696	0.10761	C.07442	C.90901	0.94119	0.95155	0.90080

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.91444

ROTOR BLADE-ROW EFFICIENCY = 0.90787

STAGE WORK = 24.132 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.89C40
STAGE STATIC EFFICIENCY = 0.80884
STAGE BLADE- TO JET-SPEED RATIO = C.56209

*** SPCOL 2 PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	0.92813	0.91667	20.842	0.89098	0.76712	0.54124
2	0.91529	0.91542	22.453	0.89286	0.80336	0.55802
3	0.91444	0.90782	24.132	0.89040	0.80884	0.56209

SPOOL WORK = 67.427 BTU PER LBM
SPOOL POWER = 11209.30 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 1.90917
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 1.95814
SPOOL TOTAL EFFICIENCY = 0.89686
SPOOL STATIC EFFICIENCY = 0.86574
SPCOL BLADE- TO JET-SPEED RATIO = 0.33355

```
*** CVERALL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

                     OVERALL WCRK =   216.1C6 BTU PER LBM
  CVERALL TOTAL- TO TOTAL-PRESSURE RATIO =   5.87934
 OVERALL TOTAL- TC STATIC-PRESSURE RATIO =   6.03015
              OVERALL TOTAL EFFICIENCY =   C.93401
             OVERALL STATIC EFFICIENCY =   C.92351
      CVERALL BLACE- TO JET-SPEED RATIO =   C.29794
```

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL   PROJECT: AXIAL TURBINE DESIGN   PROJECT NO: 1125

TITLE: SAMPLE CASE III   SHEET: 1 OF 2

LOCATION

```
1   6 7  12 13  18 19  24 25  30 31  36 37  42 43  48 49  54 55  60 61  66 67  72
THIRD LP STAGE FROM NASA TWINSPOOL
     0     0     2     0     0     1     1     1     1
$NAM1
NSPOOL=1,NAV=1,NLINES=9,GASC=53.35,FLWM=117.5,
NLT=5,RLT(1)=14.26,15.4492,16.4711,17.4097,18.3,
TOLT(1)=5*1679.35,
POLT(1)=73.8409,74.1316,74.2920,74.3768,74.4203,
BETLT(1)=-23.152,-18.716,-16.431,-14.962,-13.882 $
$NAM2
RPM=4646.,HP=4011.81,NSTG=1,FHP(1)=1.0,CP(1)=.271,.271,.268,
RANN(1,1)=14.26,14.30,14.34,
RANN(1,2)=18.30,18.85,19.40,
NSTRAC=2,RSTRAC(1,1)=14.26,18.30,
RSTRAC(1,2)=14.30,18.85,
RSTRAC(1,3)=14.34,19.40,
ASTR(1,1)=1.528,20.136,
ASTR(1,2)=1.528,20.136,
ASTR(1,3)=1.528,20.136,
CSTR(1,1)=2*0.0,
CSTR(1,2)=2*0.0,
```

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL PROJECT: AXIAL TURBINE DESIGN PROJECT NO: 1125

TITLE: SAMPLE CASE III SHEET: 2 OF 2

LOCATION

```
CSTR(1,3)=2*0.0,
XMIX(1,1)=9*1.0,
XMIX(1,2)=9*0.0,
NXT=5,RNXT(1,1)=14.30,15.4375,16.5750,17.7125,18.85,
WRL(1,1)=900.,837.5,784.2,738.32,698.51,
IPOF(1)=0,
YOSS(1,1)=.103,.100,.101,.103,.108,
RSXT(1,1)=14.34,16.1595,17.3327,18.3972,19.40,
YOSS(1,2)=.882,.896,.899,.900,.901 $
```

** PROGRAM TD - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

THIRD LP STAGE FROM NASA TWINSPOOL

*** GENERAL INPUT DATA ***

```
                      NUMBER OF SPOOLS =     1
  NUMBER OF SETS OF ANALYSIS VARIABLES =     1
                 NUMBER OF STREAMLINES =     9

                          GAS CONSTANT =   53.35000 LBF FT/LBM DEG R
                       INLET MASS FLOW =  117.50000 LBM/SEC
```

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.2600	1679.35	73.8409	-23.152
15.4492	1679.35	74.1316	-18.716
16.4711	1679.35	74.2920	-16.431
17.4097	1679.35	74.3768	-14.962
18.3000	1679.35	74.4203	-13.882

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 4C11.81 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 1

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL PCWER OLTPUT
1	1.CCC00

* SPECIFIC-HEAT SPECIFICATICN *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	C.271CC
2	C.2710C
3	C.26800

* ANNULUS SPECIFICATICN *

DESIGN STATION NUMBER	HUB RADIUS (IN)	CASING RADIUS (IN)
1	14.2600	18.3000
2	14.3000	18.8500
3	14.3400	19.4000

* STREAMLINF SPFCIFICATIONS *

DESIGN STATION 1	RADIAL COORDINATE (IN)	ANGLE OF INCLINATION (DEG)	CURVATURE (PER IN)
	14.26000	1.52800	C.
	18.30000	2C.13600	0.

DESIGN STATION 2	RADIAL COORDINATE (IN)	ANGLE OF INCLINATION (DEG)	CURVATURE (PER IN)
	14.30000	1.5280C	C.
	18.85000	2C.13600	C.

DESIGN STATION 3	RADIAL COORDINATE (IN)	ANGLE OF INCLINATION (DEG)	CURVATURE (PER IN)
	14.3400C	1.52800	C.
	19.4000C	2C.1360C	0.

* MIXING COEFFICIENTS *

STREAMLINE NUMBER	BLADE ROW 1	BLADE ROW 2
1	1.000CO	0.
2	1.0COCO	C.
3	1.00000	C.
4	1.000CO	0.
5	1.0COCO	0.
6	1.C00CO	C.
7	1.C0000	C.
8	1.00000	0.
9	1.000CO	0.

* BLADE-ROW EXIT CONDITIONS *

STATOR 1	RADIAL POSITION (IN)	WHIRL VELOCITY (FPS)	PRESSURE LOSS CCEFFICIENT
	14.3000	90C.CC0	0.10300
	15.4375	837.50C	C.10000
	16.5750	784.2CC	C.10100
	17.7125	738.320	C.1C300
	18.8500	698.510	0.10800

RCTOR 1	STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTICN	RADIAL POSITICN (IN)	STAGE ISENTRCPIC EFFICIENCY
	1	C.	14.34C0	C.88200
	2	0.12500	16.1595	0.89600
	3	0.25000	17.3327	0.89900
	4	0.375C0	18.3972	0.9C000
	5	0.5C0C0	19.4000	C.90100
	6	0.625C0		
	7	0.750C0		
	8	0.875C0		
	9	1.00000		

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

* PASS 1 *

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	744.353	228.52487	1	702.548	-300.737	73.8409
			2	718.634	-272.343	73.9930
			3	730.066	-249.022	74.1157
			4	738.410	-230.526	74.2119
			5	744.353	-216.929	74.2838
			6	748.756	-204.319	74.3380
			7	752.064	-193.891	74.3746
			8	754.572	-184.159	74.4026
			9	756.445	-175.522	74.4203
2	620.294	194.83747	1	578.503	-247.285	73.8409
			2	593.728	-225.007	73.9930
			3	605.410	-206.502	74.1157
			4	614.056	-191.704	74.2119
			5	620.294	-180.774	74.2837
			6	624.911	-170.524	74.3380
			7	628.343	-161.995	74.3746
			8	630.913	-153.979	74.4026
			9	632.790	-146.830	74.4203
3	372.176	119.91294	1	318.561	-136.171	73.8409
			2	337.761	-128.002	73.9930
			3	352.669	-120.294	74.1157
			4	363.916	-113.612	74.2119
			5	372.176	-108.464	74.2837
			6	378.236	-103.212	74.3380
			7	382.622	-98.645	74.3746
			8	385.807	-94.159	74.4026
			9	388.012	-90.033	74.4203
4	364.186	117.35238	1	309.692	-132.380	73.8409
			2	329.219	-124.765	73.9930
			3	344.369	-117.462	74.1157

		4	355.794	-111.077	74.2119
		5	364.186	-106.136	74.2837
		6	370.338	-101.057	74.3380
		7	374.785	-96.624	74.3746
		8	378.012	-92.257	74.4026
		9	38C.241	-88.229	74.4203
364.647	117.50025	1	31C.205	-132.599	73.8409
		2	329.712	-124.952	73.9930
		3	344.848	-117.626	74.1157
		4	356.263	-111.223	74.2119
		5	364.647	-106.270	74.2837
		6	37C.793	-1C1.181	74.3380
		7	375.237	-96.741	74.3746
		8	378.461	-92.366	74.4026
		9	38C.689	-88.333	74.4203
364.646	117.50000	1	31C.204	-132.599	73.84C9
		2	329.712	-124.952	73.9930
		3	344.847	-117.626	74.1157
		4	356.262	-111.223	74.2119
		5	364.646	-106.270	74.2837
		6	370.792	-101.181	74.3380
		7	375.236	-96.741	74.3746
		8	378.460	-92.366	74.4026
		9	380.688	-88.333	74.4203

STREAMLINE NUMBER	RADIAL POSITICN (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELCCITY (FPS)	ABSCLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSCLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2600	0.	310.204	310.C94	-132.599	337.356	0.17217	73.8409	1679.35	-23.152
2	14.8253	13.41426	329.712	328.855	-124.952	352.594	0.17999	73.9930	1679.35	-20.805
3	15.3699	27.51542	344.847	342.534	-117.626	364.356	0.18602	74.1157	1679.35	-18.952
4	15.8958	42.10398	356.262	351.815	-111.223	373.220	0.19058	74.2119	1679.35	-17.544
5	16.4048	57.00996	364.646	357.443	-106.270	379.815	0.19397	74.2837	1679.35	-16.557
6	16.8986	72.09717	370.792	360.272	-101.181	384.349	0.19630	74.3380	1679.35	-15.687
7	17.3783	87.25970	375.236	360.897	-96.741	387.506	0.19792	74.3746	1679.35	-15.006
8	17.8451	102.41554	378.460	359.854	-92.366	389.568	0.19898	74.4026	1679.35	-14.396
9	18.3000	117.50000	380.688	357.419	-88.333	390.802	0.19961	74.4203	1679.35	-13.882

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	72.3939	1670.96	1.528	0.
2	72.4102	1670.19	4.132	C.
3	72.4236	1669.57	6.640	0.
4	72.4349	1669.09	9.062	0.
5	72.4423	1668.72	11.407	0.
6	72.4514	1668.46	13.681	C.
7	72.4562	1668.28	15.891	0.
8	72.4631	1668.17	18.041	0.

9	72.4682	1668.10	20.136	0.

• PASS 2 •

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	364.646	117.26169	1	309.412	-132.260	73.8409
			2	330.546	-123.971	74.0056
			3	345.660	-116.506	74.1290
			4	356.596	-110.827	74.2207
			5	364.646	-105.465	74.2906
			6	370.548	-100.596	74.3418
			7	374.751	-96.315	74.3764
			8	377.839	-92.090	74.4031
			9	379.999	-88.173	74.4203
2	365.387	117.49993	1	310.238	-132.614	73.8409
			2	331.338	-124.268	74.0056
			3	346.429	-116.765	74.1290
			4	357.349	-111.060	74.2207
			5	365.387	-105.679	74.2906
			6	371.281	-100.795	74.3418
			7	375.478	-96.502	74.3764
			8	378.562	-92.267	74.4031
			9	380.720	-88.341	74.4203
3	365.387	117.50000	1	310.239	-132.614	73.8409
			2	331.339	-124.268	74.0056
			3	346.430	-116.765	74.1290
			4	357.349	-111.061	74.2207
			5	365.387	-105.679	74.2906
			6	371.281	-100.795	74.3418
			7	375.479	-96.502	74.3764
			8	378.562	-92.267	74.4031
			9	380.720	-88.341	74.4203

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.7600	0.	310.239	310.128	-132.614	337.393	0.17219	73.8409	1679.35	-23.152
2	14.8766	14.69395	331.339	330.376	-124.268	353.875	0.18064	74.0056	1679.35	-20.613
3	15.4360	29.30078	346.430	343.888	-116.765	365.578	0.18665	74.1290	1679.35	-18.755
4	15.9604	43.95224	357.349	352.591	-111.061	374.209	0.19109	74.2207	1679.35	-17.484
5	16.4595	58.64619	365.387	357.848	-105.679	380.363	0.19425	74.2906	1679.35	-16.453

6	16.9394	73.36493	371.281	360.456	-100.795	384.719	C.19649	74.3418	1679.35	-15.623
7	17.4042	88.08756	375.479	360.915	-96.502	387.681	0.19801	74.3764	1679.35	-14.970
8	17.8569	102.80056	378.562	359.840	-92.267	389.644	0.19902	74.4031	1679.35	-14.381
9	18.3500	117.50000	380.720	357.450	-88.341	390.835	C.19963	74.4203	1679.35	-13.882

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	72.3936	1670.96	1.528	0.
2	72.4111	1670.12	4.368	0.
3	72.4253	1669.50	6.945	0.
4	72.4342	1669.03	9.360	0.
5	72.4437	1668.69	11.659	0.
6	72.4514	1668.44	13.869	0.
7	72.4562	1668.27	16.010	0.
8	72.4629	1668.16	18.095	0.
9	72.4679	1668.09	20.136	0.

* PASS 3 *

ITERATIVE CETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	365.387	117.49364	1	310.259	-132.623	73.84C9
			2	331.350	-124.279	74.0055
			3	346.514	-116.736	74.1295
			4	357.438	-111.025	74.2213
			5	365.387	-105.629	74.2910
			6	371.161	-100.957	74.3395
			7	375.422	-96.474	74.3765
			8	378.591	-92.270	74.4032
			9	380.736	-88.344	74.4203
2	365.407	117.50000	1	31C.281	-132.632	73.8409
			2	331.371	-124.287	74.0055
			3	346.535	-116.743	74.1295
			4	357.458	-111.031	74.2213
			5	365.4C7	-105.635	74.2910
			6	371.180	-100.962	74.3395
			7	375.442	-96.479	74.3765
			8	378.610	-92.275	74.4032
			9	38C.755	-88.349	74.4203

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2600	0.	310.281	310.171	-132.632	337.440	0.17221	73.8409	1679.35	-23.152
2	14.8763	14.68932	331.371	330.410	-124.287	353.913	0.18066	74.0055	1679.35	-20.614
3	15.4188	29.37872	346.535	343.983	-116.743	365.671	0.18670	74.1295	1679.35	-18.746
4	15.9642	44.06744	357.458	352.681	-111.031	374.305	0.19113	74.2213	1679.35	-17.475
5	16.4630	58.75495	365.407	357.847	-105.635	380.369	0.19425	74.2910	1679.35	-16.446
6	16.9417	73.43928	371.180	360.342	-100.962	38[illegible].666	0.19646	74.3395	1679.35	-15.652
7	17.4053	88.12340	375.442	360.870	-96.479	387.640	0.19799	74.3765	1679.35	-14.968
8	17.8572	102.81098	378.610	359.882	-92.275	389.693	0.19904	74.4032	1679.35	-14.381
9	18.3000	117.50000	380.755	357.482	-88.349	390.871	0.19965	74.4203	1679.35	-13.882

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	72.3932	1670.96	1.528	0.
2	72.4107	1670.12	4.367	0.
3	72.4250	1669.50	6.957	0.
4	72.4339	1669.03	9.378	0.
5	72.4440	1668.69	11.675	0.
6	72.4497	1668.45	13.880	0.
7	72.4567	1668.28	16.015	0.
8	72.4625	1668.16	18.097	0.
9	72.4675	1668.09	20.136	0.

● CONVERGED PASS ●

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)
1	365.407	117.50075

STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	310.284	-132.633	73.8409
2	331.372	-124.289	74.0055
3	346.534	-116.746	74.1295
4	357.457	-111.034	74.2213
5	365.407	-105.637	74.2910
6	371.182	-100.963	74.3395
7	375.444	-96.479	74.3765
8	378.613	-92.275	74.4032
9	380.757	-88.349	74.4203

2 365.405 117.50000

1	310.281	-132.632	73.8409
2	331.369	-124.288	74.0055
3	346.532	-116.745	74.1295
4	357.455	-111.033	74.2213
5	365.405	-105.637	74.2910
6	371.180	-100.963	74.3395
7	375.442	-96.479	74.3765
8	378.610	-92.274	74.4032
9	380.755	-88.349	74.4203

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2600	0.	310.281	310.171	-132.632	337.440	0.17221	73.8409	1679.35	-23.152
2	14.8763	14.68749	331.369	330.407	-124.288	353.911	0.18066	74.0055	1679.35	-20.615
3	15.4387	29.37499	346.532	343.980	-116.745	365.669	0.18670	74.1295	1679.35	-18.747
4	15.9641	44.06248	357.455	352.679	-111.033	374.303	0.19113	74.2213	1679.35	-17.475
5	16.4628	58.74998	365.405	357.846	-105.637	380.368	0.19425	74.2910	1679.35	-16.447
6	16.9417	73.43749	371.180	360.342	-100.963	384.666	0.19646	74.3395	1679.35	-15.652
7	17.4054	88.12499	375.442	360.870	-96.479	387.640	0.19799	74.3765	1679.35	-14.968
8	17.8573	102.81249	378.610	359.882	-92.274	389.693	0.19904	74.4032	1679.35	-14.381
9	18.3000	117.50000	380.755	357.482	-88.349	390.871	0.19965	74.4203	1679.35	-13.882

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	72.3932	1670.96	1.528	0.
2	72.4107	1670.12	4.366	0.
3	72.4250	1669.50	6.957	0.
4	72.4339	1669.03	9.377	0.
5	72.4440	1668.69	11.674	0.
6	72.4497	1668.45	13.880	0.
7	72.4567	1668.28	16.015	0.
8	72.4625	1668.16	18.097	0.
9	72.4675	1668.09	20.136	0.

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	74.2371	1679.35
2	74.2371	1679.35

3	74.2371	1679.35
4	74.2371	1679.35
5	74.2371	1679.35
6	74.2371	1679.35
7	74.2371	1679.35
8	74.2371	1679.35
9	74.2371	1679.35

** STATOR EXIT - ROTOR INLET 1 **

* PASS 1 *

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	458.030	154.64417	1	453.510	900.000	72.9972
			2	456.821	863.447	73.0909
			3	458.515	831.182	73.1596
			4	458.626	802.919	73.2048
			5	458.030	777.495	73.2440
			6	457.055	754.863	73.2783
			7	455.535	734.233	73.3025
			8	453.470	715.501	73.3191
			9	450.779	698.510	73.3294
2	381.692	129.91654	1	376.112	900.000	73.0695
			2	380.043	863.447	73.1626
			3	382.096	831.182	73.2312
			4	382.309	802.919	73.2774
			5	381.692	777.495	73.3174
			6	380.623	754.863	73.3526
			7	378.929	734.233	73.3781
			8	376.618	715.501	73.3963
			9	373.580	698.510	73.4087
3	343.360	117.21853	1	337.077	900.000	73.1012
			2	341.431	863.447	73.1939
			3	343.723	831.182	73.2625
			4	343.998	802.919	73.3090
			5	343.360	777.495	73.3495
			6	342.221	754.863	73.3850
			7	340.401	734.233	73.4111
			8	337.911	715.501	73.4301
			9	334.623	698.510	73.4433
4	344.209	117.50191	1	337.944	900.000	73.1005
			2	342.288	863.447	73.1932
			3	344.573	831.182	73.2619
			4	344.847	802.919	73.3084
			5	344.209	777.495	73.3488
			6	343.073	754.863	73.3843
			7	341.255	734.233.	73.4104

		8	338.770	715.501	73.4293
		9	335.489	698.510	73.4426
344.204	117.50000	1	337.938	900.000	73.1005
		2	342.282	863.447	73.1932
		3	344.567	831.182	73.2619
		4	344.841	802.919	73.3084
		5	344.204	777.495	73.3488
		6	343.067	754.863	73.3843
		7	341.250	734.233	73.4104
		8	338.764	715.501	73.4293
		9	335.483	698.510	73.4426

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.	337.938	337.818	900.000	961.354	0.49963	73.1005	1679.35	69.426
2	14.9447	14.59690	342.282	341.378	863.447	928.816	0.48204	73.1932	1679.35	68.428
3	15.5627	29.41655	344.567	342.220	831.182	899.772	0.46640	73.2619	1679.35	67.622
4	16.1571	44.32570	344.841	340.479	802.919	873.839	0.45249	73.3084	1679.35	67.021
5	16.7304	59.22239	344.204	337.332	777.495	850.279	0.43988	73.3488	1679.35	66.545
6	17.2847	74.04282	343.067	333.258	754.863	829.164	0.42862	73.3843	1679.35	66.179
7	17.8217	88.73189	341.250	328.144	734.233	805.660	0.41823	73.4104	1679.35	65.919
8	18.3431	103.23526	338.764	322.069	715.501	791.646	0.40866	73.4293	1679.35	65.766
9	18.8500	117.50000	335.483	314.978	698.510	774.897	0.39978	73.4426	1679.35	65.728

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	PRESSURE LOSS COEFFICIENT	BLADE-ROW EFFICIENCY	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	62.0652	1611.24	0.10300	0.91561	579.779	465.557	0.24196	64.5330	1627.21	43.468
2	62.8377	1615.77	0.10081	0.91668	605.918	428.344	0.22230	64.9421	1629.30	37.030
3	63.5011	1619.69	0.09991	0.91687	630.974	398.510	0.20657	65.3342	1631.39	30.329
4	64.0686	1623.08	0.10052	0.91599	655.074	375.198	0.19428	65.7026	1633.45	23.472
5	64.5726	1626.07	0.10121	0.91508	678.317	358.207	0.18531	66.0696	1635.53	16.384
6	65.0152	1628.68	0.10190	0.91422	700.790	347.302	0.17953	66.4291	1637.57	9.216
7	65.4109	1631.04	0.10335	0.91281	722.564	341.449	0.17638	66.7835	1639.63	2.037
8	65.7655	1633.17	0.10540	0.91096	743.701	339.936	0.17548	67.1314	1641.68	-5.004
9	66.0857	1635.10	0.10800	0.90872	764.254	341.864	0.17637	67.4724	1643.71	-11.790

* PASS 2 *

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

MERIDIONAL

PASS NUMBER	VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	344.204	117.49278	1	337.925	900.000	73.1005
			2	342.293	863.236	73.1937
			3	344.550	831.267	73.2617
			4	344.819	803.394	73.3076
			5	344.204	778.268	73.3477
			6	343.102	755.768	73.3831
			7	341.314	735.070	73.4094
			8	338.825	716.038	73.4289
			9	335.458	698.510	73.4426
2	344.225	117.49983	1	337.947	900.000	73.1005
			2	342.314	863.236	73.1937
			3	344.571	831.267	73.2617
			4	344.840	803.394	73.3076
			5	344.225	778.268	73.3477
			6	343.123	755.768	73.3831
			7	341.336	735.070	73.4094
			8	338.846	716.038	73.4289
			9	335.480	698.510	73.4426

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.	337.947	337.827	900.000	961.357	0.49963	73.1005	1679.35	69.426
2	14.9486	14.68809	342.314	341.404	863.236	928.631	0.48194	73.1937	1679.35	68.422
3	15.5610	29.37592	344.571	342.228	831.267	899.852	0.46645	73.2617	1679.35	67.623
4	16.1468	44.06282	344.840	340.519	803.394	874.275	0.45272	73.3076	1679.35	67.030
5	16.7123	58.74601	344.225	337.441	778.268	850.995	0.44027	73.3477	1679.35	66.559
6	17.2619	73.42737	343.123	333.444	755.768	830.011	0.42907	73.3831	1679.35	66.193
7	17.7992	88.11169	341.336	328.376	735.070	810.456	0.41865	73.4094	1679.35	65.928
8	18.3276	102.80310	338.846	322.263	716.038	792.166	0.40894	73.4289	1679.35	65.769
9	18.8500	117.49983	335.480	314.974	698.510	774.895	0.39978	73.4426	1679.35	65.728

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	PRESSURE LOSS COEFFICIENT	BLADE-ROW EFFICIENCY	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	62.0651	1611.24	0.10300	0.91561	579.779	465.564	0.24196	64.5330	1627.21	43.467
2	62.8420	1615.80	0.10080	0.91668	606.075	428.148	0.22220	64.9445	1629.31	36.989
3	63.4993	1619.68	0.09991	0.91687	630.906	398.589	0.20661	65.3331	1631.39	30.347
4	64.0532	1623.02	0.10051	0.91600	654.655	375.551	0.19447	65.6961	1633.42	23.596
5	64.5574	1625.98	0.10119	0.91511	677.583	358.648	0.18555	66.0579	1635.46	16.614
6	64.9977	1628.58	0.10185	0.91427	699.866	347.647	0.17971	66.4142	1637.49	9.517
7	65.3950	1630.95	0.10328	0.91288	721.652	341.599	0.17646	66.7685	1639.54	2.340
8	65.7554	1633.11	0.10533	0.91102	743.075	339.923	0.17548	67.1211	1641.62	-4.796
9	66.0857	1635.10	0.10800	0.90872	764.254	341.861	0.17637	67.4724	1643.71	-11.790

* CONVERGED PASS *

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	344.225	117.49992	1	337.947	900.000	73.1005
			2	342.314	863.237	73.1937
			3	344.571	831.269	73.2617
			4	344.841	803.395	73.3076
			5	344.225	778.262	73.3477
			6	343.122	755.754	73.3831
			7	341.334	735.053	73.4095
			8	338.845	716.027	73.4289
			9	335.480	698.510	73.4426
2	344.225	117.50000	1	337.947	900.000	73.1005
			2	342.315	863.237	73.1937
			3	344.571	831.269	73.2617
			4	344.841	803.395	73.3076
			5	344.225	778.262	73.3477
			6	343.123	755.754	73.3831
			7	341.334	735.053	73.4094
			8	338.845	716.027	73.4289
			9	335.460	698.510	73.4426

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.	337.947	337.827	900.000	961.358	0.49963	73.1005	1679.35	69.426
2	14.9486	14.68749	342.315	341.404	863.237	928.632	0.48194	73.1937	1679.35	68.422
3	15.5610	29.37500	344.571	342.228	831.269	899.854	0.46645	73.2617	1679.35	67.623
4	16.1468	44.06249	344.841	340.519	803.395	874.276	0.45272	73.3076	1679.35	67.030
5	16.7124	58.74999	344.225	337.441	778.262	850.989	0.44026	73.3477	1679.35	66.559
6	17.2623	73.43749	343.123	333.441	755.754	829.998	0.42906	73.3831	1679.35	66.193
7	17.7997	88.12498	341.334	328.372	735.053	810.439	0.41864	73.4094	1679.35	65.928
8	18.3280	102.81248	338.845	322.259	716.027	792.155	0.40893	73.4289	1679.35	65.769
9	18.8500	117.50000	335.480	314.975	698.510	774.896	0.39978	73.4426	1679.35	65.728

STREAMLINE NUMBER	STATIC PRESSURE	STATIC TEMPERATURE	STREAMLINE SLOPE ANGLE	STREAMLINE CURVATURE	BLADE VELOCITY	RELATIVE VELOCITY	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE	RELATIVE TOTAL TEMPERATURE	RELATIVE FLOW ANGLE

	(PSI)	(DEG R)	(DEG)	(PER IN)	(FPS)	(FPS)		(PSI)	(DEG R)	(DEG)	
1	62.0651	1611.24	1.528	C.	579.779	465.564	0.24196	64.5330	1627.21	43.467	*
2	62.8420	1615.80	4.180	0.	606.074	428.150	0.22720	64.9445	1629.31	36.989	*
3	63.4997	1619.68	6.685	0.	630.904	398.591	0.20661	65.3331	1631.39	30.348	*
4	64.0591	1623.02	9.081	0.	654.654	375.552	0.19447	65.6961	1633.42	23.596	*
5	64.5576	1625.98	11.394	0.	677.589	358.644	C.18555	66.0580	1635.46	16.612	
6	64.9980	1628.58	13.643	0.	699.881	347.642	0.17971	66.4144	1637.49	9.512	*
7	65.3953	1630.95	15.841	0.	721.672	341.597	0.17646	66.7688	1639.55	2.333	*
8	65.7556	1633.11	18.001	0.	743.C88	339.924	0.17548	67.1213	1641.62	-4.800	*
9	66.0857	1635.10	20.136	0.	764.254	341.861	0.17637	67.4724	1643.71	-11.790	*

** ROTOR 1 MIXED ANC/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	73.1005	1679.35	64.5330	1627.22
2	73.1937	1679.35	64.9445	1629.31
3	73.2617	1679.35	65.3331	1631.39
4	73.3076	1679.35	65.6961	1633.42
5	73.3477	1679.35	66.0580	1635.46
6	73.3831	1679.35	66.4144	1637.49
7	73.4094	1679.35	66.7688	1639.55
8	73.4289	1679.35	67.1213	1641.62
9	73.4426	1679.35	67.4724	1643.71

** STAGE EXIT 1 **

* PASS 1 *

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	472.993	161.93392	1	403.955	-141.697	57.7882
			2	431.885	-132.604	58.0316
			3	451.312	-124.798	58.2095
			4	464.431	-117.512	58.3333
			5	472.993	-111.103	58.4106
			6	478.735	-105.013	58.4652
			7	482.825	-99.535	58.5004
			8	486.007	-94.397	58.5304
			9	488.577	-89.434	58.5530
2	394.161	134.90781	1	307.622	-141.697	57.7882
			2	343.583	-132.604	58.0316
			3	367.778	-124.798	58.2095
			4	383.812	-117.512	58.3333
			5	394.161	-111.103	58.4106
			6	401.053	-105.013	58.4652
			7	405.941	-99.535	58.5004
			8	409.730	-94.397	58.5304
			9	412.785	-89.434	58.5530
3	343.384	116.82889	1	238.909	-141.697	57.7882
			2	283.788	-132.604	58.0316
			3	312.693	-124.798	58.2095
			4	331.434	-117.512	58.3333
			5	343.384	-111.103	58.4106
			6	351.286	-105.013	58.4652
			7	356.865	-99.535	58.5004
			8	361.177	-94.397	58.5304
			9	364.643	-89.434	58.5530
4	345.269	117.51140	1	241.617	-141.697	57.7882
			2	286.070	-132.604	58.0316
			3	314.764	-124.798	58.2095
			4	333.387	-117.512	58.3333
			5	345.269	-111.103	58.4106
			6	353.128	-105.013	58.4652
			7	358.678	-99.535	58.5004
			8	362.968	-94.397	58.5304

			9	366.417	-89.434	58.5530
5	345.238	117.50001	1	241.572	-141.697	57.7882
			2	286.032	-132.604	58.0316
			3	314.729	-124.798	58.2095
			4	333.355	-117.512	58.3333
			5	345.238	-111.103	58.4106
			6	353.098	-105.013	58.4652
			7	358.648	-99.535	58.5004
			8	362.938	-94.397	58.5304
			9	366.388	-89.434	58.5530

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.	241.572	241.486	-141.697	280.063	0.14652	57.7882	1589.81	-30.403
2	15.0657	11.93574	286.032	285.265	-132.604	315.275	0.16503	58.0316	1589.81	-24.931
3	15.7581	25.48299	314.729	312.552	-124.798	338.569	0.17728	58.2095	1589.81	-21.766
4	16.4212	40.02804	333.355	329.083	-117.512	353.461	0.18512	58.3333	1589.81	-19.651
5	17.0587	55.16056	345.238	338.276	-111.103	362.675	0.18998	58.4106	1589.81	-18.102
6	17.6731	70.61079	353.098	342.927	-105.013	368.382	0.19299	58.4652	1589.81	-17.026
7	18.2669	86.21245	358.648	344.808	-99.535	372.204	0.19500	58.5004	1589.81	-16.102
8	18.8420	101.86416	362.938	345.010	-94.397	375.013	0.19649	58.5304	1589.81	-15.302
9	19.4000	117.50001	366.388	343.993	-89.434	377.145	0.19761	58.5529	1589.81	-14.574

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	PRESSURE LOSS COEFFICIENT	BLADE-ROW EFFICIENCY	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	56.9622	1583.96	0.19650	0.85087	581.401	762.382	0.39886	63.2972	1627.27	-71.533
2	56.9819	1582.40	0.15403	0.88057	610.825	796.555	0.41694	63.9322	1629.68	-69.007
3	56.9965	1581.26	0.12583	0.90144	638.895	826.003	0.43251	64.5071	1632.11	-67.742
4	57.0093	1580.50	0.10712	0.91584	665.783	851.279	0.44586	65.0103	1634.50	-67.211
5	57.0155	1580.00	0.09643	0.92434	691.626	873.821	0.45773	65.4718	1636.90	-67.149
6	57.0249	1579.69	0.08948	0.93001	716.538	894.217	0.46846	65.9057	1639.28	-67.344
7	57.0294	1579.48	0.08474	0.93396	740.612	913.497	0.47860	66.3214	1641.67	-67.686
8	57.0366	1579.33	0.08040	0.93760	763.928	931.904	0.48827	66.7314	1644.04	-68.102
9	57.0417	1579.21	0.07679	0.94067	786.553	949.523	0.49752	67.1310	1646.39	-68.560

● PASS 2 ●

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS	MERIDIONAL VELOCITY AT THE MEAN	CALCULATED	STREAMLINE	MERIDIONAL	WHIRL	ABSOLUTE TOTAL

NUMBER	STREAMLINE (FPS)	MASS FLOW (LBM/SEC)	NUMBER	VELOCITY (FPS)	VELOCITY (FPS)	PRESSURE (PSI)
1	345.238	116.74739	1	241.352	-141.697	57.7882
			2	289.266	-131.280	58.0517
			3	316.462	-123.473	58.2250
			4	334.057	-116.395	58.3419
			5	345.238	-110.253	58.4149
			6	352.761	-104.474	58.4671
			7	358.171	-99.177	58.5014
			8	362.396	-94.235	58.5309
			9	365.786	-89.434	58.5530
2	347.463	117.55819	1	244.534	-141.697	57.7882
			2	291.922	-131.280	58.0517
			3	318.890	-123.473	58.2250
			4	336.358	-116.395	58.3419
			5	347.463	-110.253	58.4149
			6	354.939	-104.424	58.4671
			7	360.316	-99.177	58.5014
			8	364.516	-94.235	58.5309
			9	367.886	-89.434	58.5530
3	347.291	117.49558	1	244.289	-141.697	57.7882
			2	291.717	-131.280	58.0517
			3	318.703	-123.473	58.2250
			4	336.180	-116.395	58.3419
			5	347.291	-110.253	58.4149
			6	354.771	-104.424	58.4671
			7	360.150	-99.177	58.5014
			8	364.352	-94.235	58.5309
			9	367.723	-89.434	58.5530
4	347.304	117.50033	1	244.307	-141.697	57.7882
			2	291.733	-131.280	58.0517
			3	318.717	-123.473	58.2250
			4	336.193	-116.395	58.3419
			5	347.304	-110.253	58.4149
			6	354.783	-104.424	58.4671
			7	360.162	-99.177	58.5014
			8	364.364	-94.235	58.5309
			9	367.736	-89.434	58.5530

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.	244.307	244.220	-141.697	282.425	0.14776	57.7882	1589.81	-30.122
2	15.2177	14.74115	291.733	290.729	-131.280	319.910	0.16746	58.0517	1589.81	-24.302
3	15.9271	28.97701	318.717	316.088	-123.473	341.798	0.17898	58.2250	1589.81	-21.337
4	16.5789	43.54571	336.193	331.326	-116.395	355.772	0.18634	58.3419	1589.81	-19.356
5	17.1902	58.26204	347.304	339.703	-110.253	364.384	0.19088	58.4149	1589.81	-17.981
6	17.7728	73.06154	354.783	344.016	-104.424	369.832	0.19375	58.4671	1589.81	-16.885
7	18.3329	87.89034	360.162	345.841	-99.177	373.568	0.19572	58.5014	1589.81	-16.001
8	18.8744	102.71173	364.364	346.130	-94.235	376.353	0.19719	58.5309	1589.81	-15.230
9	19.4000	117.50033	367.736	345.259	-89.434	378.455	0.19830	58.5530	1589.81	-14.522

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	PRESSURE LOSS COEFFICIENT	BLADE-ROW EFFICIENCY	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	56.9483	1583.86	0.19606	0.85117	581.401	763.253	0.39933	63.2972	1627.27	-71.338
2	56.9707	1582.18	0.14857	0.88457	616.985	803.124	0.42041	64.0408	1630.24	-68.767
3	56.9886	1581.10	0.12176	0.90457	645.748	832.635	0.43601	64.6207	1632.76	-67.661
4	57.0005	1580.37	0.10461	0.91784	672.174	857.244	0.44900	65.1190	1635.13	-67.210
5	57.0066	1579.91	0.09493	0.92557	696.958	878.755	0.46033	65.5679	1637.46	-67.177
6	57.0154	1579.61	0.08859	0.93075	720.579	898.054	0.47049	65.9758	1639.71	-67.364
7	57.0197	1579.41	0.08418	0.93444	743.288	916.223	0.48004	66.3693	1641.96	-67.681
8	57.0265	1579.25	0.08010	0.93786	765.243	933.522	0.48912	66.7558	1644.19	-68.064
9	57.0313	1579.13	0.07671	0.94074	786.553	950.044	0.49780	67.1310	1646.39	-68.489

* PASS 3 *

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	347.304	117.42445	1	244.175	-141.697	57.7882
			2	291.493	-131.305	58.0513
			3	318.967	-123.327	58.2267
			4	336.279	-116.241	58.3430
			5	347.304	-110.129	58.4155
			6	354.735	-104.340	58.4673
			7	360.093	-99.130	58.5016
			8	364.286	-94.217	58.5310
			9	367.651	-89.434	58.5530
2	347.528	117.50584	1	244.494	-141.697	57.7882
			2	291.760	-131.305	58.0513
			3	319.211	-123.327	58.2267
			4	336.510	-116.241	58.3430
			5	347.528	-110.129	58.4155
			6	354.954	-104.340	58.4673
			7	360.308	-99.130	58.5015
			8	364.499	-94.217	58.5310
			9	367.862	-89.434	58.5530
3	347.511	117.49955	1	244.469	-141.697	57.7882
			2	291.739	-131.305	58.0513
			3	319.192	-123.327	58.2267
			4	336.492	-116.241	58.3430
			5	347.511	-110.129	58.4155
			6	354.937	-104.340	58.4673
			7	360.292	-99.130	58.5015
			8	364.482	-94.217	58.5310

9	367.846	-89.434	58.5530

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.	244.469	244.382	-141.697	282.565	0.14784	57.7882	1589.81	-30.106
2	15.2147	14.69485	291.739	290.739	-131.305	319.926	0.16747	58.0513	1589.81	-24.305
3	15.9460	29.38616	319.192	316.509	-123.327	342.189	0.17919	58.2267	1589.81	-21.288
4	16.6008	44.05677	336.492	331.539	-116.241	356.004	0.18646	58.3430	1589.81	-19.321
5	17.2096	58.73606	347.511	339.815	-110.129	364.543	0.19097	58.4155	1589.81	-17.957
6	17.7870	73.42347	354.937	344.085	-104.340	369.556	0.19382	58.4673	1589.81	-16.869
7	18.3415	88.11489	360.292	345.910	-99.130	373.680	0.19578	58.5015	1589.81	-15.991
8	18.8780	102.80733	364.482	346.215	-94.217	376.462	0.19725	58.5310	1589.81	-15.223
9	19.4000	117.49955	367.846	345.362	-89.434	378.562	0.19836	58.5530	1589.81	-14.518

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	PRESSURE LOSS COEFFICIENT	BLADE-ROW EFFICIENCY	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	56.9474	1583.86	0.19604	0.85119	581.401	763.305	0.39936	63.2972	1627.27	-71.327
2	56.9702	1582.18	0.14866	0.88450	616.866	803.039	0.42037	64.0387	1630.23	-68.764
3	56.9874	1581.08	0.12132	0.90490	646.512	833.388	0.43641	64.6339	1632.84	-67.651
4	56.9999	1580.36	0.10429	0.91809	673.064	858.038	0.44942	65.1342	1635.22	-67.216
5	57.0060	1579.90	0.09472	0.92574	697.744	879.444	0.46070	65.5764	1637.54	-67.187
6	57.0147	1579.61	0.08847	0.93085	721.157	898.569	0.47076	65.9859	1639.77	-67.373
7	57.0190	1579.40	0.08411	0.93449	743.638	916.552	0.48021	66.3755	1642.00	-67.685
8	57.0257	1579.24	0.08007	0.93788	765.399	933.686	0.48921	66.7585	1644.21	-68.082
9	57.0304	1579.13	0.07670	0.94074	786.553	950.086	0.49782	67.1310	1646.39	-68.483

• CONVERGED PASS •

ITERATIVE DETERMINATION OF MERIDIONAL VELOCITY AT THE MEAN STREAMLINE

PASS NUMBER	MERIDIONAL VELOCITY AT THE MEAN STREAMLINE (FPS)	CALCULATED MASS FLOW (LBM/SEC)	STREAMLINE NUMBER	MERIDIONAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE TOTAL PRESSURE (PSI)
1	347.511	117.49857	1	244.462	-141.697	57.7882
			2	291.726	-131.308	58.0513
			3	319.179	-123.331	58.2266
			4	336.453	-116.239	58.3430
			5	347.511	-110.125	58.4155
			6	354.936	-104.337	58.4673

			7	360.290	-99.128	58.5016
			8	364.480	-94.216	58.5310
			9	367.843	-89.434	58.5530
2	347.515	117.50011	1	244.468	-141.697	57.7882
			2	291.731	-131.308	58.0513
			3	319.183	-123.331	58.2266
			4	336.497	-116.239	58.3430
			5	347.515	-110.125	58.4155
			6	354.940	-104.337	58.4673
			7	360.294	-99.128	58.5016
			8	364.484	-94.216	58.5310
			9	367.847	-89.434	58.5530

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.	244.468	244.381	-141.697	282.564	0.14784	57.7882	1589.81	-30.106
2	15.2143	14.68760	291.731	290.732	-131.308	319.920	0.16747	58.0513	1589.81	-24.306
3	15.9454	29.37555	319.183	316.502	-123.331	342.182	0.17918	58.2266	1589.81	-21.209
4	16.6011	44.06326	336.497	331.544	-116.239	356.008	0.18647	58.3430	1589.81	-19.321
5	17.2101	58.75059	347.515	339.816	-110.125	364.546	0.19097	58.4155	1589.81	-17.956
6	17.7876	73.43786	354.940	344.085	-104.337	369.957	0.19382	58.4673	1589.81	-16.869
7	18.3419	88.12521	360.294	345.909	-99.128	373.682	0.19578	58.5016	1589.81	-15.991
8	18.8782	102.81263	364.484	346.216	-94.216	376.464	0.19725	58.5310	1589.81	-15.223
9	19.4000	117.50011	367.847	345.363	-89.434	378.563	0.19836	58.5530	1589.81	-14.518

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	56.9474	1583.86	1.528	0.	581.401	763.305	0.39936	63.2972	1627.27	-71.327
2	56.9702	1582.18	4.743	0.	616.849	803.024	0.42036	64.0384	1630.23	-68.704
3	56.9874	1581.08	7.432	0.	646.491	833.369	0.43640	64.6336	1632.83	-67.651
4	56.9998	1580.36	9.843	0.	673.074	858.047	0.44942	65.1343	1635.22	-67.216
5	57.0059	1579.90	12.083	0.	697.766	879.463	0.46071	65.5768	1637.54	-67.107
6	57.0147	1579.61	14.206	0.	721.178	898.587	0.47077	65.9862	1639.78	-67.373
7	57.0190	1579.40	16.245	0.	743.652	916.564	0.48022	66.3758	1642.00	-67.605
8	57.0257	1579.24	18.217	0.	765.397	933.693	0.48921	66.7587	1644.21	-68.063
9	57.0304	1579.13	20.136	0.	786.553	950.087	0.49782	67.1310	1646.39	-68.489

** STAGE 1 PERFORMANCE **

STREAMLINE	STATOR	ROTOR	STATOR PRESSURE LOSS	ROTOR PRESSURE LOSS	STATOR BLADE ROW	ROTOR BLADE ROW	ROTOR ISENTROPIC	STAGE ISENTROPIC

NUMBER	REACTION	REACTION	COEFFICIENT	COEFFICIENT	EFFICIENCY	EFFICIENCY	EFFICIENCY	EFFICIENCY
1	0.35100	0.60993	0.10300	0.19604	0.91561	0.85119	0.91865	0.88200
2	0.38111	0.53317	0.10080	0.14867	0.91668	0.88449	0.93121	0.89015
3	0.40636	0.47829	0.09992	0.12133	0.91687	0.90489	0.93943	0.89494
4	0.42813	0.43760	0.10051	0.10428	0.91600	0.91810	0.94491	0.89768
5	0.44697	0.40700	0.10119	0.09471	0.91511	0.92575	0.94771	0.89878
6	0.46345	0.38688	0.10185	0.08867	0.91427	0.93085	0.94934	0.89963
7	0.47831	0.37269	0.10328	0.08411	0.91288	0.93450	0.95026	0.89995
8	0.49194	0.36406	0.10533	0.08007	0.91102	0.93789	0.95123	0.90047
9	0.50442	0.35902	0.10800	0.07670	0.90872	0.94074	0.95200	0.90100

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.91437

ROTOR BLADE-ROW EFFICIENCY = 0.91655

STAGE WORK = 24.132 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.89662
STAGE STATIC EFFICIENCY = 0.82033
STAGE BLADE- TO JET-SPEED RATIO = 0.56410

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*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

                               SPOOL WORK =    24.132 BTU PER LBM
                              SPOOL POWER =   4011.81 HP
   SPOOL TOTAL- TO TOTAL-PRESSURE RATIO =   1.27253
  SPOOL TOTAL- TO STATIC-PRESSURE RATIO =   1.30237
                  SPOOL TOTAL EFFICIENCY =   0.89662
                 SPOOL STATIC EFFICIENCY =   0.82033
       SPOOL BLADE- TO JET-SPEED RATIO =   0.56410
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NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: FKL **PROJECT:** AXIAL TURBINE DESIGN **PROJECT NO:** 1125

TITLE: SAMPLE CASE IV **SHEET:** 1 **OF** 1

LOCATION

```
  1    6 7    12 13   18 19   24 25   30 31   36 37   42 43   48 49   54 55   60 61   66 67   72
  NASA M1 PUMP TURBINE, FIRST STAGE
      0      2           2    0      1    0      0    0
  $NAM1
  NSPOOL=1,NAV=3,NLINES=5,GASC=53.3,FLWM=6.808,
  NLT=1,RLT(1)=11.5875,TOLT(1)=518.7,POLT(1)=14.696,BETLT(1)=0 $
  $NAM2
  RPM=2815.4,HP=198.03,NSTG=1,FHP(1)=1,CP(1)=3*.24,
  XSTAT(1)=0,1,3.5,4.6,6,RANN(1,1)=5*10.8413,
  RANN(1,2)=5*12.3337,
  NXT=5,ISONIC(1)=1,RNXT(1,1)=10.8413,11.2144,11.5875,11.9606,12.3337,
  WRL(1,1)=5*74.5,IPOF(1)=0,XMIX(1,1)=5*0,XMIX(1,2)=5*1,
  YCON(1)=.055,.15,.6,1.0,0.0,.03,.157255,3.6,1.0,
* YOSS(1,1)=5*3.4,RSXT(1,1)=5*11.0,YOSS(1,2)=5*1.0 $
  $NAM2
  IPOF(1)=1,POF(1,1)=0.0,.24810605,.49747474,.74810605,1.0 $
  $NAM2
  IPOF(1)=1,POF(1,1)=0.0,.24617346,.49489795,.74617346,1.0 $
```

* Five identical values of RSXT are here specified to simplify the specification of input quantities. However, for computer systems which do not set a division by zero equal to zero, monotonically increasing values of RSXT should be specified.

