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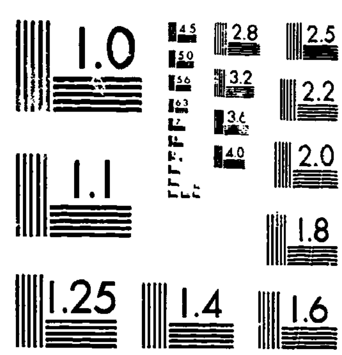

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AXIAL-FLOW PUMP DESIGN DIGITAL COMPUTER PROGRAM

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TECHNICAL REPORT

AXIAL-FLOW PUMP DESIGN DIGITAL COMPUTER PROGRAM

P. Kavanagh
M. J. Miller

September 1970

This project is partially supported by the National Aeronautics and Space Administration through NASA Grant NGL 16-002-005 and is a part of the Turbomachinery Components Research Program of the Engineering Research Institute.

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ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY AMES

SUMMARY

A Fortran computer program for design of axial-flow pumps based on conventional radial equilibrium blade-element analysis is presented. A program listing and examples of computed results obtained on an IBM System 360/model 65 computer are included.

Flow determination is based on axisymmetric analysis at between-blade-row stations, accounting for blade-element head losses and for streamline radial shift. A Runge-Kutta procedure is used for numerical integration of the simple radial equilibrium equation. The program input for single or multiple blade row configurations consists of machine flow coefficient, annulus inner and outer radii at computing stations, blade row design specifications, and loss correlations. Computed results consist of blade element velocity diagram and mass-averaged flow parameters. Parametric variations for design studies can be made by supplying variable design specifications and loss correlations per blade row.

An outline of the flow analysis method and a complete documentation of the program are given.

CONTENTS

FIGURES

NOTATIONS

c	blade chord
d	nondimensional streamline radial spacing, $\Delta r/r_t$
D	diffusion factor, Eq. (7a)
D_{eq}	equivalent diffusion ratio, Eq. (7b)
g_c	force-mass conversion factor
h	static head
H	total head
$\mathcal{H}$	blade wake form factor
j_{lim}	number of streamlines for radial equilibrium solution
m	meridional streamline coordinate
n	normal coordinate
r_m	radius of curvature of meridional streamline
R	reaction, ratio of static to total head rise
s	blade spacing
T_ϕ	flow continuity iteration tolerance
T_{H_L}	head-loss iteration tolerance
U	blade tangential speed
V	flow velocity
% Pass. Hgt.	percent passage height measured from outer casing
β	flow angle (see Fig. 2)
γ	blade stagger angle, angle between chord and axial direction (see Fig. 2)
η	hydraulic efficiency
θ	blade-wake momentum thickness
κ	blade angle, angle between tangent to blade camber line and axial direction (see Fig. 2)

λ	whirl coefficient, V_θ/U_t
ν	stream function, Eq. (6)
ξ	radius ratio, r/r_t
σ	blade solidity, c/s
ϕ	flow coefficient, V_m/U_t
φ^o	blade camber angle (see Fig. 2)
ψ	head rise coefficient $g_c(H_2 - H_1)/U_t^2$
$\overline{\omega}$	total head loss coefficient, $2g_c(H'_{2,i} - H'_2)/(V'_1)^2$

Subscripts

h	inner casing
i	ideal
L	loss
m	meridional component
t	reference value, outer casing
θ	tangential component
1	blade row entering station
2	blade row leaving station

Superscripts

'	relative to blade row
*	nondimensional
-	mass-averaged

AXIAL-FLOW PUMP DESIGN DIGITAL COMPUTER PROGRAM

INTRODUCTION

Blade-element methods of design and analysis have been successfully used in the axial-flow compressor field for many years. The increasingly higher performance of the axial-flow compressor in response to the continuing efforts spent in developing practical design procedures based on blade-element methods has been most rewarding, particularly in the field of aircraft gas turbines.

During about the past 10 years the Lewis Research Center of the National Aeronautics and Space Administration (NASA) has conducted research on the application of similar blade-element methods to the hydrodynamic design of blade rows for axial-flow pumps[1*]. Concurrent with these programs, the Engineering Research Institute at Iowa State University has conducted investigations in the blade-element approach to performance prediction of axial-flow pumps for off-design, as well as for design operating conditions[2]. As a result of these research efforts, a considerable amount of theoretical and experimental information has been obtained regarding the design of highly loaded stages. Based on this information a FORTRAN IV computer program has been written which computes design velocity diagrams and performance parameters for multistage axial-flow pumps. Development of this program has been partially supported by NASA through Grant NGL 16-002-005.

Flow determination is based on axisymmetric analysis at between-blade-row stations, accounting for blade-element head losses and for streamline radial shift. All calculations are made using nondimensional parameters. A Runge-Kutta procedure is used for numerical integration of the simple

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*Superscript numbers refer to references at end of report.

radial equilibrium equation. Program input for single or multiple blade row configurations consists of machine average flow coefficient, hub and casing radii at computing stations, blade row design specifications, and loss correlations. Output in the form of velocity diagram and mass-averaged flow results is obtained. Parametric variations for design studies can be made by supplying variable design specifications and loss correlations per blade row.

An outline of the flow analysis method, a program listing, and examples of computed results obtained on an IBM System 360/model 65 computer are given.

BASIS OF THE PROGRAMMED FLOW ANALYSIS AND DESIGN METHOD

The basis for the flow analysis contained in the programmed procedures is the so-called blade-element flow model[3]. This model for the flow in rotating or stationary blade rows is characterized by that found in two-dimensional (2-D) stationary blade cascades. The form of the empiricism used to account for head losses through a blade row is based on correlation procedures for real fluid effects in low-speed, 2-D stationary cascade experimental results. Similar notations for the flow characteristics and geometries in 2-D cascade and in blade-element flows are obviously employed.

Radial equilibrium and continuity requirements are applied in the analysis at between-blade-row stations in the meridional plane. Steady, axisymmetric, noncavitating flow across a blade row is assumed. Also, the flow at computing stations is considered locally inviscid. The intersection of meridional-plane streamlines with the blades, as shown in Fig. 1, define the blade-elements for a blade row. Figure 2 shows a set of blade elements and corresponding cascade notation. The blade-to-blade flow thus implied in Fig. 2 is on stream surfaces of revolution generated by rotating the meridional streamlines about the machine axis. This approach forms the basis for incorporation of empirical loss correlations in the analysis.

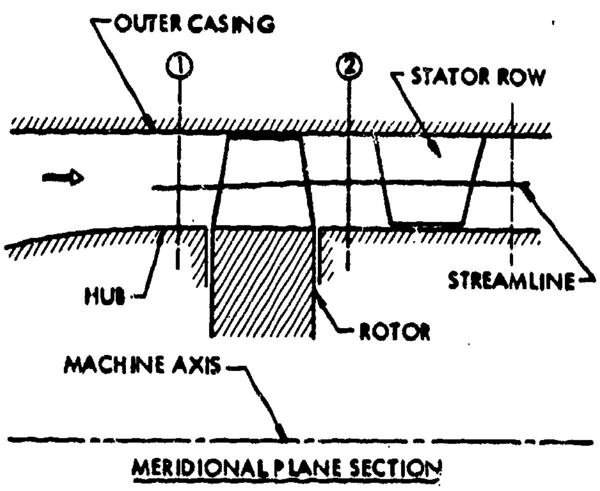


Fig. 1. Meridional plane section and streamlines for typical main pressure-producing stage in an axial-flow pump.

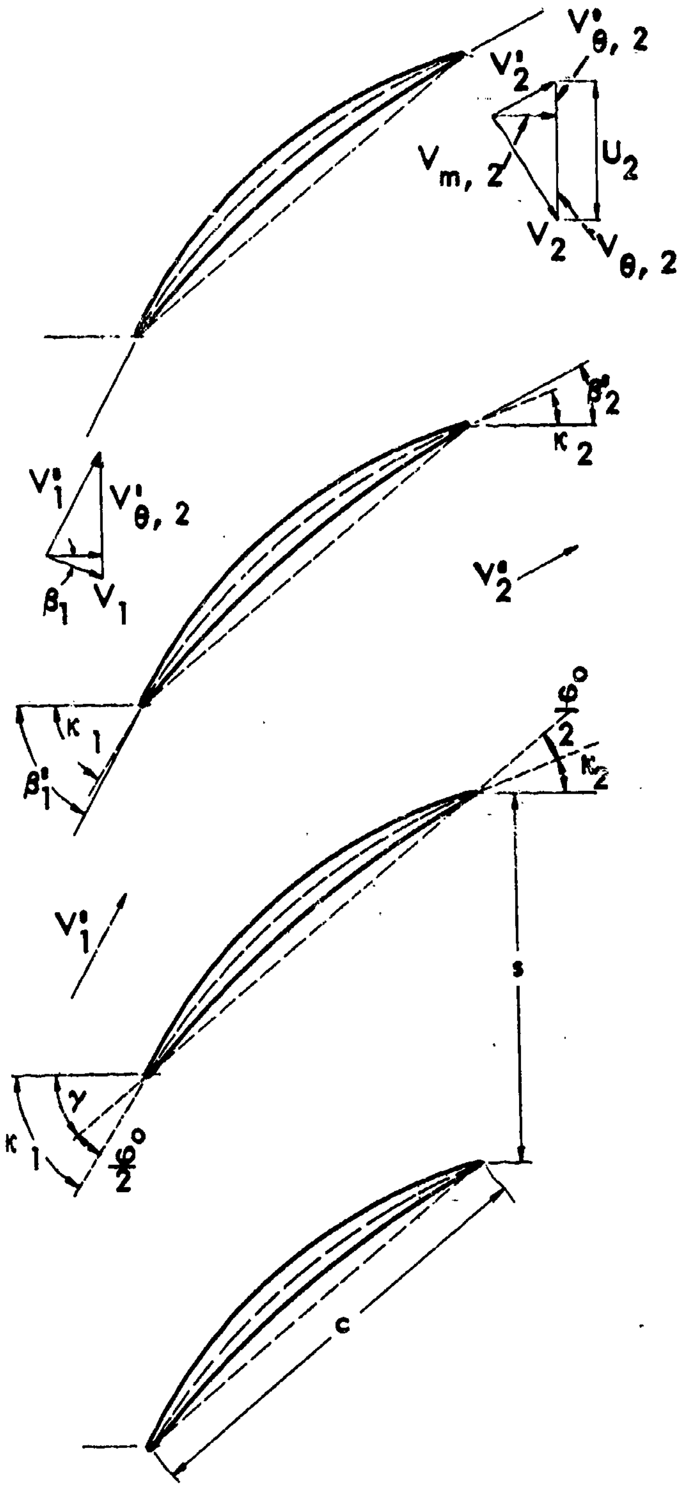


Fig. 2. Typical blade elements and accompanying velocity diagram rotation.