** PROGRAM TD - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

NASA H1 PUMP TURBINE, FIRST STAGE

*** GENERAL INPUT DATA ***

```
                 NUMBER OF SPOOLS =    1
NUMBER OF SETS OF ANALYSIS VARIABLES =    3
            NUMBER OF STREAMLINES =    5

                     GAS CONSTANT =   53.30000 LBF FT/LBM DEG R
                  INLET MASS FLOW =    6.80800 LBM/SEC
```

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
11.5875	518.70	14.6960	0.

*** SPCOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 2815.4 RPM
POWER OUTPUT = 198.C3 HP

** SET 1 OF ANALYSIS VARIABLES **

NUMBER OF STAGES = 1

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	1.CCCCC

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LPM DEG R)
1	C.24C0C
2	C.24CCC
3	C.24C00

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	0.	10.8413	12.3337
2	1.0000	10.E413	12.3337
3	3.5000	10.8413	12.3337
4	4.6000	10.8413	12.3337
5	6.0000	10.8413	12.3337

• MIXING COEFFICIENTS •

STREAMLINE NUMBER	BLADE ROW 1	BLADE ROW 2
1	0.	1.00000
2	0.	1.00000
3	0.	1.00000
4	0.	1.00000
5	0.	1.00000

• BLADE-ROW EXIT CONDITIONS •

STATOR 1

RADIAL POSITION (IN)	WHIRL ANGLE (DEG)	ADDITIONAL LOSS FACTOR
10.8413	74.500	3.40000
11.2144	74.500	3.40000
11.5875	74.500	3.40000
11.9606	74.500	3.40000
12.3337	74.500	3.40000

ROTOR 1

STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTION	RADIAL POSITION (IN)	ADDITIONAL LOSS FACTOR
1	0.	11.0000	1.00000
2	0.25000	11.0000	1.00000
3	0.50000	11.0000	1.00000
4	0.75000	11.0000	1.00000
5	1.00000	11.0000	1.00000

• BASIC INTERNAL LOSS CORRELATION •

```
      TAN(INLET ANGLE) + TAN(EXIT ANGLE)                 (0.02999999 + 0.15725499 * (V RATIO)** 3.60)  IF (V RATIO) .LT. 0.60000000 *
Y = ---------------------------------------- *TIMES*
     1.00000000 + 0.        * COS(EXIT ANGLE)            (0.05500000 + 0.15000000 *((V RATIO)-0.600))   IF (V RATIO) .GT. 0.60000000 *
```

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 1.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS (SET 1 OF ANALYSIS VARIABLES) ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	10.8413	0.	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
2	11.2330	1.70200	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
3	11.6115	3.40400	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
4	11.9780	5.10600	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
5	12.3337	6.80800	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	14.5802	517.53	0.	0.
2	14.5802	517.53	0.	0.
3	14.5802	517.53	0.	0.
4	14.5802	517.53	0.	0.
5	14.5802	517.53	0.	0.

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	14.6960	518.70
2	14.6960	518.70
3	14.6960	518.70
4	14.6960	518.70
5	14.6960	518.70

CALCULATION ABANDONED ON PASS 3 BECAUSE OF TWO REPETITIONS OF A MEANLINE MERIDIONAL VELOCITY WITHOUT MASS FLOW CONVERGENCE 0

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	10.8413	0.	388.078	388.078	1399.363	1452.178	1.60011	11.4684	518.70	74.500
2	11.2576	1.70207	375.612	375.612	1354.413	1405.531	1.52428	11.5603	518.70	74.500
3	11.6404	3.40415	364.965	364.965	1316.023	1365.692	1.46224	11.6433	518.70	74.500
4	11.9974	5.10620	355.670	355.670	1282.506	1330.910	1.40994	11.7191	518.70	74.500
5	12.3337	6.80825	347.421	347.421	1252.758	1300.040	1.36487	11.7889	518.70	74.500

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	2.6984	343.22	0.	0.	266.360	1197.623	1.31963	7.6776	462.57	71.093
2	3.0407	354.31	0.	0.	276.588	1141.398	1.23783	7.7479	462.72	70.787
3	3.3493	363.50	0.	0.	285.993	1092.777	1.17003	7.8123	462.87	70.489
4	3.6322	371.30	0.	0.	294.763	1045.827	1.11217	7.0719	463.02	70.197
5	3.8923	378.06	0.	0.	303.027	1011.282	1.06171	7.9276	463.16	69.907

** ROTOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	11.6378	518.70	7.7511	462.57
2	11.6378	518.70	7.7599	462.72
3	11.6378	518.70	7.8086	462.87
4	11.6378	518.70	7.8173	463.02
5	11.6378	518.70	7.8260	463.16

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)

1	10.8413	0.	229.678	229.678	-533.C91	580.463	0.5888C	4.5055	433.04	-66.692
2	11.3410	1.78326	384.434	384.434	-502.855	632.971	0.64630	4.6903	433.04	-52.602
3	11.7281	3.71685	436.511	436.511	-480.153	648.914	0.66399	4.8166	433.04	-47.726
4	12.0462	5.54741	469.116	469.116	-461.856	658.316	0.67448	4.9088	433.04	-44.593
5	12.3337	7.37189	494.121	494.121	-445.869	665.549	0.68257	4.9857	433.04	-42.061

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	PRESSURE LOSS COEFFICIENT	BLADE-ROW EFFICIENCY	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	3.5635	405.00	1.C0000	0.62206	266.360	831.789	0.86373	5.6773	462.97	-73.971
2	3.5423	399.70	0.79214	0.67560	278.636	87C.930	0.88927	5.9211	462.02	-63.003
3	3.5838	398.00	0.68965	0.70399	288.140	883.649	0.90418	6.0878	462.97	-60.397
4	3.6136	396.97	0.62236	0.72318	295.964	891.269	0.91316	6.2C92	463.07	-50.241
5	3.6505	396.18	0.56970	0.73949	303.027	897.214	0.92017	6.3106	463.10	-50.909

CALCULATION ABANDONED ON PASS 3 BECAUSE OF TWO REPETITIONS OF A MEANLINE MERIDIONAL VELOCITY WITHOUT MASS FLOW CONVERGENCE

** PROGRAM TD - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

NASA M1 PUMP TURBINE, FIRST STAGE

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS =	1
NUMBER OF SETS OF ANALYSIS VARIABLES =	3
NUMBER OF STREAMLINES =	5
GAS CONSTANT =	53.30000 LBF FT/LBM DEG R
INLET MASS FLOW =	6.80800 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
11.5875	518.70	14.6960	0.

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 2815.4 RPM
POWER OUTPUT = 198.03 HP

** SET 2 OF ANALYSIS VARIABLES **

NUMBER OF STAGES = 1

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	1.00000

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	0.24000
2	0.24000
3	0.24000

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	0.	10.8413	12.3337
2	1.0000	10.8413	12.3337
3	3.5000	10.8413	12.3337
4	4.6000	10.8413	12.3337
5	6.0000	10.8413	12.3337

* MIXING COEFFICIENTS *

STREAMLINE NUMBER	BLADE ROW 1	BLADE ROW 2
1	0.	1.00000
2	0.	1.00000
3	0.	1.00000
4	0.	1.00000
5	0.	1.00000

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	WHIRL ANGLE (DEG)	ADDITIONAL LOSS FACTOR
10.8413	74.500	3.40000
11.2144	74.500	3.40000
11.5875	74.500	3.40000
11.9606	74.500	3.40000
12.3337	74.500	3.40000

ROTOR 1

STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTION	RADIAL POSITION (IN)	ADDITIONAL LOSS FACTOR
1	0.	11.0000	1.00000
2	0.24811	11.0000	1.00000
3	0.49747	11.0000	1.00000
4	0.74811	11.0000	1.00000
5	1.00000	11.0000	1.00000

* BASIC INTERNAL LOSS CORRELATION *

```
     TAN(INLET ANGLE) + TAN(EXIT ANGLE)           (0.02999999 + 0.15725495 * (V RATIO)** 3.60)  IF (V RATIO) .LT. 0.60000000 O
Y = ------------------------------------------ *TIMES*
    1.00000000 + 0.          * COS(EXIT ANGLE)    (0.05500000 + 0.19000000 *((V RATIO)-0.600))  IF (V RATIO) .GT. 0.60000000 O
```

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF   1.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS (SET 2 OF ANALYSIS VARIABLES) ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	10.8413	0.	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
2	11.2330	1.70200	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
3	11.6115	3.40400	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
4	11.9780	5.10600	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
5	12.3337	6.80800	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	14.5802	517.53	0.	0.
2	14.5802	517.53	0.	0.
3	14.5802	517.53	0.	0.
4	14.5802	517.53	0.	0.
5	14.5802	517.53	0.	0.

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	14.6960	518.70
2	14.6960	518.70
3	14.6960	518.70
4	14.6960	518.70
5	14.6960	518.70

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	10.8413	0.	388.078	388.078	1399.363	1452.178	1.60011	11.4684	518.70	74.500
2	11.2576	1.70207	375.612	375.612	1354.413	1405.531	1.52428	11.5603	518.70	74.500
3	11.6404	3.40415	364.965	364.965	1316.021	1365.692	1.46724	11.6433	518.70	74.500
4	11.9774	5.10620	355.670	355.670	1282.506	1330.910	1.40994	11.7191	518.70	74.500
5	12.3337	6.80825	347.421	347.421	1252.758	1300.040	1.36487	11.7889	518.70	74.500

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	2.6984	343.22	0.	0.	266.360	1197.623	1.31963	7.6776	462.57	71.093
2	3.0407	354.31	0.	0.	276.588	1141.398	1.23783	7.7479	462.72	70.787
3	3.3499	363.50	0.	0.	285.593	1092.777	1.17003	7.8123	462.87	70.489
4	3.6322	371.30	0.	0.	294.763	1045.827	1.11217	7.8719	463.02	70.197
5	3.8923	378.06	0.	0.	303.027	1011.282	1.06171	7.9276	463.16	69.907

** ROTOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	11.6378	518.70	7.7911	462.57
2	11.6378	518.70	7.7599	462.72
3	11.6378	518.70	7.8086	462.87
4	11.6378	518.70	7.8173	463.02
5	11.6378	518.70	7.8260	463.16

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)

1	10.8411	0.	269.445	269.445	-513.571	579.962	0.58762	4.5536	433.90	-62.316
2	11.3077	1.70196	353.799	353.799	-494.971	608.416	0.61893	4.6843	433.47	-54.443
3	11.6833	3.40376	384.512	384.512	-481.995	616.578	0.62823	4.7739	433.04	-51.419
4	12.0207	5.10563	402.320	402.320	-471.640	619.924	0.63225	4.8376	432.60	-49.535
5	12.3337	6.80749	414.240	414.240	-463.023	621.277	0.63408	4.8880	432.17	-48.183

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	3.6048	405.91	0.	0.	266.360	825.162	0.83606	5.6980	462.57	-70.941
2	3.6180	402.67	0.	0.	277.823	845.531	0.86463	5.8912	462.78	-65.401
3	3.6597	401.40	0.	0.	287.047	859.811	0.87605	6.0314	462.92	-63.435
4	3.6963	400.63	0.	0.	295.336	866.091	0.88331	6.1392	463.04	-62.321
5	3.7292	400.05	0.	0.	303.027	870.877	0.88882	6.2305	463.16	-61.598

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.08163	1.45138	0.36803	1.00000	0.88211	0.62036	0.70549	0.57519
2	0.08434	1.34293	0.36806	0.84115	0.87513	0.65947	0.72302	0.59017
3	0.08680	1.27095	0.36809	0.75056	0.86912	0.68293	0.73513	0.60163
4	0.08907	1.21214	0.36812	0.68764	0.86386	0.70023	0.74380	0.61079
5	0.09118	1.16122	0.36815	0.63787	0.85918	0.71463	0.75084	0.61877

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.86969

ROTOR BLADE-ROW EFFICIENCY = 0.67753

STAGE WORK = 20.569 BTU PER LBP
STAGE TOTAL EFFICIENCY = 0.59576
STAGE STATIC EFFICIENCY = [illegible]
STAGE BLADE- [illegible] RATIO = [illegible]

```
*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***


                              SPOOL WORK =    20.559 BTU PER LBM
                             SPOOL POWER =    198.03 HP
 SPOOL TOTAL- TO TOTAL-PRESSURE RATIO =   3.09118
SPOOL TOTAL- TO STATIC-PRESSURE RATIO =   4.01501
                 SPOOL TOTAL EFFICIENCY =   0.59975
                SPOOL STATIC EFFICIENCY =   0.50432
      SPOOL BLADE- TO JET-SPEED RATIO =   0.20008
```

** PROGRAM TC - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

NASA M1 PUMP TURBINE, FIRST STAGE

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 3
NUMBER OF STREAMLINES = 5

GAS CONSTANT = 53.30000 LBF FT/LBM DEG R
INLET MASS FLOW = 6.80800 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
11.5875	518.70	14.6960	0.

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 2815.4 RPM
POWER OUTPUT = 198.C3 HP

** SET 3 OF ANALYSIS VARIABLES **

NUMBER OF STAGES = 1

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	1.CCCCC

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	C.24C0C
2	C.24C0C
3	C.24C00

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	0.	1C.8413	12.3337
2	1.0000	10.8413	12.3337
3	3.5000	1C.8413	12.3337
4	4.6000	10.8413	12.3337
5	6.0000	10.8413	12.3337

• MIXING COEFFICIENTS •

STREAMLINE NUMBER	BLADE ROW 1	BLADE ROW 2
1	0.	1.0CCC0
2	C.	1.CCCC0
3	0.	1.0C0C0
4	0.	1.0C0C0
5	0.	1.CCCC0

• BLADE-ROW EXIT CONDITIONS •

STATOR 1

RADIAL POSITION (IN)	WHIRL ANGLE (DEG)	ADDITIONAL LOSS FACTOR
10.8413	74.5C0	3.40000
11.2144	74.5CC	3.40000
11.5875	74.500	3.40C00
11.9606	74.500	3.4CC00
12.3337	74.500	3.40000

RCTOR 1

STREAMLINE NUMBER	NONDIMENSIONAL POWER OUTPUT FUNCTION	RADIAL POSITION (IN)	ADDITICNAL LOSS FACTOR
1	0.	11.0000	1.00000
2	0.24617	11.0000	1.00000
3	0.49490	11.CCC0	1.00000
4	0.74617	11.0000	1.00000
5	1.CC0C0	11.0000	1.00000

• BASIC INTERNAL LOSS CORRELATICN •

```
     TAN(INLET ANGLE) + TAN(EXIT ANGLE)           (0.02999999 + 0.15725495 * (V RATIO)** 3.60)  IF (V RATIO) .LT. 0.60000C00
Y = ---------------- -------------------------- *TIMES*
   1.00000000 + 0.          * COS(EXIT ANGLE)     (0.055CCC00 + 0.15CC0C00 *((V RATIO)-0.600))  IF (V RATIO) .GT. 0.60000000 *
```

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 1.CCCC0000

*** OUTPUT OF SPOOL DESIGN ANALYSIS (SET 3 OF ANALYSIS VARIABLES) ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	10.8413	0.	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
2	11.2330	1.70200	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
3	11.6115	3.40400	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
4	11.9780	5.10600	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.
5	12.3337	6.80800	118.540	118.540	0.	118.540	0.10637	14.6960	518.70	0.

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	14.5802	517.53	0.	0.
2	14.5802	517.53	0.	0.
3	14.5802	517.53	0.	0.
4	14.5802	517.53	0.	0.
5	14.5802	517.53	0.	0.

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	14.6960	518.70
2	14.6960	518.70
3	14.6960	518.70
4	14.6960	518.70
5	14.6960	518.70

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	10.6413	0.	388.078	388.078	1399.363	1452.178	1.60011	11.4684	518.70	74.500
2	11.2576	1.70207	375.612	375.612	1354.413	1405.531	1.52428	11.5603	518.70	74.500
3	11.6605	3.40416	364.966	364.966	1316.023	1365.692	1.46224	11.6433	518.70	74.500
4	11.9974	5.10620	355.670	355.670	1282.806	1330.910	1.40994	11.7191	518.70	74.500
5	12.3117	6.80826	347.421	347.421	1252.799	1300.040	1.36487	11.7889	518.70	74.500

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	2.6984	343.22	0.	0.	266.360	1197.623	1.31963	7.6776	462.57	71.093
2	3.0407	354.31	0.	0.	276.588	1141.398	1.23783	7.7479	462.72	70.787
3	3.3499	363.50	0.	0.	285.993	1092.777	1.17003	7.8123	462.87	70.489
4	3.6322	371.30	0.	0.	294.763	1049.827	1.11217	7.8719	463.02	70.197
5	3.8923	378.06	0.	0.	303.027	1011.282	1.06171	7.9276	463.16	69.907

** ROTOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	11.6378	518.70	7.7911	462.57
2	11.6378	518.70	7.7999	462.72
3	11.6378	518.70	7.8086	462.87
4	11.6378	518.70	7.8173	463.02
5	11.6378	518.70	7.8260	463.16

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)

1	10.8413	0.	385.455	385.455	-493.653	626.313	0.63756	4.7030	434.79	-52.016
2	11.2234	1.70193	379.352	379.352	-489.077	616.554	0.63015	4.7372	433.91	-52.201
3	11.5959	3.40379	369.639	369.639	-485.626	610.300	0.62133	4.7576	433.04	-52.723
4	11.9643	5.10595	356.432	356.432	-482.885	600.185	0.61093	4.7665	432.16	-53.568
5	12.3337	6.80800	339.385	339.385	-480.531	588.296	0.59860	4.7643	431.29	-54.768

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	3.5778	402.14	0.	0.	266.360	852.170	0.86747	5.8431	462.57	-63.107
2	3.6258	402.03	0.	0.	275.747	853.735	0.86918	5.9322	462.68	-63.619
3	3.6676	402.04	0.	0.	284.500	854.602	0.87005	6.0062	462.82	-64.372
4	3.7052	402.19	0.	0.	293.952	854.704	0.87000	6.0675	462.98	-65.353
5	3.7397	402.49	0.	0.	303.027	853.900	0.86885	6.1164	463.16	-66.581

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	0.08163	1.40538	0.36803	0.85992	0.88211	0.65590	0.72024	0.58278
2	0.08434	1.33695	0.36806	0.80878	0.87513	0.66774	0.72721	0.59204
3	0.08680	1.27870	0.36809	0.76941	0.86912	0.67719	0.73266	0.60008
4	0.08907	1.22829	0.36812	0.73974	0.86386	0.68444	0.73680	0.60706
5	0.09118	1.18431	0.36815	0.71928	0.85918	0.68937	0.73962	0.61297

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = 0.86969

ROTOR BLADE-ROW EFFICIENCY = 0.67550

STAGE WORK = 20.559 BTU PER LBM
STAGE TOTAL EFFICIENCY = 0.59924
STAGE STATIC EFFICIENCY = 0.50465
STAGE BLADE- TO JET-SPEED RATIO = 0.19966

```
*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGEC QUANTITIES) ***

                         SPOCL WORK =    2C.559 BTU PER LBM
                        SPOOL POWER =    198.03 HP
 SPOOL TCTAL- TO TCTAL-PRESSLRE RATIO =   3.09471
SPOOL TOTAL- TO STATIC-PRESSURE RATIO =   4.C1C55
              SPOOL TOTAL EFFICIENCY =   C.59924
             SPOOL STATIC EFFICIENCY =   0.50465
    SPCOL BLADE- TO JET-SPEED RATIO =   0.19966
```

CONCLUSIONS

1. A computer program has been written to solve the basic equations which govern the design-point performance of axial flow turbines. The program provides the turbine designer with the freedom to include the effects of arbitrary radial variations of inlet conditions, streamline angles of inclination and curvatures, loss coefficient or efficiency, whirl velocity or angle, and power output in a design. In addition, the designer may also take into account the effects of coolant flows, interfilament mixing, and a station-to-station variation of the specific heat.
2. A loss correlation has been incorporated into the computer program so that the turbine designer may make comparisons of alternative designs using performance parameters which are fully consistent with the assumed correlation of total-pressure-loss coefficients for the individual elements of the blading. Further, the program provides for the calculation of alternative designs with a minimum amount of additional input.

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1. Carter, A. F., Platt, M., and Lenherr, F. K., Analysis of Geometry and Design Point Performance of Axial Flow Turbines. I - Development of the Analysis Method and the Loss Coefficient Correlation (NASA CR-1181), National Aeronautics and Space Administration, Washington, D. C., October 1968.

2. Stabe, R. G., et al, Cold-Air Performance Evaluation of a Scale-Model Fuel Pump Turbine for the M-1 Hydrogen-Oxygen Rocket Engine (NASA TN D-3819), National Aeronautics and Space Administration, Washington, D. C., February, 1967.

3. Romanelli, M. J., "Runge-Kutta Methods for the Solution of Ordinary Differential Equations", Mathematical Methods for Digital Computers, Chapter 9, edited by A. Ralston and H. S. Wilf, John Wiley and Sons, Inc., New York, 1960.

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NOMENCLATURE

The nomenclature for axisymmetric flow in an abritrary turbine annulus is illustrated in Figure 1. The turbine velocity triangle nomenclature is shown in Figure 2. (Figures 1 and 2 appear at the end of this nomenclature.)

Symbol	Description	Units
A	Streamline angle of inclination in the meridional plane	deg, rad
a	Constants in loss correlation	--
C	Coefficient	--
c_p	Specific heat at constant pressure	Btu per lbm deg R
e	Kinetic-energy-loss coefficient	--
f, g	Function or variable	--
g_o	Constant in Newton's law	ft lbm per lbf sec^2
J	Mechanical equivalent of heat	ft lbf per Btu
j	Streamline index	--
M	Mach number	--
n	Number of streamlines	--
n'	Number of design stations on a spool	--
n''	Number of spools on the turbine	--
P	Power output	hp, ft lbf per sec
P'	Nondimensional power output function	--
p	Static pressure	psf, psi
p_o	Total pressure	psf, psi
R	Gas constant	ft lbf per lbm deg R

Symbol	Description	Units
R	Reaction of a blade row	--
r	Radial position	ft, in
r_{js}	Blade-to-jet speed ratio	--
$1/r_m$	Streamline curvature in the meridional plane	ft^{-1}, in^{-1}
r_{pts}	Total-to-static pressure ratio	--
r_{ptt}	Total-to-total pressure ratio	--
T	Static temperature	deg R
T_o	Total temperature	deg R
ΔT_o	Drop in total temperature	deg R
u	Blade velocity	fps
V	Velocity	fps
V_m	Meridional component of velocity	fps
V_u	Tangential component of velocity	fps
V_x	Axial component of velocity	fps
W	Work output along a streamline	Btu per lbm
w_T	Total mass flow at a design station	lbm per sec
w	Mass flow function	lbm per sec
x	Axial position	ft, in
X	Independent variable	--
x_m	Mixing coefficient	--
Y	Pressure-loss coefficient	--
y	Dependent variable	--
β	Flow angle	deg, rad
γ	Ratio of specific heats	--
η_B	Blade row efficiency	--

Symbol	Description	Units
η_R	Rotor isentropic efficiency	--
η_S	Stage isentropic efficiency	--
η_{stat}	Static efficiency	--
η_{Tot}	Total efficiency	--
ρ	Density	lbm per cu ft
Ω	Rotative speed	rpm, rad per sec

Subscript	Description
c	Coolant
C	Casing streamline
$exit$	Turbine exit
h	Hub streamline
i	Design station index
i'	Blade row index
i''	Stator, rotor, or stage index
i'''	Spool index
$inlet$	Turbine inlet
j	Streamline index
k	Index of the downstream design station
m	Mean streamline
n	Last streamline at a design station
n'	Last design station of a spool
new	New estimate
old	Old estimate
ov	Over-all

Subscript	Description
T	Total
y	Pertaining to loss correlation

Superscript	Description
$'$	Relative value
$'$	Nondimensional value
$-$	Average value
$*$	Value which is modified if mixing and cooling are specified

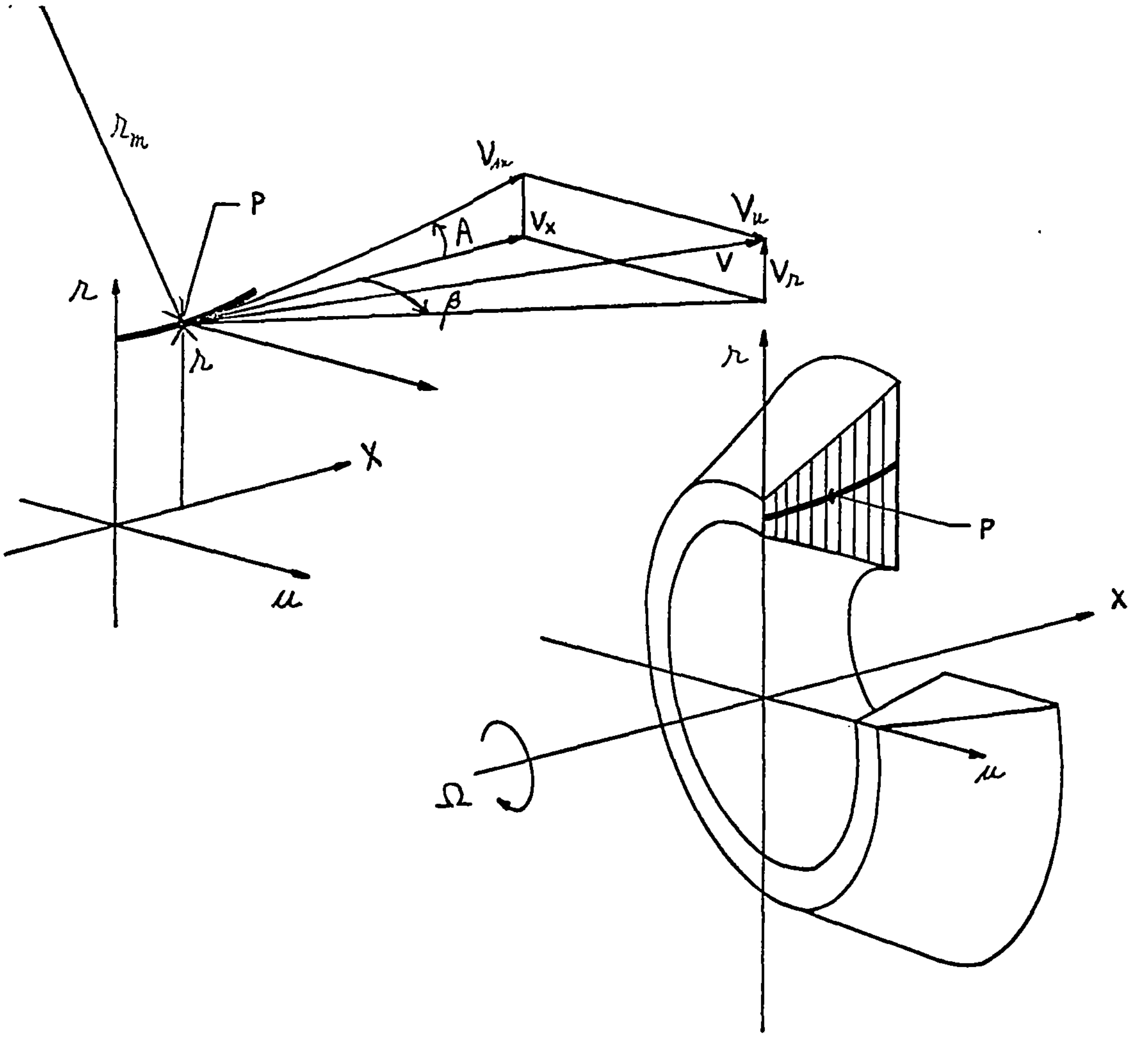

FIGURE 1 - NOMENCLATURE FOR AXISYMMETRIC FLOW IN AN ARBITRARY TURBINE ANNULUS

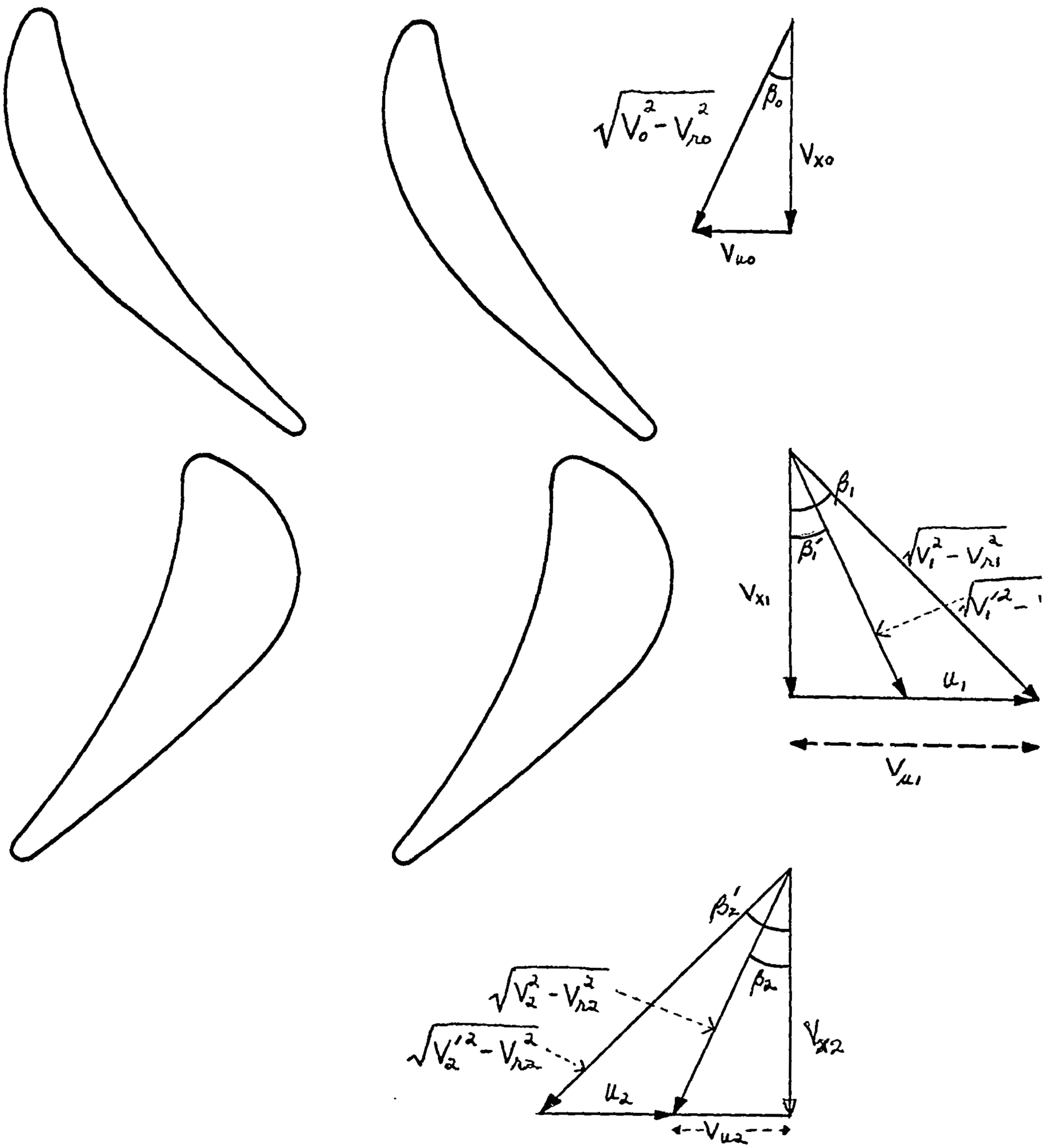

FIGURE 2 - TURBINE VELOCITY TRIANGLE NOMENCLATURE USED IN THE STREAM-FILAMENT ANALYSIS

APPENDICES

APPENDIX I

ANALYSIS PROCEDURE

This appendix presents the individual steps of the over-all analysis and the numerical techniques employed in the program.

Analysis

The development of the analysis method is presented in the Part I report (Ref 1) and the over-all program logic is given earlier in this report. In the following, the program operation is considered as eighty-six individual steps in a linear progression of the analysis. Following the step number, the portion of the program in which the step is executed is identified by either TD, which is the main program, or the name of the subroutine. The numerical techniques used for interpolation, extrapolation, differentiation, integration, the Runge-Kutta method for the forward-step solution of ordinary differential equations, and the solution of simultaneous linear equations are discussed later.

1. TD - The values of certain constants used in the calculations are set. These constants include conversion factors, tolerances and upper limits of iteration loops, and tape assignments.
2. TD - Begin case loop on the analysis of a turbine; steps 3 through 86 are performed for each case.
3. TD - The general input items for the case are read into the program. These items include the general indicators and the general design requirements.
4. TD - Streamline values of a nondimensional mass flow function are calculated from

$$w_j' = (j-1)/(n-1) \qquad j = 1, 2, \ldots, n$$

where w' is the nondimensional mass flow function, j is the streamline index, and n is the number of streamlines used in the calculations. It can be seen that w' varies from 0 at the hub (the first streamline) to 1 at the casing (the nth streamline) so that each streamtube, by definition, contains the same amount of flow.

5. TD - Begin loop on the analysis of a spool; steps 6 through 85 are performed for each spool of the turbine or, if there is only one spool, for each set of analysis variables.

6. TD - If this is a single-spool turbine or the first spool of a multi-spool turbine, print the general input items and convert the items into a consistent set of units.

7.1. TD - Read the spool input items.

7.2. INPUT - Print these spool input items out.

7.3. TD - Convert the spool input items into a consistent set of units. The items include the spool design requirements and the spool analysis variables.

8. STRAC - If tabulated values of streamline angles of inclination and curvatures as a function of radius are not specified in the input data, calculate the angle of inclination and curvature of the hub and casing streamlines at each design station from

$$A_{i\xi} = \tan^{-1}(dr_\xi/dx)_i$$

$$(1/r_m)_{i\xi} = (d^2r_\xi/dx^2)_i \Big/ \left[1 + (dr_\xi/dx)_i^2\right]^{3/2}$$

where
$$(dr_\xi/dx)_i = \frac{1}{2}\left(\frac{r_{i+1,\xi} - r_{i\xi}}{x_{i+1} - x_i} + \frac{r_{i\xi} - r_{i-1,\xi}}{x_i - x_{i-1}}\right)$$

$$(d^2r_\xi/dx^2)_i = \left(\frac{r_{i+1,\xi} - r_{i\xi}}{x_{i+1} - x_i} - \frac{r_{i\xi} - r_{i-1,\xi}}{x_i - x_{i-1}}\right) \Big/ \min(x_{i+1} - x_i,\, x_i - x_{i-1})$$

A is the angle of inclination, $1/r_m$ is the curvature, i is the design-station index, ζ denotes the hub or casing, r is the radial position, x is the axial position, and $min(x_{i+1}-x_i, x_i-x_{i-1})$ denotes the smaller of $x_{i+1}-x_i$ and x_i-x_{i-1} .

9. TD - Begin loop on the analysis of a design station. Steps 10 through 82 are performed for each design station if the first or only spool is under consideration. If a subsequent spool is under consideration, steps 68 through 82 are performed for the spool inlet and steps 10 through 82 are performed for the remaining design stations of the spool.

10. TD - If a coolant mass flow schedule is specified in the input data and the design station is not the turbine inlet, calculate the total mass flow at the design station from

$$w_{Ti} = w_{T,i-1} + w'_{ci'}\, w_{T,inlet}$$

where w_T is the total mass flow at a design station, i is the design station index, w'_c is the nondimensional coolant mass flow, i' is the blade row index and denotes the upstream blade row in this case, and $w_{T,inlet}$ is the mass flow at the turbine inlet.

11. SPECHT - Calculate the specific heat ratio corresponding to the specific heat at constant pressure specified in the input data for the design station from

$$\gamma_i = Jc_{pi}/(Jc_{pi} - R)$$

where γ is the specific heat ratio, i is the design station index, J is a conversion factor, c_p is the specific heat at constant pressure and R is the gas constant. Further, if the design station is:

a. a blade row exit, calculate the average specific heat across the blade row from

$$\bar{c}_{pi'} = \frac{1}{2}(c_{pi} + c_{p,i-1})$$

where i' is the blade row index

b. a stage exit, calculate the average specific heat across the stage from

$$\bar{c}_{pi''} = \frac{1}{2}(c_{pi} + c_{p,i-2})$$

where i'' is the stage index

c. a spool exit, calculate the average specific heat across the spool

$$\bar{c}_{pi'''} = \frac{1}{2}(c_{p,1} + c_{p,n'})$$

where i''' is the spool index and n' denotes the last design station of the spool

d. the turbine exit, calculate the average specific heat across the turbine from

$$\bar{c}_{p,ov} = \frac{1}{2}(c_{p,inlet} + c_{p,exit})$$

where — denotes the average turbine value, $c_{p,inlet}$ is the specific heat at the turbine inlet, and $c_{p,exit}$ is the specific heat at the turbine exit.

In each of these situations the corresponding specific heat ratio $\bar{\gamma}$ is calculated as above. Further, values of related parameters used in the calculations to follow are obtained.

12. PØWER - If the design station is a stage exit, obtain the derivative of the nondimensional power output function (as specified in the input data) with respect to the nondimensional mass flow function for each streamline and calculate the total temperature drop across the rotor from

$$(\Delta T_{o,i''})_j = \frac{P'_{Ti''} P_T}{J\bar{c}_{pi'} w_{Ti}} \left(\frac{dP'_i}{dw'}\right)_j \qquad j = 1, 2, \ldots, n$$

where ΔT_0 is the total temperature drop across a rotor, ℓ'' is the stage index, j is the streamline index, P'_T is the fraction of the spool power output produced by a rotor, P_T is the spool power output, ℓ' is the blade row index, and P'_ℓ is the nondimensional power output function.

13. STRIP - Obtain the initial estimate of the radial position of each interior streamline at the design station from

$$r_{ij} = \sqrt{r_{i,1}^2 + w'_j\,(r_{i,n}^2 - r_{i,1}^2)} \qquad j = 2, 3, \ldots, n-1$$

where r is the radial position of a streamline, i is the design station index, j is the streamline index, 1 denotes the hub streamline, and n denotes the casing streamline. It can be seen that this formulation results in each streamtube having the same annulus area.

14. TD - If the design station is a blade row exit and kinetic-energy-loss coefficients are specified in the input data for the design station, obtain the initial estimate of the corresponding pressure-loss coefficients at each streamline from

$$Y_{ij} = \begin{cases} 0.05 \text{ for a stator exit} \\ 0.10 \text{ for a stage exit} \end{cases} \qquad j = 1, 2, \ldots, n$$

where Y is the pressure-loss coefficient, i is the design station index, and j is the streamline index.

15. TD - Begin major iteration loop on streamline positions; steps 16 through 81 are performed for each estimate of streamline positions and, if kinetic-energy-loss coefficients are specified at the design station, pressure-loss coefficients.

16. STRVAL - Begin loop on streamlines; steps 17 through 25 are performed for each streamline of the design station, proceeding from the hub to the casing.

17. STRVAL - Interpolate the streamline value of the streamline angle of inclination and curvature from the values specified in the input data or from the hub or casing values calculated in step 8.

18. STRVAL - If the design station is the turbine inlet, interpolate the streamline value of total temperature, total pressure, and flow angle from the values specified in the input data, and return to step 17 for the remaining streamlines. Further, go to step 26 after the last streamline has been considered.

19. STRVAL - Calculate the streamline value of the adjoining rotor blade velocity from

$$u_{ij} = \Omega r_{ij}$$

where u is the rotor blade velocity, i is the design station index, j is the streamline index, Ω is the rotative speed of the spool, and r is the radial position of the streamline.

20. STRVAL - If the design station is a stator exit, (a) obtain the streamline value of the total temperature from

$$(T_{oi})_j = (T^*_{o,i-1})_j$$

where T_o is the total temperature, i is the design station index, j is the streamline index, and * denotes a value which may have been modified if a coolant schedule or a mixing schedule has been specified in the input data, and (b) interpolate the streamline value of either the whirl velocity or flow angle, whichever values have been specified in the input data.

21. STRVAL - If the design station is a stage exit, calculate the streamline value of (a) the total temperature from

$$(T_{oi})_j = (T^*_{o,i-1})_j - (\Delta T_{o,i''})_j$$

where T_o is the total temperature, i is the design station index, j is the streamline index, $*$ denotes a value which may have been modified if a coolant schedule or a mixing schedule has been specified in the input data, and i'' is the stage index, and (b) the whirl velocity from

$$(V_{ui})_j = \frac{1}{u_{ij}} \left[u_{i-1,j} (V_{u,i-1})_j - g_o J \bar{c}_{pi'} (\Delta T_{o,i''})_j \right]$$

where V_u is the whirl velocity, i is the design station index, j is the streamline index, i' is the blade row index, and i'' is the stage index.

22. STRVAL - If pressure-loss coefficients are calculated from the internal loss correlation without additional loss factors, return to step 17 for the remaining streamlines. Further, go to step 26 after the last streamline has been considered.

23. STRVAL - Interpolate the streamline value of the loss parameter specified in the input data. This loss parameter is: (a) the additional loss factor, if pressure-loss coefficients are to be calculated from the internal loss correlation with additional loss factors, (b) the kinetic-energy or pressure-loss coefficient, or (c) the rotor or stage isentropic efficiency (applies to stage exits only).

24. STRVAL - If the streamline value of rotor isentropic efficiency has been obtained, calculate the total pressure from

$$(p_{oi})_j = (p_{o,i-1})_j \left[1 - \frac{(\Delta T_{o,i''})_j}{(\eta_{R,i''})_j (T_{o,i-1})_j} \right]^{\bar{\gamma}_{i'}/(\bar{\gamma}_{i'}-1)}$$

or, if the streamline value of stage isentropic efficiency has been obtained, calculate the total pressure from

$$(p_{oi})_j = (p_{o,i-2})_j \left[1 - \frac{\bar{c}_{pi'} (\Delta T_{o,i''})_j}{\bar{c}_{pi''} (\eta_{s,i''})_j (T_{o,i-2})_j} \right]^{\bar{\gamma}_{i''}/(\bar{\gamma}_{i''}-1)}$$

where p_o is the total pressure, i is the design station index, j is the streamline index, η_R is the rotor isentropic efficiency, η_s is the stage isentropic efficiency, i' is the blade row index, and i'' is the stage index.

25. STRVAL - Return to step 17 for the remaining streamlines. After the last streamline has been considered, continue with step 26.

26. STRVAL - Obtain the derivative with respect to radial position of (a) the total temperature, (b) the whirl velocity or flow angle, whichever is known, (c) the streamline angle of inclination, and (d) the total pressure, pressure-loss coefficient, or additional loss factor, whichever is known, at each streamline of the design station.

27. VMNTL - If this is the first pass through the iteration loop on streamline position, obtain the initial estimate of the meridional velocity at the mean streamline as follows:

    a. when the flow angle is known

$$(V_{mi})_m = M \sqrt{\left[\frac{g_o R \gamma_i}{1 + \left(\frac{\gamma_i - 1}{2}\right) M^2}\right] \left[\frac{(T_{oi})_m}{1 + \cot^2(A_i)_m \tan^2(\beta_i)_m}\right]}$$

$$\text{where } M = \begin{cases} 0.4 \text{ for the turbine inlet} \\ 0.8 \text{ for a subsonic solution at a stator exit} \\ 1.2 \text{ for a supersonic solution at a stator exit} \end{cases}$$

    b. When the whirl velocity is known

        1. at a stator exit

$$(V_{mi})_m = \cot\frac{\pi}{3} \; (V_{ui})_m \Big/ \cos(A_i)_m$$

2. at a rotor exit

$$(V_{mi})_m = -\cot\frac{\pi}{3}\left\{(V_{ui})_m - u_{im}\right\} / \cos(A_i)_m$$

where the meridional velocity is limited to values between Mach numbers of 0.1 and 0.8; that is

$$\frac{0.1}{\sqrt{1+.01\left(\frac{\gamma_i-1}{2}\right)}} \leq \frac{(V_{mi})_m}{\sqrt{g_o R \gamma_i (T_{oi})_m - \left(\frac{\gamma_i-1}{2}\right)(V_{ui})_m^2}} \leq \frac{0.8}{\sqrt{1+.64\left(\frac{\gamma_i-1}{2}\right)}}$$

where V_m is the meridional velocity, i is the design station index, m denotes the mean streamline, and β is the flow angle. If this is a subsequent pass through the iteration loop on streamline position, set the estimate of the meridional velocity at the mean streamline equal to the last value from the previous pass.

28. TD - Begin minor iteration loop to satisfy continuity. Steps 29 through 57 are performed for each estimate of the meridional velocity at the mean streamline, unless three successive estimates are equal within one part in 10^6. In the latter case, calculation continues, but special action is taken when step 54 is reached.

29. RADEQL - Begin loop on streamlines; steps 30 through 46 are performed for each streamline, first proceeding from the mean streamline to the hub and then proceeding from the mean streamline to the casing.

30. RUNKUT - If the streamline is not the hub or casing, begin loop on stages of the Runge-Kutta determination of the meridional velocity at the following streamline. Steps 31 through 45 are performed for each of the four sets of values of radial position and meridional velocity; the first set being the radial position and meridional velocity of the streamline itself. If the streamline is the hub or casing, steps 31 through 39 and step 44 are performed once--for the radial position and meridional velocity at the streamline.

31. DERIV - If the tangential velocity is known: (a) calculate the maximum allowable value of the square of the meridional velocity (that for which the corresponding static temperature is still slightly positive) from:

$$(V_{mi}^2)_{max} = 2 g_o J c_{pi} T_{oi} - V_{ui}^2 - 1$$

and (b) except for the hub and casing streamlines, set the coefficients of the third equation in the set of equations used to satisfy radial equilibrium as follows:

$$C_{31} = 0$$
$$C_{32} = 0$$
$$C_{33} = 1$$
$$C_{34} = d V_{ui}/dr$$

32. DERIV - If the flow angle is known, calculate the maximum allowable value of the square of the meridional velocity from

$$(V_{mi}^2)_{max} = (2 g_o J c_{pi} T_{oi} - 1)\Big/(1 + \tan^2\beta_i \cos^2 A_i)$$

33. DERIV - Go to step 48 if $(V_{mi}^2)_{max}$ or V_{mi}^2 is less than 1 fps^2. If V_{mi}^2 is greater than $(V_{mi}^2)_{max}$, set V_{mi}^2 equal to $(V_{mi}^2)_{max}$ for all points until either the hub or casing is reached.

34. DERIV - If the flow angle is known: (a) except for the hub and casing streamline, set the coefficients of the third equation in the set of equations used to satisfy radial equilibrium as follows:

$$C_{31} = -\tfrac{1}{2} \tan\beta_i \cos A_i / V_{mi}$$
$$C_{32} = 0$$
$$C_{33} = 1$$
$$C_{34} = V_{mi} \{\cos A_i (d\beta_i/dr)/\cos^2\beta_i - \tan\beta_i \sin A_i (dA_i/dr)\}$$

and (b) calculate the tangential velocity from

$$V_{ui} = \tan\beta_i \cos A_i V_{mi}$$

35. DERIV - If the absolute total pressure is known, except for the hub

and casing streamlines, set the coefficients of the second equation in the set of equations used to satisfy radial equilibrium as follows:

$$C_{21} = 0$$
$$C_{22} = 1$$
$$C_{23} = 0$$
$$C_{24} = (dp_{oi}/dr)/p_{oi}$$

and go to step 41.

36. DERIV - If pressure-loss coefficients are not calculated from the internal loss correlation, go to step 38.

37. PLC - Using the internal loss correlation, calculate as follows: (a) the pressure-loss coefficient Y_i and (b) except for the hub and casing streamlines, the derivative of the pressure-loss coefficient with respect to radius in terms of dV_{mi}^2/dr and dV_{ui}/dr :

$$Y_i = (f_1 f_2 f_3 / f_4)_i$$

$$\frac{dY_i}{dr} = \left(\frac{dY_i}{dr}\right)_1 + C_{Y2}\frac{dV_{mi}^2}{dr} + C_{Y3}\frac{dV_{ui}}{dr}$$

where

$$\left(\frac{dY_i}{dr}\right)_1 = Y_i\left(\frac{df_1/dr}{f_1} + \frac{df_{21}/dr}{f_2} + \frac{df_{31}/dr}{f_3} - \frac{df_{41}/dr}{f_4}\right)$$

$$C_{Y2} = Y_i\left(C_{f22}/f_2 + C_{f32}/f_3 - C_{f42}/f_4\right)$$

$$C_{Y3} = Y_i\left(C_{f23}/f_2 + C_{f33}/f_3 - C_{f43}/f_4\right)$$

(1.1) if the pressure-loss coefficient Y_i exceeds the allowable maximum, a_q , which was specified as part of the input

$$Y_i = a_q$$

$$(dY_i/dr)_1 = C_{Y2} = C_{Y3} = 0$$

(1.2) if an additional loss factor is not specified for the internal loss correlation

$$f_1 = 1$$

$$df_1/dr = 0$$

(1.3) if an additional loss factor is specified for the internal loss correlation

$$f_1 = f_{Li}$$

$$df_1/dr = df_{Li}/dr$$

(2.1) for a stator exit, if $\tan\beta_i - \tan\beta_{i-1} \geq 0$

$$f_2 = \tan\beta_i - \tan\beta_{i-1}$$

(2.1.1) if flow angle is specified

$$df_{21}/dr = \sec^2\beta_i \, d\beta_i/dr - \sec^2\beta_{i-1} \, d\beta_{i-1}/dr$$

$$C_{f22} = 0$$

$$C_{f23} = 0$$

(2.1.2) if whirl velocity is specified

$$df_{21}/dr = \tan\beta_i \tan A_i \, dA_i/dr - \sec^2\beta_{i-1} \, d\beta_{i-1}/dr$$

$$C_{f22} = -\tan\beta_i / 2V_{mi}^2$$

$$C_{f23} = \tan\beta_i / V_{ui}$$

(2.2) for a stator exit, if $\tan\beta_i - \tan\beta_{i-1} < 0$

$$f_2 = \tan\beta_{i-1} - \tan\beta_i$$

(2.2.1) if flow angle is specified

$$df_{21}/dr = \sec^2\beta_{i-1} \, d\beta_{i-1}/dr - \sec^2\beta_i \, d\beta_i/dr$$

$$C_{f22} = 0$$

$$C_{f23} = 0$$

(2.2.2) if whirl velocity is specified

$$df_{21}/dr = \sec^2\beta_{i-1} \, d\beta_{i-1}/dr - \tan\beta_i \tan A_i \, dA_i/dr$$

$$C_{f22} = \tan\beta_i / 2V_{mi}^2$$

$$C_{f23} = -\tan\beta_i / V_{ui}$$

(2.3) for a stage exit, if $\tan\beta'_{i-1} - \tan\beta'_i \geq 0$

$$f_2 = \tan\beta'_{i-1} - \tan\beta'_i$$

$$df_{21}/dr = \sec^2\beta'_{i-1}\, d\beta'_{i-1}/dr - \tan\beta'_i\{\tan A_i\, dA_i/dr - \Omega/(V_{ui} - u_i)\}$$

$$C_{f22} = \tan\beta'_i/2V_{mi}^2$$

$$C_{f23} = -\tan\beta'_i/(V_{ui} - u_i)$$

(2.4) for a stage exit, if $\tan\beta'_{i-1} - \tan\beta'_i < 0$

$$f_2 = \tan\beta'_i - \tan\beta'_{i-1}$$

$$df_{21}/dr = \tan\beta'_i\ \{\tan A_i\, dA_i/dr - \Omega/(V_{ui} - u_i)\} - \sec^2\beta'_{i-1}\, d\beta'_{i-1}/dr$$

$$C_{f22} = -\tan\beta'_i/2V_{mi}^2$$

$$C_{f23} = \tan\beta'_i/(V_{ui} - u_i)$$

(3.1) for a stator exit, if $V_{i-1}/V_i < a_3$ (a specified constant)

$$f_3 = a_6 + a_7(V_{i-1}/V_i)^{a_8}$$

$$df_{31}/dr = a_7 a_8 (V_{i-1}/V_i)^{a_8 - 1}(dV_{i-1}/dr)/V_i$$

$$C_{f32} = -a_7 a_8 (V_{i-1}/V_i)^{a_8}/2V_i^2$$

$$C_{f33} = -a_7 a_8 V_{ui} (V_{i-1}/V_i)^{a_8}/V_i^2$$

(3.2) for a stator exit, if $V_{i-1}/V_i \geq a_3$

$$f_3 = a_1 + a_2(V_{i-1}/V_i - a_3)$$

$$df_{31}/dr = a_2(dV_{i-1}/dr)/V_i$$

$$C_{f32} = -a_2 V_{i-1}/2V_i^3$$

$$C_{f33} = -a_2 V_{ui} V_{i-1}/V_i^3$$

(3.3) for a stage exit, if $V'_{i-1}/V'_i < a_3$

$$f_3 = a_6 + a_7(V'_{i-1}/V'_i)^{a_8}$$

$$df_{31}/dr = a_7 a_8 (V'_{i-1}/V'_i)^{a_8 - 1}(dV'_{i-1}/dr)/V'_i - 2C_{f32}\Omega(V_{ui} - u_i)$$

$$C_{f32} = -a_7 a_8 (V'_{i-1}/V'_i)^{a_8}/2V_i'^2$$

$$C_{f33} = -a_7 a_8 (V_{ui} - u_i)(V'_{i-1}/V'_i)^{a_8}/V_i'^2$$

(3.4) for a stage exit, if $V'_{i-1}/V'_i \geq a_3$

$$f_3 = a_1 + a_2(V'_{i-1}/V'_i - a_3)$$

$$df_{31}/dr = a_2(dV'_{i-1}/dr)/V'_i - 2C_{f32}\Omega(V_{ui} - u_i)$$

$$C_{f32} = -a_2 V'_{i-1}/2V_i'^3$$

$$C_{f33} = -a_2(V_{ui}-u_i)V'_{i-1}/V_i'^3$$

(4.1) for a stator exit

$$f_4 = a_4 + a_5 \cos\beta_i$$

(4.1.1) if flow angle is specified

$$df_{41}/dr = -a_5 \sin\beta_i \, d\beta_i/dr$$

$$C_{f42} = 0$$

$$C_{f43} = 0$$

(4.1.2) if whirl velocity is specified

$$df_{41}/dr = -a_5 \sin^2\beta_i \cos\beta_i \tan A_i \, dA_i/dr$$

$$C_{f42} = a_5 \sin^2\beta_i \cos\beta_i/2V_{mi}^2$$

$$C_{f43} = -a_5 \sin^2\beta_i \cos\beta_i/V_{ui}$$

(4.2) for a stage exit

$$f_4 = a_4 + a_5 \cos\beta_i'$$

$$df_{41}/dr = -a_5 \sin^2\beta_i' \cos\beta_i' \{\tan A_i \, dA_i/dr - \Omega/(V_{ui}-u_i)\}$$

$$C_{f42} = a_5 \sin^2\beta_i' \cos\beta_i'/2V_{mi}^2$$

$$C_{f43} = -a_5 \sin^2\beta_i' \cos\beta_i'/(V_{ui}-u_i)$$

38. DERIV - If the design station is a stator exit except for the hub and casing streamlines, (a) set the coefficients of the second equation in the set of equations used to satisfy radial equilibrium as follows:

$$C_{21} = g_{1i}$$

$$C_{22} = 1$$

$$C_{23} = 2V_{ui}g_{1i}$$

$$C_{24} = (dp^*_{o,i-1}/dr)/p^*_{o,i-1} + g_{1i}V_i^2(dT_{oi}/dr)/T_{oi} - g_{2i}\,dY_i/dr$$

where

$$g_{1i} = \left(\frac{\gamma_i}{\gamma_i - 1}\right) Y_i (T_i/T_{oi})^{1/(\gamma_i-1)}/2g_oJc_{pi}T_{oi}\{1 + Y_i(1-p_i/p_{oi})\}$$

$$g_{2i} = (1-p_i/p_{oi})/\{1+Y_i(1-p_i/p_{oi})\}$$

$$T_i/T_{oi} = 1 - V_i^2/2g_oJc_{pi}T_{oi}$$

$$p_i/p_{oi} = (T_i/T_{oi})^{\gamma_i/(\gamma_i-1)}$$

and $dY_i/dr = (dY_i/dr)$, if the loss correlation is used and (b) for a streamline only, calculate the absolute total pressure from

$$p_{oi} = p_{o,i-1} / \{ 1 + Y_i (1 - p_i/p_{oi}) \}$$

39. DERIV - If the design station is a stage exit except for the hub and casing streamlines, (a) set the coefficients of the second equation in the set of equations used to satisfy radial equilibrium as follows:

$$C_{21} = g_{1i}$$
$$C_{22} = 1$$
$$C_{23} = 2(V_{ui}\, g_{1i} - u_i\, g_{3i})$$

$$C_{24} = (dp'^{*}_{o,i-1}/dr)/p'^{*}_{o,i-1} + \{ g_{1i} V_i^2 + g_{3i} u_i (u_i - 2V_{ui}) \} (dT_{oi}/dr)/T_{oi} - g_{2i}\, dY_i/dr$$
$$- g_{4i}(u_i^2 - u_{i-1}^2)(dT'^{*}_{o,i-1}/dr)/T'^{*}_{o,i-1} - g_{3i}\, 2\Omega (u_i - V_{ui}) + g_{4i}\, 2\Omega (u_i - u_{i-1})$$

where

$$g_{1i} = \left(\frac{\gamma_i}{\gamma_i - 1}\right) Y_i (T_i/T_{oi})^{1/(\gamma_i - 1)} / 2g_o J c_{pi} T_{oi} \{ p'_{oi}/p_{oi} + Y_i (p'_{oi}/p_{oi} - p_i/p_{oi}) \}$$

$$g_{2i} = (p'_{oi}/p_{oi} - p_i/p_{oi}) / \{ p'_{oi}/p_{oi} + Y_i (p'_{oi}/p_{oi} - p_i/p_{oi}) \}$$

$$g_{3i} = \left(\frac{\gamma_i}{\gamma_i - 1}\right)(1 + Y_i)(T'_{oi}/T_{oi})^{1/(\gamma_i - 1)} / 2g_o J c_{pi} T_{oi} \{ p'_{oi}/p_{oi} + Y_i (p'_{oi}/p_{oi} - p_i/p_{oi}) \}$$

$$g_{4i} = \left(\frac{\bar{\gamma}_{i'}}{\bar{\gamma}_{i'} - 1}\right) / (T'_{oi}/T'^{*}_{o,i-1})\, 2g_o J \bar{c}_{pi'} T'^{*}_{o,i-1}$$

$$T_i/T_{oi} = 1 - V_i^2/2g_o J c_{pi} T_{oi}$$
$$p_i/p_{oi} = (T_i/T_{oi})^{\gamma_i/(\gamma_i - 1)}$$
$$T'_{oi}/T_{oi} = 1 + u_i(u_i - 2V_{ui})/2g_o J c_{pi} T_{oi}$$
$$p'_{oi}/p_{oi} = (T'_{oi}/T_{oi})^{\gamma_i/(\gamma_i - 1)}$$
$$T'_{oi}/T'^{*}_{o,i-1} = 1 + (u_i^2 - u_{i-1}^2)/2g_o J \bar{c}_{pi'} T'^{*}_{o,i-1}$$

and $dY_i/dr = (dY_i/dr)_1$ if the loss correlation is used and (b) for a streamline only, calculate the absolute total pressure from

$$p_{oi} = p'^{*}_{o,i-1} (T'_{oi}/T'^{*}_{o,i-1})^{\bar{\gamma}_{i'}/(\bar{\gamma}_{i'} - 1)} / \{ p'_{oi}/p_{oi} + Y_i (p'_{oi}/p_{oi} - p_i/p_{oi}) \}$$

40. DERIV - If the loss correlation is used at the design station, set

$$C_{21} = C_{21} + g_{2i} C_{Y2}$$
$$C_{23} = C_{23} + g_{2i} C_{Y3}$$

41. DERIV - Set the coefficients of the first equation in the set of equations used to satisfy radial equilibrium, the radial equilibrium equation itself, as follows:

$$C_{11} = 1$$
$$C_{12} = (V_i^2 - 2g_o J c_{p_i} T_{oi}) / \left(\frac{\gamma_i}{\gamma_i - 1}\right)$$
$$C_{13} = 2V_{ui}$$
$$C_{14} = 2\cos A_i V_{mi}^2 (1/r_m)_i + V_i^2 (dT_{oi}/dr)/T_{oi} - 2V_{ui}^2/r$$

42. DERIV - Calculate the determinant of the 3 x 3 coefficient matrix $[C_{ij}]$ where $i = 1,2,3$ and $j = 1,2,3$. If the sign of the determinant has changed from its previous value or if the determinant is zero, go to step 48.

43. SIMEQ - Solve the set of three equations used to satisfy radial equilibrium for the unknowns dV_{mi}^2/dr, $(dp_{oi}/dr)/p_{oi}$, and dV_{ui}/dr.

44. DERIV - (a) If no solution could be obtained to the set of three equations, go to step 48 and (b) for a streamline only, (a) calculate the value of the mass flow integrand from

$$(\rho V_m \cos A\, r)_{ij} = \left[\frac{P_o}{RT_o}\left(1 - \frac{V^2}{2g_o J c_p T_o}\right)^{\frac{1}{\gamma-1}} V_m \cos A\, r\right]_{ij}$$

and (b) if the streamline is the hub, return to step 30 for the mean streamline again, but if the streamline is the casing, go to step 47.

45. RUNKUT - Substitute the obtained value for dV_{mi}^2/dr into the Runge-Kutta formulation and return to step 31 for the remaining stages of the calculation of the meridional velocity at the following streamline.

46. RADEQL - After the calculation of the meridional velocity at the following streamline is complete, return to step 30 for the remaining streamlines.

47. RADEQL - Calculate streamline values of the mass flow function from

$$w_{ij} = 2\pi \int_{r_{i1}}^{r_{ij}} (\rho V_m \cos A \; r)_i \, dr$$

using numerical integration and go to step 50.

48. TD - Choose a new value of $(V_{mi})_m$ as follows: (a) if there have been no values for which the meridional velocity distribution could be obtained, increase the last estimate of $(V_{mi})_m$ by 3 per cent or (b) if there have been values for which the meridional velocity distribution could be obtained, average the highest "bad" estimate and the lowest "good" estimate of $(V_{mi})_m$.

49. TD - If this is on or after thirty passes through the continuity loop, return to step 29 for a final pass before abandoning the analaysis of the turbine using the lowest estimate of $(V_{mi})_m$ which yielded a valid solution for the meridional velocity distribution. If no valid distribution has been found during the current continuity loop, go to step 86. Otherwise, simply return to step 29.

50. TD - If this is a final pass through the continuity loop before abandoning the analysis of the turbine, go to step 60.

51. TD - If required, print the results of the pass through the continuity loop.

52. TD - Obtain the ratio of calculated mass flow w_{in} to specified mass flow w_{Ti} at the design station and, if this is the first pass through the continuity loop, go to step 55.

53. TD - If continuity is satisfied and $(V_{mi})_m$ has converged, both

within the allowable tolerance, go to step 58. (It should be noted that the normal tolerance of 0.01 per cent is abandoned on the first or second pass through the iteration loop on streamline position in favor of a larger tolerance if (a) more than twenty passes through continuity loop have been made, (b) the current estimate of $(V_{mi})_m$ equals the last two estimates within 1 per cent in 10^6, or (c) the sign of the slope of the mass flow versus $(V_{mi})_m$ curve has changed four times. The larger tolerance is 20 per cent during the first streamline position loop and 10 per cent during the second streamline position loop.

54. TD - If the current estimate of $(V_{mi})_m$ equals the last two estimates within one part in 10^6, if the sign of the slope of the mass flow versus $(V_{mi})_m$ curve has changed four times, or if the maximum number of passes through the minor iteration loop has been exceeded, then this is the last pass before abandoning the analysis of the turbine; go to step 60.

55. VMSUB - Obtain a new estimate of $(V_{mi})_m$. If this is the first estimate of $(V_{mi})_m$ which yielded a valid meridional velocity distribution, then (a)

$$(V_{mi})_{m,new} = (w_{in}/w_{Ti})\,(V_{mi})_m$$

when a supersonic solution is desired for a specified flow angle, or (b) otherwise

$$(V_{mi})_{m,new} = (w_{Ti}/w_{in})\,(V_{mi})_m$$

where $0.833 \leq w_{Ti}/w_{in} \leq 1.2$. If there have been several estimates of $(V_{mi})_m$ which yielded valid meridional velocity distributions, then

(a) $$(V_{mi})_{m,new} = (V_{mi})_m + \left[(V_{mi})_m - (V_{mi})_{m,old}\right]\left(\frac{w_{Ti} - w_{in}}{w_{in} - w_{in,old}}\right)$$

when $\omega_{in} \neq \omega_{in,old}$ and

$$-2 \leq \frac{\omega_{Ti} - \omega_{in}}{\omega_{in} - \omega_{in,old}} \leq 2$$

or (b)

$$(V_{mi})_{m,new} = \frac{1}{2}\left[(V_{mi})_m - (V_{mi})_{m,old}\right]$$

when $\omega_{in} = \omega_{in,old}$. It should be noted that $(V_{mi})_{m,old}$ and $\omega_{in,old}$ denote the previous values of $(V_{mi})_m$ and ω_{in} , respectively.

56. TD - If $(V_{mi})_{m,new}$ is less than the highest estimate of $(V_{mi})_m$ which did not yield a valid meridional velocity distribution, then choose an alternate value of $(V_{mi})_{m,new}$ equal to one third of the highest "bad" estimate plus two thirds of the lowest "good" estimate of $(V_{mi})_m$.

57. TD - Return to step 29 with the new estimate of $(V_{mi})_m$.

58. TD - If this is the converged pass through the streamline position loop, go to step 60. Further, if the maximum number of passes through the loop on streamline position has been exceeded, assume that this is a converged pass and go to step 60.

59. TD - If the results of each pass through the streamline position loop are not to be printed, go to step 79.

60. REMAIN - Begin output loop on streamlines; steps 61 through 66 are performed for each streamline of the design station, proceeding from the hub to the casing.

61. REMAIN - Calculate the absolute velocity, axial velocity, static temperature, static pressure, and absolute Mach number from respectively,

$$V_{ij} = \sqrt{(V_{mi}^2)_j + (V_{ui}^2)_j}$$

$$(V_{xi})_j = \cos A_{ij}\,(V_{mi})_j$$

$$T_{ij} = (T_{oi})_j \left[1 - V_{ij}^2 / 2 g_o J c_{pi} (T_{oi})_j\right]$$

$$p_{ij} = (p_{oi})_j \left\{ T_{ij} / (T_{oi})_j \right\}^{\gamma_i / (\gamma_i - 1)}$$

$$M_{ij} = \sqrt{V_{ij}^2 / \gamma_i g_o R T_{ij}}$$

62. REMAIN - If the design station is the turbine inlet, return to step 61 for the remaining streamlines; after the last streamline has been considered, go to step 68 if this is the converged pass of the major iteration loop or, otherwise, go to step 77.

63. REMAIN - Calculate the relative velocity, relative Mach number, relative total temperature, relative total pressure, and relative flow angle from, respectively,

$$V'_{ij} = \sqrt{(V_{mi}^2)_j + \left[(V_{ui})_j - u_{ij}\right]^2}$$

$$M'_{ij} = \sqrt{V_{ij}'^2 / \gamma_i g_o R T_{ij}}$$

$$(T'_{oi})_j = T_{ij} \left\{ 1 + \left(\frac{\gamma_i - 1}{2}\right) M_{ij}'^2 \right\}$$

$$(p'_{oi})_j = p_{ij} \left\{ (T'_{oi})_j / T_{ij} \right\}^{\gamma_i / (\gamma_i - 1)}$$

$$\beta'_{ij} = \tan^{-1} \left\{ (V_{ui})_j - u_{ij} \right\} / (V_{xi})_j$$

64. REMAIN - If the design station is a stator exit, calculate the blade row efficiency from (a) if the kinetic-energy-loss coefficient is specified

$$(\eta_{Bi})_j = 1 - e_{ij}$$

or (b) otherwise

$$(\eta_{Bi})_j = \left\{ 1 - T_{ij} / (T_{oi})_j \right\} / \left[1 - \left\{ p_{ij} / (p^*_{o,i-1})_j \right\}^{(\bar{\gamma}_i - 1)/\bar{\gamma}_i} \right]$$

calculate the reaction from

$$R_{ij} = V_{i-1,j} / V_{ij}$$

if this is the converged pass of the major iteration loop; calculate the absolute flow angle from

$$\beta_{ij} = \tan^{-1}\{(V_{ui})_j/(V_{xi})_j\}$$

if the tangential velocity is specified; and return to step 61 for the remaining streamlines. After the last streamline has been considered, go to step 68 if this is the converged pass of the major iteration loop or, otherwise, go to step 77.

65. REMAIN - For a design station which is a stage exit, calculate the pressure-loss coefficients from

$$Y_{ij} = \left[\frac{(P'^{*}_{o,i-1})_j\{(T'_{oi})_j/(T'^{*}_{o,i-1})_j\}^{\bar{\gamma}_i/(\bar{\gamma}_i-1)} - (P'_{oi})_j}{(P'_{oi})_j - P_{ij}}\right]$$

if isentropic stage or rotor efficiency have been specified; calculate the blade row efficiency from (a) if the kinetic-energy-loss coefficient is specified

$$(\eta_{Bi})_j = 1 - e_{ij}$$

or (b) otherwise

$$(\eta_{Bi})_j = \{1 - T_{ij}/(T'_{oi})_j\}/[1 - \{P_{ij}/(P'^{*}_{o,i-1})_j\}^{(\bar{\gamma}_i-1)/\bar{\gamma}_i}(T'^{*}_{o,i-1})_j/(T'_{oi})_j]$$

calculate the absolute flow angle from

$$\beta_{ij} = \tan^{-1}\{(V_{ui})_j/(V_{xi})_j\}$$

and, if this is not the converged pass of the major iteration loop, return to step 61 for the remaining streamlines or go to step 77 after the last streamline has been considered.

66. REMAIN - For a converged pass of the major iteration loop at a stage exit, calculate the reaction from

$$R_{ij} = V'_{i-1,j}/V'_{ij}$$

if they have not been specified, calculate the isentropic stage and rotor efficiency from, respectively,

$$(\eta_{si})_j = \frac{\bar{c}_{pi'}\,(\Delta T_{o,i''})_j}{\bar{c}_{pi''}\,(T_{o,i-2})_j \left[1 - \{(P_{oi})_j / (P_{o,i-2})_j\}^{(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}}\right]}$$

$$(\eta_{Ri})_j = \frac{(\Delta T_{o,i''})_j}{(T_{o,i-1})_j \left[1 - \{(P_{oi})_j / (P_{o,i-1})_j\}^{(\bar{\gamma}_{i'}-1)/\bar{\gamma}_{i'}}\right]}$$

and return to step 61 for the remaining streamlines or simply continue with step 67 after the last streamline has been considered.

67. SETUP - If this is the last design station of a spool, go to step 72.

68. SETUP - If mixing is specified, modified streamline values of the absolute total pressure and absolute total temperature which will be used as the upstream conditions for the next design station are calculated using numerical integration from, respectively,

$$(P^*_{o,k-1})_j = \{1 - (X_{mi'})_j\}(P_{oi})_j + (X_{mi'})_j \frac{\int_0^1 X_{mi'} P_{oi}\, d\psi'}{\int_0^1 X_{mi'}\, d\psi'}$$

$$(T^*_{o,k-1})_j = \{1 - (X_{mi'})_j\}(T_{oi})_j + (X_{mi'})_j \frac{\int_0^1 X_{mi'} T_{oi}\, d\psi'}{\int_0^1 X_{mi'}\, d\psi'}$$

where

$$j = 1, 2, \ldots, n$$

$$\int_0^1 X_{mi'}\, d\psi' \neq 0$$

and k is the index of the next design station $(k = i+1)$, $*$ denotes a value which may have been modified to include the effect of interfilament mixing, i' is the blade row index and denotes the blade row upstream of design station k , and X_m is the mixing coefficient. If

$\int_0^1 X_{mi'}\, d\psi \doteq 0$ or if mixing is not specified, then

$$(P^*_{o,k-1})_j = (P_{oi})_j$$

$$(T^*_{o,k-1})_j = (T_{oi})_j$$

69. SETUP - If a coolant schedule is specified which includes the coolant total temperature, streamline values of the absolute total temperature which will be used as the upstream condition for the next design station are again modified as follows:

$$(T^*_{o,k-1})_j = \frac{\omega_{Ti}\,(T^*_{o,k-1})_j + \omega_{ci'}\,(T_{oc})_{i'}}{\omega_{Ti} + \omega_{ci'}} \qquad j = 1,2,\ldots,n$$

where k is the index of the next design station $(k = i+1)$, $*$ denotes a value which may have been modified to include the effects of interfilament mixing and cooling, i' is the blade row index and denotes the blade row upstream of design station k, and T_{oc} is the absolute total temperature of the coolant.

70. SETUP - If the design station is not a stator exit, (a) set the following streamline values which will be used as upstream conditions for the next design station

$$V_{k-1,j} = V_{ij} \qquad j = 1,2,\ldots,n$$

and, if the internal loss correlation is being used,

$$\beta_{k-1,j} = \beta_{ij} \qquad j = 1,2,\ldots,n$$

(b) obtain streamline values of the derivative with respect to radius of $P^*_{o,k-1}$, and, if the internal loss correlation is being used, V_{k-1} and β_{k-1}; and (c) go to step 72.

71. SETUP - If the design station is a stator exit, (a) set the following streamline values which will be used as upstream conditions for the next design station

$$(V_{u,k-1})_j = (V_{ui})_j$$

$$V'_{k-1,j} = V'_{ij}$$

and, if the internal loss correlation is being used,

$$\beta'_{k-1,j} = \beta_{ij}$$

(b) calculate the following streamline values which will be used as upstream conditions for the next design station

$$(T'^{*}_{o,k-1})_j = (T^{*}_{o,k-1})_j + (V'^{2}_{ij} - V^{2}_{ij})/2g_o J c_{pi}$$

$$(P'^{*}_{o,k-1})_j = (P^{*}_{o,k-1})_j \left\{ (T'^{*}_{o,k-1})_j / (T^{*}_{o,k-1})_j \right\}^{\gamma_i/(\gamma_i-1)}$$

(c) if isentropic rotor or stage efficiency is not specified for design station k , obtain streamline values of the derivative with respect to radius of $T'^{*}_{o,k-1}$ and $P'^{*}_{o,k-1}$ and, if the internal loss correlation is being used, of V'_{k-1} and β'_{k-1} ; and (d) go to step 73.

72. SETUP - Using numerical integration, obtain mass averaged values at the design station of the absolute total temperature and absolute total pressure from

$$\bar{P}_{oi} = \int_0^1 P_{oi}\, d\omega'$$

$$\bar{T}_{oi} = \int_0^1 T_{oi}\, d\omega'$$

and, if the design station is a stage exit, the static pressure and the drop in absolute total temperature across the rotor from

$$\bar{P}_i = \int_0^1 P_i\, d\omega'$$

$$\overline{\Delta T}_{o,i''} = \int_0^1 (\Delta T_{o,i''})\, d\omega'$$

Further, if the design station is a spool inlet, go to step 77.

73. SETUP - Using numerical integration, obtain mass averaged values at the blade row exit of the blade velocity and the blade row efficiency

from

$$\bar{u}_i = \int_0^1 u_i\, dw'$$

$$\bar{\eta}_{Bi} = \int_0^1 \eta_{Bi}\, dw'$$

Further, if the design station is a stator exit, go to step 77.

74. SETUP - For a stage exit, calculate mass averaged values of (a) the stage work output, power output, blade velocity, and blade-to-jet speed ratio from, respectively,

$$\bar{W}_{i''} = \bar{c}_{pi'}(\overline{\Delta T}_{o,i''})$$

$$P_{Ti''} = w_{Ti}\, \bar{W}_{i''}$$

$$\bar{u}_{i''} = \tfrac{1}{2}(\bar{u}_i + \bar{u}_{i-1})$$

$$(\bar{r}_{js})_{i''} = \bar{u}_{i''} \Big/ \sqrt{2g_o J \bar{c}_{pi''} \bar{T}_{o,i-2}\left\{1 - (\bar{p}_i/\bar{p}_{o,i-2})^{(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}}\right\}}$$

and (b) the stage total efficiency and static efficiency from, respectively, either

$$(\bar{\eta}_{Tot})_{i''} = P_{Ti''} \Big/ w_{Ti}\, \bar{c}_{pi''} \bar{T}_{o,i-2}\left\{1 - (\bar{p}_{oi}/\bar{p}_{o,i-2})^{(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}}\right\}$$

$$(\bar{\eta}_{stat})_{i''} = P_{Ti''} \Big/ w_{Ti}\, \bar{c}_{pi''} \bar{T}_{o,i-2}\left\{1 - (\bar{p}_i/\bar{p}_{o,i-2})^{(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}}\right\}$$

if a coolant temperature schedule is not provided, or

$$(\bar{\eta}_{Tot})_{i''} = P_{Ti''} \Big/ \bar{c}_{pi''}\left\{w_{T,i-2}\bar{T}_{o,i-2} + w_{c,i'-1}(T_{oc})_{i'-1} + w_{ci'}(T_{oc})_{i'}\right\}\left\{1 - (\bar{p}_{oi}/\bar{p}_{o,i-2})^{(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}}\right\}$$

$$(\eta_{stat})_{i''} = P_{Ti''} \Big/ \bar{c}_{pi''}\left\{w_{T,i-2}\bar{T}_{o,i-2} + w_{c,i'-1}(T_{oc})_{i'-1} + w_{ci'}(T_{oc})_{i'}\right\}\left\{1 - (\bar{p}_i/\bar{p}_{o,i-2})^{(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}}\right\}$$

if a coolant temperature schedule is provided.

75. SETUP - If the stage exit is also a spool exit, calculate mass averaged values of (a) the spool work output, power output, total-to-total pressure ratio, total-to-static pressure ratio, blade velocity, and blade-to-jet speed ratio from, respectively,

$$\overline{W}_{i'''} = \sum_{i''=1}^{(n'-1)/2} \overline{W}_{i''}$$

$$P_{Ti'''} = \sum_{i''=1}^{(n'-1)/2} P_{Ti''}$$

$$(\overline{r}_{ptt})_{i'''} = (\overline{P}_o)_{i=1} / (\overline{P}_o)_i$$

$$(\overline{r}_{pts})_{i'''} = (\overline{P}_o)_{i=1} / (\overline{P})_i$$

$$\overline{u}_{i'''} = \frac{2}{n'-1} \sum_{i''=1}^{(n'-1)/2} \overline{u}_{i''}$$

$$(\overline{r}_{js})_{i'''} = \overline{u}_{i'''} \Big/ \sqrt{2g_o J \overline{c}_{pi'''} (\overline{T}_o)_{i=1} \left[1 - \{\overline{P}_i / (\overline{P}_o)_{i=1}\}^{(\overline{\gamma}_{i'''}-1)/\overline{\gamma}_{i'''}}\right]}$$

and (b) the spool total efficiency and static efficiency from, respectively, either

$$(\overline{\eta}_{Tot})_{i'''} = P_{Ti'''} \Big/ w_{Ti} \overline{c}_{pi'''} (\overline{T}_o)_{i=1} \left[1 - \{\overline{P}_{oi} / (\overline{P}_o)_{i=1}\}^{(\overline{\gamma}_{i'''}-1)/\overline{\gamma}_{i'''}}\right]$$

$$(\overline{\eta}_{stat})_{i'''} = P_{Ti'''} \Big/ w_{Ti} \overline{c}_{pi'''} (\overline{T}_o)_{i=1} \left[1 - \{\overline{P}_i / (\overline{P}_o)_{i=1}\}^{(\overline{\gamma}_{i'''}-1)/\overline{\gamma}_{i'''}}\right]$$

if a coolant temperature schedule is not provided, or

$$(\overline{\eta}_{Tot})_{i'''} = P_{Ti'''} \Big/ \overline{c}_{pi'''} \left[(w_T)_{i=1} (\overline{T}_o)_{i=1} + \sum_{i'=1}^{n'-1} w_{ci'} (T_{oc})_{i'}\right]\left[1 - \{\overline{P}_{oi} / (\overline{P}_o)_{i=1}\}^{(\overline{\gamma}_{i'''}-1)/\overline{\gamma}_{i'''}}\right]$$

$$(\overline{\eta}_{stat})_{i'''} = P_{Ti'''} \Big/ \overline{c}_{pi'''} \left[(w_T)_{i=1} (\overline{T}_o)_{i=1} + \sum_{i'=1}^{n'-1} w_{ci'} (T_{oc})_{i'}\right]\left[1 - \{\overline{P}_{oi} / (\overline{P}_o)_{i=1}\}^{(\overline{\gamma}_{i'''}-1)/\overline{\gamma}_{i'''}}\right]$$

if a coolant temperature schedule is provided.

76. SETUP - If the stage exit is also the exit of a multispool turbine, calculate mass averaged values of (a) the over-all work output, power output, total-to-total pressure ratio, total-to-static pressure, blade velocity, and blade-to-jet speed ratio from, respectively,

$$\overline{W}_{ov} = \sum_{i'''=1}^{n''} \overline{W}_{i'''}$$

$$(P_T)_{ov} = \sum_{i'''=1}^{n''} P_{Ti'''}$$

$$(\overline{r}_{ptt})_{ov} = (\overline{P}_o)_{inlet} / (\overline{P}_o)_i$$

$$(\bar{r}_{pts})_{ov} = (\bar{P}_o)_{inlet} / (\bar{P})_i$$

$$\bar{u}_{ov} = \frac{1}{n''} \sum_{i'''=1}^{n''} \bar{u}_{i'''}$$

$$(\bar{r}_{js})_{ov} = \bar{u}_{ov} \Big/ \sqrt{2 g_o J \bar{c}_{p,ov} (\bar{T}_o)_{inlet} \left[1 - \{ \bar{P}_i / (\bar{P}_o)_{inlet} \}^{(\bar{\gamma}_{ov}-1)/\bar{\gamma}_{ov}} \right]}$$

where n'' denotes the number of spools of the turbine; and (b) the overall total efficiency and static efficiency from, respectively, either

$$(\bar{\eta}_{Tot})_{ov} = (P_T)_{ov} \Big/ w_{Ti} \bar{c}_{p,ov} (\bar{T}_o)_{inlet} \left[1 - \{ \bar{P}_{oi} / (\bar{P}_o)_{inlet} \}^{(\bar{\gamma}_{ov}-1)/\bar{\gamma}_{ov}} \right]$$

$$(\bar{\eta}_{stat})_{ov} = (P_T)_{ov} \Big/ w_{Ti} \bar{c}_{p,ov} (\bar{T}_o)_{inlet} \left[1 - \{ \bar{P}_i / (\bar{P}_o)_{inlet} \}^{(\bar{\gamma}_{ov}-1)/\bar{\gamma}_{ov}} \right]$$

if a coolant temperature schedule is not provided, or

$$(\bar{\eta}_{Tot})_{ov} = (P_T)_{ov} \Big/ \bar{c}_{p,ov} \left[(w_T)_{inlet} (\bar{T}_o)_{inlet} + \sum_{i'''=1}^{n''} \sum_{i'=1}^{2n'} w_{ci'} (T_{oc})_{i'} \right] \left[1 - \{ \bar{P}_{oi} / (\bar{P}_o)_{inlet} \}^{(\bar{\gamma}_{ov}-1)/\bar{\gamma}_{ov}} \right]$$

$$(\bar{\eta}_{stat})_{ov} = (P_T)_{ov} \Big/ \bar{c}_{p,ov} \left[(w_T)_{inlet} (\bar{T}_o)_{inlet} + \sum_{i'''=1}^{n''} \sum_{i'=1}^{2n'} w_{ci'} (T_{oc})_{i'} \right] \left[1 - \{ \bar{P}_i / (\bar{P}_o)_{inlet} \}^{(\bar{\gamma}_{ov}-1)/\bar{\gamma}_{ov}} \right]$$

77. ØUTPUT - Convert the output items into the original units of the input data, print the design station output, and reconvert the output items into a consistent set of units.

78. TD - If this is the converged pass of the streamline position loop, go to step 82. If this is the last pass before abandoning the analysis of the turbine, go to step 86. Otherwise, simply continue with step 79.

79. TD - Obtain new estimates of streamline position at the design station through interpolation of the curve of radial position versus calculated mass flow function for those values of radius which give equal increments in the mass flow function. Further, check whether the values of streamline position have converged within the allowable tolerance.

80. LCNV - If kinetic-energy-loss coefficients are specified at the design station, (a) calculate the streamline values of the pressure-loss coefficient from either

$$Y_{ij} = \left[\{P_{ij}/(P_{oi})_j\}\left\{\frac{1-e_{ij}}{T_{ij}/(T_{oi})_j - e_{ij}}\right\}^{\gamma_i/(\gamma_i-1)} - 1\right] \Big/ \{1 - P_{ij}/(P_{oi})_j\} \qquad j=1,2,\ldots,n$$

if the design station is a stator exit, or

$$Y_{ij} = \left[\{P_{ij}/(P'_{oi})_j\}\left\{\frac{1-e_{ij}}{T_{ij}/(T'_{oi})_j - e_{ij}}\right\}^{\gamma_i/(\gamma_i-1)} - 1\right] \Big/ \{1 - P_{ij}/(P'_{oi})_j\} \qquad j=1,2,\ldots,n$$

if the design station is a stage exit; and (b) check whether the values of pressure-loss coefficient have converged within the allowable tolerance.

81. TD - Return to step 16 for the converged pass of the major iteration loop or simply for a new pass through the major iteration loop.

82. TD - Return to step 10 for the next design station of the spool. After the last design station has been considered, simply continue with step 83.

83. TD - If the turbine has more than one spool, go to step 85.

84. TD - If there are remaining sets of analysis variables to be considered, reconvert the input data into its original units and return to step 6. Otherwise, go to step 86.

85. TD - Return to step 6 for the remaining spools of the turbine. After the last spool has been considered, simply continue with step 86.

86. Return to step 3 for the remaining turbines to be analyzed.

Numerical Techniques

The standard numerical techniques used in Program TD are discussed below. The techniques discussed are: interpolation and extrapolation, numerical differentiation, numerical integration, the Runge-Kutta method for the solution of ordinary differential equations, and the solution of simultaneous linear equations.

Interpolation and Extrapolation

Interpolation or extrapolation is performed when a function is to be evaluated for a specific value of the independent variable from tabular entries of dependent versus independent variable. If the specific value of the independent variable is within the range of the independent variable as expressed in the table, interpolation is performed; if not, extrapolation is performed.

The interpolation which is performed is always parabolic unless there are less than three tabular entries. If there are only two tabular entries, linear interpolation is performed. With only one tabular entry, the value of the dependent variable is assumed constant for all values of the independent variable. Extrapolation, on the other hand, is always linear unless there is only one tabular entry. The following nomenclature will be used in the interpolation and extrapolation formulas given below:

Y_P = interpolated or extrapolated value of the dependent variable

X_P = value of the independent variable at which interpolation or extrapolation is desired

y_{i-1}, y_i, y_{i+1} = three consecutive tabular entries of the dependent variable corresponding to x_{i-1} , x_i , and x_{i+1} , respectively

x_{i-1}, x_i, x_{i+1} = three consecutive tabular entries of the independent variable

The formula used for parabolic interpolation is:

$$y_P = a(x_P - x_{i-1})^2 + b(x_P - x_{i-1}) + y_{i-1}$$

where

$$a = \frac{(x_i - x_{i-1})(y_{i+1} - y_i) - (x_{i+1} - x_i)(y_i - y_{i-1})}{(x_{i+1} - x_{i-1})(x_i - x_{i-1})(x_{i+1} - x_i)}$$

$$b = \frac{(y_i - y_{i-1})}{(x_i - x_{i-1})} - a(x_i - x_{i-1})$$

and x_i is the tabular entry of the independent variable which is nearest to x_P. (However, since a tabular entry on either side of x_i is necessary, x_i is not allowed to be the first or last entry in the table.) The formula used for linear interpolation or extrapolation is:

$$y_P = \frac{(x_P - x_{i-1})}{(x_i - x_{i-1})}(y_i - y_{i-1}) + y_{i-1}$$

where $x_{i-1} \leq x_P \leq x_i$ for interpolation, and either x_{i-1} is the first or x_i is the last tabular entry for extrapolation.

Parabolic, rather than linear, interpolation was selected for the program so that typical variations in the analysis variables can be represented accurately with relatively few data points. However, since this interpolation is used to assign values to the streamline quantities, it is recommended that whenever more than two items are specified for any of the program input quantities, the user should consider the manner in which these data will be interpreted by the program.