It is seen, then, that the meridional-plane analysis provides the detailed radial distributions of the leaving flow, given the entering flow patterns along with stipulated design requirements for the blade row. This analysis provides the design velocity diagram requirements which must be met in the next step, namely the design or selection of blade elements which actually form the blades.

At a computing station, and for each determined streamline, the equation for radial equilibrium must be satisfied. This equation is obtained from Euler's equation for steady flow without body forces. In terms of coordinates (θ, m, n), in which θ-constant is the meridional plane, and n- and m-surfaces are stream surfaces and surfaces orthogonal, respectively, the radial equilibrium equation is[4]:

$$g_c \frac{\partial h}{\partial n} = \frac{V_\theta^2}{r} \frac{\partial r}{\partial n} + \frac{V_m^2}{r_m} . \tag{1}$$

Here h is static head, V_θ and V_m are flow velocity components, r and r_m are respectively machine radius and meridional streamline radius of curvature. In the usual case for main pressure-producing stages in axial-flow pumps, the effects of streamline slope and curvature are of secondary importance and are hence neglected. However, streamline radius change across a blade row is accounted for simply enough by continuity considerations (as explained later). In this situation Eq. (1) reduces to a simplified form, and the calculation station across the annulus may be taken as a radial line. Furthermore, to eliminate actual size and speed of the pump from consideration, dimensionless static head coefficient, $h^* = \frac{g_c h}{U_t^2}$, whirl coefficient, $\lambda = \frac{V_\theta}{U_t}$, and radius ratio, $\xi = \frac{r}{r_t}$ can be defined in terms of reference radius and blade speed values (r_t, U_t). With these coefficient definitions, and with the assumption of zero streamline slope and curvature, then at the blade-row leaving station 2, Eq. (1) becomes

$$\frac{dh_2^*}{d\xi_2} = \frac{\lambda_2^2}{\xi_2} . \tag{2}$$

This equation for radial equilibrium is, in general, a nonlinear differential equation with the right-hand side a complicated function of the blade-row design specifications, loss estimation, flow continuity requirements, and streamline shift. The integration of Eq. (2) for static head distribution across the annulus requires numerical procedures, including interpolations of various data tables and iterative computing loops for losses and continuity requirements. Further discussion of these numerical procedures is given later when details of the computer program are presented.

Selection of blade row design specifications as functions of leaving radius are made as follows: for rotors, radial distribution of ideal head-rise (or work) coefficient, ψ_i ; and for stators, radial distribution of leaving angle, β_2 . In addition, blade-row radial distribution of solidity, σ, is specified. With Euler's turbine equation, relating angular momentum change for a particular streamline across a rotor, leaving whirl for use in Eq. (2) can be expressed as

$$\lambda_2 = \frac{\psi_i + \xi_1\lambda_1}{\xi_2} . \qquad (3a)$$

In the case of stators, the leaving whirl is expressed as

$$\lambda_2 = \phi_2 \tan \beta_2 , \qquad (3b)$$

in which $\phi_2 (= \frac{V_{m,2}}{U_t})$ is local leaving flow coefficient.

Total head coefficient on a streamline in leaving flow is found from the head value for entering flow, the ideal head-rise coefficient (zero for stators), and the total head loss coefficient as determined for the flow past the blade element:

$$H_2^* = H_1^* + \psi_i - H_L^* . \qquad (4)$$

The local leaving flow coefficient is, according to the Bernoulli equation:

$$\phi_2 = [2(H_2^* - h_2^*) - \lambda_2^2]^{1/2} . \qquad (5)$$

The boundary condition imposed upon integration of Eq. (2) is the hub streamline value of static head, which in turn satisfies the flow continuity requirement. Here, with definition of a stream function ν, the particular value

$$\nu(\text{at tip}) = \int_{\xi_{2,h}}^{\xi_{2,t}} \phi_2 \xi d\xi \qquad (6)$$

must match that determined for the flow entering the blade row. Also, the stream function values at various radii, ξ_2, ranging from the hub to outer casing (or tip) serve to identify particular blade elements and thereby provide means of radial adjustment of streamlines across the blade row.

To determine head losses in the flow past blade elements, loss correlations (independent of solidity, inlet angle, and camber) in terms of blade wake momentum thickness, $(\theta/c)_2$, or in terms of loss parameter, $\bar{\omega} \cos \beta_2'/2\sigma$, which is an approximation of blade wake momentum thickness are used. The three sets of correlations shown in Fig. 3 were obtained from available experimental rotor[5], stator[3], and two-dimensional cascade data[6]. The data are most valid for NACA 65-Series, double circular-arc, and similar sections. Such correlations contain some uncertainty in particular applications; therefore good judgment should be exercised in interpreting results obtained using them. Two loading parameters, D and D_{eq}[6,7], establishing equivalent diffusion ratio values and expressed in terms of the design velocity triangles and solidity were used:

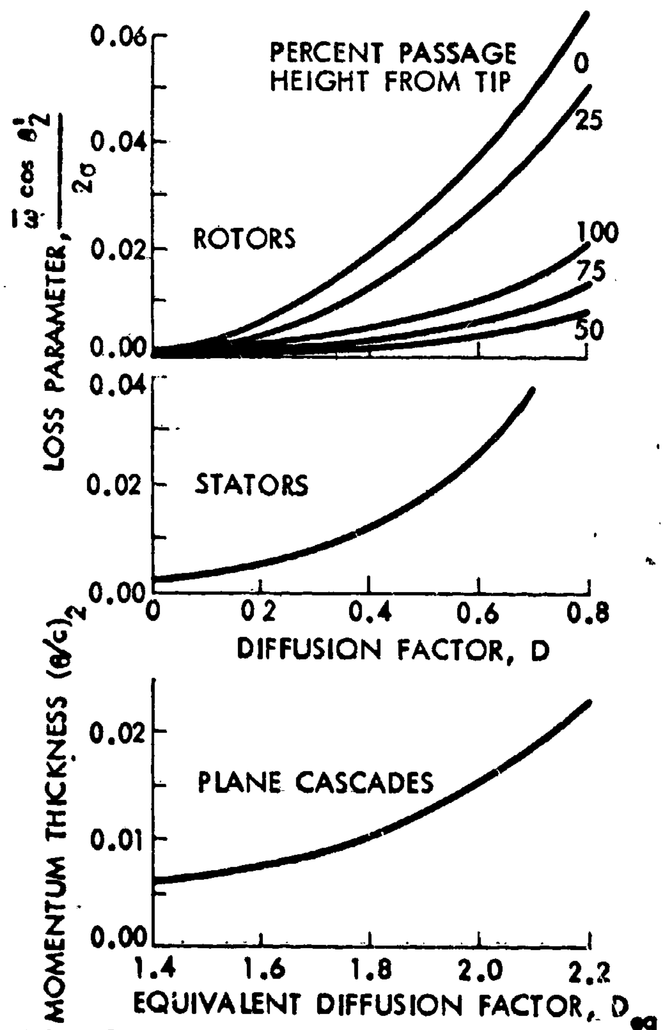


Fig. 3. Empirical loss correlations.

$$D = 1 - \frac{V_2'}{V_1'} \pm \frac{r_1 V_{\theta,1}' - r_2 V_{\theta,2}'}{(r_1 + r_2)\sigma\, V_1'} \tag{7a}$$

and

$$D_{eq} = \frac{\cos \beta_2'}{\cos \beta_1'} \left[1.12 \pm 0.61 \frac{\cos^2 \beta_1'}{\sigma} \left(\frac{r_1}{r_2} \tan \beta_1' - \frac{V_{m,2}}{V_{m,1}} \tan \beta_2'\right)\right] \frac{V_{m,1}}{V_{m,2}} . \tag{7b}$$

The $\pm$ signs in Eq. (7) apply to rotors or stators, respectively. These signs comply with adopted sign conventions that wheel speed U is always positive, absolute whirl is positive in the direction of U, relative whirl is positive in the direction opposite U, and that

$$\beta = \tan^{-1} \frac{V_\theta}{V_m} , \text{ or } \beta' = \tan^{-1} \frac{V_\theta'}{V_m} .$$

In using plane cascade correlations the loss coefficient, $\overline{\omega}$, needed in the loss calculations is computed from the relation[6]

$$\overline{\omega} = 2\left(\frac{\theta}{c}\right)_2 \frac{\sigma}{\cos \beta_2'} \frac{\cos^2 \beta_1'}{\cos^2 \beta_2'} \frac{2\mathcal{H}_2}{3\mathcal{H}_2 - 1} \left[1 - \left(\frac{\theta}{c}\right)_2 \frac{\sigma \mathcal{H}_2}{\cos \beta_2'}\right]^{-3} . \tag{8}$$

Here the blade wake form factor, H_2, is taken as 1.08. The loss coefficient, $\overline{\omega}$, in Eq. (8) is defined by

$$\overline{\omega} = \frac{2 g_c H_L}{(V_1')^2} \tag{9}$$

from which dimensionless head-loss can be expressed as

$$H_L^* = \frac{\overline{\omega}(V_1'/U_t)^2}{2} . \tag{10}$$

Additional calculations and definitions, not essential to the radial equilibrium solution:

$$\text{blade-row reaction, } R = \frac{h_2^* - h_1^*}{H_2^* - H_1^*} \quad (R = 0 \text{ for stators}) \tag{11}$$

actual head rise coefficient,

$$\psi = \psi_i - H_L^* \qquad (\psi_i = 0 \text{ for stators}) \qquad (12)$$

hydraulic efficiency, $\eta = \dfrac{\psi}{\psi_i}$ $\qquad (\eta = 0$ for stators$) \qquad (13)$

COMPUTER PROGRAM CAPABILITY AND UTILIZATION

A Fortran IV program based on the blade-element procedure just presented was written with the capability to provide design parameter studies. (A listing of the program is given in Appendix A.) The program allows arbitrary assignment of design flow coefficient, blade-row design specifications, and blade-row head-loss reference data for either single or multiple blade-row configurations. Blade-row design specifications consist of prescribed radial variation of solidity and ideal head-rise coefficient (rotors) or leaving flow angle (stators).

Variation of annulus hub and outer casing radius through the pump is possible (remembering, of course, that streamline slope and curvature are neglected) through the blade-row design specifications which are inputed as functions of blade-row leaving radii, ranging from hub to outer casing. An arbitrary number of sets of blade-row design specifications for a given flow rate and annulus configuration can be supplied as input at a given blade-row calculation station. In multiple blade-row configurations the leaving flow for the last supplied set of design conditions for a blade-row serves as input flow for the following blade row. At the inlet to the machine, the radial distributions of flow coefficient (setting the design flow for a given rotational speed) and dimensionless total head coefficient are input data. Also, if it is desired to introduce prewhirl into the first blade row (along with attendant flow coefficient distribution satisfying radial equilibrium), a zero-loss "pseudo" stator row may be inserted in front of the first rotor row and considered like any other blade row in the machine.