Numerical Differentiation

Numerical differentiation is performed to obtain streamline values of the derivative of a function with respect to the independent variable from tabular entries of the function and the independent variable at each streamline. The values are found by differentiating a second-order curve which is fitted to the streamline values of the function. Using the nomenclature given above, the formulas used to obtain the derivative are:

(a) for interior streamlines

$$(dy/dx)_i = a(x_i - x_{i-1}) + (y_i - y_{i-1})/(x_i - x_{i-1})$$

(b) for the hub streamline

$$(dy/dx)_{i-1} = (y_i - y_{i-1})/(x_i - x_{i-1}) - a(x_i - x_{i-1})$$

(c) for the casing streamline

$$(dy/dx)_{i+1} = (y_i - y_{i-1})/(x_i - x_{i-1}) + a\{(x_i - x_{i-1}) + 2(x_{i+1} - x_i)\}$$

where $$a = \frac{(x_i - x_{i-1})(y_{i+1} - y_i) - (x_{i+1} - x_i)(y_i - y_{i-1})}{(x_{i+1} - x_{i-1})(x_i - x_{i-1})(x_{i+1} - x_i)}$$

Numerical Integration

Numerical integration is performed when a function, say ϕ, is to be integrated across the annulus at a design station. The independent variable may be the radial position, r, or the nondimensional mass flow function, w'. The value of the integral is obtained from the trapezoidal rule so that ϕ is replaced by a series of chords; the chords connect adjacent streamline values of the function. Hence, if r is the independent variable, then

$$\int_{r_1}^{r_n} \phi \, dr = \frac{1}{2} \sum_{j=1}^{n-1} (\phi_{j+1} + \phi_j)(r_{j+1} - r_j)$$

where the subscripts 1 and n denote the hub and casing streamlines, respectively. If w' is the independent variable, the expression becomes

$$\int_0^1 \phi \, dw' = \frac{1}{n-1} \left[\frac{1}{2} (\phi_1 + \phi_n) + \sum_{j=2}^{n-1} \phi_j \right]$$

since $\varpi_{j+1} - \varpi_j = 1/(n-1)$ for all values of j .

Runge-Kutta Method

The Runge-Kutta method for the solution of ordinary differential equations is used to determine the remaining streamline values of the meridional velocity based on the meridional velocity at the mean streamline. The differential equation is of the form

$$d\,V_m^2/dr = f(r, V_m)$$

where $f(r,V_m)$ is obtained from the simultaneous solution of the radial equilibrium equation and the two subsidiary differential equations.

Given the value of meridional velocity at one streamline, $(V_{mi})_j$, the unknown value at the adjacent streamline, $(V_{mi})_k$, is determined in four stages:

$$(V_{mi})^2_{k1} = (V_{mi})^2_j + \tfrac{1}{2}(k_1 - 2q_o)$$

where
$$k_1 = hf\{r_{ij}, (V_{mi})_j\}$$
$$q_o = \begin{cases} 0 & \text{initially} \\ q_4 & \text{subsequently} \end{cases}$$
$$h = r_{ik} - r_{ij}$$

$$(V_{mi})^2_{k2} = (V_{mi})^2_{k1} + (1 - 1/\sqrt{2})(k_2 - q_1)$$

where
$$k_2 = hf\{r_{ij} + h/2, (V_{mi})_{k1}\}$$
$$q_1 = q_o + 3\{\tfrac{1}{2}(k_1 - 2q_o)\} - \tfrac{1}{2}k_1$$

$$(V_{mi})^2_{k3} = (V_{mi})^2_{k2} + (1 + 1/\sqrt{2})(k_3 - q_2)$$

where
$$k_3 = hf\{r_{ij} + h/2, (V_{mi})_{k2}\}$$

$$q_2 = q_1 + 3\{(1-1/\sqrt{2})(k_2 - q_1)\} - (1-1/\sqrt{2})k_2$$

$$(V_{mi})^2_k = (V_{mi})^2_{k3} + \tfrac{1}{6}(k_4 - 2q_3)$$

where
$$k_4 = hf\{r_{ik}\,,(V_{mi})_{k3}\}$$

$$q_3 = q_2 + 3\{(1+1/\sqrt{2})(k_3 - q_2)\} - (1+1/\sqrt{2})k_3$$

and
$$q_4 = q_3 + 3\{\tfrac{1}{6}(k_4 - 2q_3)\} - \tfrac{1}{2}k_4$$

The above is known as the Gill procedure; it possesses the refinement, by introducing q_0 and q_4, that some of the round-off errors accumulated during each step are cancelled. The method used is based on that given in Reference 3.

Solution of Simultaneous Linear Equations

The numerical solution of a set of simultaneous linear equations is obtained by the method known as the Gauss Reduction. That is, the set of equations are triangularized and, therefore, the final equation of the set is reduced to one unknown. After that unknown has been evaluated, the remaining unknowns are found by back substitution into the other equations. It should be noted that during the triangularization procedure, the order of the equations may be changed to maximize the leading coefficient in each equation and thereby increase the accuracy of the solution.

APPENDIX II

CØMMØN FORTRAN NOMENCLATURE

The following tables give the Fortran nomenclature for the blank and labeled blocks of CØMMØN. There are twelve blocks of labeled CØMMØN in addition to blank CØMMØN. Singly and doubly subscripted arrays are indicated by indices I to N; the nomenclature for these is as follows:

I	Design station index
J	Streamline index
K	Radial position index
L	Stator, rotor, or stage index
M	Blade row index
N	Station index

Nomenclature for Blank CØMMØN

Fortran Symbol	Symbol	Description	Units
IBR	i'	Blade row index	--
ICØEF		Indicator: ICØEF=0 if pressure-loss coefficients are either specified in the input data or calculated internally from the loss correlation ICØEF=1 if the kinetic-energy-loss coefficients are specified in the input data	--
ICØNV		Indicator: ICØNV=0, primarily, if a converged solution at a design station has not yet been obtained ICØNV=1, primarily, if a converged solution at a design station has been obtained	--

Fortran Symbol	Symbol	Description	Units
ICØØL		Indicator: ICØØL=0 if a coolant schedule is not specified in the input data ICØØL=1 if a coolant mass flow schedule is specified in the input data ICØØL=2 if a coolant mass flow and total temperature schedule is specified in the input data	--
IDLETE		Indicator: IDLETE=0 if only the converged results of the iteration loop on streamline position are to be printed at each design station IDLETE=1 if the results of each pass through the iteration loop on streamline	--
IDS	i	Design station index	--
ILLØØP		Pass index of the iteration loop on meridional velocity at the mean streamline	--
ILØØP		Pass index of the iteration loop on streamline position	--
ILØSS		Indicator: ILØSS=0 if values of the loss coefficient as a function of radius are specified at each stage exit ILØSS=1 if values of rotor isentropic efficiency as a function of radius are specified at each stage exit ILØSS=2 if values of stage isentropic efficiency as a function of radius are specified at each stage exit	--
IMIX		Indicator: IMIX=0 if a mixing schedule is not specified in the input data IMIX=1 if a mixing schedule is specified in the input data	--

Fortran Symbol	Symbol	Description	Units
ISAV		Spool index or, if there is only one spool, index of the sets of analysis variables	--
ISØN		Indicator: ISØN=0 if a subsonic solution is desired at a stator exit ISØN=1 if a supersonic solution is desired at a stator exit	--
ISPEC		Indicator: ISPEC=0 if values of a loss parameter as a function of radius are specified at each blade row exit ISPEC=1 if streamline values of pressure-loss coefficient are calculated from the internal correlation without an additional loss factor at each blade row exit ISPEC=2 if streamline values of pressure-loss coefficients are calculated from the internal correlation with an additional loss factor at each blade row exit	--
ISRI		Indicator: ISRI=1 if a design station is a stator exit ISRI=2 if a design station is a stage exit ISRI=3 if a design station is the inlet of the turbine ISRI=4 if a design station is the inlet of a subsequent spool	--
ISTG	i''	Stage index	--
IWRL		Indicator: IWRL=0 if values at whirl velocity as a function of radius are specified at each stator exit IWRL=1 if values of flow angle as a function of radius are specified at each stator exit	

Fortran Symbol	Symbol	Description	Units
		and only subsonic solutions are desired IWRL=2 if values of flow angle as a function of radius are specified at each stator exit and a supersonic solution is desired at one or more stator exits	--
NDSTAT	n'	Number of design stations on a spool	--
NLINES	n	Number of streamlines used in the calculations (including the hub and casing streamlines)	--
NSPØØL	n''	Number of spools	--
NSTG	$(n'-1)/2$	Number of stages on a spool	--
NTAPE		Output tape number	--
NTUBES	$n-1$	Number of streamtubes used in the calculations	--

Nomenclature for CØMMØN/CØM1/

Fortran Symbol	Symbol	Description	Units
AY(J)	A_{ij}	Streamline values of the streamline angle of inclination at a design station	rad, deg
BET(J)	β_{ij}	Streamline values of the absolute flow angle at a design station	rad, deg
BETR(J)	β'_{ij}	Streamline values of the relative flow angle at a blade row exit	rad, deg
BREFF(J)	$(\eta_{Bi})_j$	Streamline values of the blade row efficiency at a blade row exit	--
CRV(J)	$(1/r_m)_{ij}$	Streamline values of the streamline curvature at a design station	per ft, per in

Fortran Symbol	Symbol	Description	Units
DFLØW(J)	w_{ij}	Streamline values of the calculated mass flow function at a design station	lbm per sec
EFFR(J)	$(\eta_{Ri})_j$	Streamline values of the rotor isentropic efficiency at a stage exit	--
EFFS(J)	$(\eta_{si})_j$	Streamline values of the stage isentropic efficiency at a stage exit	--
EM(J)	M_{ij}	Streamline values of the absolute Mach number at a design station	--
EMR(J)	M'_{ij}	Streamline values of the relative Mach number at a blade row exit	--
FACL(J)	$(f_{Li})_j$	Streamline values of the additional loss factor used in conjunction with the internal loss correlation at a blade row exit	--
GRND(J)	$(\rho V_m r \cos A)_{ij}$	Streamline values of the integrand appearing in the continuity equation for nonuniform flow at a design station	lbm per ft sec
P(J)	p_{ij}	Streamline values of the static pressure at a design station	psf, psi
PØ(J)	$(p_{oi})_j$	Streamline values of the absolute total pressure at a design station	psf, psi
PØR(J)	$(p'_{oi})_j$	Streamline values of the relative total pressure at a blade row exit	psf, psi
REAC(J)	R_{ij}	Streamline values of the reaction at a blade row exit	--
T(J)	T_{ij}	Streamline values of the static temperature at a design station	deg R

Fortran Symbol	Symbol	Description	Units
TØ(J)	$(T_{oi})_j$	Streamline values of the absolute total temperature at a design station	deg R
TØR(J)	$(T'_{oi})_j$	Streamline values of the relative total temperature at a blade row exit	deg R
U(J)	u_{ij}	Streamline values of the blade velocity at a blade row exit	fps
V(J)	V_{ij}	Streamline values of the absolute velocity at a design station	fps
VM(J)	$(V_{mi})_j$	Streamline values of the meridional component of the velocity at a design station	fps
VR(J)	V'_{ij}	Streamline values of the relative velocity at a blade row exit	fps
VT(J)	$(V_{ui})_j$	Streamline values of the tangential component of the absolute velocity at a design station	fps
VX(J)	$(V_{xi})_j$	Streamline values of the axial component of the velocity at a design station	fps
WYE(J)	Y_{ij}	Streamline values of the pressure-loss coefficient at a blade row exit	--
WYK(J)	e_{ij}	Streamline values of the kinetic-energy-loss coefficient at a blade row exit	--

Nomenclature for CØMMØN/CØM2/

Fortran Symbol	Symbol	Description	Units
CP(I)	c_{pi}	Specified values of the specific heat at constant pressure at each design station of a spool	Btu per lbm deg R

Fortran Symbol	Symbol	Description	Units
CP1	c_{p_i}	Specific heat at constant pressure at a design station	Btu per lbm deg R
CP2	$\bar{c}_{p_{i'}}$	Average value of the specific heat at constant pressure across a blade row	Btu per lbm deg R
CP3	$\bar{c}_{p_{i''}}$	Average value of the specific heat at constant pressure across a stage	Btu per lbm deg R
CP4	$\bar{c}_{p_{i'''}}$	Average value of the specific heat at constant pressure across a spool	Btu per lbm deg R
CP5	$\bar{c}_{p,ov}$	Average value of the specific heat at constant pressure across the turbine	Btu per lbm deg R
EJCP1	Jc_{p_i}	Parameter related to the specific heat at a design station	ft lbf per lbm deg R
EJCP2	$J\bar{c}_{p_{i'}}$	Parameter related to the average specific heat across a blade row	ft lbf per lbm deg R
GAMA1	$\gamma_i/(\gamma_i-1)$	Parameter related to the specific heat ratio at a design station	--
GAMA2	$\bar{\gamma}_{i'}/(\bar{\gamma}_{i'}-1)$	Parameter related to the average specific heat ratio across a blade row	--
GAMA3	$\bar{\gamma}_{i''}/(\bar{\gamma}_{i''}-1)$	Parameter related to the average specific heat ratio across a stage	--
GAMB1	$1/(\gamma_i-1)$	Parameter related to the specific heat ratio at a design station	--
GAMC1	$(\gamma_i-1)/2$	Parameter related to the specific heat ratio at a design station	--
GAMD2	$(\bar{\gamma}_{i'}-1)/\bar{\gamma}_{i'}$	Parameter related to the average specific heat ratio across a blade row	--

Fortran Symbol	Symbol	Description	Units
GAMD3	$(\bar{\gamma}_{i''}-1)/\bar{\gamma}_{i''}$	Parameter related to the average specific heat ratio across a stage	--
GAMD4	$(\bar{\gamma}_{i'''}-1)/\bar{\gamma}_{i'''}$	Parameter related to the average specific heat ratio across a spool	--
GAMD5	$(\bar{\gamma}_{ov}-1)/\bar{\gamma}_{ov}$	Parameter related to the average specific heat ratio across the turbine	--
GAM1	γ_i	Specific heat ratio at a design station	--
GAM2	$\bar{\gamma}_{i'}$	Average value of the specific heat ratio across a blade row	--
GAM3	$\bar{\gamma}_{i''}$	Average value of the specific heat ratio across a stage	--
GAM4	$\bar{\gamma}_{i'''}$	Average value of the specific heat ratio across a spool	--
GAM5	$\bar{\gamma}_{ov}$	Average value of the specific heat ratio across the turbine	--
GASC	R	Gas constant of the working fluid	ft lbf per lbm deg R
GGG1	$g_o R \gamma_i$	Parameter related to the gas constant and the specific heat ratio at a design station	ft^2 per sec^2 deg R
GJCP1	$g_o J c_{pi}$	Parameter related to the specific heat at a design station	ft^2 per sec^2 deg R
GJCP12	$2 g_o J c_{pi}$	Parameter related to the specific heat at a design station	ft^2 per sec^2 deg R
GJCP2	$g_o J \bar{c}_{pi'}$	Parameter related to the average specific heat across a blade row	ft^2 per sec^2 deg R
GJCP22	$2 g_o J \bar{c}_{pi'}$	Parameter related to the average specific heat across a blade row	ft^2 per sec^2 deg R

Fortran Symbol	Symbol	Description	Units
GJCP32	$2g_oJ\bar{c}_{pi''}$	Parameter related to the average specific heat across a stage	ft^2 per sec^2 deg R
GJCP42	$2g_oJ\bar{c}_{pi'''}$	Parameter related to the average specific heat across a spool	ft^2 per sec^2 deg R
GJCP52	$2g_oJ\bar{c}_{p,ov}$	Parameter related to the average specific heat across the turbine	ft^2 per sec^2 deg R

Nomenclature for CØMMØN/CØM3/

Fortran Symbol	Symbol	Description	Units
BETRU(J)	$\beta'_{i-1,j}$	Streamline values of the relative flow angle upstream of a design station	rad
BETU(J)	$\beta_{i-1,j}$	Streamline values of the absolute flow angle upstream of a design station	rad
BREFFØ(J)	$(\eta_{B,i-1})_j$	Streamline values of the blade row efficiency at a stator exit	--
DPØUDR(J)	$(dp^*_{o,i-1}/dr)_j$	Streamline values of the derivative of the modified upstream absolute total pressure with respect to radius	lbf per ft^3
DPRUDR(J)	$(dp'^*_{o,i-1}/dr)_j$	Streamline values of the derivative of the modified upstream relative total pressure with respect to radius	lbf per ft^3
DTRUDR(J)	$(dT'^*_{o,i-1}/dr)_j$	Streamline values of the derivative of the modified upstream relative total pressure with respect to radius	deg R per ft
PØØ(J)	$(p_{o,i-1})_j$	Streamline values of absolute total pressure at the previous design station	psf

Fortran Symbol	Symbol	Description	Units
PØØ2(J)	$(p_{o,i-2})_j$	Previous set of values of PØØ	psf
PØRU(J)	$(p'^{*}_{o,i-1})_j$	Streamline values of relative total pressure upstream of a design station which may have been modified through mixing	psf
PØU(J)	$(p^{*}_{o,i-1})_j$	Streamline values of absolute total pressure upstream of a design station which may have been modified through mixing	psf
REACØ(J)	$R_{i-1,j}$	Streamline values of reaction at a stator exit	--
TØØ(J)	$(T_{o,i-1})_j$	Streamline values of absolute total temperature at the previous design station	deg R
TØØ2(J)	$(T_{o,i-2})_j$	Previous set of values of TØØ	deg R
TØRU(J)	$(T'^{*}_{o,i-1})_j$	Streamline values of relative total temperature upstream of a design station which may have been modified through mixing and/or cooling	deg R
TØU(J)	$(T^{*}_{o,i-1})_j$	Streamline values of absolute total temperature upstream of a design station which may have been modified through mixing and/or cooling	deg R
UU(J)	$u_{i-1,j}$	Streamline values of the blade velocity at the previous design station	fps
VRU(J)	$V'_{i-1,j}$	Streamline values of the relative velocity at the previous design station	fps
VTU(J)	$(V_{u,i-1})_j$	Streamline values of the tangential velocity at the previous design station	fps
VU(J)	$V_{i-1,j}$	Streamline values of the absolute velocity at the previous design station	fps

Fortran Symbol	Symbol	Description	Units
WYEØ(J)	$Y_{i-1,j}$	Streamline values of the pressure-loss coefficient at a stator exit	--

Nomenclature for CØMMØN/CØM4/

Fortran Symbol	Symbol	Description	Units
FLW(I)	w_{Ti}	Total mass flow at each design station of a spool	lbm per sec
FLWP	w_{Ti}	Total mass flow at a particular design station	lbm per sec
HP	P_T	Total power output of a spool	ft lbf per sec, hp
RPM	Ω	Rotative speed of a spool	rad per sec, rpm
RST(J)	r_{ij}	Streamline values of the streamline radial position at a design station	ft, in
WFN(J)	w'_j	Streamline values of the nondimensional mass flow function	--

Nomenclature for CØMMØN/CØM5/

Fortran Symbol	Symbol	Description	Units
ASTR(K,I)	A_i	Radial values of the streamline angle of inclination specified at each design station of a spool	rad, deg
ASTS(K)	A_i	Radial values of the streamline angle of inclination specified at a design station	rad
BETLT(K)	β_{inlet}	Radial values of the flow angle specified at the turbine inlet	rad, deg
CSTR(K,I)	$(1/r_m)_i$	Radial values of the streamline curvature specified at each design station of a spool	per ft, per in

Fortran Symbol	Symbol	Description	Units
CSTS(K)	$(1/r_m)_\iota$	Radial values of the streamline curvature specified at a design station	per ft
DTØ(J)	$(\Delta T_{o,i''})_j$	Streamline values of the drop in absolute total temperature across a rotor	deg R
FHP(L)	$P'_{Ti''}$	Fractions of the total power output of a spool produced by each stage	--
FLWC	$w_{ci'}$	Coolant mass flow added in a blade row	lbm per sec
IPØF(L)		Values of an indicator at each stage exit of a spool: IPØF(I)=0 if a uniform power output distribution is desired at a stage exit; IPØF(I)=1 if a nonuniform power output distribution is desired at a stage exit	lbm per sec
ISTRAC		Indicator: ISTRAC=0 if the streamline angles of inclination and curvatures are calculated internally at each design station; ISTRAC=1 if values of streamline angle of inclination and curvature as a function of radius are specified at each design station	--
NLT		Number of radii at which the turbine inlet conditions are specified	--
NSTAT	$n+2$	Number of stations of the spool, including one upstream station and one downstream station	--
NSTRAC		Number of radii at which streamline angles of inclination and curvatures at each design station of a spool are specified	--
NXT		Number of radii at which the exit conditions of each blade row of the spool are specified	--

Fortran Symbol	Symbol	Description	Units
PØF(J,L)	P'_{ij}	Streamline values of the nondimensional power output function specified at each stage exit of the spool	--
PØLT(K)	$(P_o)_{inlet}$	Radial values of the absolute total pressure specified at the turbine inlet	psf, psi
RANN(N,1) or RANN(N,2)	r_{hi} or r_{ci}	Radial position of the hub and casing at either each station or each design station of the spool	ft, in
RLT(K)	r_{inlet}	Radial coordinates at which the turbine inlet conditions are specified	ft, in
RSTRAC(K,I)	r_i	Radial coordinates at which the streamline angles of inclination and curvature are specified at each design station of a spool	ft, in
RSTRAS(K)	r_i	Radial coordinates at which the streamline angles of inclination and curvature are specified at a design station	ft
RXTS(K)	r_i	Radial coordinates at which the exit conditions of a blade row are specified	ft
TØC(M)	$(T_{oc})_{i'}$	Absolute total temperature of the coolant added in each blade row	deg R
TØLT(K)	$(T_o)_{inlet}$	Radial values of the absolute total temperature specified at the turbine inlet	deg R
WRLS(K)		Radial values of either the whirl velocity or the flow angle specified at a stator exit	fps or rad
XMIX(J,M)	$(X_{mi'})_j$	Streamline values of the mixing coefficient specified for each blade row of the spool	--

Fortran Symbol	Symbol	Description	Units
XSTAT(N)	x_ι	Axial position of each station of the spool	ft, in
YØS(K)		Radial values of the loss parameter specified at the exit of a blade row	--

Nomenclature for CØMMØN/CØM6/

Fortran Symbol	Symbol	Description	Units
CNV1	12	Conversion factor from ft to in	in per ft
CNV2	144	Conversion factor from sq ft to sq in	sq in per sq ft
CNV3	$180/\pi$	Conversion factor from rad to deg	deg per rad
CNV5	550	Conversion factor from hp to ft lbf per sec	ft lbf per sec hp
EJAY	J	Conversion factor from Btu to ft lbf	ft lbf per Btu
GØ	g_o	Conversion factor from lbf to lbm ft per sec^2	lbm ft per lbf sec^2
PI	π	Constant factor	--
TØLWY		Tolerance used to test the convergence of the iteration for loss coefficient	--

Nomenclature for CØMMØN/CØM7/

Fortran Symbol	Symbol	Description	Units
CØT60	$\cot \pi/3$	Constant equal to 0.57735	--
DFLWT	w_{in}	Mass flow at a design station as calculated from the continuity equation for the current estimate of meridional velocity in the mean streamline	lbm per sec

Fortran Symbol	Symbol	Description	Units
DFLWTØ	$w_{in,old}$	Mass flow at a design station as calculated from the continuity equation for the previous estimate of meridional velocity at the mean streamline	lbm per sec
EMMAX		Constant equal to 0.8	--
EMMIN		Constant equal to 0.1	--
ICNT		Index of the number of changes in sign of the derivative of calculated mass flow with respect to meridional velocity at the mean streamline in the iteration procedure	--
JJ		Variant of the streamline index	--
JJP		Index of the streamline following that streamline indicated by JJ	--
MEAN	m	Index of the mean streamline	--
RATIØ	w_{in}/w_{Ti}	Ratio of calculated mass flow based on the current estimate of meridional velocity at the mean streamline to the specified mass flow at a design station	--
VMM	$(V_{mi})_m$	Current estimate of the meridional velocity at the mean streamline of a design station	fps
VMMØ	$(V_{mi})_{m,old}$	Previous estimate of the meridional velocity at the mean streamline	fps
VMMØØ	$(V_{mi})_{m,old}$	Previous value of VMMØ	fps

Nomenclature for CØMMØN/CØM8/

Fortran Symbol	Symbol	Description	Units
DADR(J)	$(dA_i/dr)_j$	Streamline values of the derivative of streamline angle of	

Fortran Symbol	Symbol	Description	Units
		inclination with respect to radius at a design station	per ft
DBDR(J)	$(d\beta_i/dr)_j$	Streamline values of the derivative of flow angle with respect to radius at a design station	per ft
DPØDR(J)	$(dp_{oi}/dr)_j$	Streamline values of the derivative of the total pressure with respect to radius at a design station	lbf per ft^3
DTØDR(J)	$(dT_{oi}/dr)_j$	Streamline values of the derivative of the total temperature with respect to radius at a design station	deg R per ft
DVTDR(J)	$(dV_{ui}/dr)_j$	Streamline values of the derivative of the tangential velocity with respect to radius at a design station	per sec
DWYDR(J)	$(dY_i/dr)_j$	Streamline values of the derivative of the pressure-loss coefficient with respect to radius at a blade row exit	per ft

Nomenclature for CØMMØN/CØM9/

Fortran Symbol	Symbol	Description	Units
BREA(M)	$\bar{\eta}_{Bi}$	Mass averaged value of the blade row efficiency for each blade row of the spool	--
BREAP	$\bar{\eta}_{Bi}$	Mass averaged value of the blade row efficiency for a blade row	--
ENM1	$n-1$	Floating point representation of the number of streamtubes	--
FLWM	$w_{T,inlet}$	Mass flow rate at the inlet of the turbine	lbm per sec
ØJS	$(\bar{r}_{js})_{ov}$	Over-all blade-to-jet speed ratio based on mass averaged values	--

Fortran Symbol	Symbol	Description	Units
ØSE	$(\bar{\eta}_{stat})_{ov}$	Over-all static efficiency based on mass averaged values	--
ØTE	$(\bar{\eta}_{Tot})_{ov}$	Over-all total efficiency based on mass averaged values	--
ØTS	$(r_{pts})_{ov}$	Over-all total-to-static pressure ratio based on mass averaged values	--
ØTT	$(r_{ptt})_{ov}$	Over-all total-to-total pressure ratio based on mass averaged values	--
ØW	$\bar{W}_{ov}$	Over-all work output of the turbine based on mass averaged values	Btu per lbm
SJS(L)	$(\bar{r}_{js})_{i''}$	Stage blade-to-jet speed ratio based on mass averaged values for each stage of a spool	--
SJSP	$(\bar{r}_{js})_{i''}$	Stage blade-to-jet speed ratio based on mass averaged values	--
SPJS	$(\bar{r}_{js})_{i'''}$	Spool blade-to-jet speed ratio based on mass averaged values	--
SPP	$P_{Ti'''}$	Spool power output based on mass averaged values	hp
SPSE	$(\bar{\eta}_{stat})_{i'''}$	Spool static efficiency based on mass averaged values	--
SPTE	$(\bar{\eta}_{Tot})_{i'''}$	Spool total efficiency based on mass averaged values	--
SPTS	$(r_{pts})_{i'''}$	Spool total-to-static pressure ratio based on mass averaged values	--
SPTT	$(r_{ptt})_{i'''}$	Spool total-to-total pressure ratio based on mass averaged values	--
SPW	$\bar{W}_{i'''}$	Spool work output based on mass averaged values	Btu per lbm
SSE(L)	$(\eta_{stat})_{i''}$	Stage static efficiency based on mass averaged values for each stage of a spool	--

Fortran Symbol	Symbol	Description	Units
SSEP	$(\eta_{stat})_{i''}$	Stage static efficiency based on mass averaged values	--
STE(L)	$(\eta_{Tot})_{i''}$	Stage total efficiency based on mass averaged values for each stage of a spool	--
STEP	$(\eta_{Tot})_{i''}$	Stage total efficiency based on mass averaged values	--
SW(L)	$\bar{W}_{i''}$	Stage work output based on mass averaged values for each stage of a spool	Btu per lbm
SWP	$\bar{W}_{i''}$	Stage work output based on mass averaged values	Btu per lbm

Nomenclature for CØMMØN/CØM10/

Fortran Symbol	Symbol	Description	Units
FLWCN(M)	$w'_{ci'}$	Mass flow of the coolant added in each blade row of the spool expressed as a fraction of the inlet mass flow of the turbine	--
NAV		Number of sets of analysis variables	--
NBR	$n'-1$	Number of blade rows of a spool	--
RNXT(K,L)	r_i	Radial coordinates at which exit conditions are specified for each stator	ft, in
RSXT(K,L)	r_i	Radial coordinates at which exit conditions are specified for each rotor	ft, in
WRL(K,L)		Radial values of either the whirl velocity or the flow angle specified at each stator exit of a spool	fps or rad
YØSS(K,M)		Radial values of the loss parameter specified at each blade row exit of a spool	--

Nomenclature for CØMMØN/CØM11

Fortran Symbol	Symbol	Description	Units
AYP	A_i	A value of the streamline angle of inclination	rad
CØSA	$\cos A_i$	Cosine of the streamline angle of inclination	--
CØSB	$\cos \beta_i$	Cosine of the flow angle	--
CØSQB	$\cos^2 \beta_i$	Square of CØSB	--
DBDRP	$d\beta_i/dr$	A value of the derivative of flow angle with respect to radius	per ft
DBRUDR(J)	$(d\beta'_{i-1}/dr)_j$	Streamline values of the derivative of the upstream relative flow angle with respect to radius	per ft
DBUDR(J)	$(d\beta_{i-1}/dr)_j$	Streamline values of the derivative of the upstream absolute flow angle with respect to radius	per ft
DFLDR(J)	$(df_{Li}/dr)_j$	Streamline values of the derivative of the additional loss factor with respect to radius	per ft
DVRUDR(J)	$(dV'_{i-1}/dr)_j$	Streamline values of the derivative of the upstream relative velocity with respect to radius	per sec
DVUDR(J)	$(dV_{i-1}/dr)_j$	Streamline values of the derivative of the upstream absolute velocity with respect to radius	per sec
IJ		Variant of the streamline index	--
TANB	$\tan \beta_i$	Tangent of the flow angle	--
VMP	V_{mi}	A value of the meridional velocity	fps
VSQ	V_i^2	A value of the square of the absolute velocity	fps^2
VTP	V_{ui}	A value of the tangential velocity	fps

Nomenclature for CØMMØN/CØM12/

Fortran Symbol	Symbol	Description	Units
YCØN(1)	a_1	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(2)	a_2	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(3)	a_3	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(4)	a_4	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(5)	a_5	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(6)	a_6	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(7)	a_7	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(8)	a_8	Constant in the internal correlation of total-pressure-loss coefficient	--
YCØN(9)	a_9	Constant in the internal correlation of total-pressure-loss coefficient	--

APPENDIX III

MAIN RØUTINE

The primary function of the main routine (deckname TD) is to control the over-all logic flow of the computer program. In addition, the main routine reads the input data, writes sections of the output, sets certain values, and performs several elementary calculations.

The main routine calls Subroutines INPUT, STRAC, SPECHT, PØWER, STRIP, STRVAL, VMNTL, RADEQL, VMSUB, IIAP1, REMAIN, SETUP, ØUTPUT, and LCNV. The external input required by the main routine consists of:

ASTR	BETLT	CØMENT	CP	CSTR
FHP	FLWCN	FLWM	GASC	HP
ICØEF	ICØØL	IDLETE	IEXTRA	ILØSS
IMIX	IPØF	ISØNIC	ISPEC	ISTRAC
IWRL	NAV	NLINES	NLT	NSPØØL
NSTG	NSTRAC	NXT	PØF	PØLT
RANN	RLT	RNXT	RPM	RSTRAC
RSXT	TØC	TØLT	WRL	XMIX
XSTAT	YØSS			

The external output provided by the main routine, in addition to seven error messages, consists of:

BETLT	CØMENT	DFLWT	FLWM	GASC
NAV	NLINES	NSPØØL	PØ	PØLT
RLT	TØLT	VM	VMM	VT
WYE				

A majority of these symbols, as well as others used in the main routine, are described in the CØMMØN Fortran Nomenclature; the main routine has access to all of the blocks of CØMMØN.

Additional Fortran Nomenclature for the Main Routine

The following table gives the Fortran nomenclature for those symbols used in the main routine which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
CNV4	$60/2\pi$	Conversion factor rad per sec to rpm	rpm per rad per sec
CØMENT		A statement describing the case under consideration	--
DFLØWP	w_{ij}	A streamline value of the mass flow function	lbm per sec
IEXTRA		Indicator: IEXTRA=0 if the results of the passes through the iteration loop on meridional velocity at the mean streamline are <u>not</u> to be printed; IEXTRA=1 if the results of the passes through the iteration loop on meridional velocity at the mean streamline are to be printed when the results of a pass through the iteration loop on streamline position are to be printed	--
IFLIPD		Indicator: IFLIPD=0 if the slope of the curve of mass flow versus meridional velocity at the mean streamline has <u>not</u> changed in sign four times; IFLIPD=1 if the slope of the curve of mass flow versus meridional velocity at the mean streamline has changed in sign four times	
IREPET		Indicator: IREPET=0 if the last three	

Fortran Symbol	Symbol	Description	Units
		values of meridional velocity at the mean streamline did not differ by less than one part in 10^6 IREPET=1 if the last three values of meridional velocity at the mean streamline differed by less than one part in 10^6	--
ISØNIC(L)		Values of an indicator: ISØNIC=0 if a subsonic solution is desired at a stator exit ISØNIC=1 if a supersonic solution is desired at a stator exit	--
ITAPE		Input tape number	--
J		Streamline index	--
LATEST		Value of ILLØØP for the first loop in which a valid distribution of meridional velocity is obtained	--
LSTPSS		Indicator: LSTPSS=0 if difficulty has <u>not</u> been encountered in the calculation of the meridional velocity distribution on or after the thirtieth iterative loop	--
		LSTPSS=1 if difficulty has been encountered in the calculation of the meridional velocity distribution on or after the thirtieth iterative loop and a final pass is to be undertaken	--
NCNT		Maximum number of allowable changes in sign of the slope of the curve of mass flow versus meridional velocity at the mean streamline	--
NLLØØP		Maximum number of iterative loops	

Fortran Symbol	Symbol	Description	Units
		used to satisfy continuity	--
NLØØP		Maximum number of iterative loops used to converge on streamline position and, if kinetic-energy-loss coefficients are specified at a design station, pressure-loss coefficient	--
RP	r_{ij}	A streamline value of the radial position	ft
TØL		A variant of the tolerance used to check whether continuity is satisfied	--
TOLFLW		Tolerance used to check whether continuity is satisfied	--
TØLRAD		Tolerance used to check whether converged streamline positions have been obtained	--
TUBFLW	$w_{in}/(n-1)$	Mass flow in a streamtube	lbm per sec
VMMCHK	$(V_{mi})_{m,old}$	Value immediately preceding of the meridional velocity at the mean streamline which yielded a valid solution for the meridional velocity distribution	fps
VMMCK2	$(V_{mi})_{m,old}$	The previous value of VMMCHK	fps
VMMGD	$(V_{mi})_m$	Minimum value of meridional velocity at the mean streamline which yields a valid solution for the meridional velocity distribution	fps
VMMLB	$(V_{mi})_m$	Maximum value of meridional velocity at the mean streamline which fails to yield a valid solution for the meridional velocity distribution	fps
VMMLB1	$(V_{mi})_m$	Current value of meridional velocity at the mean streamline which fails to yield a valid solution for the meridional velocity distribution	fps

Internal Structure

A Fortran listing of the main routine is given on the following pages. The main routine performs many of the steps detailed in Appendix I; the steps together with the corresponding card sequence numbers are listed below.

Step of Analysis Procedure	Sequence Numbers
1	0040 - 0058
2	0059 - 0060
3	0061 - 0065
4	0066 - 0071
5	0072
6	0073 - 0096
7.1	0097
7.3	0098 - 0143
9	0145 - 0170
10	0171 - 0179
14	0200 - 0207
15	0208 - 0218
28	0246 - 0260
48	0262 - 0274
49	0275 - 0278 0287 - 0290
50	0279 - 0286
51	0302 - 0317
52	0318 - 0319
53	0320 - 0326

Step of Analysis Procedure	Sequence Numbers
54	0327 - 0340
56	0356
57	0359
58	0362 - 0368
59	0369
78	0362 - 0368
79	0372 - 0381
81	0382 - 0387
82	0388 - 0390
83	0391
84	0392 - 0422
85	0423
86	0424

```
$*
$IBFTC TD       LIST,DECK,M94
C                                                                       TD
C     TURBINE DESIGN PROGRAM - MAIN ROUTINE                             TD
C                                                                       TD
      COMMON IBR,ICOEF,ICONV,ICCCL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       TD
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,         TD
     2NSTG,NTAPE,NTUBES                                                 TD
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),           TD
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),     TD
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),         TD
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)                 TD
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,              TD
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,            TD
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,            TD
     3GJCP22,GJCP32,GJCP42,GJCP52                                       TD
      COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),            TD
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),          TD
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),               TD
     3VRU(17),VTU(17),VU(17),WYFO(17)                                   TD
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                  TD
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),          TD
     1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,                  TD
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),           TD
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),               TD
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)                            TD
      COMMON /COM6/CNV1,CNV2,CNV3,CNV5,EJAY,GO,PI,TOLWY                 TD
      COMMON /COM7/COT60,DFLWT,DFLWTO,EMMAX,EMMIN,ICNT,JJ,              TD
     1JJP,MEAN,RATIO,VMM,VMMO,VMMOO                                     TD
      COMMON /COM8/DADR(17),DBDR(17),DPODR(17),DTODR(17),               TD
     1DVTDR(17),DWYDR(17)                                               TD
      COMMON /COM9/BREA(16),BREAP,ENM1,FLWM,OJS,OSE,OTE,OTS,            TD
     1OTT,OW,SJS(8),SJSP,SPJS,SPP,SPSE,SPTE,SPTS,SPTT,SPW,SSE(8),       TD
     2SSEP,STE(8),STEP,SW(8),SWP                                        TD
      COMMON /COM10/FLWCN(16),NAV,NBR,RNXT(17,8),RSXT(17,8),            TD
     1WRL(17,8),YOSS(17,16)                                             TD
      COMMON /COM11/ AYP,COSA,COSB,COSQB,DBDRP,DBRUDR(17),DBUDR(17),    TD
     1DFLDR(17),DVRUDR(17),DVUDR(17),IJ,TANB,VMP,VSQ,VTP                TD
      COMMON /COM12/ YCON(9)                                            TD
      DIMENSION COMENT(12),ISONIC(8)                                    TD
      NAMELIST /NAM1/NSPOOL,NAV,NLINES,GASC,FLWM,NLT,RLT,TOLT,POLT,BETLTTD
      NAMELIST /NAM2/RPM,HP,NSTG,FHP,CP,XSTAT,RANN,NSTRAC,              TD
     1RSTRAC,ASTR,CSTR,FLWCN,TOC,XMIX,NXT,ISONIC,RNXT,WRL,IPOF,POF,     TD
     2RSXT,YOSS,YCON                                                    TD
      ITAPE=5                                                           TD
      NTAPE=6                                                           TD
      CNV1=12.0                                                         TD
      CNV2=144.0                                                        TD
      CNV3=57.29578                                                     TD
      CNV4=9.54930                                                      TD
      CNV5=550.0                                                        TD
      EJAY=778.16                                                       TD
      GO=32.1739                                                        TD
      COT60=0.57735                                                     TD
      EMMAX=0.8                                                         TD
      EMMIN=0.1                                                         TD
      PI=3.141593                                                       TD
      TOLFLW=0.00010                                                    TD
      NLLOOP=35                                                         TD
      NCNT=3                                                            TD
      TOLRAD=0.00010                                                    TD
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      TOLWY=0.00010                                                     TD  0057
      NLOOP=25                                                          TD  0058
C                                                                       TD
C     BEGIN CASE LOOP                                                   TD
C                                                                       TD
C     READ GENERAL INPUT DATA                                           TD
C                                                                       TD
   10 READ (ITAPE,20) COMENT                                            TD  0059
   20 FORMAT (12A6)                                                     TD  0060
      READ (ITAPE,30) ICOEF,ISPEC,ILOSS,IWRL,ICOOL,IMIX,ISTRAC,         TD  0061
     1                IDLETE,IEXTRA                                     TD  0062
   30 FORMAT (12I6)                                                     TD  0063
      IF (ICOEF.EQ.1) ISPEC=0                                           TD  0064
      READ (ITAPE,NAM1)                                                 TD  0065
      MEAN=(NLINES+1)/2                                                 TD  0066
C                                                                       TD
C     CALCULATE STREAMLINE VALUES OF NONDIMENSIONAL MASS-FLOW FUNCTION  TD
C                                                                       TD
      NTUBES=NLINES-1                                                   TD  0067
      ENM1=FLOAT(NTUBES)                                                TD  0068
      DO 40 J=1,NLINES                                                  TD  0069
   40 WFN(J)=FLOAT(J-1)/ENM1                                            TD  0070
      ISAV=0                                                            TD  0071
C                                                                       TD
C     BEGIN SPOOL LOOP OR ANALYSIS VARIABLE LOOP                        TD
C                                                                       TD
   50 ISAV=ISAV+1                                                       TD  0072
      IF (NSPOOL.GT.1.AND.ISAV.GT.1) GO TO 150                          TD  0073
C                                                                       TD
C     PRINT GENERAL INPUT                                               TD
C                                                                       TD
      WRITE (NTAPE,60) COMENT                                           TD  0074
   60 FORMAT (1H1////28X,76H** PROGRAM TD - AERODYNAMIC CALCULATIONS FORTD  0075
     1 THE DESIGN OF AXIAL TURBINES **////30X,12A6)                     TD  0076
      WRITE (NTAPE,70) NSPOOL                                           TD  0077
   70 FORMAT (////53X,26H*** GENERAL INPUT DATA ***        ////54X,     TD  0078
     119HNUMBER OF SPOOLS = ,I4)                                        TD  0079
      IF (NSPOOL.GT.1) GO TO 90                                         TD  0080
      WRITE (NTAPE,80) NAV                                              TD  0081
   80 FORMAT (34X,39HNUMBER OF SETS OF ANALYSIS VARIABLES = ,I4)        TD  0082
   90 WRITE (NTAPE,100) NLINES,GASC,FLWM                                TD  0083
  100 FORMAT (49X,24HNUMBER OF STREAMLINES = ,I4//58X,15HGAS CONSTANT = TD  0084
     1,F10.5,17H LBF FT/LBM DEG R/55X,18HINLET MASS FLOW = ,F10.5,      TD  0085
     28H LBM/SEC)                                                       TD  0086
      WRITE (NTAPE,110) (RLT(J),TOLT(J),PCLT(J),BETLT(J),J=1,NLT)       TD  0087
  110 FORMAT (///50X,32H* TABULAR INLET SPECIFICATIONS *///43X,         TD  0088
     16HRADIAL,8X,5HTOTAL,8X,5HTOTAL,6X,8HABSOLUTE/41X,10HCOORDINATE,   TD  0089
     23X,11HTEMPERATURE,3X,8HPRESSURE,4X,10HFLOW ANGLE/44X,4H(IN),      TD  0090
     38X,7H(DEG R),7X,5H(PSI),8X,5H(DEG)//(39X,F10.4,6X,F8.2,           TD  0091
     44X,F9.4,5X,F8.3))                                                 TD  0092
C                                                                       TD
C     CONVERT GENERAL INPUT INTO A CONSISTENT SET OF UNITS              TD
C                                                                       TD
      DO 120 J=1,NLT                                                    TD  0093
      RLT(J)=RLT(J)/CNV1                                                TD  0094
      POLT(J)=CNV2*POLT(J)                                              TD  0095
  120 BETLT(J)=BETLT(J)/CNV3                                            TD  0096
                                                                        TD
C     READ SPOOL INPUT                                                  TD
C                                                                       TD
  150 READ (ITAPE,NAM2)                                                 TD  0097
```

```
      NBR=2*NSTG                                                        TD  0098
      NDSTAT=NBR+1                                                      TD  0099
      NSTAT=NBR+3                                                       TD  0100
      DO 200 ISTG=1,NSTG                                                TD  0101
      IF (IPOF(ISTG).EQ.1) GO TO 200                                    TD  0102
      DO 180 J=1,NLINES                                                 TD  0103
  180 POF(J,ISTG)=WFN(J)                                                TD  0104
  200 CONTINUE                                                          TD  0105
C                                                                       TD
C     PRINT SPOOL INPUT                                                 TD
C                                                                       TD
      CALL INPUT                                                        TD  0106
      IF (NSPOOL.GT.1) GO TO 586                                        TD  0107
      IF (NAV.GT.1) GO TO 582                                           TD  0108
      WRITE (NTAPE,580)                                                 TD  0109
  580 FORMAT (1H1////46X,39H*** OUTPUT OF SPOOL DESIGN ANALYSIS ***)    TD  0110
      GO TO 590                                                         TD  0111
  582 WRITE (NTAPE,584) ISAV                                            TD  0112
  584 FORMAT (1H1////31X,41H*** OUTPUT OF SPOOL DESIGN ANALYSIS (SET ,  TD  0113
     1I2,27H OF ANALYSIS VARIABLES) ***)                                TD  0114
      GO TO 590                                                         TD  0115
  586 WRITE (NTAPE,588) ISAV                                            TD  0116
  588 FORMAT (1H1////43X,40H*** OUTPUT OF DESIGN ANALYSIS FOR SPOOL ,   TD  0117
     1I2,4H ***)                                                        TD  0118
C                                                                       TD
C     CONVERT SPOOL INPUT INTO A CONSISTENT SET OF UNITS                TD
C                                                                       TD
  590 RPM=RPM/CNV4                                                      TD  0119
      HP=CNV5*HP                                                        TD  0120
      IF (ISTRAC.EQ.1) GO TO 610                                        TD  0121
      DO 600 I=1,NSTAT                                                  TD  0122
      XSTAT(I)=XSTAT(I)/CNV1                                            TD  0123
      DO 600 J=1,2                                                      TD  0124
  600 RANN(I,J)=RANN(I,J)/CNV1                                          TD  0125
      GO TO 630                                                         TD  0126
  610 DO 620 I=1,NDSTAT                                                 TD  0127
      DO 615 J=1,2                                                      TD  0128
  615 RANN(I,J)=RANN(I,J)/CNV1                                          TD  0129
      DO 620 J=1,NSTRAC                                                 TD  0130
      RSTRAC(J,I)=RSTRAC(J,I)/CNV1                                      TD  0131
      ASTR(J,I)=ASTR(J,I)/CNV3                                          TD  0132
  620 CSTR(J,I)=CNV1*CSTR(J,I)                                          TD  0133
  630 DO 640 I=1,NSTG                                                   TD  0134
      DO 640 J=1,NXT                                                    TD  0135
      RNXT(J,I)=RNXT(J,I)/CNV1                                          TD  0136
      IF (IWRL.EQ.0) GO TO 640                                          TD  0137
      WRL(J,I)=WRL(J,I)/CNV3                                            TD  0138
  640 CONTINUE                                                          TD  0139
      IF (ISPEC.EQ.1) GO TO 660                                         TD  0140
      DO 650 I=1,NSTG                                                   TD  0141
      DO 650 J=1,NXT                                                    TD  0142
  650 RSXT(J,I)=RSXT(J,I)/CNV1                                          TD  0143
C                                                                       TD
C     IF TABULATED VALUES OF STREAMLINE ANGLES AND CURVATURES HAVE NOT  TD
C     BEEN GIVEN, ENTER SUBROUTINE STRAC                                TD
C                                                                       TD
  660 IF (ISTRAC.EQ.0) CALL STRAC                                       TD  0144
      IDS=0                                                             TD  0145
C                                                                       TD
C     BEGIN DESIGN STATION LOOP                                         TD
C                                                                       TD
```

```
  700 IDS=IDS+1                                                         TD  0146
      ISTG=IDS/2                                                        TD  0147
      IBR=IDS-1                                                         TD  0148
      IF (IDS.EQ.1) GO TO 720                                           TD  0149
      IF (2*ISTG.NE.IDS) GO TO 710                                      TD  0150
      ISRI=1                                                            TD  0151
      GO TO 750                                                         TD  0152
  710 ISRI=2                                                            TD  0153
      GO TO 750                                                         TD  0154
  720 IF (NSPOOL.GT.1.AND.ISAV.GT.1) GO TO 730                          TD  0155
      ISRI=3                                                            TD  0156
      GO TO 750                                                         TD  0157
  730 ISRI=4                                                            TD  0158
  750 IF (IDLETE.EQ.1.AND.ISRI.LT.3) WRITE (NTAPE,760)                  TD  0159
  760 FORMAT (1H1)                                                      TD  0160
      IF (ISRI.LT.3) GO TO 780                                          TD  0161
      WRITE (NTAPE,770)                                                 TD  0162
  770 FORMAT (////56X,20H** STATOR INLET 1 **)                          TD  0163
      GO TO 820                                                         TD  0164
  780 IF (ISRI.EQ.2) GO TO 800                                          TD  0165
      WRITE (NTAPE,790) ISTG                                            TD  0166
  790 FORMAT (////49X,29H** STATOR EXIT - ROTOR INLET ,I1,3H **)        TD  0167
      GO TO 820                                                         TD  0168
  800 WRITE (NTAPE,810) ISTG                                            TD  0169
  810 FORMAT (////57X,14H** STAGE EXIT ,I1,3H **)                       TD  0170
C                                                                       TD
C     OBTAIN THE MASS FLOW                                              TD
C                                                                       TD
  820 IF (ICOOL.EQ.0.OR.ISRI.EQ.3) GO TO 830                            TD  0171
      IF (ISRI.EQ.4) GO TO 840                                          TD  0172
      FLWP=FLWP+FLWC                                                    TD  0173
      IF (IDS.EQ.NDSTAT) GO TO 850                                      TD  0174
      GO TO 840                                                         TD  0175
  830 FLWP=FLWM                                                         TD  0176
      IF (ICOOL.EQ.0) GO TO 850                                         TD  0177
  840 FLWC=FLWCN(IDS)*FLWM                                              TD  0178
  850 FLW(IDS)=FLWP                                                     TD  0179
      IF (ISRI.EQ.4) GO TO 1710                                         TD  0180
      CALL SPECHT                                                       TD  0181
      IF (ISRI.EQ.2) CALL POWER                                         TD  0182
      CALL STRIP                                                        TD  0183
C                                                                       TD
C     CERTAIN DATA FOR THE DESIGN STATION ARE PUT INTO A MORE CONVENIENTTD
C     FORM                                                              TD
C                                                                       TD
      DO 900 J=1,NSTRAC                                                 TD  0184
      RSTRAS(J)=RSTRAC(J,IDS)                                           TD  0185
      ASTS(J)=ASTR(J,IDS)                                               TD  0186
  900 CSTS(J)=CSTR(J,IDS)                                               TD  0187
      IF (ISRI.EQ.3) GO TO 1050                                         TD  0188
      IF (ISRI.EQ.2) GO TO 920                                          TD  0189
      DO 910 J=1,NXT                                                    TD  0190
      RXTS(J)=RNXT(J,ISTG)                                              TD  0191
  910 WRLS(J)=WRL(J,ISTG)                                               TD  0192
      IF (IWRL.EQ.2) ISON=ISONIC(ISTG)                                  TD  0193
  920 IF (ISPEC.EQ.1) GO TO 1050                                        TD  0194
      DO 930 J=1,NXT                                                    TD  0195
  930 YOS(J)=YOSS(J,IBR)                                                TD  0196
      IF (ISRI.EQ.1) GO TO 950                                          TD  0197
      DO 940 J=1,NXT                                                    TD  0198
  940 RXTS(J)=RSXT(J,ISTG)                                              TD  0199
```

```
C
C     WHEN REQUIRED, OBTAIN INITIAL ESTIMATE OF LOSS COEFFICIENTS
C
  950 IF (ICOEF.EQ.0) GO TO 1050
      IF (ISRI.EQ.1) GO TO 990
      IF (ILOSS.NE.0) GO TO 1050
      DO 970 J=1,NLINES
  970 WYE(J)=0.10
      GO TO 1050
  990 DO 1010 J=1,NLINES
 1010 WYE(J)=0.05
 1050 ICONV=0
      ILOOP=0
      LSTPSS=0
C
C     BEGIN ITERATION LOOP ON STREAMLINE POSITION AND, WHEN REQUIRED,
C     LOSS COEFFICIENTS
C
 1100 ILOOP=ILOOP+1
      IF (IDLETE.EQ.0) GO TO 1120
      IF (ICONV.EQ.1) GO TO 1110
      WRITE (NTAPE,1105) ILOOP
 1105 FORMAT (////60X,7H* PASS ,I2,2H *)
      GO TO 1120
 1110 WRITE (NTAPE,1115)
 1115 FORMAT (////57X,18H* CONVERGED PASS *)
 1120 CALL STRVAL
      IF (ILOOP.NE.1) GO TO 1124
      CALL VMNTL
      GO TO 1126
 1124 VMM=VM(MEAN)
 1126 IF (IEXTRA.EQ.0) GO TO 1140
      IF (ICONV.EQ.0.AND.IDLETE.EQ.0) GO TO 1140
      WRITE (NTAPE,1130)
 1130 FORMAT (////31X,69HITERATIVE DETERMINATION OF MERIDIONAL VELOCITY
     1AT THE MEAN STREAMLINE)
      IF (ISRI.EQ.3.OR.ISPEC.EQ.0) GO TO 1134
      WRITE (NTAPE,1132)
 1132 FORMAT (//22X,10HMERIDIONAL/23X,8HVELOCITY,66X,8HABSOLUTE,
     14X,8HPRESSURE/12X,4HPASS,6X,11HAT THE MEAN,3X,10HCALCULATED,
     214X,10HSTREAMLINE,2X,10HMERIDIONAL,5X,5HWHIRL,7X,5HTOTAL,
     37X,4HLOSS/11X,6HNUMBER,5X,10HSTREAMLINE,4X,9HMASS FLOW,17X,
     46HNUMBER,5X,8HVELOCITY,4X,8HVELOCITY,4X,8HPRESSURE,3X,
     511HCOEFFICIENT/25X,5H(FPS),6X,9H(LBM/SEC),30X,5H(FPS), 7X,
     65H(FPS),7X,5H(PSI))
      GO TO 1140
 1134 WRITE (NTAPE,1136)
 1136 FORMAT (//28X,10HMERIDIONAL/29X,8HVELOCITY,66X,8HABSOLUTE/
     118X,4HPASS,6X,11HAT THE MEAN,3X,10HCALCULATED,14X,10HSTREAMLINE,
     22X,10HMERIDIONAL,5X,5HWHIRL,7X,5HTOTAL/17X,6HNUMBER,5X,
     310HSTREAMLINE,4X,9HMASS FLOW,17X,6HNUMBER,5X,8HVELOCITY,4X,
     48HVELOCITY,4X,8HPRESSURE/31X,5H(FPS),6X,9H(LBM/SEC),30X,
     55H(FPS),7X,5H(FPS),7X,5H(PSI))
 1140 ICNT=0
      ILLOOP=0
      NVMMGD=0
      VMMGD=0.0
      VMMLB=0.0
      VMMCHK=1.0
      VMMCK2=1.0
      TOL=TOLFLW
```

```
C                                                                        TD
C     BEGIN ITERATION LOOP ON MERIDIONAL VELOCITY AT THE MEAN STREAMLINETD
C                                                                        TD
 1150 ILLOOP=ILLOOP+1                                                    TD  0254
      IFLIPD=0                                                           TD  0255
      IREPET=0                                                           TD  0256
      IF(ABS(VMM/VMMCHK-1.0).GT.0.000001)GO TO 11501                     TD  0257
      IF(ABS(VMM/VMMCK2-1.0).LT.0.000001)IREPET=1                        TD  0258
11501 VMMCK2=VMMCHK                                                      TD  0259
      VMMCHK=VMM                                                         TD  0260
      CALL RADEQL(LSGN)                                                  TD  0261
      IF(LSGN.NE.1)GO TO 1156                                            TD  0262
C                                                                        TD
C***** DIFFICULTY HAS BEEN ENCOUNTERED IN VMM ITERATION                  TD
C                                                                        TD
      VMMLB1=VMM                                                         TD  0263
      IF(VMMLB1.LT.VMMLB)GO TO 1151                                      TD  0264
      VMMLB=VMMLB1                                                       TD  0265
 1151 IF(VMMGD.EQ.0.0)GO TO 1152                                         TD  0266
      VMM=0.5*(VMMLB+VMMGD)                                              TD  0267
      GO TO 1153                                                         TD  0268
 1152 VMM=1.03*VMM                                                       TD  0269
 1153 IF(IEXTRA.NE.1)GO TO 1154                                          TD  0270
      WRITE(NTAPE,11531)VMMLB1,ILLOOP                                    TD  0271
11531 FORMAT(15X,34HA MEANLINE MERIDIONAL VELOCITY OF ,F8.2,57HFPS HAS FTD  0272
     1AILED TO PRODUCE A VALID SOLUTION WHEN ILLOOP = ,I2)               TD  0273
 1154 LSGN=0                                                             TD  0274
      IF(ILLOOP.LT.30)GO TO 1155                                         TD  0275
      LSTPSS=1                                                           TD  0276
      IF(VMMGD.EQ.0.0)GO TO 11562                                        TD  0277
      VMM=VMMGD                                                          TD  0278
 1155 GO TO 1150                                                         TD  0279
 1156 IF(LSTPSS.NE.1)GO TO 1157                                          TD  0280
      CALL REMAIN                                                        TD  0281
      CALL OUTPUT                                                        TD  0282
      WRITE(NTAPE,11561)                                                 TD  0283
11561 FORMAT(29X,74HCALCULATION ABANDONED BECAUSE OF DIFFICULTY ON OR AFTD  0284
     1TER THE THIRTIETH PASS)                                            TD  0285
      GO TO 1160                                                         TD  0286
11562 WRITE(NTAPE,11563)                                                 TD  0287
11563 FORMAT(13X,106HCALCULATION ABANDONED BECAUSE OF DIFFICULTY ON OR ATD  0288
     1FTER 30 PASSES WITHOUT EVER OBTAINING A SUCCESSFUL PASS )          TD  0289
      GO TO 1160                                                         TD  0290
C                                                                        TD
C*****DIFFICULTY HAS NOT BEEN ENCOUNTERED IN VMM ITERATION               TD
C                                                                        TD
 1157 NVMMGD=NVMMGD+1                                                    TD  0291
      IF(VMMGD.EQ.0.0.OR.VMM.LT.VMMGD)GO TO 1158                         TD  0292
      GO TO 1200                                                         TD  0293
 1158 VMMGD=VMM                                                          TD  0294
      GO TO 1200                                                         TD  0295
 1160 IF (NSPOOL.EQ.1) GO TO 1730                                        TD  0296
      IF (ISAV.EQ.NSPOOL) GO TO 10                                       TD  0297
      ISAV=ISAV+1                                                        TD  0298
      DO 1170 IABRT=ISAV,NSPOOL                                          TD  0299
 1170 READ (ITAPE,NAM2)                                                  TD  0300
      GO TO 10                                                           TD  0301
 1200 IF (IFXTRA.EQ.0) GO TO 1250                                        TD  0302
      IF (ICONV.NE.1.AND.IDLETE.NE.1) GO TO 1250                         TD  0303
      DO 1205 J=1,NLINES                                                 TD  0304
 1205 PO(J)=PO(J)/CNV2                                                   TD  0305
```

```
      IF (ISRI.EQ.3.OR.ISPEC.EQ.0) GO TO 1215                          TD  0306
      WRITE (NTAPE,1210) ILLOOP,VMM,DFLWT,(J,VM(J),VT(J),PO(J),WYE(J),  TD  0307
     1                    J=1,NLINES)                                   TD  0308
 1210 FORMAT (/13X,I2,6X,F10.3,4X,F10.5,19X,I2,5X,F10.3,2X,F10.3,       TD  0309
     13X,F9.4,4X,F8.5/(64X,I2,5X,F10.3,2X,F10.3,3X,F9.4,4X,F8.5))       TD  0310
      GO TO 1230                                                        TD  0311
 1215 WRITE (NTAPE,1220) ILLOOP,VMM,DFLWT,(J,VM(J),VT(J),PO(J),         TD  0312
     1                    J=1,NLINES)                                   TD  0313
 1220 FORMAT (/19X,I2,6X,F10.3,4X,F10.5,19X,I2,5X,F10.3,2X,F10.3,       TD  0314
     13X,F9.4/(70X,I2,5X,F10.3,2X,F10.3,3X,F9.4))                       TD  0315
 1230 DO 1240 J=1,NLINES                                                TD  0316
 1240 PO(J)=CNV2*PO(J)                                                  TD  0317
 1250 RATIO=DFLWT/FLWP                                                  TD  0318
      IF(ILLOOP.EQ.1.OR.VMMGD.EQ.0.0)GO TO 1360                         TD  0319
      IF(ICONV.EQ.1)GO TO 1260                                          TD  0320
      IF(ILLOOP.LT.20.AND.IREPET.NE.1.AND.IFLIPD.NE.1)GO TO 1260        TD  0321
      IF(ILOOP.EQ.1)TOL=0.2                                             TD  0322
      IF(ILOOP.EQ.2)TOL=0.1                                             TD  0323
      IF(ILOOP.GE.3)TOL=TOLFLW                                          TD  0324
C                                                                       TD
C***** CONVERGENCE ON MASSFLOW AND MEANLINE VM IS CHECKED               TD
C                                                                       TD
 1260 IF(ABS(RATIO-1.0).GT.TOL)GO TO 1300                               TD  0325
      IF(ABS(VMM/VMMO-1.0).LE.TOL)GO TO 1500                            TD  0326
 1300 IF(IREPET.NE.1.AND.IFLIPD.NE.1)GO TO 1305                         TD  0327
      CALL REMAIN                                                       TD  0328
      CALL OUTPUT                                                       TD  0329
      IF(IREPET.EQ.1)WRITE(NTAPE,1302)ILOOP                             TD  0330
 1302 FORMAT(//5X,29HCALCULATION ABANDONED ON PASS,I3,91H BECAUSE OF TWOTD  0331
     1 REPETITIONS OF A MEANLINE MERIDIONAL VELOCITY WITHOUT MASS FLOW CTD  0332
     2ONVERGENCE)                                                       TD  0333
      IF(IFLIPD.EQ.1)WRITE(NTAPE,1303)ILOOP                             TD  0334
 1303 FORMAT(//5X,29HCALCULATION ABANDONED ON PASS,I3,90H BECAUSE OF INSTD  0335
     1TABILITY IN MEANLINE MERIDIONAL VELOCITY ITERATION DUE TO CHOKED CTD  0336
     2ONDITIONS)                                                        TD  0337
      IREPET=0                                                          TD  0338
      IFLIPD=0                                                          TD  0339
      GO TO 1160                                                        TD  0340
 1305 IF(ILLOOP.LT.NLLOOP)GO TO 1350                                    TD  0341
      WRITE (NTAPE,1310) ILOOP                                          TD  0342
 1310 FORMAT (//19X,92HITERATION FOR THE MERIDIONAL VELOCITY AT THE MEANTD  0343
     1 STREAMLINE HAS NOT CONVERGED WHEN ILOOP = ,I2)                   TD  0344
      CALL REMAIN                                                       TD  0345
      CALL OUTPUT                                                       TD  0346
      GO TO 1160                                                        TD  0347
C                                                                       TD
C***** MAKE NEXT ESTIMATE OF MEANLINE MERIDIONAL VELOCITY               TD
C                                                                       TD
 1350 VMMOO=VMMO                                                        TD  0348
 1360 VMMO=VMM                                                          TD  0349
      IF(NVMMGD.GE.2)GO TO 1370                                         TD  0350
      LATEST=ILLOOP                                                     TD  0351
      ILLOOP=1                                                          TD  0352
 1370 CALL VMSUB                                                        TD  0353
      IF(NVMMGD.GE.2)GO TO 1380                                         TD  0354
      ILLOOP=LATEST                                                     TD  0355
 1380 IF(VMM.LE.VMMLB)VMM=(VMMLB+2.0*VMMGD)/3.0                         TD  0356
      IF (ICNT.GT.NCNT) GO TO 1400                                      TD  0357
      DFLWTO=DFLWT                                                      TD  0358
      GO TO 1150                                                        TD  0359
 1400 IFLIPD=1                                                          TD  0360
```

```
      GO TO 1300                                                        TD  0361
 1500 IF (ICONV.EQ.1) GO TO 1700                                        TD  0362
      IF(ILOOP.LT.NLOOP)GO TO 1520                                      TD  0363
      WRITE (NTAPE,1510)                                                TD  0364
 1510 FORMAT (//12X,108HITERATION FOR STREAMLINE POSITIONS OR PRESSURE LTD  0365
     1OSS COEFFICIENTS, WHEN THEY ARE NOT KNOWN, HAS NOT CONVERGED)     TD  0366
      ICONV=1                                                           TD  0367
      GO TO 1700                                                        TD  0368
 1520 IF (IDLETE.EQ.0) GO TO 1550                                       TD  0369
      CALL REMAIN                                                       TD  0370
      CALL OUTPUT                                                       TD  0371
C                                                                       TD
C     OBTAIN NEW ESTIMATES OF STREAMLINE POSITIONS                      TD
C                                                                       TD
 1550 ICONV=1                                                           TD  0372
      TUBFLW=DFLWT/ENM1                                                 TD  0373
      DFLOWP=0.0                                                        TD  0374
      DO 1560 J=2,NTUBES                                                TD  0375
      DFLOWP=DFLOWP+TUBFLW                                              TD  0376
      CALL IIAP1(DFLOWP,RP,DFLOW,RST,NLINES)                            TD  0377
      IF (ICONV.EQ.0) GO TO 1560                                        TD  0378
      IF (ABS(RP/RST(J)-1.0).LE.TOLRAD) GO TO 1560                      TD  0379
      ICONV=0                                                           TD  0380
 1560 RST(J)=RP                                                         TD  0381
      IF (ISRI.EQ.3.OR.ICOEF.EQ.0) GO TO 1100                           TD  0382
 1610 IF (ISRI.EQ.1) GO TO 1620                                         TD  0383
      IF (ILOSS.NE.0) GO TO 1100                                        TD  0384
C                                                                       TD
C     CONVERT KINETIC-ENERGY LOSS COEFFICIENTS TO PRESSURE LOSS         TD
C     COEFFICIENTS                                                      TD
C                                                                       TD
 1620 CALL LCNV                                                         TD  0385
      GO TO 1100                                                        TD  0386
 1700 CALL REMAIN                                                       TD  0387
 1710 CALL SETUP                                                        TD  0388
      CALL OUTPUT                                                       TD  0389
      IF (IDS.LT.NDSTAT) GO TO 700                                      TD  0390
      IF (NSPOOL.GT.1) GO TO 2000                                       TD  0391
 1730 IF (ISAV.GE.NAV) GO TO 10                                         TD  0392
C                                                                       TD
C     RECONVERT INPUT DATA INTO THE ORIGINAL UNITS                      TD
C                                                                       TD
      DO 1800 J=1,NLT                                                   TD  0393
      RLT(J)=CNV1*RLT(J)                                                TD  0394
      POLT(J)=POLT(J)/CNV2                                              TD  0395
 1800 BETLT(J)=CNV3*BETLT(J)                                            TD  0396
      RPM=CNV4*RPM                                                      TD  0397
      HP=HP/CNV5                                                        TD  0398
      IF (ISTRAC.EQ.1) GO TO 1820                                       TD  0399
      DO 1810 I=1,NSTAT                                                 TD  0400
      XSTAT(I)=CNV1*XSTAT(I)                                            TD  0401
      DO 1810 J=1,2                                                     TD  0402
 1810 RANN(I,J)=CNV1*RANN(I,J)                                          TD  0403
      GO TO 1840                                                        TD  0404
 1820 DO 1830 I=1,NDSTAT                                                TD  0405
      DO 1825 J=1,2                                                     TD  0406
 1825 RANN(I,J)=CNV1*RANN(I,J)                                          TD  0407
      DO 1830 J=1,NSTRAC                                                TD  0408
      RSTRAC(J,I)=CNV1*RSTRAC(J,I)                                      TD  0409
      ASTR(J,I)=CNV3*ASTR(J,I)                                          TD  0410
 1830 CSTR(J,I)=CSTR(J,I)/CNV1                                          TD  0411
```

```
1840 DO 1850 I=1,NSTG                                                    TD  0412
     DO 1850 J=1,NXT                                                     TD  0413
     RNXT(J,I)=CNV1*RNXT(J,I)                                            TD  0414
     IF (IWRL.EQ.0) GO TO 1850                                           TD  0415
     WRL(J,I)=CNV3*WRL(J,I)                                              TD  0416
1850 CONTINUE                                                            TD  0417
     IF (ISPEC.EQ.1) GO TO 50                                            TD  0418
     DO 1860 I=1,NSTG                                                    TD  0419
     DO 1860 J=1,NXT                                                     TD  0420
1860 RSXT(J,I)=CNV1*RSXT(J,I)                                            TD  0421
     GO TO 50                                                            TD  0422
2000 IF (ISAV.LT.NSPOOL) GO TO 50                                        TD  0423
     GO TO 10                                                            TD  0424
     END                                                                 TD  0425
```

APPENDIX IV

SUBRØUTINE INPUT

The function of Subroutine INPUT (deckname SUBM1) is to write the input data for a spool onto the output tape unit.

Subroutine INPUT is called by the main routine; it does not call any other subroutines. The subroutine does not require external input. Internal input to the subroutine is transmitted through blank CØMMØN, CØMMØN /CØM2/, CØMMØN/CØM4/, CØMMØN/CØM5/, CØMMØN/CØM10/, and CØMMØN/CØM12/. The internal input consists of:

ASTR	CP	CSTR	FHP	FLWCN
HP	ICØEF	ICØØL	ILØSS	IMIX
ISAV	ISPEC	ISTRAC	IWRL	NAV
NBR	NDSTAT	NLINES	NSTAT	NSTG
NSTRAC	NSPØØL	NTAPE	NXT	PØF
RANN	RNXT	RPM	RSTRAC	RSXT
TØC	WNF	WRL	XMIX	XSTAT
YCØN	YØSS			

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.) Subroutine INPUT does not provide internal output. The external output of the subroutine consists of:

ASTR	CP	CSTR	FHP	FLWCN
HP	ISAV	NSTG	PØF	RANN
RNXT	RPM	RSTRAC	RSXT	TØC
WRL	XMIX	XSTAT	YCØN	YØSS

Additional Fortran Nomenclature for Subroutine INPUT

The following table gives the Fortran nomenclature for those symbols used in Subroutine INPUT which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
CØN1		Alternative name for YCØN(1)	--
CØN2		Alternative name for YCØN(2)	--
CØN3		Alternative name for YCØN(3)	--
CØN4		Alternative name for YCØN(4)	--
CØN5		Alternative name for YCØN(5)	--
CØN6		Alternative name for YCØN(6)	--
CØN7		Alternative name for YCØN(7)	--
CØN8		Alternative name for YCØN(8)	--
CØN9		Alternative name for YCØN(9)	--
FMT1		Format specification	--
FMT2		Format specification	--
FMT3		Format specification	--
FMT4		Format specification	--
HW1		Alphanumeric information	--
HW2		Alphanumeric information	--
HW3		Alphanumeric information	--
HW4		Alphanumeric information	--
ISTG	i''	Stage index	--
IW		Integer used to control format specifications	--
NB		Integer used to control format specifications	--
NBLNK		Integer used to control format specifications	--
NE		Integer used to control format specifications	--

Fortran Symbol	Symbol	Description	Units
NF		Integer used to control format specifications	--
NFILL		Integer used to control format specifications	--

Internal Structure

This subroutine performs step 7.2 of the analysis procedure. A Fortran listing is given in the following pages.

```
$*
$IBFTC SUBM1    LIST,DECK,M94
C                                                                        INPT
C      INPUT - PRINT THE SPOOL INPUT DATA                                INPT
C                                                                        INPT
       SUBROUTINE INPUT                                                  INPT0001
       COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       INPT0002
      1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NOSTAT,NLINES,NSPOOL,        INPT0003
      2NSTG,NTAPE,NTUBES                                                 INPT0004
       COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,              INPT0005
      1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,           INPT0006
      2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,           INPT0007
      3GJCP22,GJCP32,GJCP42,GJCP52                                       INPT0008
       COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                  INPT0009
       COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),          INPT0010
      1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,                  INPT0011
      2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),          INPT0012
      3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),               INPT0013
      4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)                            INPT0014
       COMMON /COM10/FLWCN(16),NAV,NBR,RNXT(17,8),RSXT(17,8),            INPT0015
      1WRL(17,8),YOSS(17,16)                                             INPT0016
       COMMON /COM12/ CON1,CON2,CON3,CON4,CON5,CON6,CON7,CON8,CON9      INPT0017
       DIMENSION FMT1(3),FMT2(3),FMT3(5),FMT4(7),HW1(8),HW2(5),         INPT0018
      1HW3(12),HW4(30)                                                   INPT0019
       DATA FMT1(1),FMT1(3)/6H(//    ,6H,18A6)/,FMT2(1),FMT2(3)         INPT0020
      1/6H(      ,6H,18A6)/,FMT3(1),(FMT3(I),I=3,5)/6H(                  INPT0021
      2,6H,8(4X,,6HI2,6X),6H)      /,FMT4(1),(FMT4(I),I=3,7)            INPT0022
      3/6H(      ,6H,5X,  ,6HI2,5X ,6H,8(1X,,6HF8.5, ,6H3X))  /          INPT0023
       DATA (HW1(I),I=1,8)/6H STREA,6HMLINE ,6H   BLA,6HDE    ,          INPT0024
      16H   NUM,6HBER   ,6H    RO,6HW      /                             INPT0025
       DATA (HW2(I),I=1,5)/6H12X   ,6H24X   ,6H36X   ,6H48X   ,         INPT0026
      26H60X   /                                                         INPT0027
       DATA (HW3(I),I=1,12)/6H   WHI,6HRL    ,6H  VELO,6HCITY  ,        INPT0028
      16H   (FP,6HS)    ,6H   WHI,6HRL    ,6H   ANG,6HLE    ,           INPT0029
      36H   (DE,6HG)    /                                                INPT0030
       DATA (HW4(I),I=1,30)/6H  PRES,6HSURE  ,6H    LO,6HSS    ,        INPT0031
      16HCOEFFI,6HCIENT ,6H  KINE,6HTIC-  ,6HENERGY,6H LOSS ,           INPT0032
      26HCOEFFI,6HCIENT ,6H ADDIT,6HIONAL ,6H    LO,6HSS    ,           INPT0033
      36H   FAC,6HTOR   ,6H   ROT,6HOR    ,6H ISENT,6HROPIC ,           INPT0034
      46H EFFIC,6HIENCY ,6H   STA,6HGE    ,6H ISENT,6HROPIC ,           INPT0035
      56H EFFIC,6HIENCY /                                                INPT0036
       IF (NSPOOL.GT.1) GO TO 170                                        INPT0037
       WRITE (NTAPE,160)                                                 INPT0038
  160  FORMAT (1H1///54X,24H*** SPOOL INPUT DATA ***)                    INPT0039
       GO TO 190                                                         INPT0040
  170  WRITE (NTAPE,180) ISAV                                            INPT0041
  180  FORMAT (1H1///51X,25H*** INPUT DATA FOR SPOOL ,I1,4H ***)         INPT0042
  190  WRITE (NTAPE,200) RPM,HP                                          INPT0043
  200  FORMAT (////53X,25H** DESIGN REQUIREMENTS **///51X,   17HROTATIVE INPT0044
      1SPEED = ,F9.1,4H RPM/53X,15HPOWER OUTPUT = ,F9.2,3H HP)          INPT0045
       IF (NSPOOL.EQ.1.AND.NAV.GT.1) GO TO 220                           INPT0046
       WRITE (NTAPE,210)                                                 INPT0047
  210  FORMAT (////54X,24H** ANALYSIS VARIABLES **)                      INPT0048
       GO TO 240                                                         INPT0049
  220  WRITE (NTAPE,230) ISAV                                            INPT0050
  230  FORMAT (////49X, 7H** SET ,I2,25H OF ANALYSIS VARIABLES **)       INPT0051
  240  WRITE (NTAPE,250) NSTG                                            INPT0052
  250  FORMAT (///56X,19HNUMBER OF STAGES = ,I1)                         INPT0053
       WRITE (NTAPE,260) (I,FHP(I),I=1,NSTG)                             INPT0054
  260  FORMAT (///55X,22H* POWER-OUTPUT SPLIT *///69X,11HFRACTION OF/    INPT0055
      151X,12HSTAGE NUMBER,3X,18HSPOOL POWER OUTPUT//(56X,I1,13X,F8.5))  INPT0056
```

```
      WRITE (NTAPE,270) (I,CP(I),I=1,NDSTAT)
  270 FORMAT (///50X,31H* SPECIFIC-HEAT SPECIFICATION *///44X,
     121HDESIGN STATION NUMBER,5X,13HSPECIFIC HEAT/69X,
     215H(BTU/LBM DEG R)//(54X,I2,16X,F8.5))
      WRITE (NTAPE,280)
  280 FORMAT (///53X,25H* ANNULUS SPECIFICATION *)
      IF (ISTRAC.EQ.1) GO TO 300
      WRITE (NTAPE,290) (I,XSTAT(I),(RANN(I,J),J=1,2),I=1,NSTAT)
  290 FORMAT (//32X,14HSTATION NUMBER,4X,14HAXIAL POSITION,6X,
     110HHUB RADIUS,6X,13HCASING RADIUS/55X,4H(IN),14X,4H(IN),
     214X,4H(IN)//(38X,I2,2X,3F18.4))
      GO TO 350
  300 WRITE (NTAPE,310) (I,(RANN(I,J),J=1,2),I=1,NDSTAT)
  310 FORMAT (//37X,21HDESIGN STATION NUMBER,4X,10HHUB RADIUS,6X,
     113HCASING RADIUS/65X,4H(IN),14X,4H(IN)//(46X,I2,5X,2F18.4))
      WRITE (NTAPE,320)
  320 FORMAT (///51X,29H* STREAMLINE SPECIFICATIONS *)
      DO 330 I=1,NDSTAT
  330 WRITE (NTAPE,340) I,(RSTRAC(J,I),ASTR(J,I),CSTR(J,I),J=1,NSTRAC)
  340 FORMAT (//57X,6HRADIAL,7X,8HANGLE OF/36X,14HDESIGN STATION,
     1I3,2X,10HCOORDINATE,3X,11HINCLINATION,4X,9HCURVATURE/58X,4H(IN),
     29X,5H(DEG),8X,8H(PER IN)//(50X,3F14.5))
  350 IF (ICOOL.EQ.0) GO TO 400
      WRITE (NTAPE,360)
  360 FORMAT (///56X,20H* COOLANT SCHEDULE *)
      IF (ICOOL.EQ.1) GO TO 380
      WRITE (NTAPE,370) (I,FLWCN(I),TOC(I),I=1,NBR)
  370 FORMAT (//60X,11HFRACTION OF,8X,5HTOTAL/40X,        16HBLADE ROW
     1NUMBER,2X,15HINLET MASS FLOW,3X,11HTEMPERATURE/78X,7H(DEG R)//
     2(47X,I2,4X,F16.5,F16.2))
      GO TO 400
  380 WRITE (NTAPE,390) (I,FLWCN(I),I=1,NBR)
  390 FORMAT (//68X,11HFRACTION OF/48X,     16HBLADE ROW NUMBER,2X,
     115HINLET MASS FLOW//(55X,I2,4X,F16.5))
  400 IF (IMIX.EQ.0) GO TO 460
      WRITE (NTAPE,410)
  410 FORMAT (///54X,23H* MIXING COEFFICIENTS *)
      IW=0
  420 IW=IW+1
      NB=1
      NE=NBR
      IF (IW.EQ.2) NB=9
      IF (IW.EQ.1.AND.NBR.GT.8) GO TO 430
      NFILL=NBR-8*(IW-1)
      NBLNK=(10-NFILL)/2
      GO TO 440
  430 NE=8
      NFILL=8
      NBLNK=1
  440 NBLNK1=NBLNK+1
      FMT1(2)=HW2(NBLNK)
      FMT2(2)=HW2(NBLNK)
      FMT3(2)=HW2(NBLNK1)
      FMT4(2)=HW2(NBLNK)
      WRITE (NTAPE,FMT1) HW1(1),HW1(2),(HW1(3),HW1(4),I=1,NFILL)
      WRITE (NTAPE,FMT2) HW1(5),HW1(6),(HW1(7),HW1(8),I=1,NFILL)
      WRITE (NTAPE,FMT3) (I,I=NB,NE)
      WRITE (NTAPE,445)
  445 FORMAT (1X)
      DO 450 J=1,NLINES
  450 WRITE (NTAPE,FMT4) J,(XMIX(J,I),I=NB,NE)
```

```
      IF (IW.EQ.1.AND.NBR.GT.8) GO TO 420                                   INPT0118
  460 WRITE (NTAPE,470)                                                     INPT0119
  470 FORMAT (///51X,29H* BLADE-ROW EXIT CONDITIONS *)                      INPT0120
      NB=1                                                                  INPT0121
      IF (IWRL.NE.0) NB=7                                                   INPT0122
      NE=13                                                                 INPT0123
      IF (ISPEC.NE.0) GO TO 480                                             INPT0124
      IF (ICOEF.EQ.0) NE=1                                                  INPT0125
      IF (ICOEF.EQ.1) NE=7                                                  INPT0126
  480 NF=NE                                                                 INPT0127
      IF (ISPEC.NE.0) GO TO 490                                             INPT0128
      IF (ILOSS.EQ.1) NF=19                                                 INPT0129
      IF (ILOSS.EQ.2) NF=25                                                 INPT0130
  490 DO 670 I=1,NBR                                                        INPT0131
      ISTG=(I+1)/2                                                          INPT0132
      IF (2*(I/2).EQ.I) GO TO 530                                           INPT0133
      IF (ISPEC.EQ.1) GO TO 510                                             INPT0134
      WRITE (NTAPE,500) HW4(NE),HW4(NE+1),HW3(NB),HW3(NB+1),HW4(NE+2),      INPT0135
     1HW4(NE+3),ISTG,      HW3(NB+2),HW3(NB+3),HW4(NE+4),HW4(NE+5),         INPT0136
     2HW3(NB+4),HW3(NB+5),(RNXT(J,ISTG),WRL(J,ISTG),YOSS(J,I),J=1,NXT)      INPT0137
  500 FORMAT (//81X,2A6/56X,6HRADIAL,5X,2A6,2X,2A6/40X,6HSTATOR,            INPT0138
     1I2,7X,8HPOSITION,4X,2A6,2X,2A6/57X,4H(IN),6X,2A6//(52X,F10.4,         INPT0139
     24X,F10.3,4X,F10.5))                                                   INPT0140
      GO TO 670                                                             INPT0141
  510 WRITE (NTAPE,520) HW3(NB),HW3(NB+1),ISTG,HW3(NB+2),HW3(NB+3),         INPT0142
     1HW3(NB+4),HW3(NB+5),(RNXT(J,ISTG),WRL(J,ISTG),J=1,NXT)                INPT0143
  520 FORMAT (//63X,6HRADIAL,5X,2A6/47X,6HSTATOR,I2,7X,8HPOSITION,          INPT0144
     14X,2A6/64X,4H(IN),6X,2A6//(59X,F10.4,4X,F10.3))                       INPT0145
      GO TO 670                                                             INPT0146
  530 IF (ISPEC.EQ.1) GO TO 650                                             INPT0147
      WRITE (NTAPE,560) HW4(NF),HW4(NF+1),HW4(NF+2),HW4(NF+3),ISTG,         INPT0148
     1                          HW4(NF+4),HW4(NF+5)                         INPT0149
  560 FORMAT (//58X,14HNONDIMENSIONAL,18X,2A6/46X,10HSTREAMLINE,            INPT0150
     13X,12HPOWER OUTPUT,10X,6HRADIAL,3X,2A6/31X,5HROTOR,I2,10X,            INPT0151
     26HNUMBER,7X,8HFUNCTION,11X,8HPOSITION,2X,2A6/82X,4H(IN)//)            INPT0152
      IF (NLINES.LT.NXT) GO TO 610                                          INPT0153
      DO 600 J=1,NLINES                                                     INPT0154
      IF (J.GT.NXT) GO TO 580                                               INPT0155
      WRITE (NTAPE,570) J,POF(J,ISTG),RSXT(J,ISTG),YOSS(J,I)                INPT0156
  570 FORMAT (50X,I2, 9X,F8.5,8X,F10.4,2X,F10.5)                            INPT0157
      GO TO 600                                                             INPT0158
  580 WRITE (NTAPE,590) J,PCF(J,ISTG)                                       INPT0159
  590 FORMAT (50X,I2, 9X,F8.5)                                              INPT0160
  600 CONTINUE                                                              INPT0161
      GO TO 670                                                             INPT0162
  610 DO 640 J=1,NXT                                                        INPT0163
      IF (J.GT.NLINES) GO TO 620                                            INPT0164
      WRITE (NTAPE,570) J,POF(J,ISTG),RSXT(J,ISTG),YOSS(J,I)                INPT0165
      GO TO 640                                                             INPT0166
  620 WRITE (NTAPE,630) RSXT(J,ISTG),YOSS(J,I)                              INPT0167
  630 FORMAT (77X,F10.4,2X,F10.5)                                           INPT0168
  640 CONTINUE                                                              INPT0169
      GO TO 670                                                             INPT0170
  650 WRITE (NTAPE,660) ISTG,(J,POF(J,ISTG),J=1,NLINES)                     INPT0171
  660 FORMAT (//73X,14HNONDIMENSIONAL/59X,10HSTREAMLINE,5X,                 INPT0172
     112HPOWER OUTPUT/44X,5HROTOR,I2,10X,6HNUMBER,9X,8HFUNCTION             INPT0173
     2//(63X,I2,11X,F8.5))                                                  INPT0174
  670 CONTINUE                                                              INPT0175
      IF(ISPEC.EQ.0) GO TO 700                                              INPT0176
      WRITE(NTAPE,675)                                                      INPT0177
675   FORMAT(///48X,35H* BASIC INTERNAL LOSS CORRELATION *  ,///)           INPT0178
```

```
      WRITE(NTAPE,680) CON6,CON7,CON8,CON3                              INPT0179
  680 FORMAT(57H               TAN(INLET ANGLE) + TAN(EXIT ANGLE)       INPT0180
     1(  ,F10.8,3H +    ,F10.8,14H * (V RATIO)**  ,F5.2,21H)  IF (V RATIOINPT0181
     2) .LT.    ,F10.8)                                                 INPT0182
      WRITE(NTAPE,685)                                                  INPT0183
  685 FORMAT(2X,53HY = ---------------------------------------- *TIMES*INPT0184
     1  )                                                               INPT0185
      WRITE(NTAPE,690) CON4,CON5,CON1,CON2,CON3,CON3                    INPT0186
  690 FORMAT(6X,F10.8,3H +    ,F10.8,28H * COS(EXIT ANGLE)         (  ,F1INPT0187
     10.8,3H +    ,F10.8,13H *((V RATIO)- ,F5.3,22H))  IF (V RATIO) .GT. INPT0188
     2 ,F10.8)                                                          INPT0189
      WRITE(NTAPE,695) CON9                                             INPT0190
  695 FORMAT(///20X,82HTHE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MAINPT0191
     1NNER MAY NOT EXCEED A LIMIT OF    ,F10.8)                         INPT0192
  700 CONTINUE                                                          INPT0193
      RETURN                                                            INPT0194
      END                                                               INPT0195
```

APPENDIX V

SUBRØUTINE STRAC

The function of Subroutine STRAC (deckname SUB1) is to obtain the angles of inclination and curvatures of the hub and casing streamlines at each design station of a spool. This is done in a manner such that the obtained values can be treated as if they had been specified in the input data.

Subroutine STRAC is called by the main routine when streamline angles of inclination and curvatures are not specified in the input data; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output of the subroutine are transmitted through blank CØMMØN, and CØMMØN/CØM5/. The internal input consists of:

NDSTAT RANN XSTAT

The internal output consists of:

ASTR CSTR NSTRAC RSTRAC

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine STRAC

The following table gives the Fortran nomenclature for those symbols used in Subroutine STRAC which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
DTDX	$(d^2r/dx^2)_i$	Second derivative of the radial position of the hub or casing at a design station with respect to axial position	per ft

Fortran Symbol	Symbol	Description	Units
DX	$\min(X_{i+1}-X_i, X_i-X_{i-1})$	Smaller of DXL and DXR	ft
DXL	X_i-X_{i-1}	Axial distance between a design station and the upstream station	ft
DXR	$X_{i+1}-X_i$	Axial distance between the downstream station and a design station	ft
TANA	$(dr/dX)_i$	Derivative of the radial position of the hub or casing at a design station with respect to axial position	--
TANL	$\frac{r_i-r_{i-1}}{X_i-X_{i-1}}$	Straight-line slope of the hub or casing streamline between a design station and the upstream station	--
TANR	$\frac{r_{i+1}-r_i}{X_{i+1}-X_i}$	Straight-line slope of the hub or casing streamline between the downstream station and a design station	--

Internal Structure

Subroutine STRAC performs the calculations described in step 8 of the Analysis Procedure and stores the obtained values, together with the hub and casing radii and the specification that there are two sets of values at each design station, in the locations used when angle of inclination and curvature are specified in the input data. This is accomplished, primarily, in two nested DØ loops. The steps within the outer loop are performed twice, first for the hub and then for the casing. The steps within the inner loop are performed at each design station of a spool, starting at the spool inlet and continuing to the spool exit. The Fortran listing of the subroutine is given on the following pages.

```
$*
$IBFTC SUB1     LIST,DECK,M94
C                                                                       STRC
C     STRAC - DETERMINATION OF HUB AND CASING VALUES OF STREAMLINE      STRC
C             ANGLES OF INCLINATION AND CURVATURES                      STRC
C                                                                       STRC
      SUBROUTINE STRAC                                                  STRC0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       STRC0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,         STRC0003
     2NSTG,NTAPE,NTUBES                                                 STRC0004
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),          STRC0005
     1CSTS(17),DTO(17),FHP(8),FLWC,IPCF(8),ISTRAC,NLT,                  STRC0006
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),           STRC0007
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),               STRC0008
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)                            STRC0009
      NSTRAC=2                                                          STRC0010
      DO 200 J=1,2                                                      STRC0011
      DXL=XSTAT(2)-XSTAT(1)                                             STRC0012
      TANL=(RANN(2,J)-RANN(1,J))/DXL                                    STRC0013
      DO 200 I=1,NDSTAT                                                 STRC0014
      DXR=XSTAT(I+2)-XSTAT(I+1)                                         STRC0015
      TANR=(RANN(I+2,J)-RANN(I+1,J))/DXR                                STRC0016
      TANA=0.5*(TANR+TANL)                                              STRC0017
      ASTR(J,I)=ATAN(TANA)                                              STRC0018
      IF (DXR.GT.DXL) GO TO 50                                          STRC0019
      DX=DXR                                                            STRC0020
      GO TO 100                                                         STRC0021
   50 DX=DXL                                                            STRC0022
  100 DTDX=(TANR-TANL)/DX                                               STRC0023
      CSTR(J,I)=DTDX/(1.0+TANA**2)**1.5                                 STRC0024
      RSTRAC(J,I)=RANN(I+1,J)                                           STRC0025
      DXL=DXR                                                           STRC0026
  200 TANL=TANR                                                         STRC0027
      RETURN                                                            STRC0028
      END                                                               STRC0029
```

APPENDIX VI

SUBRØUTINE SPECHT

The function of Subroutine SPECHT (deckname SUB2) is to determine various values of the specific heat at constant pressure, specific heat ratio, and related parameters which are required to perform the calculations at a particular design station.