The numerical calculation of the flow proceeds on a streamline-by-streamline basis from the hub to outer casing at successive blade-row computing stations through the machine. A brief overview of the program is given in Fig. 4. A detailed description of the program is given in the "Computer Program Description" section of this report.

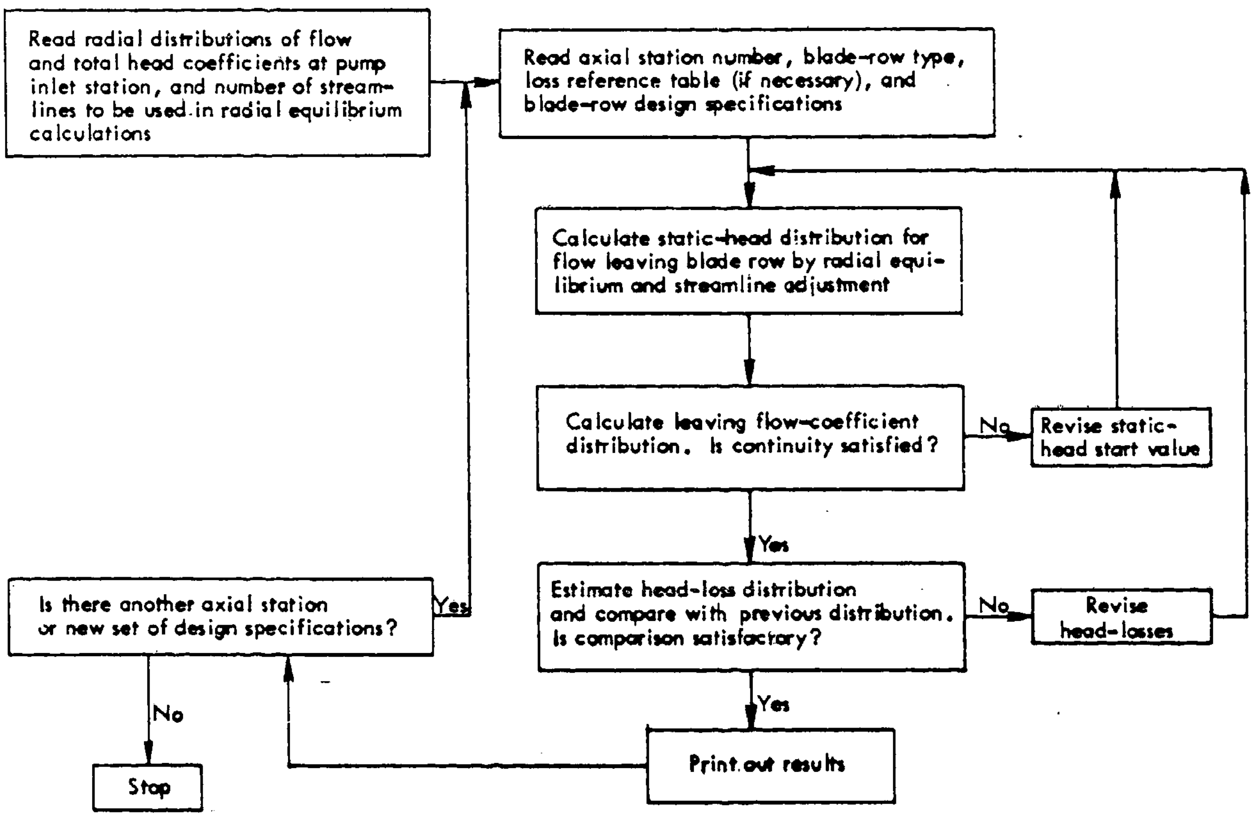


Fig. 4. General scheme of computer program radial equilibrium solution method.

INPUT LOAD DESCRIPTION

The following describes the input data cards 1-9 required. All data are read under format specification FORMAT (10F7.0). Note that cards 5a, 6a, or cards 5b, 6b are read only when new tables of reference loss data are inputed. Card parametric sets 4, (5, 6), 7,8 are read for each blade-row computing station or new set of blade-row design conditions. (Refer to the "Computer Program Description" section of this report for Fortran variable definitions. See also example input load, Appendix B.)

Note that a single reference pair, radius r_t and blade speed U_t, is used in all nondimensional definitions. Caution should be taken to use these reference values consistently in preparation of input data for single or multiple blade-row configurations. Normally r_t, U_t would be those values at the inlet to the first rotor blade row of the machine.

Precautions should be taken that independent variable elements of data reference tables inputed are spaced to adequately describe the desired functional relationship. This requirement arises because these data are interpolated in the course of the problem solution. Roughly, where rapid function variation is indicated, closer spacing of independent variable elements should be used. These independent variable elements should cover the expected range of the independent variable and are required to be monotone nondecreasing.

Limit values: j_{lim}, T_ϕ, T_{H_L}

Card 1. JLIM, TPHI, THL (Restriction; $3 \leq$ JLIM ≤ 11)

Inlet station: $\phi(\xi)$, $\Pi^*(\xi)$

Card 2. KLIM (Restriction; $3 \leq k_{lim} \leq 11$)

Card(s) 3. XI(1), PHI(1), HTP(1),..., XI(KLIM), PHI(KLIM), HTP(KLIM)

(Restrictions; XI(1) = $\xi_{h,inlet}$, XI(KLIM) = $\xi_{t,inlet}$)

Blade-row identification (first identification made): station no.; type no.; type loss

Card 4a. STANO, TYPNO, TYPLOS {Restrictions; STANO = 1, TYPNO = 1 (rotor), = 2 (stator), TYPLOS = 0 $\left[\frac{\bar{\omega} \cos \beta_2'}{2\sigma} = f\,(D, \%\ \text{Pass. Hgt.})\right]$, $\neq 0$ $[\theta/c = f\,(D_{eq})]$}

Blade-row identification (not first identification): station no.; type no.; if loss, type loss

Card 4b. STANO, TYPNO, IFLOS, TYPLOS [Restrictions; STANO $\geq$ 1, IFLOS (= 0, cards 5, 6 follow; $\neq$ 0 cards 5, 6 do not follow)]

Loss table: $\frac{\bar{\omega} \cos \beta_2'}{2\sigma}$ (D, % Pass. Hgt.)

Card 5a. KLIMP, LLIMP. (Restrictions; $3 \leq$ KLIMP ≤ 12, $3 \leq$ LLIMP ≤ 6)

Card(s) 6a. DFACB(1), PPHFTB(1), OMGB(1,1), DFACB(1), PPHFTB(2), OMGB(1,2),..., DFACB(KLIMP), PPHFTB(LLIMP), OMGB(KLIMP, LLIMP)

Loss table: $\theta/c\ (D_{eq})$

Card 5b. KLIM (Restriction; $3 \leq$ KLIM ≤ 11)

Card(s) 6b. DEQB(1), THACB(1),..., DEQB(KLIM), THACB(KLIM)

Rotor blade-row design specifications: $\psi_1(\xi)$, $\sigma(\xi)$:

Card 7a. KLIM (Restriction; $3 \leq$ KLIM ≤ 11)

Card(s) 8a. YXI(1), Y(1), YSIG(1),...YXI(KLIM), Y(KLIM), YSIG(KLIM) [Restrictions; YXI(1) = ξ_h, YXI(KLIM) = ξ_t]

Stator blade-row design specifications: $\beta_2(\xi)$, deg., $\sigma(\xi)$:

Card 7b. KLIM (Restriction; $3 \leq$ KLIM ≤ 11)

Card(s) 8b. YXI(1), Y(1), YSIG(1),..., YXI(KLIM), Y(KLIM), YSIG(KLIM) [Restrictions; YXI(1) = ξ_h, YXI(KLIM) = ξ_t]

Sentinel card (end of input):

Card 9. (Blank card)

PROGRAM OUTPUT DESCRIPTION

Computed Output

The computer program prints output in the following arrangement. (See example listings, Appendix B. Refer also to the "Computer Program Description" section for Fortran variable definitions.):

Limit values j_{lim}, T_{ϕ}, T_{H_L} used in the problem solution.

Inputed inlet station $\phi(\xi)$, $H^*(\xi)$ data tables.

Computed inlet station average flow coefficient, $\bar{\phi}$.

Blade-row computing station identification [per each input parametric card set 4, (5, 6), 7, 8].

Inputed loss coefficient reference data tables, $\frac{\bar{\omega}\cos\beta_2'}{2\sigma}$ (D, % Pass. Hgt.), or θ/c (D_{eq}).

Total number of loss computation and continuity-radial equilibrium computation iterations made.

Computed streamline results for blade-row entering flow: % Pass. Hgt., ξ_1, ϕ_1, λ_1, β_1, β_1', H_1^*, ν (normalized).

Computed streamline results for blade-row leaving flow: % Pass. Hgt., ξ_2, ϕ_2, λ_2, β_2, β_2', H_2^*, h_2^*, ν (normalized).

Computed streamline results for blade-row leaving flow: % Pass. Hgt., ξ_2, ψ, ψ_i, R, η, H_L^*, $\bar{\omega}$, $\frac{\bar{\omega}\cos\beta_2'}{2\sigma}$, D, D_{eq}.

Annulus mass-averaged computing station values: ϕ_2, $\bar{\psi}$, $\bar{\psi}_i$, $\bar{\eta}$.

The blade element results are printed out following a streamline through each blade row. In a multi-blade-row configuration, however, the same streamlines are not used for every blade row. (A given streamline could be traced through the machine by using a constant value of stream function ν at each calculation station.)

Abnormal Problem Completions

Abnormal problem completions are noted by printing out the following messages (refer also to the "Computer Program Description" section, Flow Charts 4, 5, 11 and 12, and to program listing, Appendix A):

"EPS(1), EPS(2), EPS(3), YS(1), YS(2), YS(3) Cont. Failed" (last 3 sets of continuity errors and best estimate h_2^* hub values; continuity requirements not satisfied within 5 radial-equilibrium, continuity iterations)

"$\nu_1, \nu_2, \ldots \nu_{jlim}$" (last best solution after 5 radial-equilibrium, continuity iterations for normalized stream function distribution across annulus)

"Stalled Flow-Abort" (at least one streamline flow coefficient $\phi_2 \leq 0$; program operation aborted)

"Loss failed HLOSSP(1), YHLOSS(1),..., HLOSSP(JLIM), UHLOSS(JLIM)" (loss solution failed to converge within 25 iterations; last 2 distributions across annulus of blade-element head losses)

"Incorrect array size in FIT1D, JP = XXX"

"Incorrect array size in FIT2D, IP = XXX, JP = XXX, JL = XXX"

COMPUTER PROGRAM DESCRIPTION

The computer program comprises a MAIN program and additional subroutines RUNGK1, RUNGK2, LOSS, OUTPUT, MAVE, FIT1D and FIT2D operating under the control of MAIN. A program listing is presented in Appendix A. Also graphic description of the program is given in the following Flow Charts 1 – 12.