Subroutine SPECHT is called by the main routine; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output of the subroutine are transmitted through blank CØMMØN, CØMMØN/CØM2/, and CØMMØN/CØM6/. The internal input consists of:

CP	EJAY	GASC	GØ	ISAV
ISRI	NDSTAT	NSPØØL		

The internal output consists of:

CP1	CP2	CP3	CP4	CP5
EJCP1	EJCP2	GAMA1	GAMA2	GAMA3
GAMB1	GAMC1	GAMD2	GAMD3	GAMD4
GAM5	GG1	GJCP1	GJCP12	GJCP2
GJCP22	GJCP32	GJCP42	GJCP52	

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine SPECHT

The following table gives the Fortran nomenclature for those symbols used in Subroutine SPECHT which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
CP10	$c_{p,1}$	Specific heat at constant pressure at the inlet of a spool	Btu per lbm deg R
CP100	$c_{p,inlet}$	Specific heat at constant pressure at the inlet of the turbine	Btu per lbm deg R
FUN1		Arithmetic statement function defining specific heat ratio in terms of specific heat at constant pressure and gas constant	--
FUN2		Arithmetic statement function defining a parameter related to specific heat ratio	--
FUN3		Arithmetic statement function defining a parameter related to specific heat ratio	--

Internal Structure

Subroutine SPECHT performs the calculations described in step 11 of the Analysis Procedure and stores the obtained values for later usage. This is accomplished in five calculational segments. In each segment a value of specific heat is established and related parameters are calculated. The first segment applies to each design station; local values of the above quantities at the design station are obtained. The second segment applies to the exit of each blade row; average values of the quantities for the blade row are obtained. The third segment applies to the exit of each stage; average values of the quantities for the stage are obtained. The fourth segment applies to the exit of each spool; average values of the quantities for the spool are obtained. The fifth segment applies to the exit of the turbine; average values of the quantities for the stage are obtained.

The subroutine listing is given on the following pages.

```
$*
$IBFTC SUB2     LIST,DECK,M94
C                                                                       SPCT
C     SPECHT - DETERMINATION OF SPECIFIC HEATS, SPECIFIC-HEAT RATIOS,   SPCT
C              AND RELATED PARAMETERS                                   SPCT
C                                                                       SPCT
      SUBROUTINE SPECHT                                                 SPCT0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       SPCT0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,         SPCT0003
     2NSTG,NTAPE,NTUBES                                                 SPCT0004
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,              SPCT0005
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,            SPCT0006
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,            SPCT0007
     3GJCP22,GJCP32,GJCP42,GJCP52                                       SPCT0008
      COMMON /COM6/CNV1,CNV2,CNV3,CNV5,EJAY,GO,PI,TOLWY                 SPCT0009
      FUN1(A)=EJAY*A/(EJAY*A-GASC)                                      SPCT0010
      FUN2(A)=A/(A-1.0)                                                 SPCT0011
      FUN3(A)=2.0*GO*EJAY*A                                             SPCT0012
      CP1=CP(IDS)                                                       SPCT0013
      GAM1=FUN1(CP1)                                                    SPCT0014
      GAMA1=FUN2(GAM1)                                                  SPCT0015
      GAMB1=GAMA1/GAM1                                                  SPCT0016
      GAMC1=0.5/GAMB1                                                   SPCT0017
      GGG1=GO*GASC*GAM1                                                 SPCT0018
      EJCP1=EJAY*CP1                                                    SPCT0019
      GJCP1=GO*EJCP1                                                    SPCT0020
      GJCP12=2.0*GJCP1                                                  SPCT0021
      IF (ISRI.NE.3) GO TO 100                                          SPCT0022
      CP100=CP1                                                         SPCT0023
      CP10=CP1                                                          SPCT0024
      RETURN                                                            SPCT0025
  100 CP2=0.5*(CP1+CP(IDS-1))                                           SPCT0026
      GAM2=FUN1(CP2)                                                    SPCT0027
      GAMA2=FUN2(GAM2)                                                  SPCT0028
      GAMD2=1.0/GAMA2                                                   SPCT0029
      EJCP2=EJAY*CP2                                                    SPCT0030
      GJCP2=GO*EJCP2                                                    SPCT0031
      GJCP22=2.0*GJCP2                                                  SPCT0032
      IF (ISRI.EQ.1) RETURN                                             SPCT0033
      CP3=0.5*(CP1+CP(IDS-2))                                           SPCT0034
      GAM3=FUN1(CP3)                                                    SPCT0035
      GAMA3=FUN2(GAM3)                                                  SPCT0036
      GAMD3=1.0/GAMA3                                                   SPCT0037
      GJCP32=FUN3(CP3)                                                  SPCT0038
      IF (IDS.NE.NDSTAT) RETURN                                         SPCT0039
      CP4=0.5*(CP1+CP10)                                                SPCT0040
      GAM4=FUN1(CP4)                                                    SPCT0041
      GAMD4=1.0/FUN2(GAM4)                                              SPCT0042
      GJCP42=FUN3(CP4)                                                  SPCT0043
      CP10=CP1                                                          SPCT0044
      IF (NSPOOL.EQ.1) RETURN                                           SPCT0045
      IF (ISAV.LT.NSPOOL) RETURN                                        SPCT0046
      CP5=0.5*(CP1+CP100)                                               SPCT0047
      GAM5=FUN1(CP5)                                                    SPCT0048
      GAMD5=1.0/FUN2(GAM5)                                              SPCT0049
      GJCP52=FUN3(CP5)                                                  SPCT0050
      RETURN                                                            SPCT0051
      END                                                               SPCT0052
```

APPENDIX VII

SUBRØUTINE PØWER

The function of Subroutine PØWER (deckname SUB3) is to determine the drop in the absolute total temperature across each streamline of a rotor.

Subroutine PØWER is called by the main routine; it calls, in turn, Subroutine SLØPE. Subroutine PØWER does not require external input and does not provide external output. Internal input and output of the subroutine are transmitted through blank CØMMØN, CØMMØN/CØM2/, CØMMØN/CØM4/, and CØMMØN/CØM5/. The internal input consists of:

EJCP2	FHP	FLWP	HP	ISTG
NLINES	WFN			

The internal output consists of:

DTØ

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine PØWER

The following table gives the Fortran nomenclature for those symbols used in Subroutine PØWER which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
DPØDW(J)	$(dP_i'/dw')_j$	Streamline values of the derivative of the nondimensional power output function with respect to the nondimensional mass flow function at a stage exit	--
J	j	Streamline index	--
PARAM	$P_{Ti''}/Jc_{pi'}w_{Ti}$	Average drop in absolute total temperature across a rotor	deg R

Fortran Symbol	Symbol	Description	Units
PØFS(J)	P'_{ij}	Streamline values of the nondimensional power output function at a stage exit	--
PØW	$P_{Ti''}$	Power output of a stage	ft lbf per sec

Internal Structure

Subroutine PØWER performs the calculations described in step 12 of the Analysis Procedure and stores the obtained values for later usage. This is accomplished in three calculational segments. First, several preliminary operations are performed. Then, Subroutine SLØPE is called to obtain DPØDN, streamline values of the derivative of the nondimensional power output function with respect to the nondimensional mass flow function. Finally, a simple calculation is performed at each streamline to obtain the drop in absolute total temperature.

The Fortran listing of the subroutine follows.

```
$*
$IBFTC SUB3    LIST,DECK,M94
C
C     POWER - DETERMINATION OF THE TOTAL TEMPERATURE DROP ACROSS EACH
C             STREAMLINE OF A ROTOR
C
      SUBROUTINE POWER
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,
     2NSTG,NTAPE,NTUBES
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,
     3GJCP22,GJCP32,GJCP42,GJCP52
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),
     1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)
      DIMENSION POFS(17),DPODW(17)
      POW=FHP(ISTG)*HP
      PARAM=POW/(FLWP*EJCP2)
      DO 50 J=1,NLINES
   50 POFS(J)=POF(J,ISTG)
      CALL SLOPE(WFN,POFS,DPODW,NLINES)
      DO 100 J=1,NLINES
  100 DTO(J)=PARAM*DPODW(J)
      RETURN
      END
```

APPENDIX VIII

SUBRØUTINE I1AP1

The primary function of Subroutine I1AP1 (deckname SUB4A) is to perform parabolic interpolation of a tabulated function of one variable. If parabolic interpolation cannot be performed, linear interpolation or extrapolation, or extrapolation of a single value is performed.

Subroutine I1AP1 is called by the main routine and Subroutines STRVAL, DERIV, and PLC; it does not call any other subroutines. Subroutine I1AP1 does not require external input and does not provide external output. Internal input and output are transmitted as arguments of the subroutine. The internal input consists of:

IMX X XP Y

The internal output consists of:

YP

Fortran Nomenclature for Subroutine I1AP1

The following table gives the Fortran nomenclature for those symbols used in Subroutine I1AP1. Since the subroutine may be used with any consistent set of units, the units of the symbols are not specified. The subscript I, where indicated, is a tabular entry index.

Fortran Symbol	Symbol	Description	Units
A	a	Coefficient of the second-order term in the expression for y as a function of x	--
B	b	Coefficient of the first-order term in the expression for y as a function of x	--
DI	$\|x-x_p\|$	Distance between a tabular entry of x and the value of x at which a value of y is to be obtained	--

APPENDIX VIII

SUBRØUTINE I1AP1

The primary function of Subroutine I1AP1 (deckname SUB4A) is to perform parabolic interpolation of a tabulated function of one variable. If parabolic interpolation cannot be performed, linear interpolation or extrapolation, or extrapolation of a single value is performed.

Subroutine I1AP1 is called by the main routine and Subroutines STRVAL, DERIV, and PLC; it does not call any other subroutines. Subroutine I1AP1 does not require external input and does not provide external output. Internal input and output are transmitted as arguments of the subroutine. The internal input consists of:

IMX X XP Y

The internal output consists of:

YP

Fortran Nomenclature for Subroutine I1AP1

The following table gives the Fortran nomenclature for those symbols used in Subroutine I1AP1. Since the subroutine may be used with any consistent set of units, the units of the symbols are not specified. The subscript I, where indicated, is a tabular entry index.

Fortran Symbol	Symbol	Description	Units
A	a	Coefficient of the second-order term in the expression for y as a function of x	--
B	b	Coefficient of the first-order term in the expression for y as a function of x	--
DI	$\lvert x-x_P \rvert$	Distance between a tabular entry of x and the value of x at which a value of y is to be obtained	--

Fortran Symbol	Symbol	Description	Units
DREF	$\min \lvert x - x_p \rvert$	Smallest distance between a tabular entry of x and the value of x at which a value of y is to be obtained	--
IE		Index of the first tabular entry used to obtain a linear variation of y as a function of x	--
IMX		Number of tabular entries	--
IREF	i	Index of the tabular entry of x which gives DREF	--
IRM	$i-1$	Index of the tabular entry preceding IREF	--
IRP	$i+1$	Index of the tabular entry following IREF	--
NE		Index of the second tabular entry used to obtain a linear variation of y as a function of x	--
X(I)	x	Tabular entries of the independent variable	--
XP	x_p	The value of the independent variable at which a value of the dependent variable is to be obtained	--
XP1	$x_p - x_{i-1}$	Difference in two values of the independent variable	--
X21	$x_i - x_{i-1}$	Difference in two values of the independent variable	--
X32	$x_{i+1} - x_i$	Difference in two values of the independent variable	--
Y(I)	y	Tabular entries of the dependent variable	--
YP	y_p	The value of the dependent variable to be obtained	--
Y21	$y_i - y_{i-1}$	Difference in two values of the dependent variable	--

Fortran Symbol	Symbol	Description	Units
Y32	$y_{i+1} - y_i$	Difference in two values of the dependent variable	--

Internal Structure

The structure of this service subroutine is described in the Numerical Techniques section of Appendix I. A Fortran listing is given on the following page.

```
$*
$IBFTC SUB4A   LIST,DECK,M94
C
C     I1AP1 - PARABOLIC INTERPOLATION OR LINEAR EXTRAPOLATION OF A
C             FUNCTION OF ONE VARIABLE
C
      SUBROUTINE I1AP1(XP,YP,X,Y,IMX)
      DIMENSION X(17),Y(17)
      IF (IMX-2) 10,30,20
   10 YP=Y(1)
      RETURN
   20 IF (XP.GT.X(1)) GO TO 40
   30 IE=1
      NE=2
      GO TO 50
   40 IF (XP.LT.X(IMX)) GO TO 60
      IE=IMX-1
      NE=IMX
   50 YP=Y(IE)+(XP-X(IE))*(Y(NE)-Y(IE))/(X(NE)-X(IE))
      RETURN
   60 IM1=IMX-1
      IREF=2
      DREF=ABS(X(2)-XP)
      DO 70 I=2,IM1
      DI=ABS(X(I)-XP)
      IF (DI.GE.DREF) GO TO 70
      IREF=I
      DREF=DI
   70 CONTINUE
      IRM=IREF-1
      IRP=IREF+1
      X21=X(IREF)-X(IRM)
      X32=X(IRP)-X(IREF)
      Y21=Y(IREF)-Y(IRM)
      Y32=Y(IRP)-Y(IREF)
      A=(X21*Y32-X32*Y21)/(X21*X32*(X32+X21))
      B=Y21/X21-X21*A
      XP1=XP-X(IRM)
      YP=A*XP1**2+B*XP1+Y(IRM)
      RETURN
      END
```

APPENDIX IX

SUBRØUTINE SLØPE

The function of Subroutine SLØPE (deckname SUB5) is to obtain the derivative of a tabulated function with respect to the independent variable at each tabular entry of the variable.

Subroutine SLØPE is called by Subroutines PØWER, STRVAL, and SETUP; it does not call any other subroutines. Subroutine SLØPE does not require external input and does not provide external output. Internal input and output are transmitted as arguments of the subroutine. The internal input consists of:

X Y IMX

The internal output consists of:

DYDX

Fortran Nomenclature for Subroutine SLØPE

The following table gives the Fortran nomenclature for those symbols used in Subroutine SLØPE. Since the subroutine may be used with any consistent set of units, the units of the symbols are not specified. The subscript I , where indicated, is a tabular entry index.

Fortran Symbol	Symbol	Description	Units
A	a	Coefficient of the first-order term in the expression for y as a function of x	--
DYDX(I)	$(dy/dx)_i$	Tabulated values of the derivative of y with respect to x	--
I	i	Index of the tabular entries	--
IMX		Number of tabular entries	--
IM1		Number of tabular entries minus one	--

Fortran Symbol	Symbol	Description	Units
X(I)	x_i	Tabular entries of the independent variable	--
X21	$x_i - x_{i-1}$	Difference in two values of the independent variable	--
X32	$x_{i+1} - x_i$	Difference in two values of the independent variable	--
Y(I)	y_i	Tabular entries of the dependent variable	--
Y21	$y_i - y_{i-1}$	Difference in two values of the dependent variable	--
Y32	$y_{i+1} - y_i$	Difference in two values of the dependent variable	--

Internal Structure

A Fortran listing of this service subroutine is given on the following page(s). The structure of the subroutine follows the procedure outlined in the Numerical Techniques section of Appendix I.

```
$*
$IBFTC SUB5     LIST,DECK,M94
C                                                                       SLOP
C     SLOPE - DETERMINATION OF DY/DX AT EACH TABULAR ENTRY OF X         SLOP
C                                                                       SLOP
      SUBROUTINE SLOPE(X,Y,DYDX,IMX)                                    SLOP0001
      DIMENSION X(17),Y(17),DYDX(17)                                    SLOP0002
      IF (IMX-2) 10,20,30                                               SLOP0003
   10 DYDX(1)=0.0                                                       SLOP0004
      RETURN                                                            SLOP0005
   20 DYDX(1)=(Y(2)-Y(1))/(X(2)-X(1))                                   SLOP0006
      DYDX(2)=DYDX(1)                                                   SLOP0007
      RETURN                                                            SLOP0008
   30 IM1=IMX-1                                                         SLOP0009
      X21=X(2)-X(1)                                                     SLOP0010
      Y21=Y(2)-Y(1)                                                     SLOP0011
      DO 40 I=2,IM1                                                     SLOP0012
      X32=X(I+1)-X(I)                                                   SLOP0013
      Y32=Y(I+1)-Y(I)                                                   SLOP0014
      A=(Y21*Y32-X32*Y21)/(X21*X32*(X21+X32))                           SLOP0015
      DYDX(I)=Y21/X21+X21*A                                             SLOP0016
      IF (I.EQ.2) DYDX(1)=Y21/X21-X21*A                                 SLOP0017
      IF (I.EQ.IM1) DYDX(IMX)=Y21/X21+(X21+2.0*X32)*A                   SLOP0018
      X21=X32                                                           SLOP0019
   40 Y21=Y32                                                           SLOP0020
      RETURN                                                            SLOP0021
      END                                                               SLOP0022
```

APPENDIX X

SUBRØUTINE STRIP

The function of Subroutine STRIP (deckname SUB6) is to obtain the initial estimate of the radial position of each streamline at a design station.

Subroutine STRIP is called by the main routine; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output of the subroutine are transmitted through blank CØMMØN, CØMMØN/CØM4/, and CØMMØN/CØM5/. The internal input consists of:

IDS ISTRAC NLINES NTUBES RANN
WFN

The internal output consists of:

RST

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine STRIP

The following table gives the Fortran nomenclature for those symbols used in Subroutine STRIP which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
ISTAT		Station index	--
J	j	Streamline index	--

Internal Structure

Subroutine STRIP performs the calculations described in step 13 of the Analysis Procedure. This is accomplished in two segments. The first segment sets the values of the radial position of the hub and casing streamlines. The second segment obtains the radial position of the interior streamlines.

The Fortran lisitng is given on the following page(s).

```
$*
$IBFTC SUB6     LIST,DECK,M94
C                                                                       STRP
C     STRIP - DETERMINATION OF INITIAL STREAMLINE POSITIONS             STRP
C                                                                       STRP
      SUBROUTINE STRIP                                                  STRP0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       STRPCC02
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,         STRP0003
     2NSTG,NTAPE,NTUBES                                                 STRP0004
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                  STRP0C05
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),          STRP0C06
     1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,                  STRP0007
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),           STRPCC08
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TCC(16),TOLT(17),               STRP0009
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)                            STRPCC1C
      IF (ISTRAC.EQ.1) GO TO 50                                         STRP0011
      ISTAT=IDS+1                                                       STRP0C12
      RST(1)=RANN(ISTAT,1)                                              STRP0C13
      RST(NLINES)=RANN(ISTAT,2)                                         STRP0C14
      GO TO 100                                                         STRPCC15
   50 RST(1)=RANN(IDS,1)                                                STRP0016
      RST(NLINES)=RANN(IDS,2)                                           STRP0C17
  100 DO 200 J=2,NTUBES                                                 STRP0C18
  200 RST(J)=SQRT(RST(1)**2+WFN(J)*(RST(NLINES)**2-RST(1)**2))          STRP0C19
      RETURN                                                            STRP0020
      END                                                               STRP0021
```

APPENDIX XI

SUBRØUTINE STRVAL

The function of Subroutine STRVAL (deckname SUB7) is to obtain streamline values of the items which are required for the solution of the radial equilibrium equation at a design station.

Subroutine STRVAL is called by the main routine; it, in turn, calls Subroutine IIAP1 and SLØPE. Subroutine STRVAL does not require external input and does not provide external output. Internal input and output of the subroutine are transmitted through blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM2/, CØMMØN/CØM3/, CØMMØN/CØM4/, CØMMØN/CØM5/, CØMMØN/CØM8/, and CØMMØN/CØM11/. The internal input consists of:

ASTS	BETLT	CP2	CP3	CSTS
DTØ	GAMA2	GAMA3	GJCP2	ICØEF
ILØSS	ISPEC	ISRI	IWRL	NLINES
NLT	NSTRAC	NXT	PØLT	PØØ
PØØ2	RLT	RPM	RST	RSTRAS
RXTS	TØLT	TØØ	TØØ2	TØU
UU	VTU	WRLS	YØS	

The internal output consists of:

AY	BET	CRV	DADR	DBDR
DFLDR	DPØDR	DTØDR	DVTDR	DWYDR
EFFR	EFFS	FACL	PØ	TØ
U	VT	WYE	WYK	

(These symbols are described in the appropriate sections of the CØMMØN Fortran nomenclature.)

Additional Fortran Nomenclature for Subroutine STRVAL

The following table gives the Fortran nomenclature for those symbols used in Subroutine STRVAL which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
AYP	A_{ij}	Streamline value of the streamline angle of inclination	rad
BETP	β_{ij}	Streamline value of the flow angle	rad
CRVP	$(1/r_m)_{ij}$	Streamline value of the streamline curvature	per ft
PØP	$(p_{oi})_j$	Streamline value of the total pressure	psif
RP	r_{ij}	Radial position of a streamline	ft
TØP	$(T_{oi})_j$	Streamline value of the total temperature	deg R
WRLP		Streamline value of the quantity used to specify the whirl at a stator exit	--
YØSP		Streamline value of the quantity used to specify the loss	--

Internal Structure

Subroutine STRVAL performs the calculations described in steps 16 to 26 of the Analysis Procedure. The individual steps are identified in the following tabulation by the card sequence numbers.

Step of Analysis Procedure	Sequence Numbers
16	0027
17	0028 - 0032
18	0033 - 0040
19	0041

Step of Analysis Procedure	Sequence Numbers
20	0042 - 0049
21	0050 - 0051
22	0052
23	0053
24	0054 - 0062
26	0070 - 0087

The Fortran listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB7    LIST,DECK,M94
C
C     STRVAL - CALCULATION OF STREAMLINE VALUES OF INPUT ITEMS TO THE
C              RADIAL EQUILIBRIUM EQUATION
C
      SUBROUTINE STRVAL
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NOSTAT,NLINES,NSPOOL,
     2NSTG,NTAPE,NTUBES
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,
     3GJCP22,GJCP32,GJCP42,GJCP52
      COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),
     3VRU(17),VTU(17),VU(17),WYEO(17)
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),
     1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)
      COMMON /COM8/DADR(17),DBDR(17),DPODR(17),DTODR(17),
     1DVTDR(17),DWYDR(17)
      COMMON /COM11/ AYP,COSA,COSB,COSQB,DBDRP,DBRUDR(17),DBLDR(17),
     1DFLDR(17),DVRUDR(17),DVUDR(17),IJ,TANB,VMP,VSQ,VTP
      DO 500 J=1,NLINES
      RP=RST(J)
      CALL I1AP1(RP,AYP,RSTRAS,ASTS,NSTRAC)
      AY(J)=AYP
      CALL I1AP1(RP,CRVP,RSTRAS,CSTS,NSTRAC)
      CRV(J)=CRVP
      IF (ISRI.NE.3) GO TO 50
      CALL I1AP1(RP,TOP,RLT,TOLT,NLT)
      TO(J)=TOP
      CALL I1AP1(RP,POP,RLT,POLT,NLT)
      PO(J)=POP
      CALL I1AP1(RP,BETP,RLT,BETLT,NLT)
      BET(J)=BETP
      GO TO 500
   50 U(J)=RPM*RP
      IF (ISRI.NE.1) GO TO 150
      TO(J)=TOU(J)
      CALL I1AP1(RP,WRLP,RXTS,WRLS,NXT)
      IF (IWRL.GT.0) GO TO 100
      VT(J)=WRLP
      GO TO 200
  100 BET(J)=WRLP
      GO TO 200
  150 TO(J)=TOU(J)-DTO(J)
      VT(J)=(UU(J)*VTU(J)-GJCP2*DTO(J))/U(J)
  200 IF (ISPEC.EQ.1) GO TO 500
      CALL I1AP1(RP,YOSP,RXTS,YOS,NXT)
      IF (ISPEC.EQ.2) GO TO 450
      IF (ISRI.EQ.1) GO TO 350
```

```
      IF (ILOSS-1) 350,250,300
  250 EFFR(J)=YOSP
      PO(J)=POO(J)*(1.0-DTO(J)/(YOSP*TOO(J)))**GAMA2
      GO TO 500
  300 EFFS(J)=YOSP
      PO(J)=POO2(J)*(1.0-CP2*DTO(J)/(YOSP*CP3*TOO2(J)))**GAMA3
      GO TO 500
  350 IF (ICCEF.NE.0) GO TO 400
      WYE(J)=YOSP
      GO TO 500
  400 WYK(J)=YOSP
      GO TO 500
  450 FACL(J)=YOSP
  500 CONTINUE
      CALL SLOPE(RST,TO,DTODR,NLINES)
      IF (ISRI-2) 550,600,650
  550 IF (IWRL.GT.0) GO TO 650
  600 CALL SLOPE(RST,VT,DVTDR,NLINES)
      IF (ISPEC.EQ.0) GO TO 700
      GO TO 675
  650 CALL SLOPE(RST,BET,DBDR,NLINES)
  675 CALL SLOPE(RST,AY,DADR,NLINES)
  700 IF (ISRI.GT.2) GO TO 800
      IF (ISPEC-1) 750,950,900
  750 IF (ISRI.EQ.1.OR.ILOSS.EQ.0) GO TO 850
  800 CALL SLOPE(RST,PO,DPODR,NLINES)
      RETURN
  850 CALL SLOPE(RST,WYE,DWYDR,NLINES)
      RETURN
  900 CALL SLOPE(RST,FACL,DFLDR,NLINES)
  950 RETURN
      END
```

APPENDIX XII

SUBRØUTINE VMNTL

The function of Subroutine VMNTL (deckname SUB8) is to obtain an initial estimate of the meridional velocity at the mean streamline of a design station.

Subroutine VMNTL is called by the main routine on the first pass through the iterative loop on streamline position; the subroutine does not call any other subroutines. Subroutine VMNTL does not require external input and does not provide external output. The internal input and output of the subroutine are transmitted through blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM2/, and CØMMØN/CØM7/. The internal input consists of:

AY	BET	CØT60	EMMAX	EMMIN
GAMCI	GGGI	ISØN	ISRI	IWRL
TØ	U	VT		

The internal output consists of:

VMM

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine VMNTL

The following table gives the Fortran nomenclature for those symbols used in Subroutine VMNTL which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
EKAY	$M\sqrt{\frac{g_0 R \gamma_i}{1+\left(\frac{\gamma_i - 1}{2}\right)M^2}}$	Parameter related to specific heat ratio and Mach number	fps per deg $R^{\frac{1}{2}}$.
EMI	M	Assumed value of Mach number when flow angle is specified at a design station	--

Fortran Symbol	Symbol	Description	Units
PARAM	$\sqrt{g_o R \gamma_i (T_{oi})_m - \left(\frac{\gamma_i - 1}{2}\right)(V_{ui}^2)_m}$	Parameter related to specific heat ratio, and total temperature and tangential velocity at the mean streamline	fps
VMMAX	$\max\{(V_{mi})_m\}$	Maximum allowable estimate of the meridional velocity at the mean streamline	fps
VMMIN	$\min\{(V_{mi})_m\}$	Minimum allowable estimate of the meridional velocity at the mean streamline	fps

Internal Structure

Subroutine VMNTL performs the calculations described by step 27 of the Analysis Procedure. A Fortran listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB8    LIST,DECK,M94
C                                                                        VMNT
C      VMNTL - OBTAIN AN INITIAL ESTIMATE OF THE MERIDIONAL VELOCITY AT  VMNT
C              THE MEAN STREAMLINE                                       VMNT
C                                                                        VMNT
      SUBROUTINE VMNTL                                                   VMNT0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,        VMNT0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,          VMNT0003
     2NSTG,NTAPE,NTUBES                                                  VMNT0004
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),            VMNT0005
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),      VMNT0006
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),          VMNT0007
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)                  VMNT0008
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,               VMNT0009
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,             VMNT0010
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,             VMNT0011
     3GJCP22,GJCP32,GJCP42,GJCP52                                        VMNT0012
      COMMON /COM7/COT60,DFLWT,DFLWTO,EMMAX,EMMIN,ICNT,JJ,               VMNT0013
     1JJP,MEAN,RATIO,VMM,VMMO,VMMOO                                      VMNT0014
      IF (ISRI-2) 50,350,200                                             VMNT0015
   50 IF (IWRL-1) 300,150,100                                            VMNT0016
  100 IF (ISON.EQ.0) GO TO 150                                           VMNT0017
      EMI=1.2                                                            VMNT0018
      GO TO 250                                                          VMNT0019
  150 EMI=0.8                                                            VMNT0020
      GO TO 250                                                          VMNT0021
  200 EMI=0.4                                                            VMNT0022
  250 EKAY=SQRT(GGG1/(1.0+GAMC1*EMI**2))*EMI                             VMNT0023
      VMM=EKAY*SQRT(TO(MEAN)/(1.0+(COS(AY(MEAN))*TAN(BET(MEAN)))**2))    VMNT0024
      RETURN                                                             VMNT0025
  300 VMM=COT60*VT(MEAN)/COS(AY(MEAN))                                   VMNT0026
      GO TO 400                                                          VMNT0027
  350 VMM=-COT60*(VT(MEAN)-U(MEAN))/COS(AY(MEAN))                        VMNT0028
  400 PARAM=SQRT(GGG1*TO(MEAN)-GAMC1*VT(MEAN)**2)                        VMNT0029
      VMMAX=PARAM*EMMAX/SQRT(1.0+GAMC1*EMMAX**2)                         VMNT0030
      VMMIN=PARAM*EMMIN/SQRT(1.0+GAMC1*EMMIN**2)                         VMNT0031
      IF (VMM.GT.VMMAX) VMM=VMMAX                                        VMNT0032
      IF (VMM.LT.VMMIN) VMM=VMMIN                                        VMNT0033
      RETURN                                                             VMNT0034
      END                                                                VMNT0035
```

APPENDIX XIII

SUBRØUTINE RADEQL

The primary function of Subroutine RADEQL (deckname SUB9) is to control the logic of the calculation of the meridional velocity distribution. In addition, the subroutine obtains streamline values of the mass flow function corresponding to the meridional velocity distribution.

Subroutine RADEQL is called by the main routine; it, in turn, calls Subroutines RUNKUT and DERIV. Further, Subroutine RADEQL specifies that Subroutine DERIV be called by Subroutine RUNKUT. Subroutine RADEQL does not require external input and does not provide external output. The subroutine has access to blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM4/, CØMMØN/CØM6/, and CØMMØN/CØM7/. The internal input transmitted through CØMMØN consists of:

MEAN NLINES PI RST VMM

The internal output transmitted through CØMMØN consists of:

DFLØW DFLWT

(These symbols, as well as others used in Subroutine RADEQL, are described in the appropriate sections of the CØMMØN Fortran Nomenclature.) One item of the internal output is transmitted as an argument of the subroutine; namely,

LSGN

Additional Fortran Nomenclature for Subroutine RADEQL

The following table gives the Fortran Nomenclature for those symbols used in Subroutine RADEQL which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
DELR	$r_{j+1}-r_j$ or r_j-r_{j-1}	Radial distance between adjacent streamlines	ft
IUPDN		Indicator: IUPDN=1 if the calculation proceeds from the mean streamline to the hub IUPDN=2 if the calculation proceeds from the mean streamline to the casing	-- --
J	j	Streamline index	--
JM	$j-1$	Index of the streamline preceding that indicated by J	--
LSGN		Indicator: LSGN=0 if the calculation of the meridional velocity distribution corresponding to a particular value at the mean streamline is proceeding normally LSGN=1 if the calculation of the meridional velocity distribution corresponding to a particular value at the mean streamline has been abandoned	
QUE	q	A measure of the round-off error in the Runge-Kutta determination of the meridional velocity distribution	fps^2
RP	r_{i_j}	A streamline value of radial position	ft
VMSQ	$(V_{mi}^2)_j$	A streamline value of the square of the meridional velocity	fps^2

Internal Structure

Subroutine RADEQL performs the calculations of steps 29, 46, and 47 of the Analysis Procedure. The sequence numbers corresponding to the three steps are 0014 - 0018, 0029, and 0034 - 0037, respectively. A Fortran listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB9     LIST,DECK,M94
C                                                                       RDEQ
C     RADEQL - OBTAIN THE SOLUTION OF THE RADIAL EQUILIBRIUM EQUATION   RDEQ
C              BASED ON AN ESTIMATED VALUE OF VM(MEAN)                  RDEQ
C                                                                       RDEQ
      SUBROUTINE RADEQL(LSGN)                                           RDEQ0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       RDEQ0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NOSTAT,NLINES,NSPOOL,         RDEQ0003
     2NSTG,NTAPE,NTUBES                                                 RDEQ0004
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),           RDEQ0005
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),     RDEQ0006
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),         RDEQ0007
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)                 RDEQ0008
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                  RDEQ0009
      COMMON /COM6/CNV1,CNV2,CNV3,CNV5,EJAY,GO,PI,TOLWY                 RDEQ0010
      COMMON /COM7/COT60,DFLWT,DFLWTO,EMMAX,EMMIN,ICNT,JJ,              RDEQ0011
     1JJP,MEAN,RATIO,VMM,VMMO,VMMOO                                     RDEQ0012
      EXTERNAL DERIV                                                    RDEQ0013
      IUPDN=0                                                           RDEQ0014
   50 IUPDN=IUPDN+1                                                     RDEQ0015
      RP=RST(MEAN)                                                      RDEQ0016
      VMSQ=VMM**2                                                       RDEQ0017
      QUE=0.0                                                           RDEQ0018
      DO 300 J=2,MEAN                                                   RDEQ0019
      IF (IUPDN.EQ.2) GO TO 100                                         RDEQ0020
      JJ=MEAN-J+2                                                       RDEQ0021
      JJP=JJ-1                                                          RDEQ0022
      GO TO 150                                                         RDEQ0023
  100 JJ=MEAN+J-2                                                       RDEQ0024
      JJP=JJ+1                                                          RDEQ0025
  150 DELR=RST(JJP)-RST(JJ)                                             RDEQ0026
      CALL RUNKUT(RP,DELR,VMSQ,QUE,DERIV,LSGN)                          RDEQ0027
      IF (LSGN.EQ.1) RETURN                                             RDEQ0028
  300 CONTINUE                                                          RDEQ0029
      JJ=JJP                                                            RDEQ0030
      CALL DERIV(RP,VMSQ,DUMMY,5,LSGN)                                  RDEQ0031
      IF(LSGN.EQ.1)RETURN                                               RDEQ0032
      IF (IUPDN.EQ.1) GO TO 50                                          RDEQ0033
      DFLOW(1)=0.0                                                      RDEQ0034
      DO 400 J=2,NLINES                                                 RDEQ0035
      JM=J-1                                                            RDEQ0036
  400 DFLOW(J)=DFLOW(JM)+PI*(GRND(JM)+GRND(J))*(RST(J)-RST(JM))         RDEQ0037
      DFLWT=DFLOW(NLINES)                                               RDEQ0038
      RETURN                                                            RDEQ0039
      END                                                               RDEQ0040
```

APPENDIX XIV

SUBRØUTINE RUNKUT

The function of Subroutine RUNKUT (deckname SUB10) is to obtain the solution of a first-order ordinary differential equation by the Gill variation of the Runge-Kutta method.

Subroutine RUNKUT is called by Subroutine RADEQL; it, in turn, calls Subroutine DERIV which has been specified as an argument in the CALL statement for Subroutine RUNKUT. The subroutine does not require external input and does not provide external output. Internal input and output are transmitted as arguments of the subroutine. The internal input consists of:

DELX FUNCTN Q X Y

The internal output consists of:

LSGN Q X Y

Fortran Nomenclature for Subroutine RUNKUT

The following table gives the Fortran nomenclature for those symbols used in Subroutine RUNKUT. Since the subroutine may be used with any consistent set of units, the units of the symbols are not specified. The subscript K , where it appears, is the index of the step in the Runge-Kutta solution.

Fortran Symbol	Symbol	Description	Units
A(K)	a_i	A set of constants used to determine DIFF	--
B(K)	b_i	A set of constants used to determine DIFF	--
C(K)	c_i	A set of constants used to determine Q	--

Fortran Symbol	Symbol	Description	Units
D(K)	d_i	A set of constants used to determine X	--
DELX	h	Increment in the independent variable across which the differential equation is to be solved	--
DELY	k_i	Product of YPRIME and DELX at each stage of the solution	--
DIFF		The change in the value of the dependent variable at each stage of the solution	--
FUNCTN		An argument in the CALL statement for RUNKUT; it operates as a dummy name for Subroutine DERIV	--
IK		Index of the stage of the solution for Subroutine FUNCTN	--
K	i	Index of the stage of the solution	--
LSGN		Indicator: LSGN=0 if no difficulties have been encountered in the solution of the differential equation LSGN=1 if a solution to the differential equation cannot be found	--
Q	q_i	Quantity used to calculate DIFF at each stage of the solution; the value of Q in the final stage of the solution is a measure of the round-off error in Y	--
X	x_i	Value of the independent variable at each stage of the solution	--
Y	y_i	Value of the dependent variable at each stage of the solution	--

Fortran Symbol	Symbol	Description	Units
YPRIME	$f(x_i, y_i)$	Value of dy/dx at each stage of the solution	--

Internal Structure

Subroutine RUNKUT performs the calculations of steps 30 and 45 of the Analysis Procedure; the card sequence numbers corresponding to the steps are 0006 - 0013 and 0014, respectively. The Fortran listing is given on the following page.

```
$*
$IBFTC SUB10    LIST,DECK,M94
C                                                                       RNKT
C     RUNKUT - SOLUTION OF A FIRST-ORDER ORDINARY DIFFERENTIAL EQUATION RNKT
C              BY THE GILL VARIATION OF THE RUNGE-KUTTA METHOD          RNKT
C                                                                       RNKT
      SUBROUTINE RUNKUT(X,DELX,Y,Q,FUNCTN,LSGN)                         RNKT0001
      DIMENSION A(4),B(4),C(4),D(4)                                     RNKT0002
      DATA (A(I),I=1,4)/0.5,0.2928932,1.7071068,0.1666667/,(B(I),I=1,4) RNKT0003
     1/2.0,1.0,1.0,2.0/,(C(I),I=1,4)/0.5,0.2928932,1.7071068,0.5/,      RNKT0004
     2(D(I),I=1,4)/0.0,0.5,0.0,0.5/                                     RNKT0005
      DO 100 K=1,4                                                      RNKT0006
      X=X+D(K)*DELX                                                     RNKT0007
      IK=K                                                              RNKT0008
      CALL FUNCTN(X,Y,YPRIME,IK,LSGN)                                   RNKT0009
      IF (LSGN.EQ.1) RETURN                                             RNKT0010
      DELY=YPRIME*DELX                                                  RNKT0011
      DIFF=A(K)*(DELY-B(K)*Q)                                           RNKT0012
      Y=Y+DIFF                                                          RNKT0013
  100 Q=Q+3.0*DIFF-C(K)*DELY                                            RNKT0014
      RETURN                                                            RNKT0015
      END                                                               RNKT0016
```

APPENDIX XV

SUBRØUTINE DERIV

The primary function of Subroutine DERIV (deckname SUB11), is to obtain a value of the derivative of the square of the meridional velocity with respect to radial position for a specified value of meridional velocity and radial position. In addition, Subroutine DERIV obtains values of absolute total pressure and tangential velocity, if they are not known, and the mass flow function for a streamline.

Subroutine DERIV is called by Subroutine RUNKUT to perform its primary and secondary functions; it is also called by Subroutine RADEQL to perform its secondary function alone. Subroutine DERIV calls Subroutines 11AP1, PLC, and SIMEQ. The subroutine does not require external input and does not provide external output except for one error message. The subroutine has access to blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM2/, CØMMØN/CØM3/, CØMMØN/CØM4/, CØMMØN/CØM7/, CØMMØN/CØM8/, and CØMMØN/CØM11/. The internal input transmitted through CØMMØN consists of:

AY	BET	CRV	DADR	DBDR
DPØDR	DPØUDR	DPRUDR	DTØDR	DTRUDR
DVTDR	DWYDR	GAMA1	GAMA2	GAMB1
GASC	GJCP12	GJCP22	ICØNV	IDLETE
ILLØØP	ILØØP	ILØSS	ISPEC	ISRI
IWRL	JJ	JJP	MEAN	NLINES
PØ	PØRU	PØU	RPM	RST
TØ	TØRU	U	UU	VT
WYE				

The internal output transmitted through CØMMØN consists of:

GRND PØ VM VMM VT

(These symbols, as well as others used in Subroutine DERIV, are described in the appropriate sections of the CØMMØN Fortran Nomenclature.) The internal input transmitted as arguments of the subroutine consists of:

IK RP VMSQ

The internal output transmitted as arguments of the subroutine consists of:

DVMSDR LSGN

Additional Fortran Nomenclature for Subroutine DERIV

The following table gives the Fortran nomenclature for those symbols used in Subroutine DERIV which are not part of CØMMØN. Subscripts I and J are row and column indices, respectively.

Fortran Symbol	Symbol	Description	Units
BETP	β_i	A value of the absolute flow angle	rad
CØF(I,J)		Coefficient matrix augmented by a constant vector which represents the set of three equations used to satisfy radial equilibrium	--*
CØFT(I,J)		Duplicate of CØF	--*
CRVP	$(1/r_m)_i$	A value of the streamline curvature	ft^{-1}
DADRP	dA_i/dr	A value of the derivative of the streamline angle of inclination with respect to radius	rad per ft

* Since the units of the elements of the matrix differ from one another, no units are shown.

Fortran Symbol	Symbol	Description	Units
DDR(I)		Solution vector for the set of three equations used to satisfy radial equilibrium	--*
DENØM		Determinant of the coefficient matrix	--
DENØMØ		Previous value of DENØM	--
DPØDRP	dp_{oi}/dr	A value of the derivative of the absolute total pressure with respect to radius	lbf per ft^3
DPØUDP	$dp^{*}_{o,i-1}/dr$	A value of the derivative of the modified upstream absolute total pressure with respect to radius	lbf per ft^3
DPRUDP	$dp'^{*}_{o,i-1}/dr$	A value of the derivative of the modified upstream relative total pressure with respect to radius	lbf per ft^3
DTØDRP	dT_{oi}/dr	A value of the derivative of the absolute total temperature with respect to radius	deg R per ft
DTRUDP	$dT'^{*}_{o,i-1}/dr$	A value of the derivative of the modified upstream relative total temperature with respect to radius	deg R per ft
DVMSDR	dV^2_{mi}/dr	A value of the derivative of the square of the meridional velocity with respect to radius	ft per sec^2
DVMSØ	dV^2_{mi}/dr	A value of DVMSDR at the previous streamline	ft per sec^2
DVTDRP	dV_{ui}/dr	A value of the derivative of the tangential velocity with respect to radius	per sec
DWYDRP	dY_i/dr or $(dY_i/dr)_1$	A value of the derivative of either the pressure-loss coefficient or the known part of the pressure-loss coefficient with respect to radius	sec^2 per ft^2

* Since the units of the elements of the matrix differ from one another, no units are shown.

Fortran Symbol	Symbol	Description	Units
DWYVM	C_{y2}	A value of the coefficient of that part of the derivative of the pressure-loss coefficient with respect to radius which is dependent on dV_{mi}^2/dr	sec^2 per ft^2
DWYVT	C_{y3}	A value of the coefficient of that part of the derivative of the pressure-loss coefficient with respect to radius which is dependent on dV_{ui}/dr	fps^{-1}
FUN1		A grouping of terms in the second equation of the set used to satisfy radial equilibrium	--
FUN2		Similar to FUN1	fps^{-2}
FUN3		Similar to FUN1	fps^{-2}
FUN4		Similar to FUN1	fps^{-2}
FUN5		Similar to FUN1	--
GJCPT1	$2g_oJc_{pi}T_{oi}$	Parameter related to the absolute total temperature at a design station	fps^2
GJCPT2	$2g_oJ\bar{c}_{pi'}T_{o,i-1}^{'*}$	Parameter related to the modified upstream relative total temperature	fps^2
IK		Index of the stage of the Runge-Kutta solution	--
IVMSMN		Indicator: IVMSMN=0 if an allowable value of the square of the meridional velocity has been obtained IVMSMN=1 if a value of the square of the meridional velocity below the allowable minimum has been obtained IVMSMN=2 if a value of the square of the meridional velocity above the allowable maximum has been obtained	--

Fortran Symbol	Symbol	Description	Units
LSGN		Indicator: LSGN=0 if the calculation of the meridional velocity distribution corresponding to a particular value at the mean streamline is proceeding normally LSGN=1 if the calculation of the meridional velocity distribution corresponding to a particular value at the mean streamline cannot be continued	--
PØP	P_{oi}	A value of the absolute total pressure	psf
PØRUP	$P_{oi}'^{*}$	A value of the modified upstream relative total pressure	psf
PØUP	P_{oi}^{*}	A value of the modified upstream absolute total pressure	psf
PRAT	P_i/P_{oi}	Static-to-total pressure ratio	--
PRRAT	P_{oi}'/P_{oi}	Relative-to-absolute total pressure ratio	--
RP	r_i	A value of the radial position	ft
SINA	$\sin A_i$	Sine of streamline angle of inclination	--
SIGN		Product of DENØM and DENØMØ	--
TØP	T_{oi}	A value of the absolute total temperature	deg R
TØRUP	$T_{oi}'^{*}$	A value of the modified upstream relative total temperature	deg R
TRAT	T_i/T_{oi}	Static-to-total temperature ratio	--
TRRAT	T_{oi}'/T_{oi}	Relative-to-absolute total temperature ratio	--
TRRRAT	$T_{oi}'/T_{o,i-1}'^{*}$	Design station-to-upstream relative total temperature ratio	--
UP	u_i	A value of the blade velocity	fps

Fortran Symbol	Symbol	Description	Units
UUP	u_{i-1}	A value of the upstream blade velocity	fps
VMSQ	V_{mi}^2	Square of the meridional velocity	fps^2
VMSQMN		Minimum allowable value of the square of the meridional velocity	fps
VMSQMX		Maximum allowable value of the square of the meridional velocity	fps
VTSQ	V_{ui}^2	Square of the tangential velocity	fps^2
WYEP	Y_i	A value of the pressure-loss coefficient	--

Internal Structure

Subroutine DERIV performs the calculations of steps 31 through 36, 38 through 42, and step 44 of the Analysis Procedure. The card sequence numbers corresponding to the individual steps are identified in the following tabulation.

Step of Analysis Procedure	Sequence Numbers
31	0026 - 0059
32	0060 - 0073
33	0074 - 0086
34	0087 - 0101
35	0119 - 0123
36	0106
38	0124 - 0148
39	0149 - 0188
40	0189 - 0191
41	0192 - 0195

Step of Analysis Procedure	Sequence Numbers
42	0199 - 0208
44	0210 - 0219

A Fortran listing of the subroutine is presented on the following page(s).

```
$*
 IBFTC SUB11    LIST,DECK,M94
C
C      DERIV - DETERMINATION OF THE DERIVATIVE OF CM**2 WITH RESPECT TO R
C
       SUBROUTINE DERIV(RP,VMSC,DVMSDR,IK,LSGN)
       COMMON IBR,ICOEF,ICONV,ICOCL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,
     2NSTG,NTAPE,NTUBES
       COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)
       COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,
     3GJCP22,GJCP32,GJCP42,GJCP52
       COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),
     3VRU(17),VTU(17),VU(17),WYEO(17)
       COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)
       COMMON /COM7/CCT60,DFLWT,DFLWTO,EMMAX,EMMIN,ICNT,JJ,
     1JJP,MEAN,RATIO,VMM,VMMO,VMMOO
       COMMON /COM8/DADR(17),DBDR(17),DPCDR(17),DTODR(17),
     1DVTDR(17),DWYDR(17)
       COMMON /COM11/ AYP,COSA,COSB,COSQB,DBDRP,DBRUDR(17),DBUDR(17),
     1DFLDR(17),DVRUDR(17),DVUDR(17),IJ,TANB,VMP,VSQ,VTP
       DIMENSION COF(3,4),DDR(3),COFT(3,4)
       DATA VMSQMN/1.0/
       GO TO (100,130,200,110,200),IK
  100 IF (JJ.NE.MEAN) GO TO 200
       IVMSMN=0
       IJ=JJ
       GO TO 120
  110 IJ=JJP
  120 AYP=AY(IJ)
       CRVP=CRV(IJ)
       TOP=TO(IJ)
       DTODRP=DTODR(IJ)
       GO TO 140
  130 CALL I1AP1(RP,AYP,RST,AY,NLINES)
       CALL I1AP1(RP,CRVP,RST,CRV,NLINES)
       CALL I1AP1(RP,TOP,RST,TO,NLINES)
       CALL I1AP1(RP,DTODRP,RST,DTODR,NLINES)
  140 GJCPT1=GJCP12*TOP
       COSA=COS(AYP)
  200 IF (ISRI-2) 210,220,300
  210 IF (IWRL.NE.0) GO TO 300
  220 GO TO (230,250,270,240,355),IK
  230 IF (JJ.NE.MEAN) GO TO 270
  240 VTP=VT(IJ)
       DVTDRP=DVTDR(IJ)
       GO TO 260
  250 CALL I1AP1(RP,VTP,RST,VT,NLINES)
       CALL I1AP1(RP,DVTDRP,RST,DVTDR,NLINES)
  260 VTSQ=VTP**2
       VMSQMX=GJCPT1-VTSQ-VMSQMN
       IF (VMSQMX.LT.VMSQMN) GO TO 345
  270 COF(3,1)=0.0
       COF(3,2)=0.0
```

```
      COF(3,3)=1.0
      COF(3,4)=DVTDRP
      GO TO 355
  300 GO TO (310,330,355,320,355),IK
  310 IF (JJ.NE.MEAN) GO TO 355
  320 BETP=BET(IJ)
      DBDRP=DBDR(IJ)
      DADRP=DADR(IJ)
      GO TO 340
  330 CALL I1AP1(RP,BETP,RST,BET,NLINES)
      CALL I1AP1(RP,DBDRP,RST,DBDR,NLINES)
      CALL I1AP1(RP,DADRP,RST,DADR,NLINES)
  340 SINA=SIN(AYP)
      TANB=TAN(BETP)
      COSB=COS(BETP)
      COSQB=COSB**2
      VMSQMX=(GJCPT1-VMSQMN)/(1.0+(TANB*COSA)**2)
      IF (VMSQMX.GE.VMSQMN) GO TO 355
  345 LSGN=1
      RETURN
  355 IF (IVMSMN-1) 356,362,358
  356 IF (VMSQ.LE.VMSQMX) GO TO 360
      IVMSMN=2
  358 VMSQ=VMSQMX
      GO TO 365
  360 IF (VMSQ.GE.VMSQMN) GO TO 380
      IVMSMN=1
      LSGN=1
      RETURN
  362 VMSQ=VMSQMN
  365 IF (IK.EQ.1.AND.JJ.EQ.MEAN) GO TO 375
      GO TO 380
  375 VMM=SQRT(VMSQ)
      VMP=VMM
      VM(MEAN)=VMM
      GO TO 385
  380 VMP=SQRT(VMSQ)
      IF (IK.EQ.1.OR.IK.EQ.5) VM(JJ)=VMP
  385 IF (ISRI.EQ.2.OR.(ISRI.EQ.1.AND.IWRL.EQ.0)) GO TO 395
      IF (IK.EQ.5) GO TO 390
      COF(3,1)=-0.5*TANB*COSA/VMP
      COF(3,2)=0.0
      COF(3,3)=1.0
      COF(3,4)=VMP*(COSA*DBDRP/COSQB-TANB*SINA*DADRP)
  390 VTP=TANB*COSA*VMP
      IF (IK.EQ.1.OR.IK.EQ.5) VT(JJ)=VTP
      VTSQ=VTP**2
  395 VSQ=VMSQ+VTSQ
      IF (ISRI.EQ.3) GO TO 410
      IF (ISPEC.EQ.0) GO TO 400
      CALL PLC(RP,VMSQ,IK,WYEP,DWYDRP,DWYVM,DWYVT)
      IF (ISRI.EQ.1) GO TO 500
      GO TO 600
  400 IF (ISRI.EQ.1) GO TO 500
      IF (ILOSS.EQ.0) GO TO 600
  410 GO TO (420,440,450,430,910),IK
  420 IF (JJ.NE.MEAN) GO TO 450
  430 POP=PO(IJ)
      DPODRP=DPODR(IJ)
      GO TO 450
  440 CALL I1AP1(RP,POP,RST,PO,NLINES)
```

```
      CALL I1AP1(RP,DPODRP,RST,DPODR,NLINES)
  450 COF(2,1)=0.0
      COF(2,2)=1.0
      COF(2,3)=0.0
      COF(2,4)=DPODRP/POP
      GO TO 705
  500 GO TO (510,530,540,520,540),IK
  510 IF (JJ.NE.MEAN) GO TO 540
  520 IF (ISPEC.NE.0) GO TO 525
      WYEP=WYE(IJ)
      DWYDRP=DWYDR(IJ)
  525 POUP=POU(IJ)
      DPOUDP=DPOUDR(IJ)
      GO TO 540
  530 IF (ISPEC.NE.0) GO TO 535
      CALL I1AP1(RP,WYEP,RST,WYE,NLINES)
      CALL I1AP1(RP,DWYDRP,RST,DWYDR,NLINES)
  535 CALL I1AP1(RP,POUP,RST,POU,NLINES)
      CALL I1AP1(RP,DPOUDP,RST,DPOUDR,NLINES)
  540 TRAT=1.0-VSQ/GJCPT1
      PRAT=TRAT**GAMA1
      FUN1=1.0+WYEP*(1.0-PRAT)
      IF (IK.EQ.1.OR.IK.EQ.5) PO(JJ)=POUP/FUN1
      IF (IK.EQ.5) GO TO 910
      FUN2=GAMA1*WYEP*TRAT**GAMB1/(GJCPT1*FUN1)
      FUN5=(1.0-PRAT)/FUN1
      COF(2,1)=FUN2
      COF(2,2)=1.0
      COF(2,3)=2.0*VTP*FUN2
      COF(2,4)=DPOUDP/POUP+FUN2*VSQ*DTODRP/TOP-FUN5*DWYDRP
      GO TO 700
  600 GO TO (610,630,640,620,640),IK
  610 IF (JJ.NE.MEAN) GO TO 640
  620 IF (ISPEC.NE.0) GO TO 625
      WYEP=WYE(IJ)
      DWYDRP=DWYDR(IJ)
  625 PORUP=PORU(IJ)
      DPRUDP=DPRUDR(IJ)
      UP=U(IJ)
      UUP=UU(IJ)
      TORUP=TORU(IJ)
      DTRUDP=DTRUDR(IJ)
      GO TO 640
  630 IF (ISPEC.NE.0) GO TO 635
      CALL I1AP1(RP,WYEP,RST,WYE,NLINES)
      CALL I1AP1(RP,DWYDRP,RST,DWYDR,NLINES)
  635 CALL I1AP1(RP,PORUP,RST,PORU,NLINES)
      CALL I1AP1(RP,DPRUDP,RST,DPRUDR,NLINES)
      UP=RPM*RP
      CALL I1AP1(RP,UUP,RST,UU,NLINES)
      CALL I1AP1(RP,TORUP,RST,TORU,NLINES)
      CALL I1AP1(RP,DTRUDP,RST,DTRUDR,NLINES)
  640 TRAT=1.0-VSQ/GJCPT1
      TRRAT=1.0+UP*(UP-2.0*VTP)/GJCPT1
      GJCPT2=GJCP22*TORUP
      TRRRAT=1.0+(UP**2-UUP**2)/GJCPT2
      PRAT=TRAT**GAMA1
      PRRAT=TRRAT**GAMA1
      FUN1=PRRAT+WYEP*(PRRAT-PRAT)
      IF (IK.EQ.1.OR.IK.EQ.5) PO(JJ)=PORUP*TRRRAT**GAMA2/FUN1
      IF (IK.EQ.5) GO TO 910
```

```
      FUN2=GAMA1*WYEP*TRAT**GAMB1/(GJCPT1*FUN1)                         DRIV0179
      FUN3=GAMA1*(1.0+WYEP)*TRRAT**GAMB1/(GJCPT1*FUN1)                  DRIV0180
      FUN4=GAMA2/(TRRRAT*GJCPT2)                                        DRIV0181
      FUN5=(PRRAT-PRAT)/FUN1                                            DRIV0182
      COF(2,1)=FUN2                                                     DRIV0183
      COF(2,2)=1.0                                                      DRIV0184
      COF(2,3)=2.0*(VTP*FUN2-UP*FUN3)                                   DRIV0185
      COF(2,4)=DPRUDP/PORUP+(FUN2*VSQ+FUN3*UP*(UP-2.0*VTP))*DTODRP/TOP  DRIV0186
     1          -FUN5*DWYDRP-FUN4*(UP**2-UUP**2)*DTRUDP/                DRIV0187
     2          TORUP-2.0*RPM*(FUN3*(UP-VTP)-FUN4*(UP-UUP))             DRIV0188
  700 IF (ISPEC.EQ.0) GO TO 705                                         DRIV0189
      COF(2,1)=COF(2,1)+FUN5*DWYVM                                      DRIV0190
      COF(2,3)=COF(2,3)+FUN5*DWYVT                                      DRIV0191
  705 COF(1,1)=1.0                                                      DRIV0192
      COF(1,2)=(VSQ-GJCPT1)/GAMA1                                       DRIV0193
      COF(1,3)=2.0*VTP                                                  DRIV0194
      COF(1,4)=2.0*CCSA*VMSQ*CRVP+VSQ*DTODRP/TOP-2.0*VTSQ/RP            DRIV0195
      DO 710 J1=1,3                                                     DRIV0196
      DO 710 J2=1,4                                                     DRIV0197
  710 COFT(J1,J2)=COF(J1,J2)                                            DRIV0198
715   IF(ISRI.GT.2)GC TO 760                                            DRIV0199
      DENOM=COF(1,1)*COF(2,2)*COF(3,3)+COF(1,2)*COF(2,3)*COF(3,1)-      DRIV0200
     1     COF(3,1)*COF(2,2)*COF(1,3)-COF(2,1)*COF(1,2)*COF(3,3)        DRIV0201
      IF(IK.EQ.1.AND.JJ.EQ.MEAN)GO TO 720                               DRIV0202
      SIGN=DENOM*DENOMO                                                 DRIV0203
      IF(SIGN)750,750,760                                               DRIV0204
720   DENOMO=DENOM                                                      DRIV0205
      GO TO 760                                                         DRIV0206
750   LSGN=1                                                            DRIV0207
      RETURN                                                            DRIV0208
760   CALL SIMEQ(COF,DDR,3,LSGN,3,4)                                    DRIV0209
      IF(LSGN.NE.1)GO TO 900                                            DRIV0210
      WRITE(NTAPE,800)RP,ILOOP,ILLOOP                                   DRIV0211
  800 FORMAT ( //4X,82HA UNIQUE SOLUTION TO THE RADIAL EQUILIBRIUM EQUATDRIV0212
     1ION COULD NOT BE OBTAINED AT R = ,F10.4,14H WHEN ILOOP = ,I2,     DRIV0213
     214H AND ILLOOP = ,I2)                                             DRIV0214
      RETURN                                                            DRIV0215
  900 DVMSDR=DDR(1)                                                     DRIV0216
  905 IF (IK.NE.1) RETURN                                               DRIV0217
  910 GRND(JJ)=COSA*VMP*RP*PO(JJ)*(1.0-VSQ/GJCPT1)**GAMB1/(GASC*TOP)    DRIV0218
      DVMSO=DVMSDR                                                      DRIV0219
      RETURN                                                            DRIV0220
      END                                                               DRIV0221
```

APPENDIX XVI

SUBRØUTINE SIMEQ

The function of Subroutine SIMEQ (deckname SUB12) is to obtain the solution to a set of simultaneous linear algebraic equations.

Subroutine SIMEQ is called by Subroutine DERIV; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output are transmitted as arguments of the subroutine. The internal input consists of:

A ND NDP NR

The internal output consists of:

LSGN X

Fortran Nomenclature for Subroutine SIMEQ

The following table gives the Fortran nomenclature for the symbols used in Subroutine SIMEQ. Since the subroutine may be used with any consistent set of units, the units of the symbols are not specified. The subscripts I and J refer to row and column indices, respectively.

Fortran Symbol	Symbol	Description	Units
A(I,J)		Coefficient matrix augmented by a constant vector	--
I		Row or column index	--
J		Row or column index	--
		Row or column index	--
		Indicator: LSGN=0 if the coefficient matrix is nonsingular LSGN=1 if the coefficient matrix is singular	--

Fortran Symbol	Symbol	Description	Units
NC		Number of simultaneous equations to be solved plus one	--
ND		Maximum number of simultaneous equations	--
NDP		Maximum number of simultaneous equations plus one	--
NR		Number of simultaneous equations to be solved	--
R		Dummy matrix element	--
S		Maximum absolute value of a column element	--
T		Absolute value of a column element	--
X(I)		Solution vector	--

Internal Structure

This subroutine performs step 43 of the Analysis Procedure and uses the method of solution detailed in the Numerical Techniques section of Appendix I. The Fortran listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB12   LIST,DECK,M94
C                                                                      SMEQ
C     SIMEQ - SOLUTION OF SIMULTANEOUS LINEAR ALGEBRAIC EQUATIONS      SMEQ
C                                                                      SMEQ
      SUBROUTINE SIMEQ(A,X,NR,LSGN,ND,NDP)                             SMEQ0001
      DIMENSION A(ND,NDP),X(ND)                                        SMEQ0002
      NC=NR+1                                                          SMEQ0003
      I=1                                                              SMEQ0004
C                                                                      SMEQ
C     THE PIVOTAL ELEMENT IS MAXIMIZED                                 SMEQ
C                                                                      SMEQ
  100 S=ABS(A(I,I))                                                    SMEQ0005
      J=I                                                              SMEQ0006
      IF (I-NR) 150,300,600                                            SMEQ0007
  150 K=I+1                                                            SMEQ0008
  200 T=ABS(A(K,I))                                                    SMEQ0009
      IF (T.LE.S) GO TO 250                                            SMEQ0010
      S=T                                                              SMEQ0011
      J=K                                                              SMEQ0012
  250 K=K+1                                                            SMEQ0013
      IF (K.LE.NR) GO TO 200                                           SMEQ0014
  300 IF (S.EQ.0.0) GO TO 750                                          SMEQ0015
C                                                                      SMEQ
C     THE ROWS ARE INTERCHANGED IF NECESSARY                           SMEQ
C                                                                      SMEQ
      IF (J.LE.I) GO TO 375                                            SMEQ0016
      LSGN=-LSGN                                                       SMEQ0017
      K=I                                                              SMEQ0018
  350 R=A(I,K)                                                         SMEQ0019
      A(I,K)=A(J,K)                                                    SMEQ0020
      A(J,K)=R                                                         SMEQ0021
      K=K+1                                                            SMEQ0022
      IF (K.LE.NC) GO TO 350                                           SMEQ0023
C                                                                      SMEQ
C     REDUCE THE ELEMENTS WITH A ZERO CHECK                            SMEQ
C                                                                      SMEQ
  375 J=I+1                                                            SMEQ0024
  400 IF (J.LE.NC) GO TO 450                                           SMEQ0025
      I=I+1                                                            SMEQ0026
      GO TO 100                                                        SMEQ0027
  450 IF (A(I,J).EQ.0.0) GO TO 550                                     SMEQ0028
      A(I,J)=A(I,J)/A(I,I)                                             SMEQ0029
      K=I+1                                                            SMEQ0030
  500 IF (K.GT.NR) GO TO 550                                           SMEQ0031
      A(K,J)=A(K,J)-A(I,J)*A(K,I)                                      SMEQ0032
      K=K+1                                                            SMEQ0033
      GO TO 500                                                        SMEQ0034
  550 J=J+1                                                            SMEQ0035
      GO TO 400                                                        SMEQ0036
C                                                                      SMEQ
C     COMPUTE THE SOLUTION                                             SMEQ
C                                                                      SMEQ
  600 K=NR+1                                                           SMEQ0037
      X(NR)=A(NR,K)                                                    SMEQ0038
      I=NR-1                                                           SMEQ0039
  650 J=I+1                                                            SMEQ0040
      R=0.0                                                            SMEQ0041
  700 R=R+A(I,J)*X(J)                                                  SMEQ0042
      J=J+1                                                            SMEQ0043
      IF (J.LE.NR) GO TO 700                                           SMEQ0044
```

```
      X(I)=A(I,K)-R                                                   SMEQ0045
      I=I-1                                                           SMEQ0046
      IF (I.GT.0) GO TO 650                                           SMEQ0047
      LSGN=0                                                          SMEQ0048
      RETURN                                                          SMEQ0049
  750 LSGN=1                                                          SMEQ0050
      RETURN                                                          SMEQ0051
      END                                                             SMEQ0052
```

APPENDIX XVII

SUBRØUTINE VMSUB

The function of Subroutine VMSUB (deckname SUB13) is to obtain a new estimate of the meridional velocity at the mean streamline which will satisfy continuity.

Subroutine VMSUB is called by the main routine; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output of the subroutine are transmitted through blank CØMMØN, CØMMØN/CØM4/, and CØMMØN/COM7/. The internal input consists of:

DFLWT	DFLWTØ	FLWP	ICNT	ILLØØP
ISØN	ISRI	IWRL	RATIØ	VMMØ
VMMØØ				

The internal output consists of:

ICNT	VMMØ

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine SPECHT

The following table gives the Fortran nomenclature for those symbols used in Subroutine VMSUB which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
DENØM	$w_{in} - w_{in,old}$	Difference in the calculated mass flow based on the two previous estimates of meridional velocity at the mean streamline	lbm per sec
DVMM	$(V_{mi})_m - (V_{mi})_{m,old}$	Difference in the two previous estimates of meridional velocity at the mean streamline	fps

Fortran Symbol	Symbol	Description	Units
DWRAT	$\frac{w_{Ti}-w_{in}}{w_{in}-w_{in,old}}$	Ratio of the difference between the actual mass flow and the previously calculated mass flow to DENØM	--
ISGN		Indicator: ISGN=0 if the ratio of DVMM to DENØM is negative ISGN=1 if the ratio of DVMM to DENØM is positive ISGN=ISGNØ if the ratio of DVMM to DENØM is zero	--
ISGNØ		Previous value of the indicator ISGN	--

Internal Structure

The subroutine performs the calculations of step 55 of the Analysis Procedure. A Fortran listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB13    LIST,DECK,M94
C                                                                         VMSB
C     VMSUB - OBTAIN A NEW ESTIMATE OF THE MERIDIONAL VELOCITY AT THE     VMSB
C             MEAN STREAMLINE                                             VMSB
C                                                                         VMSB
      SUBROUTINE VMSUB                                                    VMSB0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,         VMSB0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NOSTAT,NLINES,NSPOOL,           VMSB0003
     2NSTG,NTAPE,NTUBES                                                   VMSB0004
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                    VMSB0005
      COMMON /COM7/COT60,DFLWT,DFLWTO,EMMAX,EMMIN,ICNT,JJ,                VMSB0006
     1JJP,MEAN,RATIO,VMM,VMMO,VMMOO                                       VMSB0007
      IF (ILLOOP.GT.1) GO TO 200                                          VMSB0008
      ISGNO=0                                                             VMSB0009
      IF (RATIO.LE.1.2) GO TO 50                                          VMSB0010
      RATIO=1.2                                                           VMSB0011
      GO TO 100                                                           VMSB0012
   50 IF (RATIO.LT.0.833) RATIO=0.833                                     VMSB0013
  100 IF (ISRI.NE.1.OR.IWRL.NE.2) GO TO 150                               VMSB0014
      IF (ISON.EQ.0) GO TO 150                                            VMSB0015
      VMM=VMMO*RATIO                                                      VMSB0016
      RETURN                                                              VMSB0017
  150 VMM=VMMO/RATIO                                                      VMSB0018
      RETURN                                                              VMSB0019
  200 DENOM=DFLWT-DFLWTO                                                  VMSB0020
      IF (DENOM.NE.0.0) GO TO 250                                         VMSB0021
      VMM=0.5*(VMMO+VMMOO)                                                VMSB0022
      RETURN                                                              VMSB0023
  250 DWRAT=(FLWP-DFLWT)/DENOM                                            VMSB0024
      IF (DWRAT.LE.2.0) GO TO 300                                         VMSB0025
      DWRAT=2.0                                                           VMSB0026
      GO TO 350                                                           VMSB0027
  300 IF (DWRAT.LT.-2.0) DWRAT=-2.0                                       VMSB0028
  350 DVMM=VMMO-VMMOO                                                     VMSB0029
      VMM=VMMO+DWRAT*DVMM                                                 VMSB0030
      IF (DVMM/DENOM) 400,450,500                                         VMSB0031
  400 ISGN=0                                                              VMSB0032
      GO TO 550                                                           VMSB0033
  450 ISGN=ISGNO                                                          VMSB0034
      GO TO 550                                                           VMSB0035
  500 ISGN=1                                                              VMSB0036
  550 IF (ILLOOP.EQ.2) GO TO 600                                          VMSB0037
      IF (ISGN.NE.ISGNO) ICNT=ICNT+1                                      VMSB0038
  600 ISGNO=ISGN                                                          VMSB0039
      RETURN                                                              VMSB0040
      END                                                                 VMSB0041
```

APPENDIX XVIII

SUBRØUTINE REMAIN

The function of Subroutine REMAIN (deckname SUB14) is to obtain streamline values for those quantities tabulated in the output for a design station which have not already been obtained.

Subroutine REMAIN is called by the main routine; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output are transmitted through blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM2/, CØMMØN/CØM3/, and CØMMØN/CØM5/. The internal input consists of:

AY	CP2	CP3	DTØ	GAMA1
GAMA2	GAMC1	GAMD2	GAMD3	GGG1
GJCP12	ICØEF	ICØNV	ILØSS	ISPEC
ISRI	IWRL	NLINES	PØ	PØØ
PØØ2	PØRU	PØU	TØ	TØØ
TØØ2	TØRU	U	VM	VRU
VT	VU	WYK		

The internal output consists of:

BET	BETR	BREFF	EFFR	EFFS
EM	EMR	P	PØR	REAC
T	TØR	V	VR	VX
WYE				

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine REMAIN

The following table gives the Fortran nomenclature for those symbols used in Subroutine REMAIN which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
CØSA	$\cos A_{ij}$	Cosine of a streamline value of the streamline angle of inclination	--
GJCPT1	$2g_0Jc_{pi}(T_{oi})_j$	Parameter related to a streamline value of the total temperature and the specific heat at a design station	fps^2
PØP	$(p_{oi})_j$	A streamline value of the absolute total pressure	psf
PØRP	$(p'_{oi})_j$	A streamline value of the relative total pressure	psf
PP	p_{ij}	A streamline value of the static pressure	psf
TØP	$(T_{oi})_j$	A streamline value of the absolute total temperature	deg R
TØRP	$(T'_{oi})_j$	A streamline value of the relative total temperature	deg R
TP	T_{ij}	A streamline value of the static temperature	deg R
VMP	$(V_{mi})_j$	A streamline value of the meridional velocity	fps
VMSQ	$(V^2_{mi})_j$	A streamline value of the square of the meridional velocity	fps^2
VRSQ	V'^2_{ij}	A streamline value of the square of the relative velocity	fps^2
VSQ	V^2_{ij}	A streamline value of the square of the absolute velocity	fps^2
VTP	$(V_{ui})_j$	A streamline value of the tangential velocity	fps
VTRP	$(V_{ui})_j - u_{ij}$	A streamline value of the relative tangential velocity	fps
VTSQ	$(V^2_{ui})_j$	A streamline value of the square of the tangential velocity	fps^2

Fortran Symbol	Symbol	Description	Units
VXP	$(V_{x\iota})_j$	A streamline value of the axial velocity	fps

Internal Structure

This subroutine performs the calculations for steps 60 through 66 of the Analysis Procedure. The card sequence numbers corresponding to the various steps are identified in the following table.

Step of Analysis Procedure	Sequence Numbers
60	0022
61	0023 - 0039
62	0040
63	0041 - 0050
64	0051 - 0058
65	0059 - 0067
66	0068 - 0074

A Fortran listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB14   LIST,DECK,M94
C                                                                       REMN
C     REMAIN - OBTAIN THE REMAINDER OF THE TABULAR OUTPUT               REMN
C                                                                       REMN
      SUBROUTINE REMAIN                                                 REMN0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,       REMN0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NOSTAT,NLINES,NSPOOL,         REMN0003
     2NSTG,NTAPE,NTUBES                                                 REMN0004
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),           REMN0005
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),     REMN0006
     2P(17),PO(17),PCR(17),REAC(17),T(17),TO(17),TOR(17),U(17),         REMN0007
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)                 REMN0008
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,              REMN0009
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMC2,GAMD3,GAMD4,GAMD5,            REMN0010
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,            REMN0011
     3GJCP22,GJCP32,GJCP42,GJCP52                                       REMN0012
      COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),            REMN0013
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),          REMN0014
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),               REMN0015
     3VRU(17),VTU(17),VU(17),WYEO(17)                                   REMN0016
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),          REMN0017
     1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,                  REMN0018
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),           REMN0019
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),               REMN0020
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)                            REMN0021
      DO 500 J=1,NLINES                                                 REMN0022
      VMP=VM(J)                                                         REMN0023
      VMSQ=VMP**2                                                       REMN0024
      VTP=VT(J)                                                         REMN0025
      VTSQ=VTP**2                                                       REMN0026
      VSQ=VMSQ+VTSQ                                                     REMN0027
      V(J)=SQRT(VSQ)                                                    REMN0028
      COSA=COS(AY(J))                                                   REMN0029
      VXP=COSA*VMP                                                      REMN0030
      VX(J)=VXP                                                         REMN0031
      TOP=TO(J)                                                         REMN0032
      GJCPT1=GJCP12*TOP                                                 REMN0033
      TP=TOP*(1.0-VSQ/GJCPT1)                                           REMN0034
      T(J)=TP                                                           REMN0035
      POP=PO(J)                                                         REMN0036
      PP=POP*(TP/TOP)**GAMA1                                            REMN0037
      P(J)=PP                                                           REMN0038
      EM(J)=SQRT(VSQ/(GGG1*TP))                                         REMN0039
      IF (ISRI.EQ.3) GO TO 500                                          REMN0040
      VTRP=VTP-U(J)                                                     REMN0041
      VRSQ=VMSQ+VTRP**2                                                 REMN0042
      VR(J)=SQRT(VRSQ)                                                  REMN0043
      EMRSQ=VRSQ/(GGG1*TP)                                              REMN0044
      EMR(J)=SQRT(EMRSQ)                                                REMN0045
      TORP=TP*(1.0+GAMC1*EMRSQ)                                         REMN0046
      TOR(J)=TORP                                                       REMN0047
      PORP=PP*(TORP/TP)**GAMA1                                          REMN0048
      POR(J)=PORP                                                       REMN0049
      BETR(J)=ATAN(VTRP/VXP)                                            REMN0050
      IF (ISRI.EQ.2) GO TO 150                                          REMN0051
      IF (ICOEF.EQ.0) GO TO 50                                          REMN0052
      BREFF(J)=1.0-WYK(J)                                               REMN0053
      GO TO 100                                                         REMN0054
   50 BREFF(J)=(1.0-TP/TOP)/(1.0-(PP/POU(J))**GAMD2)                    REMN0055
  100 IF (ICONV.EQ.1) REAC(J)=VU(J)/V(J)                                REMN0056
```

```
      IF (IWRL.EQ.0) GO TO 450
      GO TO 500
  150 IF (ISPEC.NE.0) GO TO 250
      IF (ILOSS.EQ.0) GO TO 200
      WYE(J)=(PORU(J)*(TORP/TORU(J))**GAMA2-PORP)/(PORP-PP)
      GO TO 250
  200 IF (ICOEF.EQ.0) GO TO 250
      BREFF(J)=1.0-WYK(J)
      GO TO 300
  250 BREFF(J)=(1.0-TP/TORP)/(1.0-(PP/PORU(J))**GAMD2*TORU(J)/TORP)
  300 IF (ICONV.EQ.0) GO TO 450
      REAC(J)=VRU(J)/VR(J)
      IF (ISPEC.NE.0) GO TO 350
      IF (ILOSS.EQ.2) GO TO 400
  350 EFFS(J)=CP2*DTO(J)/(CP3*TOO2(J)*(1.0-(POP/POO2(J))**GAMD3))
      IF (ISPEC.NE.0) GO TO 400
      IF (ILOSS.EQ.1) GO TO 450
  400 EFFR(J)=(DTO(J)/TOO(J))/(1.0-(POP/POO(J))**GAMD2)
  450 BET(J)=ATAN(VTP/VXP)
  500 CONTINUE
      RETURN
      END
```

APPENDIX XIX

SUBRØUTINE SETUP

The function of Subroutine SETUP (deckname SUB15) is to obtain:

1. Streamline values of quantities which are required for the calculations at the following design station.
2. Mass averaged values which are to be printed in the output.

Subroutine SETUP is called by the main routine; it, in turn, calls Subroutine SLØPE. Subroutine SETUP does not require external input and does not provide external output. Internal input and output are transmitted by blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM2/, CØMMØN/CØM3/, CØMMØN/CØM4/, CØMMØN/CØM5/, CØMMØN/CØM6/, CØMMØN/CØM9/, and CØMMØN/CØM11/. The internal input consists of:

BET	BETR	BREFF	CNV5	CP2
CP3	CP4	CP5	DTØ	EJAY
ENM1	FLW	FLWC	FLWM	FLWP
GAMA1	GAMD3	GAMD4	GAMD5	GJCP12
GJCP32	GJCP42	GJCP52	ICØØL	IDS
ILØSS	IMIX	ISAV	ISPEC	ISRI
ISTG	NDSTAT	NLINES	NSPØØL	NSTG
NTUBES	P	PØ	REAC	RST
TØ	TØC	U	V	VR
VT	WYE	XMIX		

The internal output consists of:

BETRU	BETU	BREA	BREAP	BREFFØ
DBRUDR	DBUDR	DPØUDR	DPRUDR	DTRUDR
DVRUDR	DVUDR	ØJS	ØSE	ØTE

ØTS	ØTT	ØW	PØØ	PØØ2
PØRU	PØU	REACØ	SJS	SJSP
SPJS	SPP	SPSE	SPTE	SPTS
SPTT	SPW	SSE	SSEP	STE
STEP	SW	SWP	TØØ	TØØ2
TØRU	TØU	UU	VRU	VTU
VU	WYEØ			

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine SETUP

The following table gives the Fortran nomenclature for those symbols used in Subroutine SETUP which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
DTØA	$\overline{\Delta T}_{0i''}$	Mass averaged value of the absolute total temperature drop across a rotor	deg R
FLWCØ	$w_{c,i-1}$	Coolant mass flow added to the upstream blade row	lbm per sec
J	j	Streamline index	--
ØP	$(P_T)_{ov}$	Over-all power output of the turbine	hp
ØPB	$(P_T)_{ov}$	Over-all power output of the turbine	Btu per sec
PA	$\bar{P}_i$	Mass averaged value of the static pressure at a design station	psf
PARAM		Product of the specific heat, mass flow, and mass averaged total temperature	Btu per sec
PARMB	$\dfrac{\int_0^1 x_{m_i'} P_{0i}\, dw'}{\int_0^1 x_{m_i'}\, dw'}$	Quotient containing SUMB and SUMA	psf

Fortran Symbol	Symbol	Description	Units
PARMC	$\dfrac{\int_0^1 X_{mi'} T_{oi}\, dw'}{\int_0^1 X_{mi'}\, dw'}$	Quotient containing SUMC and SUMA	deg R
PØA	$\bar{P}_{oi}$	Mass averaged value of the absolute total pressure at a stage exit	psf
PØAØ	$\bar{P}_{o,i-2}$	Mass averaged value of the absolute total pressure at a stage inlet	psf
PØAØØ	$(\bar{P}_o)_{i=1}$	Mass averaged value of the absolute total pressure at a spool inlet	psf
PØAØØØ	$(\bar{P}_o)_{inlet}$	Mass averaged value of the absolute total pressure at the turbine inlet	psf
SP	$P_{Ti''}$	Stage power output	hp
SPB	$P_{Ti''}$	Stage power output	Btu per sec
SPPB	$P_{Ti'''}$	Spool power output	Btu per sec
SUMA	$\int_0^1 X_{mi'}\, dw'$	Integral of the mixing coefficient with respect to the non-dimensional mass flow function	lbm per sec
SUMB	$\int_0^1 X_{mi'} P_{oi}\, dw'$	Integral of the product of the mixing coefficient and absolute total pressure with respect to the mass flow function	psf lbm per sec
SUMC	$\int_0^1 X_{mi'} T_{oi}\, dw'$	Integral of the product of the mixing coefficient and absolute total temperature with respect to the mass flow function	deg R lbm per sec
TFLWC		Sum of the product of coolant total temperature and coolant mass flow for a stage	deg R lbm per sec
TFLWCØ		Sum of the product of coolant total temperature and coolant mass flow for the turbine	deg R lbm per sec
TFLWCT		Sum of the product of coolant total temperature and coolant mass flow for a spool	deg R lbm per sec

Fortran Symbol	Symbol	Description	Units
TØA	$\bar{T}_{oi}$	Mass averaged value of the absolute total temperature at a stage exit	deg R
TØAØ	$\bar{T}_{o,i-2}$	Mass averaged value of the absolute total temperature at a stage inlet	deg R
TØAØØ	$(\bar{T}_o)_{i=1}$	Mass averaged value of the absolute total temperature at a spool inlet	deg R
TØAØØØ	$(\bar{T}_o)_{inlet}$	Mass averaged value of the absolute total temperature at the turbine inlet	deg R
TØCP	$(T_{oc})_{i'}$	Total temperature of the coolant added to the downstream blade row	deg R
TØCPØ	$(T_{oc})_{i'-1}$	Total temperature of the coolant added to the upstream blade row	deg R
TSRAT		Mass averaged static-to-total temperature ratio	--
TTRAT		Mass averaged total-to-total temperature ratio	--
UA	$\bar{u}_{i'}$	Mass averaged blade velocity at a blade row exit	fps
UAA	$\bar{u}_{i''}$	Average blade velocity for a rotor	fps
UAAA	$\bar{u}_{i'''}$	Average blade velocity for a spool	fps
UAAAA	$\bar{u}_{ov}$	Average blade velocity for the turbine	fps
UAØ	$\bar{u}_{i'-1}$	Mass averaged blade velocity at a stator exit	fps
XMIXP	$(x_{mi'})_j$	A streamline value of the mixing coefficient	--

Internal Structure

Subroutine SETUP corresponds to steps 67 through 76 of the Analysis Procedure. The individual steps are identified by the card sequence numbers in the following table.

Step of Analysis Procedure	Sequence Number
67	0029
68	0030 - 0050
69	0051 - 0054
70	0055 - 0066
71	0067 - 0087
72	0088 - 0102
73	0103 - 0111
74	0112 - 0141
75	0142 - 0148
76	0149 - 0197

A Fortran listing is given on the following page(s).

```
$*
$IBFTC SUB15   LIST,DECK,M94
C
C     SETUP - OBTAIN THE QUANTITIES WHICH ARE REQUIRED BEFORE
C             PROCEEDING TO THE NEXT DESIGN STATION
C
      SUBROUTINE SETUP
      COMMON IBR,ICOEF,ICONV,ICCOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,
     2NSTG,NTAPE,NTUBES
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,
     3GJCP22,GJCP32,GJCP42,GJCP52
      COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),
     3VRU(17),VTU(17),VU(17),WYEO(17)
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)
      COMMON /COM5/ASTR(17,17),ASTS(17),BETLT(17),CSTR(17,17),
     1CSTS(17),DTO(17),FHP(8),FLWC,IPOF(8),ISTRAC,NLT,
     2NSTAT,NSTRAC,NXT,POF(17,8),POLT(17),RANN(19,2),RLT(17),
     3RSTRAC(17,17),RSTRAS(17),RXTS(17),TOC(16),TOLT(17),
     4WRLS(17),XMIX(17,16),XSTAT(19),YOS(17)
      COMMON /COM6/CNV1,CNV2,CNV3,CNV5,EJAY,GO,PI,TOLWY
      COMMON /COM9/BREA(16),BREAP,ENM1,FLWM,OJS,OSE,OTE,OTS,
     1OTT,OW,SJS(8),SJSP,SPJS,SPP,SPSE,SPTE,SPTS,SPTT,SPW,SSE(8),
     2SSEP,STE(8),STEP,SW(8),SWP
      COMMON /COM11/ AYP,COSA,COSB,COSQB,DBDRP,DBRUDR(17),DBUDR(17),
     1DFLDR(17),DVRUDR(17),DVUDR(17),IJ,TANB,VMP,VSQ,VTP
      IF (IDS.EQ.NDSTAT) GO TO 800
      IF (IMIX.EQ.0) GO TO 200
C
C     OBTAIN THE MIXED VALUES OF TOTAL TEMPERATURE AND PRESSURE
C
      SUMA=0.0
      SUMB=0.0
      SUMC=0.0
      DO 100 J=1,NLINES
      XMIXP=XMIX(J,IDS)
      IF (J.EQ.1.OR.J.EQ.NLINES) XMIXP=0.5*XMIXP
      SUMA=SUMA+XMIXP
      SUMB=SUMB+XMIXP*PO(J)
  100 SUMC=SUMC+XMIXP*TO(J)
      IF (SUMA.EQ.0.0) GO TO 200
      PARMB=SUMB/SUMA
      PARMC=SUMC/SUMA
      DO 150 J=1,NLINES
      XMIXP=XMIX(J,IDS)
      POU(J)=(1.0-XMIXP)*PO(J)+PARMB*XMIXP
  150 TOU(J)=(1.0-XMIXP)*TO(J)+PARMC*XMIXP
      GO TO 300
  200 DO 250 J=1,NLINES
      POU(J)=PO(J)
  250 TOU(J)=TO(J)
  300 IF (ICCOL.NE.2) GO TO 500
C
```

```
C     OBTAIN THE COOLED VALUES OF TOTAL TEMPERATURE                      STUP
C                                                                        STUP
      TOCP=TCC(IDS)                                                      STUP0052
      DO 400 J=1,NLINES                                                  STUP0053
  400 TOU(J)=(FLWP*TOU(J)+FLWC*TOCP)/(FLWP+FLWC)                         STUP0054
  500 IF (ISRI.EQ.1) GO TO 600                                           STUP0055
      DO 550 J=1,NLINES                                                  STUP0056
      POO2(J)=PO(J)                                                      STUP0057
      TOO2(J)=TO(J)                                                      STUP0058
  550 VU(J)=V(J)                                                         STUP0059
      CALL SLOPE(RST,POU,DPOUDR,NLINES)                                  STUP0060
      IF (ISPEC.EQ.0) GO TO 800                                          STUP0061
      DO 575 J=1,NLINES                                                  STUP0062
  575 BETU(J)=BET(J)                                                     STUP0063
      CALL SLOPE(RST,VU,DVUDR,NLINES)                                    STUP0064
      CALL SLOPE(RST,BETU,DBUDR,NLINES)                                  STUP0065
      GO TO 800                                                          STUP0066
  600 DO 650 J=1,NLINES                                                  STUP0067
      POO(J)=PO(J)                                                       STUP0068
      TOO(J)=TO(J)                                                       STUP0069
      REACO(J)=REAC(J)                                                   STUP0070
      WYEO(J)=WYE(J)                                                     STUP0071
      BREFFO(J)=BREFF(J)                                                 STUP0072
      UU(J)=U(J)                                                         STUP0073
      VTU(J)=VT(J)                                                       STUP0074
      VRU(J)=VR(J)                                                       STUP0075
      TORU(J)=TOU(J)+(VR(J)**2-V(J)**2)/GJCP12                           STUP0076
  650 PORU(J)=POU(J)*(TORU(J)/TOU(J))**GAMA1                             STUP0077
      IF (ISPEC.NE.0) GO TO 700                                          STUP0078
      IF (ILOSS.NE.0) GO TO 950                                          STUP0079
  700 CALL SLOPE(RST,TORU,DTRUDR,NLINES)                                 STUP0080
      CALL SLOPE(RST,PORU,DPRUDR,NLINES)                                 STUP0081
      IF (ISPEC.EQ.0) GO TO 950                                          STUP0082
      DO 750 J=1,NLINES                                                  STUP0083
  750 BETRU(J)=BETR(J)                                                   STUP0084
      CALL SLOPE(RST,VRU,DVRUDR,NLINES)                                  STUP0085
      CALL SLOPE(RST,BETRU,DBRUDR,NLINES)                                STUP0086
      GO TO 950                                                          STUP0087
  800 TOA=0.5*TO(1)                                                      STUP0088
      POA=0.5*PO(1)                                                      STUP0089
      DO 850 J=2,NTUBES                                                  STUP0090
      TOA=TOA+TO(J)                                                      STUP0091
  850 POA=POA+PO(J)                                                      STUP0092
      TOA=(TOA+0.5*TO(NLINES))/ENM1                                      STUP0093
      POA=(PCA+0.5*PO(NLINES))/ENM1                                      STUP0094
      IF (ISRI-3) 875,1600,1650                                          STUP0095
  875 PA=0.5*P(1)                                                        STUP0096
      DTOA=0.5*DTO(1)                                                    STUP0097
      DO 900 J=2,NTUBES                                                  STUP0098
      PA=PA+P(J)                                                         STUP0099
  900 DTOA=DTOA+DTO(J)                                                   STUP0100
      PA=(PA+0.5*P(NLINES))/ENM1                                         STUP0101
      DTOA=(DTOA+0.5*DTO(NLINES))/ENM1                                   STUP0102
  950 UA=0.5*U(1)                                                        STUP0103
      BREAP=0.5*BREFF(1)                                                 STUP0104
      DO 1000 J=2,NTUBES                                                 STUP0105
      UA=UA+U(J)                                                         STUP0106
 1000 BREAP=BREAP+BREFF(J)                                               STUP0107
      UA=(UA+0.5*U(NLINES))/ENM1                                         STUP0108
      BREAP=(BREAP+0.5*BREFF(NLINES))/ENM1                               STUP0109
      BREA(IBR)=BREAP                                                    STUP0110
```

```
      IF (ISPI.EQ.1) GO TO 1750
      SWP=CP2*DTCA
      SW(ISTG)=SWP
      SPB=FLWP*SWP
      SP=EJAY*SPB/CNV5
      TTRAT=(POA/POAO)**GAMD3
      IF (ICOOL.EQ.2) GO TO 1050
      PARAM=CP3*FLWP*TOAO
      GO TO 1150
 1050 TFLWC=FLWC*TOCP+FLWCO*TOCPO
      PARAM=CP3*(FLW(IDS-2)*TOAO+TFLWC)
      IF (ISTG.NE.1) GO TO 1100
      TFLWCT=TFLWC
      GO TO 1150
 1100 TFLWCT=TFLWCT+TFLWC
 1150 STEP=SPB/(PARAM*(1.0-TTRAT))
      TSRAT=(PA/POAO)**GAMD3
      SSEP=SPB/(PARAM*(1.0-TSRAT))
      STE(ISTG)=STEP
      SSE(ISTG)=SSEP
      UAA=0.5*(UA+UAO)
      SJSP=UAA/SQRT(GJCP32*TOAO*(1.0-TSRAT))
      SJS(ISTG)=SJSP
      IF (ISTG.NE.1) GO TO 1200
      SPW=SWP
      SPP=SP
      UAAA=UAA
      GO TO 1250
 1200 SPW=SPW+SWP
      SPP=SPP+SP
      UAAA=UAAA+UAA
 1250 IF (ISTG.NE.NSTG) GO TO 1700
      SPTT=POAOO/POA
      SPTS=POAOO/PA
      IF (ICOOL.EQ.2) GO TO 1300
      PARAM=CP4*FLWP*TOAOO
      GO TO 1400
 1300 PARAM=CP4*(FLW(1)*TOAOO+TFLWCT)
      IF (NSPOOL.EQ.1) GO TO 1400
      IF (ISAV.NE.1) GO TO 1350
      TFLWCO=TFLWCT
      GO TO 1400
 1350 TFLWCO=TFLWCO+TFLWCT
 1400 SPPB=CNV5*SPP/EJAY
      TTRAT=1.0/SPTT**GAMD4
      TSRAT=1.0/SPTS**GAMD4
      SPTE=SPPB/(PARAM*(1.0-TTRAT))
      SPSE=SPPB/(PARAM*(1.0-TSRAT))
      UAAA=UAAA/FLOAT(NSTG)
      SPJS=UAAA/SQRT(GJCP42*TOAOO*(1.0-TSRAT))
      IF (NSPOOL.EQ.1) RETURN
      IF (ISAV.NE.1) GO TO 1450
      OW=SPW
      OP=SPP
      UAAAA=UAAA
      RETURN
 1450 OW=OW+SPW
      OP=OP+SPP
      UAAAA=UAAAA+UAAA
      IF (ISAV.NE.NSPOOL) RETURN
      OTT=POAOOC/POA
```

```
      OTS=POA000/PA                                                     STUP0172
      IF (ICOOL.EQ.2) GO TO 1500                                        STUP0173
      PARAM=CP5*FLWP*TOA000                                             STUP0174
      GO TO 1550                                                        STUP0175
 1500 PARAM=CP5*(FLWP*TOA000+TFLWCO)                                    STUP0176
 1550 OPB=CNV5*OP/EJAY                                                  STUP0177
      TTRAT=1.0/OTT**GAMD5                                              STUP0178
      TSRAT=1.0/OTS**GAMD5                                              STUP0179
      OTE=OPB/(PARAM*(1.0-TTRAT))                                       STUP0180
      OSE=OPB/(PARAM*(1.0-TSRAT))                                       STUP0181
      UAAAA=UAAAA/FLOAT(NSPOOL)                                         STUP0182
      OJS=UAAAA/SQRT(GJCP52*TOA000*(1.0-TSRAT))                         STUP0183
      RETURN                                                            STUP0184
 1600 TOA000=TOA                                                        STUP0185
      POA000=POA                                                        STUP0186
 1650 TOA00=TOA                                                         STUP0187
      POA00=POA                                                         STUP0188
 1700 TOA0=TOA                                                          STUP0189
      POA0=POA                                                          STUP0190
      RETURN                                                            STUP0191
 1750 UA0=UA                                                            STUP0192
      IF (ICOOL.NE.2) RETURN                                            STUP0193
      TOCP0=TOCP                                                        STUP0194
      FLWC0=FLWC                                                        STUP0195
      RETURN                                                            STUP0196
      END                                                               STUP0197
```

APPENDIX XX

SUBRØUTINE ØUTPUT

The function of Subroutine ØUTPUT (deckname SUB16) is to write the results of the calculations at a design station onto the output tape unit.