In the following, the primary objectives and the major aspects of the numerical procedures involved in the main program and subroutines are presented.

Program MAIN

Inputing of data (limit parameters, inlet station flow conditions, blade-row design specifications and loss reference tables) is accomplished in MAIN (see list of program variables and arrays and Flow Charts 1 – 5, pp. 23 – 27). The inlet flow conditions PHI1B(K), XLM1B(K) = 0, HTP1B(K), XI1B(K) and stream function distribution PHI1BB(K) to the first blade row are computed for the assigned number of streamlines from the given inlet station flow, PHI(K), HTP(K).

Next, leaving flow conditions from the blade row, PSI(J) [or BTA(J)], PHI(J), HLOSSP(J), PHIBB(J), SIG(J) are initialized, and start value for static head at the hub HP(1) is obtained. The radial equilibrium solution is arranged in terms of two iteration loops: (1) head-loss calculation, and nested within, (2) radial equilibrium and flow continuity calculation. The continuity-requirement and head-loss revision calculations are performed in MAIN, with dependent calculations made in subroutines RUNGK1, RUNGK2, LOSS, and FIT1D.

To satisfy continuity, up to five sets of three tries for HP(1) with corresponding radial equilibrium solution and normalized stream function error,

$$EPS(K) = YYB(JLIM) - 1$$

are attempted. The normalized stream function YYB is obtained by quadrature of the local flow coefficient using trapezoidal rule[8]. (Trapezoidal rule is also used to obtain other quadratures wherever required in the program.) Each EPS(K) is compared with the given tolerance value, T_{ϕ}. On the basis of three solutions within a set, the best estimate HP(1) for the next set of three tries is interpolated for zero stream function error (XEPS = 0) in FIT1D.

In the head-loss calculation loop, the absolute value of the difference in previous HLOSSP(K) and YHLOSS(K) loss distributions is compared with the given tolerance value T_{H_L}. To revise the loss distribution for the next loss calculation iteration the following equation is used:

$$HLOSSP(K) = HLOSSP(K)_{old} + XJOE\ [YHLOSS(K) - HLOSSP(K)_{old}] \quad (14)$$

in which XJOE is a variable "damping" factor.

Finally, for multiple blade row calculations, the determined leaving flow parameters are transferred streamline by streamline as reference tables for the flow entering the following blade row:

$$XI1B(I) = XI(I),\ XLM1B(I) = XLM(I),\ PHI1B(I) = PHI(I),\ HTP1B(I) = HTP(I),\ PHI1BB(J) = PHIBB(I). \quad (15)$$

Note that these data tables act only as reference for the inlet flow [as functions of the PHI1BB(J) table] to the next blade row. The inlet flow corresponding to the blade exit streamlines is determined in the course of radial equilibrium solution for the next blade row by reference to the data in Eqs. (15).

Program MAIN Variables

A	leaving whirl coefficient at rotor hub, or difference between ideal leaving total head coefficient and whirl dynamic head coefficient at rotor hub
D	the radial distance between streamlines leaving blade row, d
DD	D/2
EPSP	increment in estimated static head coefficient at hub
I	a streamline index
IIN	card reader reference number
IOUT	printer reference number
J	input table index
JLIM	number of streamlines, j_{lim}
JPX	number of pairs of hub static head coefficient and streamline function error interpolated to obtain improved estimate of hub static head coefficient
JQ	stated dimension size of all computed blade-element arrays
K	an index
KK	JLIM-1
KLIM	number of radii at which blade design specifications are given
KLIMP	number of D-factor or D_{eq} values in loss correlation tables
KN	radial equilibrium and continuity solution index
KNCT	radial equilibrium and continuity total iteration counter
LJ	input table index
LL	input table index
LLIMP	number of spanwise positions at which loss correlations are supplied
LLK	LOK

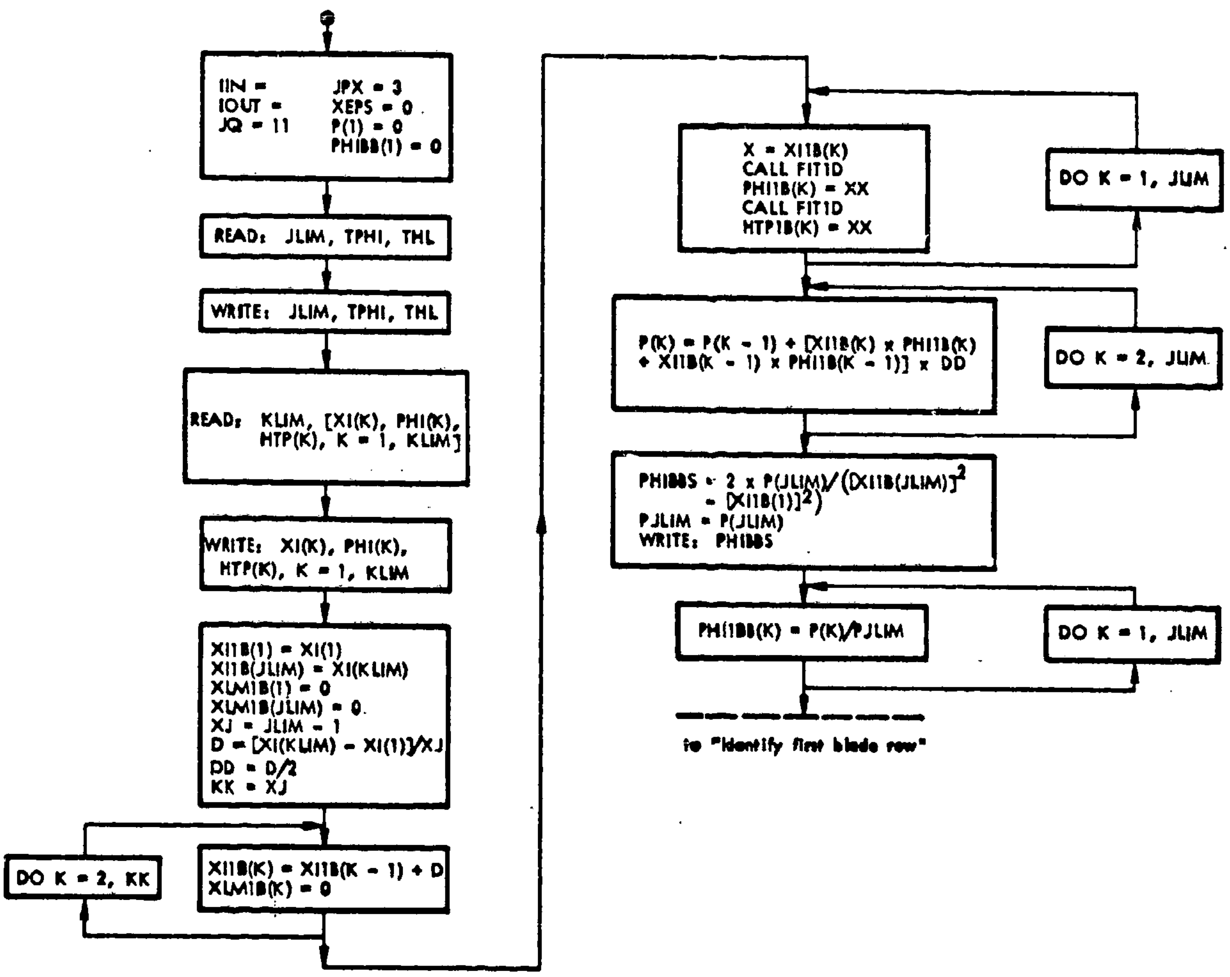
LOK	loss iteration index
PHIBBS	machine average inlet flow coefficient
PJLIM	machine nondimensional flow rate
STANO	axial computing station number
THL	head-loss iteration tolerance, T_{H_L}
TIFLOS	head-loss correlation table input indicator
TPHI	flow continuity iteration tolerance, T_ϕ
TYPLOS	head-loss correlation table type indicator
TYPNO	blade row type indicator
X	read and call list variable
XEPS	interpolate to determine estimated hub static head coefficient for zero stream function error
XJ	JLIM - 1
XJOE	damping factor for estimated head loss revision
XPHI	initialized value of leaving flow coefficient
XX	read and call list variable
YHP	interpolated estimate of hub static head coefficient for zero stream function error
YSTANO	axial computing station number