Subroutine ØUTPUT is called by the main routine; it does not call any other subroutines. The subroutine does not require external input. The internal input is transmitted through blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM3/, CØMMØN/CØM4/, CØMMØN/CØM6/, and CØMMØN/CØM9/; it consists of:

AY	BET	BETR	BREA	BREAP
BREFF	BREFFØ	CNV1	CNV2	CNV3
CRV	DFLØW	EFFR	EFFS	EM
EMR	ICØNV	ICØØL	IDS	IMIX
ISAV	ISRI	ISTG	NDSTAT	NLINES
NSPØØL	NSTG	NTAPE	ØJS	ØSE
ØTE	ØTS	ØTT	ØW	P
PØ	PØR	PØRU	PØU	REAC
REACØ	RST	SJS	SJSP	SPJS
SPP	SPSE	SPTE	SPTS	SPTT
SPW	SSE	SSEP	STE	STEP
SW	SWP	T	TØ	TØR
TØRU	TØU	U	V	VM
VR	VT	VX	WYE	WYEØ

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.) The external output consists of:

AY	BET	BETR	BREA	BREAP
BREFF	BREFFØ	CRV	DFLØW	EFFR
EFFS	EM	EMR	ØJS	ØSE
ØTE	ØTS	ØTT	ØW	P
PØ	PØR	PØRU	PØU	REAC
REACØ	RST	SJS	SJSP	SPJS
SPP	SPSE	SPTE	SPTS	SPTT
SPW	SSE	SSEP	STE	STEP
SW	SWP	T	TØ	TØR
TØRU	TØU	U	V	VM
VR	VT	VX	WYE	WYEØ

Subroutine ØUTPUT does not provide internal output.

Additional Fortran Nomenclature for Subroutine ØUTPUT

The following table gives the Fortran nomenclature for those symbols used in Subroutine ØUTPUT which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
HW5		Alphanumeric information	--
HW6		Alphanumeric information	--
I		General index	--
J	j	Streamline index	--

Internal Structure

The subroutine performs step 77 of the Analysis Procedure. A Fortran listing is presented on the following page(s).

```
$*
$IBFTC SUB16   LIST,DECK,M94
C                                                                       OUTP
C     OUTPUT - PRINT THE OUTPUT OF THE CALCULATIONS                     OUTP
C                                                                       OUTP
      SUBROUTINE OUTPUT                                                 OUTP0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILCOP,ILOSS,       OUTP0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,         OUTP0003
     2NSTG,NTAPE,NTUBES                                                 OUTP0004
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),           OUTP0005
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),     OUTP0006
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),         OUTP0007
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)                 OUTP0008
      COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),            OUTP0009
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),          OUTP0010
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),               OUTP0011
     3VRU(17),VTU(17),VU(17),WYEO(17)                                   OUTP0012
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                  OUTP0013
      COMMON /COM6/CNV1,CNV2,CNV3,CNV5,EJAY,GO,PI,TOLWY                 OUTP0014
      COMMON /COM9/BREA(16),BREAP,ENM1,FLWM,OJS,OSE,OTE,OTS,            OUTP0015
     1OTT,OW,SJS(8),SJSP,SPJS,SPP,SPSE,SPTE,SPTS,SPTT,SPW,SSE(8),       OUTP0016
     2SSEP,STE(8),STEP,SW(8),SWP                                        OUTP0017
      DIMENSION HW5(28),HW6(2)                                          OUTP0018
      DATA (HW5(I),I=1,28)/6H  PRES,6HSURE  ,6H    LO,6HSS    ,         OUTP0019
     16H  BLAD,6HE-ROW ,6H COEFF,6HICIENT,6H EFFIC,6HIENCY ,            OUTP0020
     24*6H      ,6H STREA,6HMLINE ,6H    SL,6HOPE   ,6H STREA,          OUTP0021
     36HMLINE ,6H    AN,6HGLE   ,6H  CURV,6HATURE ,6H    (D,            OUTP0022
     46HEG)   ,6H  (PER,6H IN)  /                                       OUTP0023
      DATA (HW6(I),I=1,2)/6HSTATOR,6H ROTOR/                            OUTP0024
C                                                                       OUTP
C     CONVERT THE TABULAR OUTPUT INTO THE UNITS OF THE INPUT            OUTP
C                                                                       OUTP
      DO 200 J=1,NLINES                                                 OUTP0025
      RST(J)=CNV1*RST(J)                                                OUTP0026
      PO(J)=PO(J)/CNV2                                                  OUTP0027
      BET(J)=CNV3*BET(J)                                                OUTP0028
      P(J)=P(J)/CNV2                                                    OUTP0029
      IF (ICONV.EQ.0.AND.ISRI.LT.3) GO TO 100                           OUTP0030
      AY(J)=CNV3*AY(J)                                                  OUTP0031
      CRV(J)=CRV(J)/CNV1                                                OUTP0032
      IF (ISRI.GE.3) GO TO 150                                          OUTP0033
  100 POR(J)=POR(J)/CNV2                                                OUTP0034
      BETR(J)=CNV3*BETR(J)                                              OUTP0035
      IF (IDS.EQ.NDSTAT) GO TO 200                                      OUTP0036
  150 IF (ICONV.EQ.0.OR.(IMIX.EQ.0.AND.ICOOL.NE.2)) GO TO 200           OUTP0037
      POU(J)=POU(J)/CNV2                                                OUTP0038
      IF (ISRI.NE.1) GO TO 200                                          OUTP0039
      PORU(J)=PORU(J)/CNV2                                              OUTP0040
  200 CONTINUE                                                          OUTP0041
C                                                                       OUTP
C     PRINT THE TABULAR OUTPUT                                          OUTP
C                                                                       OUTP
      WRITE (NTAPE,300) (J,RST(J),DFLOW(J),VM(J),VX(J),VT(J),V(J),      OUTP0042
     1                  EM(J),PO(J),TO(J),BET(J),J=1,NLINES)            OUTP0043
  300 FORMAT (////82X,4(4X,8HABSOLUTE)/1X,10HSTREAMLINE,4X,             OUTP0044
     16HRADIAL,5X,9HMASS-FLOW,2X,10HMERIDIONAL,5X,5HAXIAL,7X,           OUTP0045
     25HWHIRL,5X,8HABSOLUTE,6X,5HMACH ,2(7X,5HTOTAL),7X,4HFLOW/         OUTP0046
     33X,6HNUMBER,5X,8HPOSITION,4X,8HFUNCTION,4(4X,8HVELOCITY),         OUTP0047
     45X,6HNUMBER,5X,8HPRESSURE,3X,11HTEMPERATURE,4X,5HANGLE/           OUTP0048
     516X,4H(IN),6X,9H(LBM/SEC),5X,4(5H(FPS),7X),12X,5H(PSI),           OUTP0049
     66X,7H(DEG R),6X,5H(DEG)//(5X,I2,5X,F10.4,3X,F10.5,1X,             OUTP0050
```

```
     74(F10.3,2X),2X,F8.5,3X,F9.4,4X,F8.2,3X,F8.3))
      IF (ISRI.LT.3) GO TO 400
      WRITE (NTAPE,350) (J,P(J),T(J),AY(J),CRV(J),J=1,NLINES)
  350 FORMAT (////37X,10HSTREAMLINE/1X,10HSTREAMLINE,4X,
     12(6HSTATIC,6X),1X,5HSLOPE,4X,10HSTREAMLINE/3X,6HNUMBER,
     25X,8HPRESSURE,3X,11HTEMPERATURE,4X,5HANGLE,5X,9HCURVATURE/
     316X,5H(PSI),6X,7H(DEG R),6X,5H(DEG),5X,8H(PER IN)//
     4(5X,I2,6X,F9.4,4X,F8.2,4X,F8.3,3X,F10.5))
      IF (ICONV.EQ.0) GO TO 1800
      GO TO 1500
  400 IF (ICONV.EQ.1) GO TO 600
      WRITE (NTAPE,450) (HW5(I),I=1,14)
  450 FORMAT (////36X,2A6,34X,4(4X,8HRELATIVE)/1X,10HSTREAMLINE,4X,
     16HSTATIC,6X,6HSTATIC,3X,4A6,4X,5HBLADE,5X,8HRELATIVE,6X,
     24HMACH,8X,2(5HTOTAL,7X),4HFLOW/3X,6HNUMBER,5X,8HPRESSURE,3X,
     311HTEMPERATURE,4A6,2X,2(8HVELOCITY,4X),7H NUMBER,5X,
     48HPRESSURE,3X,11HTEMPERATURE,4X,5HANGLE/16X,5H(PSI),6X,
     57H(DEG R),2X,4A6,4X,2(5H(FPS),7X),12X,5H(PSI),6X,7H(DEG R),
     66X,5H(DEG)//)
      WRITE (NTAPE,500) (J,P(J),T(J),WYE(J),BREFF(J),U(J),VR(J),
     1                  EMR(J),POR(J),TOR(J),BETR(J),J=1,NLINES)
  500 FORMAT((5X,I2,6X,F9.4,4X,F8.2,4X,F8.5,4X,F8.5,2X,2(F10.3,2X),
     12X,F8.5,3X,F9.4,4X,F8.2,3X,F8.3))
      GO TO 1800
  600 WRITE (NTAPE,450) (HW5(I),I=15,28)
      WRITE (NTAPE,650) (J,P(J),T(J),AY(J),CRV(J),U(J),VR(J),
     1                  EMR(J),POR(J),TOR(J),BETR(J),J=1,NLINES)
  650 FORMAT((5X,I2,6X,F9.4,4X,F8.2,3X,F8.3,3X,F10.5,2X,2(F10.3,2X),
     12X,F8.5,3X,F9.4,4X,F8.2,3X,F8.3))
      IF (ISRI.EQ.1) GO TO 1500
      WRITE (NTAPE,700) ISTG
  700 FORMAT (////53X, 8H** STAGE,I2,15H PERFORMANCE **)
      WRITE (NTAPE,750) (J,REACO(J),REAC(J),WYEO(J),WYE(J),BREFFO(J),
     1                  BREFF(J),EFFR(J),EFFS(J),J=1,NLINES)
  750 FORMAT (////51X,6HSTATOR,7X,5HROTOR/50X,2(8HPRESSURE,4X),
     17H STATOR,7X,2(5HROTOR,7X),5HSTAGE/13X,10HSTREAMLINE,4X,
     26HSTATOR,7X,5HROTOR,3X,2(4X,4HLOSS,4X),2(2X,9HBLADE ROW,1X),
     32(1X,10HISENTROPIC,1X)/15X,7HNUMBER ,2(4X,8HREACTION),2X,
     42(1X,11HCOEFFICIENT),1X,4(10HEFFICIENCY,2X)//(17X,I2,6X,
     52(F9.5,3X),1X,6(F8.5,4X)))
      WRITE (NTAPE,800)
  800 FORMAT (////52X,28H* MASS-AVERAGED QUANTITIES *)
      WRITE (NTAPE,850) BREA(IBR-1),BREAP,SWP,STEP,SSEP,SJSP
  850 FORMAT (//43X,30HSTATOR BLADE-ROW EFFICIENCY = ,F9.5//44X,
     129HROTOR BLADE-ROW EFFICIENCY = ,F9.5//60X,13HSTAGE WORK = ,
     2F9.3,12H BTU PER LBM    /48X,25HSTAGE TOTAL EFFICIENCY = ,
     3F9.5/47X,26HSTAGE STATIC EFFICIENCY = ,F9.5/39X,
     434HSTAGE BLADE- TO JET-SPEED RATIO = ,F9.5)
      IF (IDS.NE.NDSTAT) GO TO 1500
      IF (NSPOOL.GT.1) GO TO 950
      WRITE (NTAPE,900)
  900 FORMAT (1H1////36X,60H*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGE
     1D QUANTITIES) ***)
      GO TO 1050
  950 WRITE (NTAPE,1000) ISAV
 1000 FORMAT (1H1////35X,9H*** SPOOL,I2,51H PERFORMANCE SUMMARY (MASS-A
     1VERAGED QUANTITIES) ***)
 1050 IF (NSTG.EQ.1) GO TO 1150
      WRITE (NTAPE,1100) (I,BREA(2*I-1),BREA(2*I),SW(I),STE(I),SSE(I),
     1                   SJS(I),I=1,NSTG)
 1100 FORMAT (////100X,5HSTAGE/39X,6HSTATOR,7X,5HROTOR,12X,
```

```
     12(7X,5HSTAGE),5X,9HBLADE- TO/28X,5HSTAGE,2X,2(3X,9HBLADE-ROW),    OUTP0112
     25X,5HSTAGE,7X,5HTOTAL,6X,6HSTATIC,5X,9HJET-SPEED/27X,             OUTP0113
     38HNUMBER  ,2(2X,10HEFFICIENCY),5X,4HWORK,3X,2(2X,10HEFFICIENCY),  OUTP0114
     45X,5HRATIO/62X,9H(BTU/LBM)//(29X,I2,6X,2(F9.5,3X),F9.3,           OUTP0115
     53(3X,F9.5)))                                                      OUTP0116
 1150 WRITE (NTAPE,1200) SPW,SPP,SPTT,SPTS,SPTE,SPSE,SPJS               OUTP0117
 1200 FORMAT (////60X,13HSPOOL WORK = ,F9.3,12H BTU PER LBM/            OUTP0118
     159X,14HSPOOL POWER = ,F9.2,3H HP/34X,                             OUTP0119
     239HSPOOL TOTAL- TO TOTAL-PRESSURE RATIO = ,F9.5/33X,              OUTP0120
     340HSPOOL TOTAL- TO STATIC-PRESSURE RATIO = ,F9.5/48X,             OUTP0121
     425HSPOOL TOTAL EFFICIENCY = ,F9.5/47X,                            OUTP0122
     526HSPOOL STATIC EFFICIENCY = ,F9.5/39X,                           OUTP0123
     634HSPOOL BLADE- TO JET-SPEED RATIO = ,F9.5)                       OUTP0124
      IF (NSPOOL.EQ.1.OR.ISAV.NE.NSPOOL) GO TO 1800                     OUTP0125
      WRITE (NTAPE,1250)                                                OUTP0126
 1250 FORMAT (1H1/////35X,62H*** OVERALL PERFORMANCE SUMMARY (MASS-AVERAOUTP0127
     1GED QUANTITIES) ***)                                              OUTP0128
      WRITE (NTAPE,1300) OW,OTT,OTS,OTE,OSE,OJS                         OUTP0129
 1300 FORMAT (////58X,15HOVERALL WORK = ,F9.3,12H BTU PER LBM/32X,      OUTP0130
     141HOVERALL TOTAL- TO TOTAL-PRESSURE RATIO = ,F9.5/31X,            OUTP0131
     242HOVERALL TOTAL- TO STATIC-PRESSURE RATIO = ,F9.5/46X,           OUTP0132
     327HOVERALL TOTAL EFFICIENCY = ,F9.5/45X,                          OUTP0133
     428HOVERALL STATIC EFFICIENCY = ,F9.5/37X,                         OUTP0134
     536HOVERALL BLADE- TO JET-SPEED RATIO = ,F9.5)                     OUTP0135
      GO TO 1800                                                        OUTP0136
 1500 IF (IMIX.EQ.0.AND.ICOOL.NE.2) GO TO 1800                          OUTP0137
      IF (ISRI.NE.1) GO TO 1700                                         OUTP0138
      WRITE (NTAPE,1550) HW6(2),ISTG                                    OUTP0139
 1550 FORMAT (////43X, 3H** ,A6,I2,34H MIXED AND/OR COOLED QUANTITIES **OUTP0140
     1)                                                                 OUTP0141
      WRITE (NTAPE,1600) (J,POU(J),TOU(J),PORU(J),TORU(J),J=1,NLINES)   OUTP0142
 1600 FORMAT (////50X,2(8HABSOLUTE,4X),2(8HRELATIVE,4X)/37X,            OUTP0143
     110HSTREAMLINE,5X,4(5HTOTAL,7X)/39X,6HNUMBER,3X,2(2X,8HPRESSURE,   OUTP0144
     23X,11HTEMPERATURE)/46X,2(6X,5H(PSI),6X,7H(DEG R))//(41X,I2,       OUTP0145
     33X,2(3X,F9.4,4X,F8.2)))                                           OUTP0146
      GO TO 1800                                                        OUTP0147
 1700 ISTGP=ISTG+1                                                      OUTP0148
      WRITE (NTAPE,1550) HW6(1),ISTGP                                   OUTP0149
      WRITE (NTAPE,1750) (J,POU(J),TOU(J),J=1,NLINES)                   OUTP0150
 1750 FORMAT (////62X,2(8HABSOLUTE,4X)/49X,10HSTREAMLINE,5X,            OUTP0151
     12(5HTOTAL,7X)/51X,6HNUMBER,5X,8HPRESSURE,3X,11HTEMPERATURE/       OUTP0152
     264X,5H(PSI),6X,7H(DEG R)//(53X,I2,6X,F9.4,4X,F8.2))               OUTP0153
C                                                                       OUTP
C     RECONVERT THE TABULAR OUTPUT INTO A CONSISTENT SET OF UNITS       OUTP
C                                                                       OUTP
 1800 DO 2000 J=1,NLINES                                                OUTP0154
      RST(J)=RST(J)/CNV1                                                OUTP0155
      PO(J)=CNV2*PO(J)                                                  OUTP0156
      BET(J)=BET(J)/CNV3                                                OUTP0157
      P(J)=CNV2*P(J)                                                    OUTP0158
      IF (ICONV.EQ.0.AND.ISRI.LT.3) GO TO 1850                          OUTP0159
      AY(J)=AY(J)/CNV3                                                  OUTP0160
      CRV(J)=CNV1*CRV(J)                                                OUTP0161
      IF (ISRI.GE.3) GO TO 1900                                         OUTP0162
 1850 POR(J)=CNV2*POR(J)                                                OUTP0163
      BETR(J)=BETR(J)/CNV3                                              OUTP0164
      IF (IDS.EQ.NDSTAT) GO TO 2000                                     OUTP0165
 1900 IF (ICONV.EQ.0.OR.(IMIX.EQ.0.AND.ICOOL.NE.2)) GO TO 2000          OUTP0166
      POU(J)=CNV2*POU(J)                                                OUTP0167
      IF (ISRI.NE.1) GO TO 2000                                         OUTP0168
      PORU(J)=CNV2*PORU(J)                                              OUTP0169
```

```
 2000 CONTINUE                                                   OUTP017C
      RETURN                                                     OLTP0171
      END                                                        OUTP0172
```

APPENDIX XXI

SUBRØUTINE PLC

The primary function of Subroutine PLC (deckname SUB17) is to obtain those terms which are required to incorporate the loss correlation into the determination of the derivative of the square of the meridional velocity with respect to radial position. In addition, the value of the total-pressure-loss coefficients for each streamline is obtained and transferred to Subroutine DERIV.

Subroutine PLC is called by Subroutine DERIV; it, in turn, calls Subroutine I1AP1. The subroutine does not require external input and does not provide external output. The subroutine has access to blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM3/, CØMMØN/CØM4/, CØMMØN/CØM7/, CØMMØN/CØM8/, CØMMØN/CØM11/, and CØMMØN/CØM12/. The internal input transmitted through CØMMØN consists of:

AYP	BETU	BETRU	CØSA	CØSB
CØSQB	DADR	DBDRP	DBRUDR	DBUDR
DFLDR	DVRUDR	DVUDR	FACL	IJ
ISPEC	ISRI	IWRL	JJ	MEAN
NLINES	RPM	RST	TANB	U
VMP	VRU	VSQ	VTP	VU
YCØN				

The internal output transmitted through CØMMØN consists of:

WYE

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.) The internal input transmitted as arguments of the subroutine consists of:

IK RP VMSQ

The internal output transmitted as arguments of the subroutine consists of:

DWYDRP DWYVM DWYVT WYEP

Additional Fortran Nomenclature for Subroutine PLC

The following table gives the Fortran nomenclature for those symbols used in Subroutine PLC which are not part of CØMMØN.

Fortran Symbol	Symbol	Description	Units
BETUP	β_{i-1}	A value of the upstream absolute flow angle	rad
BETRUP	β'_{i-1}	A value of the upstream relative flow angle	rad
CØN1	a_1	Alternative name for YCØN(1)	--
CØN2	a_2	Alternative name for YCØN(2)	--
CØN3	a_3	Alternative name for YCØN(3)	--
CØN4	a_4	Alternative name for YCØN(4)	--
CØN5	a_5	Alternative name for YCØN(5)	--
CØN6	a_6	Alternative name for YCØN(6)	--
CØN7	a_7	Alternative name for YCØN(7)	--
CØN8	a_8	Alternative name for YCØN(8)	--
CØN9	a_9	Alternative name for YCØN(9)	--
CØSBR	$\cos\beta'_i$	Cosine of the relative flow angle	--
COSQBU	$\cos^2\beta_{i-1}$	Square of the cosine of the upstream flow angle	--
CSQBRU	$\cos^2\beta'_{i-1}$	Square of the cosine of the upstream relative flow angle	--

Fortran Symbol	Symbol	Description	Units
DADRP	dA_i/dr	A value of the derivative of the streamline angle of inclination with respect to radius	--
DBUDRP	$d\beta_{i-1}/dr$	A value of the derivative of the upstream flow angle with respect to radius	--
DBRUDP	$d\beta'_{i-1}/dr$	A value of the derivative of the upstream relative flow angle with respect to radius	--
DFUN1	df_1/dr	Derivative of term 1 of the internal loss correlation with respect to radius	per ft
DFUN2	df_{21}/dr	Component of the derivative of term 2 of the internal loss correlation with respect to radius	per ft
DFUN2A	C_{f22}	Coefficient of the dV_{mi}^2/dr component of the derivative of term 2 of the internal loss correlation with respect to radius	fps^{-2}
DFUN2B	C_{f23}	Coefficient of the dV_{ui}/dr component of the derivative of term 2 of the internal loss correlation with respect to radius	fps^{-1}
DFUN3	df_{31}/dr	Component of the derivative of term 3 of the internal loss correlation with respect to radius	per ft
DFUN3A	C_{f32}	Coefficient of the dV_{mi}^2/dr component of the derivative of term 3 of the internal loss correlation with respect to radius	fps^{-2}
DFUN3B	C_{f33}	Coefficient of the dV_{ui}/dr component of the derivative of term 3 of the internal loss correlation with respect to radius	fps^{-1}
DFUN4	df_{41}/dr	Component of the derivative of term 4 of the internal loss correlation with respect to radius	per ft

Fortran Symbol	Symbol	Description	Units
DFUN4A	C_{f42}	Coefficient of the dV_{mi}^2/dr component of the derivative of term 4 of the internal loss correlation with respect to radius	fps^{-2}
DFUN4B	C_{f43}	Coefficient of the dV_{ui}/dr component of the derivative of term 4 of the internal loss correlation with respect to radius	fps^{-1}
DVRUDP	dV'_{i-1}/dr	A value of the derivative of the upstream relative velocity with respect to radius	per sec
DVUDRP	dV_{i-1}/dr	A value of the derivative of the upstream absolute velocity with respect to radius	per sec
DWYDRP	$(dY_i/dr)_1$	Component of the derivative of the internal loss correlation with respect to radius	per ft
DWYVM	C_{y2}	Coefficient of the dV_{mi}^2/dr component of the internal loss correlation with respect to radius	fps^{-2}
DWYVT	C_{Y3}	Coefficient of the dV_{ui}/dr component of the internal loss correlation with respect to radius	fps^{-1}
FUN1	f_1	Term 1 of the internal loss correlation	--
FUN2	f_2	Term 2 of the internal loss correlation	--
FUN3	f_3	Term 3 of the internal loss correlation	--
FUN4	f_4	Term 4, the denominator, of the internal loss correlation	--
IK		Index of the stage of the Runge-Kutta solution	--
PARM1		Grouping of items related to term 4 of the internal loss correlation	--

Fortran Symbol	Symbol	Description	Units
PARM2		Grouping of items related to term 3 of the internal loss correlation	--
PARM4		Grouping of items related to term 2 of the internal loss correlation	per ft
REACP	R_i	A value of the reaction at a blade row exit	--
RP	r_i	A value of the radial position	ft
SINSQ	$sin^2\beta_i$ or $sin^2\beta_i'$	Square of the sine of either the absolute or the relative flow angle	--
TANA	$tan A_i$	Tangent of the streamline angle of inclination	--
TANBR	$tan\,\beta_i'$	Tangent of the relative flow angle	--
TANBRU	$tan\,\beta_{i-1}'$	Tangent of the upstream relative flow angle	--
TANBU	$tan\,\beta_{i-1}$	Tangent of the upstream absolute flow angle	--
UP	u_i	A value of the blade velocity	fps
VMSQ	V_{mi}^2	Square of the meridional velocity	fps^2
VP	V_i	A value of the absolute velocity	fps
VRP	V_i'	A value of the relative velocity	fps
VRSQ	$V_i'^2$	Square of the relative velocity	fps^2
VRUP	V_{i-1}'	A value of the upstream relative velocity	fps
VTRP	$V_{ui}-u_i$	A value of the relative tangential velocity	fps
VUP	V_{i-1}	A value of the upstream absolute velocity	fps
WYEP	Y_i	A value of the pressure-loss coefficient	fps

Internal Structure

The subroutine performs the calculations of step 37 of the Analysis Procedure. This particular step calculates the component parts of the derivative of the total-pressure-loss coefficient with respect to radius for the assumed correlation. The computed quantities are ultimately combined with others in Subroutine DERIV to form the coefficients of the second equation of a set of three which are then solved to obtain the meridional velocity gradient. Step 37 is broken down into substeps to compute the constituent parts of the loss coefficient derivative for the various options. The sequence numbers corresponding to the substeps are identified in the following table.

Substep of Analysis Procedure	Sequence Number
1.1	0157 - 0160
1.2	0030 - 0031
1.3	0024 - 0025
2.11 and 4.1.1	0043 - 0047
2.12 and 4.1.2	0048 - 0065
2.2.1, 2.22, and 2.4	0136 - 0146
2.3 and 4.2	0087 - 0114
3.1	0081 - 0086
3.2	0068 - 0080
3.3	0131 - 0135
3.4	0117 - 0130

A listing of the subroutine is given on the following page(s).

```
$*
$IBFTC SUB17   LIST,DECK,M94
C                                                                        PLC
C     PLC - INCORPORATE CORRELATION OF PRESSURE LOSS COEFFICIENT         PLC
C           INTO SOLUTION OF RADIAL EQUILIBRIUM                          PLC
C                                                                        PLC
      SUBROUTINE PLC(RP,VMSQ,IK,WYEP,DWYDRP,DWYVM,DWYVT)                 PLC 0001
      COMMON IBR,ICOEF,ICONV,ICOOL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,        PLC 0002
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,          PLC 0003
     2NSTG,NTAPE,NTUBES                                                  PLC 0004
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),            PLC 0005
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),      PLC 0006
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),          PLC 0007
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)                  PLC 0008
      COMMON /COM3/BETRU(17),BETU(17),BREFFO(17),DPOUDR(17),             PLC 0009
     1DPRUDR(17),DTRUDR(17),POO(17),POO2(17),PORU(17),POU(17),           PLC 0010
     2REACO(17),TOO(17),TOO2(17),TORU(17),TOU(17),UU(17),                PLC 0011
     3VRU(17),VTU(17),VU(17),WYEO(17)                                    PLC 0012
      COMMON /COM4/FLW(17),FLWP,HP,RPM,RST(17),WFN(17)                   PLC 0013
      COMMON /COM7/COT60,DFLWT,DFLWTO,EMMAX,EMMIN,ICNT,JJ,               PLC 0014
     1JJP,MEAN,RATIO,VMM,VMMO,VMMOO                                      PLC 0015
      COMMON /COM8/DADR(17),DBDR(17),DPODR(17),DTODR(17),                PLC 0016
     1DVTDR(17),DWYDR(17)                                                PLC 0017
      COMMON /COM11/ AYP,COSA,COSB,COSQB,DBDRP,DBRUDR(17),DBUDR(17),     PLC 0018
     1DFLDR(17),DVRUDR(17),DVUDR(17),IJ,TANB,VMP,VSQ,VTP                 PLC 0019
      COMMON /COM12/ CON1,CON2,CON3,CON4,CON5,CON6,CON7,CON8,CON9        PLC 0020
      IF (ISPEC.EQ.1) GO TO 140                                          PLC 0021
      GO TO (110,130,150,120,150),IK                                     PLC 0022
  110 IF (JJ.NE.MEAN) GO TO 150                                          PLC 0023
  120 FUN1=FACL(IJ)                                                      PLC 0024
      DFUN1=DFLDR(IJ)                                                    PLC 0025
      GO TO 150                                                          PLC 0026
  130 CALL I1AP1(RP,FUN1,RST,FACL,NLINES)                                PLC 0027
      CALL I1AP1(RP,DFUN1,RST,DFLDR,NLINES)                              PLC 0028
      GO TO 150                                                          PLC 0029
  140 FUN1=1.0                                                           PLC 0030
      DFUN1=0.0                                                          PLC 0031
  150 IF (ISRI.EQ.2) GO TO 500                                           PLC 0032
      GO TO (160,180,200,170,200),IK                                     PLC 0033
  160 IF (JJ.NE.MEAN) GO TO 200                                          PLC 0034
  170 BETUP=BETU(IJ)                                                     PLC 0035
      DBUDRP=DBUDR(IJ)                                                   PLC 0036
      GO TO 190                                                          PLC 0037
  180 CALL I1AP1(RP,BETUP,RST,BETU,NLINES)                               PLC 0038
      CALL I1AP1(RP,DBUDRP,RST,DBUDR,NLINES)                             PLC 0039
  190 COSQBU=COS(BETUP)**2                                               PLC 0040
      TANBU=TAN(BETUP)                                                   PLC 0041
  200 IF (IWRL.EQ.0) GO TO 250                                           PLC 0042
      FUN2=TANB-TANBU                                                    PLC 0043
      DFUN2=DBDRP/COSQB-DBUDRP/COSQBU                                    PLC 0044
      FUN4=CON4+CON5*COSB                                                PLC 0045
      DFUN4=-CON5*TANB*DBDRP*COSB                                        PLC 0046
      GO TO 350                                                          PLC 0047
  250 GO TO (260,280,300,270,300),IK                                     PLC 0048
  260 IF (JJ.NE.MEAN) GO TO 300                                          PLC 0049
  270 DADRP=DADR(IJ)                                                     PLC 0050
      GO TO 290                                                          PLC 0051
  280 CALL I1AP1(RP,DADRP,RST,DADR,NLINES)                               PLC 0052
  290 TANA=TAN(AYP)                                                      PLC 0053
  300 TANB=VTP/(COSA*VMP)                                                PLC 0054
      COSB=1.0/SQRT(1.0+TANB**2)                                         PLC 0055
```

```
      SINSQ=1.0-COSB**2
      FUN2=TANB-TANBU
      DFUN2=TANB*TANA*DADRP-DBUDRP/COSQBU
      DFUN2A=-0.5*TANB/VMSQ
      DFUN2B=TANB/VTP
      FUN4=CON4+CON5*COSB
      PARM1=-CON5*SINSQ*COSB
      DFUN4=PARM1*TANA*DADRP
      DFUN4A=-0.5*PARM1/VMSQ
      DFUN4B=PARM1/VTP
  350 GO TO (360,380,400,370,400),IK
  360 IF (JJ.NE.MEAN) GO TO 400
  370 VUP=VU(IJ)
      DVUDRP=DVUDR(IJ)
      GO TO 400
  380 CALL IIAP1(RP,VUP,RST,VU,NLINES)
      CALL IIAP1(RP,DVUDRP,RST,DVUDR,NLINES)
  400 VP=SQRT(VSQ)
      REACP=VUP/VP
      IF (REACP.LT.CON3) GO TO 410
      FUN3=CON1+CON2*(REACP-CON3)
      DFUN3=CON2*DVUDRP/VP
      DFUN3A=-0.5*CON2*REACP/VSQ
      DFUN3B=2.0*VTP*DFUN3A
      GO TO 700
  410 FUN3=CON6+CON7*REACP**CON8
      PARM2=CON7*CON8*REACP**(CON8-1.0)
      DFUN3=PARM2*DVUDRP/VP
      DFUN3A=-0.5*PARM2*REACP/VSQ
      DFUN3B=2.0*VTP*DFUN3A
      GO TO 700
  500 GO TO (510,530,550,520,550),IK
  510 IF (JJ.NE.MEAN) GO TO 550
  520 BETRUP=BETRU(IJ)
      DBRUDP=DBRUDR(IJ)
      UP=U(IJ)
      DADRP=DADR(IJ)
      GO TO 540
  530 CALL IIAP1(RP,BETRUP,RST,BETRU,NLINES)
      CALL IIAP1(RP,DBRUDP,RST,DBRUDR,NLINES)
      UP=RPM*RP
      CALL IIAP1(RP,DADRP,RST,DADR,NLINES)
  540 TANA=TAN(AYP)
      CSQBRU=COS(BETRUP)**2
      TANBRU=TAN(BETRUP)
  550 VTRP=VTP-UP
      TANBR=VTRP/(COSA*VMP)
      COSBR=1.0/SQRT(1.0+TANBR**2)
      SINSQ=1.0-COSBR**2
      FUN2=TANBRU-TANBR
      PARM4=RPM/VTRP
      DFUN2=DBRUDP/CSQBRU-TANBR*(TANA*DADRP-PARM4)
      DFUN2A=0.5*TANBR/VMSQ
      DFUN2B=-TANBR/VTRP
      FUN4=CON4+CON5*COSBR
      PARM1=-CON5*SINSQ*COSBR
      DFUN4=PARM1*(TANA*DADRP-PARM4)
      DFUN4A=-0.5*PARM1/VMSQ
      DFUN4B=PARM1/VTRP
      GO TO (610,630,650,620,650),IK
  610 IF (JJ.NE.MEAN) GO TO 650
```

```
  620 VRUP=VRU(IJ)                                                      PLC 0117
      DVRUDP=DVRUDR(IJ)                                                 PLC 0118
      GO TO 650                                                         PLC 0119
  630 CALL I1AP1(RP,VRUP,RST,VRU,NLINES)                                PLC 0120
      CALL I1AP1(RP,DVRUDP,RST,DVRUDR,NLINES)                           PLC 0121
  650 VRSQ=VRSQ+VTRP**2                                                 PLC 0122
      VRP=SQRT(VRSQ)                                                    PLC 0123
      REACP=VRUP/VRP                                                    PLC 0124
      IF (REACP.LT.CON3) GO TO 660                                      PLC 0125
      FUN3=CON1+CON2*(REACP-CON3)                                       PLC 0126
      DFUN3A=-0.5*CON2*REACP/VRSQ                                       PLC 0127
      DFUN3=CON2*DVRUDP/VRP-2.0*DFUN3A*RPM*VTRP                         PLC 0128
      DFUN3B=2.0*VTRP*DFUN3A                                            PLC 0129
      GO TO 700                                                         PLC 0130
  660 FUN3=CON6+CON7*REACP**CON8                                        PLC 0131
      PARM2=CON7*CON8*REACP**(CON8-1.0)                                 PLC 0132
      DFUN3A=-0.5*PARM2*REACP/VRSQ                                      PLC 0133
      DFUN3=PARM2*DVRUDP/VRP-2.0*DFUN3A*RPM*VTRP                        PLC 0134
      DFUN3B=2.0*VTRP*DFUN3A                                            PLC 0135
  700 IF (FUN2) 710,720,750                                             PLC 0136
  710 FUN2=-FUN2                                                        PLC 0137
      DFUN2=-DFUN2                                                      PLC 0138
      IF (ISRI.EQ.1.AND.IWRL.NE.0) GO TO 750                            PLC 0139
      DFUN2A=-DFUN2A                                                    PLC 0140
      DFUN2B=-DFUN2B                                                    PLC 0141
      GO TO 750                                                         PLC 0142
  720 DFUN2=0.0                                                         PLC 0143
      IF (ISRI.EQ.1.AND.IWRL.NE.0) GO TO 750                            PLC 0144
      DFUN2A=0.0                                                        PLC 0145
      DFUN2B=0.0                                                        PLC 0146
750   WYEP=FUN1*FUN2*FUN3/FUN4                                          PLC 0147
      IF(WYEP.GT.CON9) GO TO 875                                        PLC 0148
      DWYDRP=WYEP*(DFUN1/FUN1+DFUN2/FUN2+DFUN3/FUN3-DFUN4/FUN4)         PLC 0149
      IF(ISRI.EQ.1.AND.IWRL.NE.0) GO TO 850                             PLC 0150
      DWYVM=WYEP*(DFUN2A/FUN2+DFUN3A/FUN3-DFUN4A/FUN4)                  PLC 0151
      DWYVT=WYEP*(DFUN2B/FUN2+DFUN3B/FUN3-DFUN4B/FUN4)                  PLC 0152
      GO TO 900                                                         PLC 0153
850   DWYVM=WYEP*DFUN3A/FUN3                                            PLC 0154
      DWYVT=WYEP*DFUN3B/FUN3                                            PLC 0155
      GO TO 900                                                         PLC 0156
875   WYEP=CON9                                                         PLC 0157
      DWYDRP=0.0                                                        PLC 0158
      DWYVM=0.0                                                         PLC 0159
      DWYVT=0.0                                                         PLC 0160
  900 IF (IK.EQ.1.OR.IK.EQ.5) WYE(JJ)=WYEP                              PLC 0161
      RETURN                                                            PLC 0162
      END                                                               PLC 0163
```

APPENDIX XXII

SUBRØUTINE LCNV

The function of Subroutine LCNV (deckname SUB18) is to obtain new estimates of the streamline values of the total-pressure-loss coefficient based on the old estimates and the specified values of kinetic-energy-loss coefficient.

Subroutine LCNV is called by the main routine; it does not call any other subroutines. The subroutine does not require external input and does not provide external output. Internal input and output are transmitted through blank CØMMØN, CØMMØN/CØM1/, CØMMØN/CØM2/, and CØMMØN/CØM6/. The internal input consists of:

GAMA1	GAMA2	GJCP12	ICØNV	IDLETE
ISRI	NLINES	T	TØ	TØLWY
U	VM	VT	WYE	WYK

The internal output consists of:

WYE

(These symbols are described in the appropriate sections of the CØMMØN Fortran Nomenclature.)

Additional Fortran Nomenclature for Subroutine LCNV

Fortran Symbol	Symbol	Description	Units
CØN6		Damping factor used in the reestimation of the pressure-loss coefficients	--
PRAT	$(p_i/P_{oi})_j$ or $(p_i/P'_{oi})_j$	A streamline value of either the static-to-absolute total pressure ratio or the static-to-relative total pressure ratio at a blade row exit	--

Fortran Symbol	Symbol	Description	Units
TØP	$(T_{oi})_j$	A streamline value of the absolute total temperature	deg R
TP	T_{ij}	A streamline value of the static temperature	deg R
TRAT	$(T_i/T_{oi})_j$ or $(T_i/T'_{oi})_j$	A streamline value of either the static-to-absolute total temperature ratio or the static-to-relative total temperature ratio at a blade row exit	--
VMSQ	$(V_{mi}^2)_j$	A streamline value of the square of the meridional velocity	fps^2
VRSQ	V'^2_{ij}	A streamline value of the square of the relative velocity	fps^2
VSQ	V^2_{ij}	A streamline value of the square of the absolute velocity	fps^2
VTP	$(V_{ui})_j$	A streamline value of the tangential velocity	fps
VTRP	$(V_u)_j - u_{ij}$	A streamline value of the relative tangential velocity	fps
WYKP	e_{ij}	A streamline value of the kinetic-energy-loss coefficient	--
WYN	Y_{ij}	A streamline value of the pressure-loss coefficient which has been obtained from the specified kinetic-energy-loss coefficient	--
WYP	$Y_{ij,new}$	A new estimate of a streamline value of the pressure-loss coefficient	--

Internal Structure

The subroutine performs step 80 of the Analysis Procedure. A Fortran listing is given on the following page(s).

```
$*
$IBFTC SUB18   LIST,DECK,M94
C
C     LCNV - OBTAIN NEW ESTIMATES OF THE PRESSURE LOSS COEFFICIENT
C            FROM KINETIC-ENERGY LOSS COEFFICIENTS
C
      SUBROUTINE LCNV
      COMMON IBR,ICOEF,ICONV,ICCCL,IDLETE,IDS,ILLOOP,ILOOP,ILOSS,
     1IMIX,ISAV,ISON,ISPEC,ISRI,ISTG,IWRL,NDSTAT,NLINES,NSPOOL,
     2NSTG,NTAPE,NTUBES
      COMMON /COM1/AY(17),BET(17),BETR(17),BREFF(17),CRV(17),
     1DFLOW(17),EFFR(17),EFFS(17),EM(17),EMR(17),FACL(17),GRND(17),
     2P(17),PO(17),POR(17),REAC(17),T(17),TO(17),TOR(17),U(17),
     3V(17),VM(17),VR(17),VT(17),VX(17),WYE(17),WYK(17)
      COMMON /COM2/CP(17),CP1,CP2,CP3,CP4,CP5,EJCP1,EJCP2,
     1GAMA1,GAMA2,GAMA3,GAMB1,GAMC1,GAMD2,GAMD3,GAMD4,GAMD5,
     2GAM1,GAM2,GAM3,GAM4,GAM5,GASC,GGG1,GJCP1,GJCP12,GJCP2,
     3GJCP22,GJCP32,GJCP42,GJCP52
      COMMON /COM6/CNV1,CNV2,CNV3,CNV5,EJAY,GO,PI,TOLWY
      DATA CON6/0.0/
      DO 300 J=1,NLINES
      IF (IDLETE.EQ.0) GO TO 200
      IF (ISRI.EQ.2) GO TO 100
      TOP=TO(J)
      GO TO 150
  100 TOP=TOR(J)
  150 TP=T(J)
      TRAT=TP/TOP
      GO TO 250
  200 VMSQ=VM(J)**2
      VTP=VT(J)
      TOP=TO(J)
      VSQ=VMSQ+VTP**2
      TRAT=1.0-VSQ/(GJCP12*TOP)
      IF (ISRI.EQ.1) GO TO 250
      VTRP=VTP-U(J)
      VRSQ=VMSQ+VTRP**2
      TRAT=1.0/(1.0+VRSQ/(GJCP12*TRAT*TOP))
  250 PRAT=TRAT**GAMA1
      WYKP=WYK(J)
      WYN=(PRAT*((1.0-WYKP)/(TRAT-WYKP))**GAMA1-1.0)/(1.0-PRAT)
      WYP=(1.0-CON6)*WYN+CON6*WYE(J)
      IF (ICONV.EQ.0) GO TO 300
      IF (WYP.EQ.0.0) GO TO 270
      IF (ABS(WYE(J)/WYP-1.0).LE.TOLWY) GO TO 300
      GO TO 280
  270 IF (ABS(WYE(J)).LE.TOLWY) GO TO 300
  280 ICONV=0
  300 WYE(J)=WYP
      RETURN
      END
```