Program MAIN Arrays

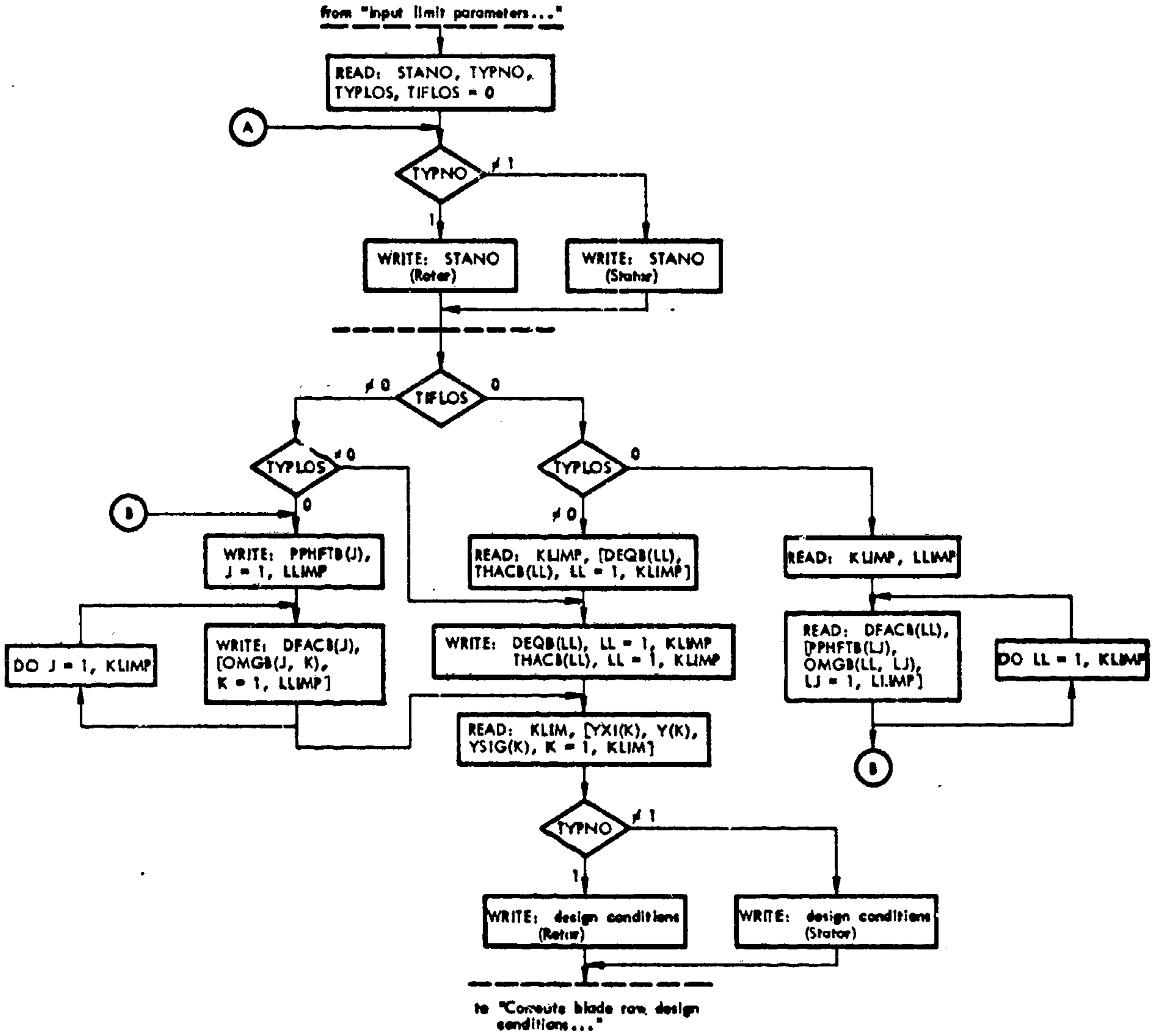
BTA	leaving absolute flow angle, β_2
BTAP	leaving relative flow angle, β'_2
BTA1	entering absolute flow angle, β_1
BTA1P	entering relative flow angle, β'_1
DEQ	D_{eq}
DEQB	input table of D_{eq}
DFAC	diffusion factor, D

DFACB	input table of D
EPS	normalized stream function error
HLOSSP	H_L^*
HP	h_2^*
HTP	input table of H^* at machine inlet station, or H_2^*
HTP1	H_1^*
HTP1B	reference table of H_1^*
OMG	$\bar{\omega}$
OMGB	input table of $\frac{\bar{\omega} \cos \beta_2'}{2\sigma}$
P	nondimension flow rate between hub and given radius at machine inlet station
PHI	input table of ϕ_1 at machine inlet station, or ϕ_2
PHIBB	blade row exit station stream function, ν
PHI1	ϕ_1
PHI1B	reference table of ϕ_1
PHI1BB	blade row inlet station stream function, ν
PPHFTB	input table of % Pass. Hgt.
PSI	ψ_1
SIG	σ
THACB	input table of $(\theta/c)_2$
VPUT	V_2'/U_t
VUT	V_2/U_t
V1PUT	V_1'/U_t
V1UT	V_1/U_t
XI	input table of ξ at machine inlet station, or ξ_2
XI1	ξ_1
XI1B	reference table of ξ_1

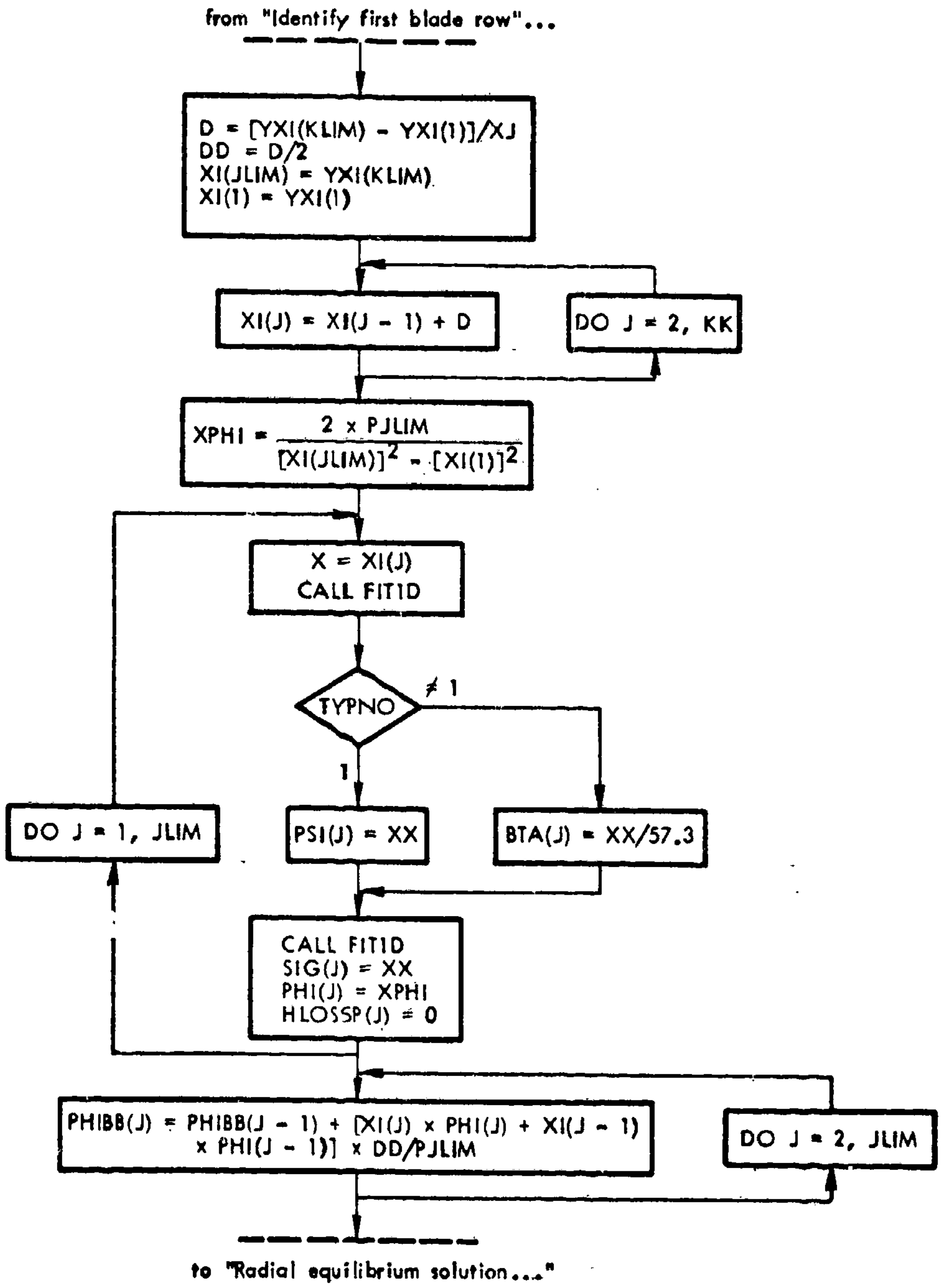
XLM	λ_2
XLMP	λ_2'
XLM1	λ_1
XLM1B	reference table of λ_1
XLM1P	λ_1'
Y	read variable for ψ_i and β_2
YHLOSS	latest estimate of H_L^*
YS	estimates of $h_{2,h}^*$
YSIG	input table of σ
YXI	input table of ξ_2
YYB	blade row exit station stream function, ν



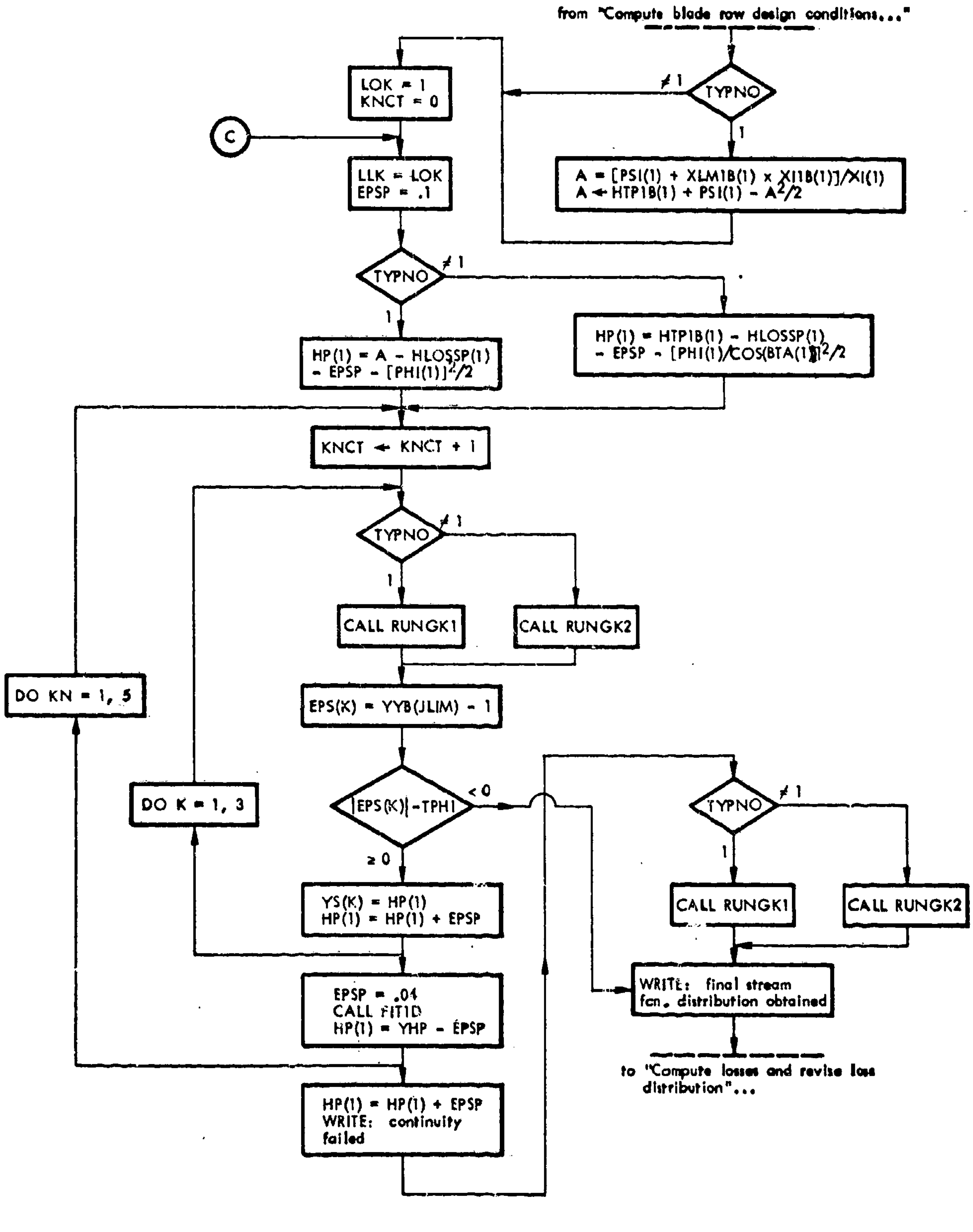
Flow Chart 1. Program segment "Input limit parameters and calculate inlet station flow conditions" of program MAIN.



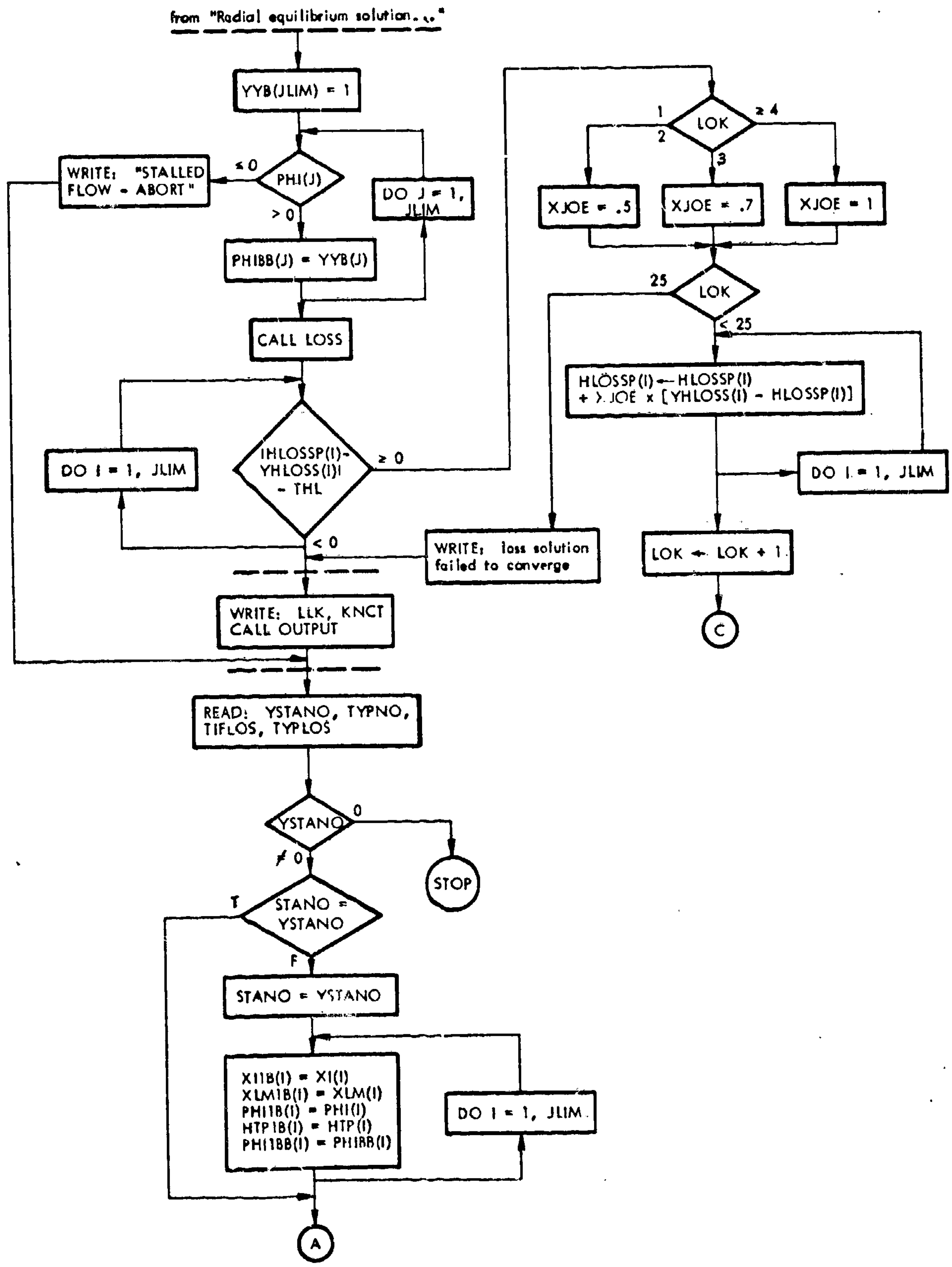
Flow Chart 2. Program segments "Identify first blade row" and "Input loss tables, blade-row design condition tables" of program MAIN.



Flow Chart 3. Program segment "Compute blade-row design conditions and initialized leaving flow conditions" of program MAIN.



Flow Chart 4. Program segment "Radial equilibrium solution for blade row leaving flow with existing loss distribution" of program MAIN.



Flow Chart 5. Program segments "Compute losses and revise loss distribution," "Compute additional results and print answers," and "Read next problem and transfer leaving flow results (if necessary) as input to next blade row" of program MAIN (concluded).

Subroutine RUNGK1

This subroutine determines the radial equilibrium solution for a rotor, i.e., Y(J), HTP(J), and YYB(J), given the entering flow conditions, head-loss distribution HLOSSP(J), prior continuity solution stream function distribution PHIBB(J), and initial value static head Y(1). This solution is obtained by integration of Eq. (2), using constant streamline radial spacing, d, across the annulus and a fourth-order Runge-Kutta method[8], and by accounting for streamline shift across the blade row.

A total of j_{lim} streamlines is used, equally spaced from hub to outer casing at station 2 (blade row leaving flow). In the integration process, a "working" radius X is used; interpolations at X for PSIS and prior solution stream function value XPX are made, followed by interpolations XI1S at XPX and XLM1S, HTP1S at XI1S. Leaving whirl XLMS is computed from Eq. (3a). Z is the "working" right-hand side of Eq. (2) during the integration process. Y and YY correspond respectively to h_2^* and ϕ_2, and YYB is tentative normalized stream function ν_2 (until continuity is satisfied).

Note that YY on a streamline is arbitrarily set equal to zero if flow reversal tendency is indicated by the square of YY being negative. Also, as is necessarily the case, the Runge-Kutta procedure must satisfy the continuity requirement (as a boundary condition) exterior to the integration process itself. This in effect linearizes Eq. (2) during any one integration across the annulus; in this case the Runge-Kutta form is analogous to Simpson's rule[8].

RUNGK1 Variables

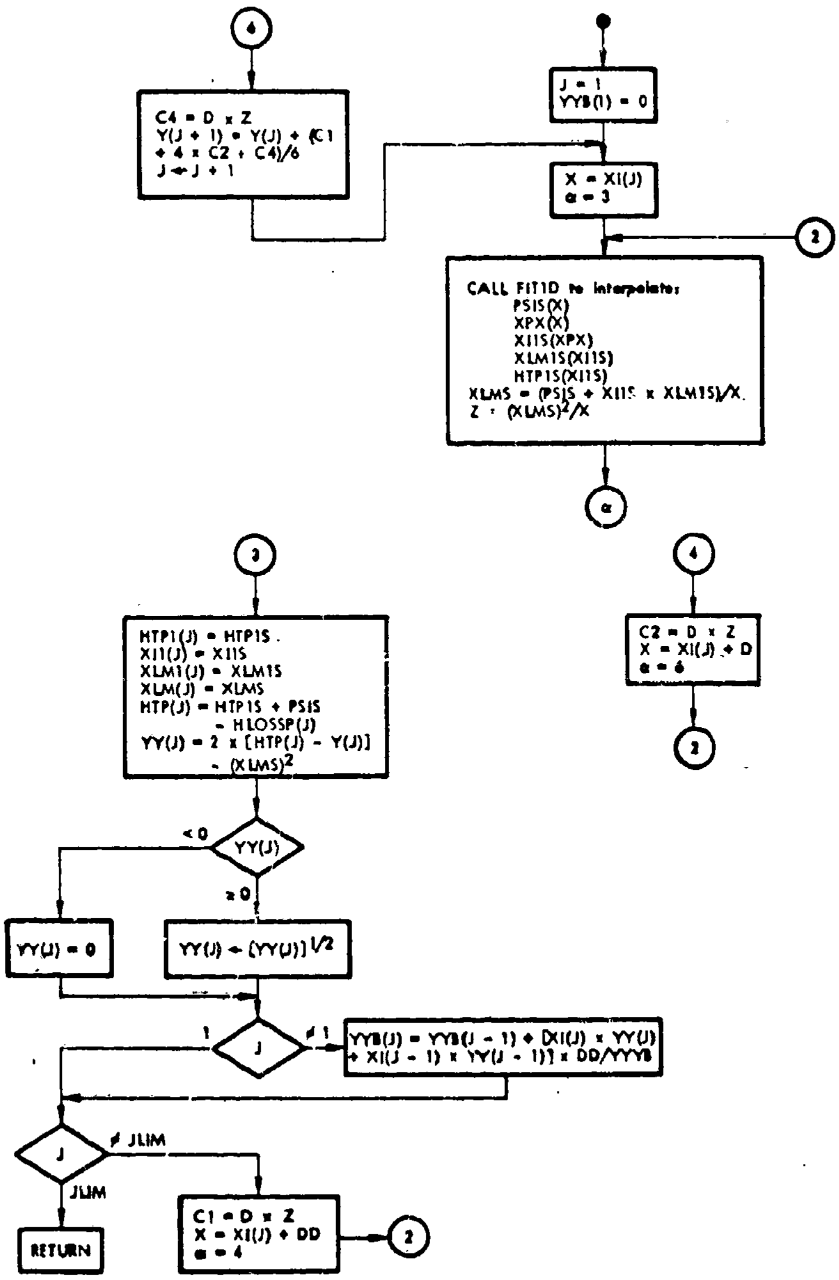
C1	coefficient in Runge-Kutta formula for integration of Eq. (2)
C2	coefficient in Runge-Kutta formula for integration of Eq. (2)

C4	coefficient in Runge-Kutta formula for integration of Eq. (2)
D	d
DD	D/2
HTP1S	H_1^*
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
N	branching index
PSIS	ψ_i
X	ξ_2
XI1S	ξ_1
XLMS	λ_2
XLM1S	λ_1
XPX	ν
YYYB	normalizing factor for stream function
Z	right-hand side of Eq. (2)

RUNCK1 Arrays

HLOSSP	H_L^*
HTP	H_2^*
HTP1	H_1^*
HTP1B	reference table of H_1^*
PH1BB	blade row exit station stream function, ν
PH11BB	blade row inlet station stream function, ν
PSI	ψ_i
XI	ξ_2
XI1	ξ_1

XI1B	reference table of ξ_1
XLM	λ_2
XLM1	λ_1
XLM1B	reference table of λ_1
XPX	ν
Y	h_2^*
YY	ϕ_2, or ϕ_2^2
YYB	ν_2



Flow Chart 6. Subroutine RUNGK1.

Subroutine RUNGK2

This subroutine determines the radial equilibrium solution for a stator. The same approach to the solution is made as in RUNGK1 with the following exceptions:

1. leaving whirl XLMS is computed from Eq. (3b);
2. design specification is BTAS (instead of PSIS);
3. additional interpolation PHIS is required [from previous solution PHI(K) with continuity satisfied (array S)].

RUNGK2 Variables (for remaining variables see RUNGK1)

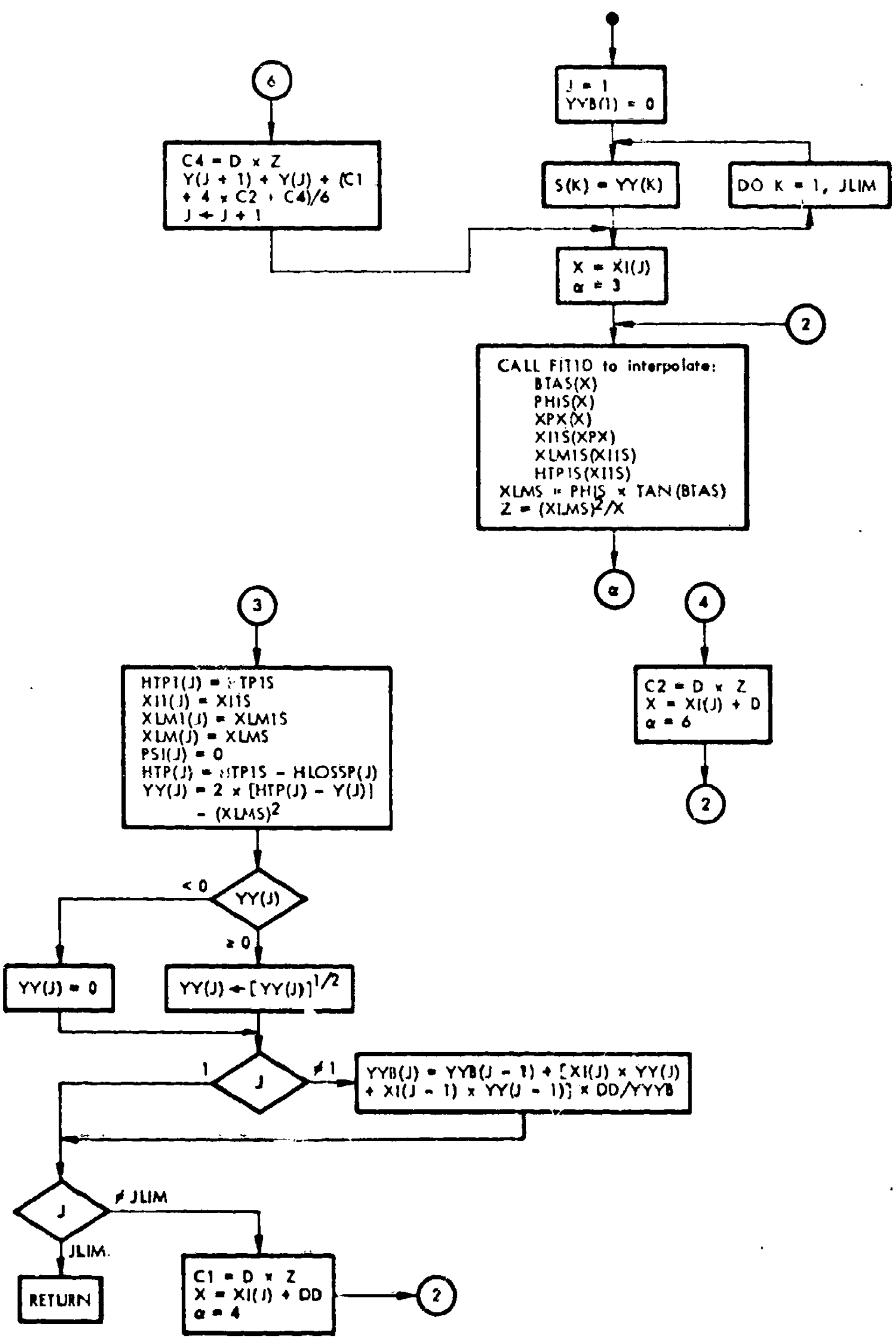
BTAS β_2

K streamline index

PHIS ϕ_2

RUNGK2 Array

S previous solution ϕ_2



Flow Chart 7. Subroutine RUNCK2.

Subroutine LOSS

This subroutine estimates the new blade-element head-loss distribution, YHLOSS(J), based on flow solution for the blade row satisfying radial equilibrium and continuity requirements. Head losses are computed using either Eqs. (8) and (10), involving interpolations (FIT1D) Y at X, i.e., $(\theta/c)_2$ as function of D_{eq}, or using Eq. (10), involving interpolations (FIT2D) OMG(J) at DFAC(J), PPHFT(J). To obtain X and DFAC(J), using Eqs. (7a) and (7b), additional velocity-triangle results [i.e., interpolations PHI1(J), angles BTA1(J), BTA(J), BTAP(J), relative whirl coefficients, XLM1P(J), XLMP(J), and dimensionless velocities V1UT(J), VUT(J), V1PUT(J), VPUT(J) are computed by the subroutine.

Blade-row type (rotor or stator) and head-loss type calculation are indicated by TYPNO and TYPLOS, respectively.

LOSS Variables

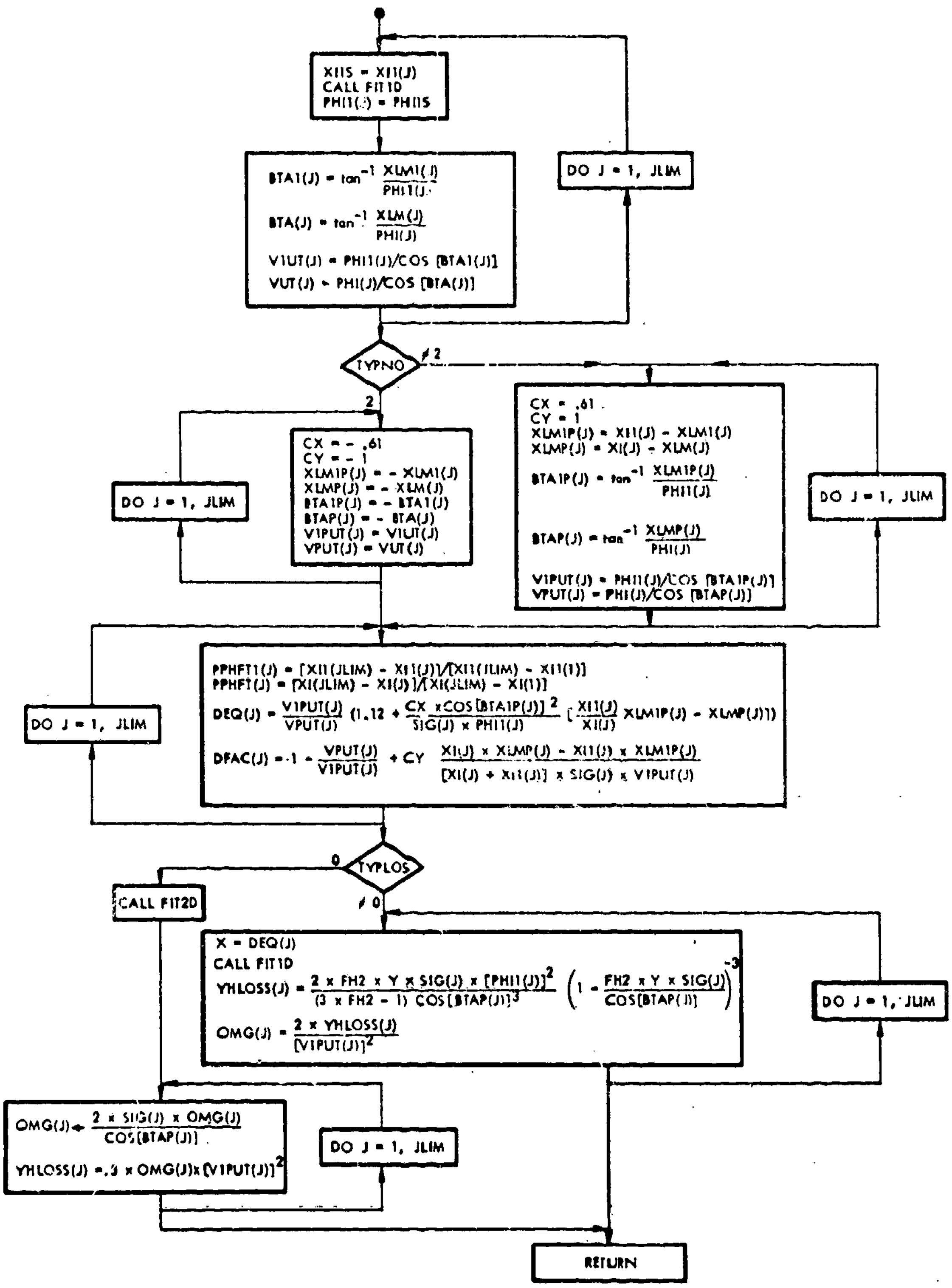
CX	coefficient in Eq. (7b)
CY	coefficient in Eq. (7a)
C3	intermediate result in evaluating Eqs. (8) and (10)
C4	intermediate result in evaluating Eqs. (8) and (10)
C5	intermediate result in evaluating Eqs. (8) and (10)
FH2	blade element wake shape factor
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
L	TYPNO
PHI1S	ϕ_1
TYPLOS	head-loss correlation table type indicator

TYPNO	blade-row type indicator
X	D_{eq}, or $(\xi_{1,t} - \xi_{1,h})$
XI1S	ξ_1
XX	$(\xi_{2,t} - \xi_{2,h})$
Y	$(\theta/c)_2$

<u>LOSS Arrays</u>

BTA	β_2
BTAP	β_2'
BTA1	β_1
BTA1P	β_1'
DEQ	D_{eq}
DEQB	reference table of D_{eq}
DFAC	diffusion factor, D
DFACB	reference table of D
PHI	ϕ_2
PHI1	ϕ_1
PHI1B	reference table of ϕ_1
OMG	$\left(\frac{\bar{\omega} \cos \beta_2'}{2\sigma}\right)$, or $\bar{\omega}$
PPHFT	% Pass. Hgt. for blade-row exit station
PPHFTB	reference table of % Pass. Hgt.
PPHFT1	% Pass. Hgt. for blade-row inlet station
THACB	reference table of $(\theta/c)_2$
VPUT	V_2'/U_t
VUT	V_2/U_t
V1PUT	V_1'/U_t
V1UT	V_1/U_t

XI1	ξ_1
XI1B	reference table of ξ_1
XLM	λ_2
XLMP	λ_2'
XLM1	λ_1
XLM1P	λ_1'
YHLOSS	H_L^*



Flow Chart 8. Subroutine LOSS.

Subroutine OUTPUT

This subroutine prints out the computed blade-element results for a blade row. Reaction, actual head-rise coefficient and hydraulic efficiency are computed from Eqs. (11), (12), and (13). Also loss parameter is computed for printout.

Subroutine MAVE is called to obtain mass-averaged results.

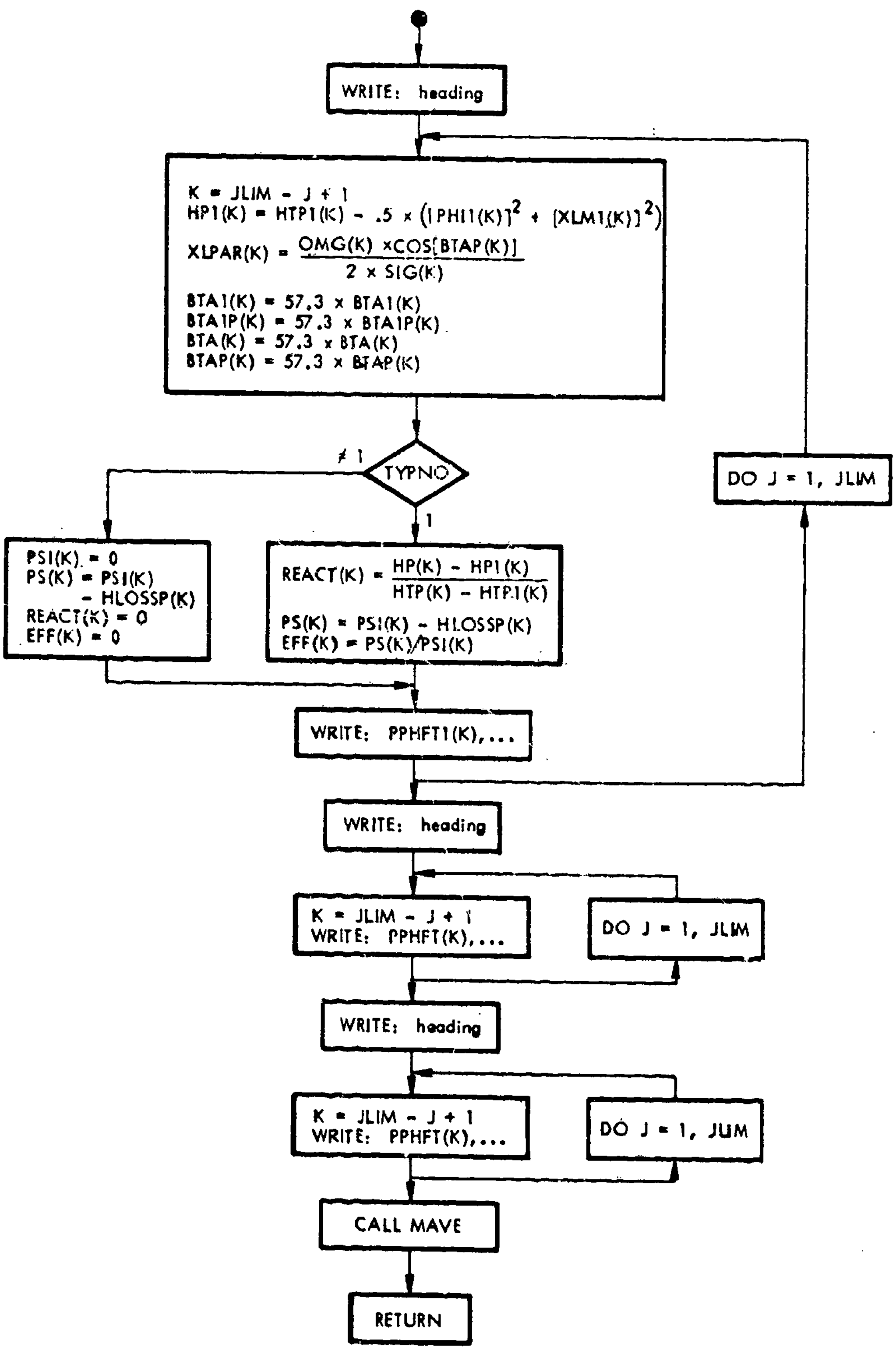
OUTPUT Variables

DD	one half the radial distance between streamlines leaving blade row
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
K	streamline index
TYPNO	blade-row type indicator

OUTPUT Arrays

BTA	β_2
BTAP	β_2'
BTA1	β_1
BTA1P	β_1'
DEQ	D_{eq}
DFAC	diffusion factor, D
EFF	η
HLOSSP	H_L^*
HP	h_2^*
HP1	h_1^*
HTP	H_2^*

HTP1	H_1^*
OMG	$\overline{\omega}$
PHI	ϕ_2
PHIBB	ν
PHI1	ϕ_1
PPHFT	% Pass. Hgt. at blade-row exit
PPHFT1	% Pass. Hgt. at blade-row inlet
PS	ψ
PSI	ψ_i
REACT	R
SIG	σ
XI	ξ_2
XI1	ξ_1
XLM	λ_2
XLM1	λ_1
XLPAR	$\frac{\overline{\omega} \cos \beta_2'}{2\sigma}$



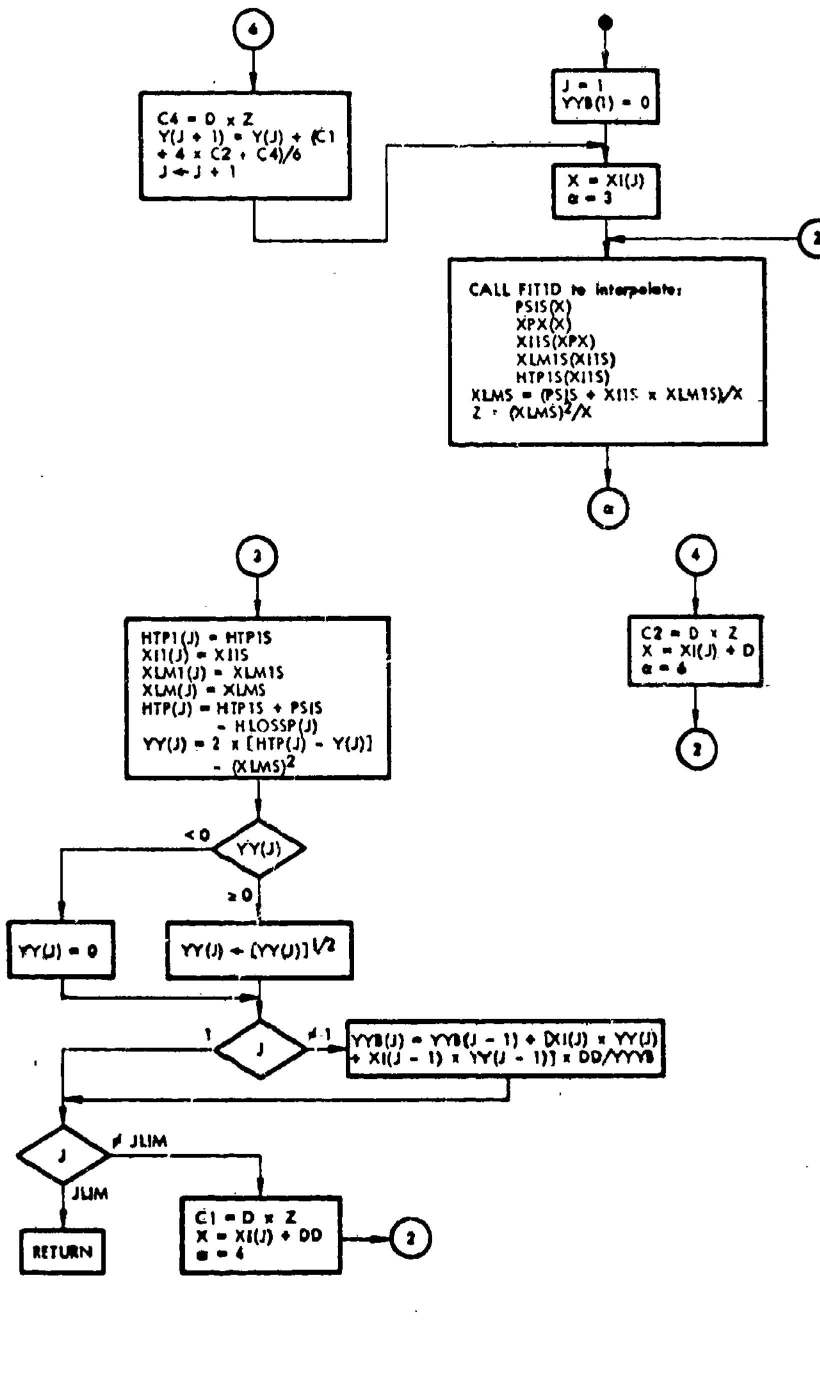
Flow Chart 9. Subroutine OUTPUT.

C4	coefficient in Runge-Kutta formula for integration of Eq. (2)
D	d
DD	D/2
HTP1S	H_1^*
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
N	branching index
PSIS	ψ_i
X	ξ_2
XI1S	ξ_1
XLMS	λ_2
XLM1S	λ_1
XPX	ν
YYYB	normalizing factor for stream function
Z	right-hand side of Eq. (2)

RUNCK1 Arrays

HLOSSP	H_L^*
HTP	H_2^*
HTP1	H_1^*
HTP1B	reference table of H_1^*
PHIBB	blade row exit station stream function, ν
PHI1BB	blade row inlet station stream function, ν
PSI	ψ_i
XI	ξ_2
XI1	ξ_1

XI1B	reference table of ξ_1
XLM	λ_2
XLM1	λ_1
XLM1B	reference table of λ_1
XPX	ν
Y	h_2^*
YY	ϕ_2, or ϕ_2^2
YYB	ν_2



Flow Chart 6. Subroutine RUNGK1.

Subroutine RUNGK2

This subroutine determines the radial equilibrium solution for a stator. The same approach to the solution is made as in RUNGK1 with the following exceptions:

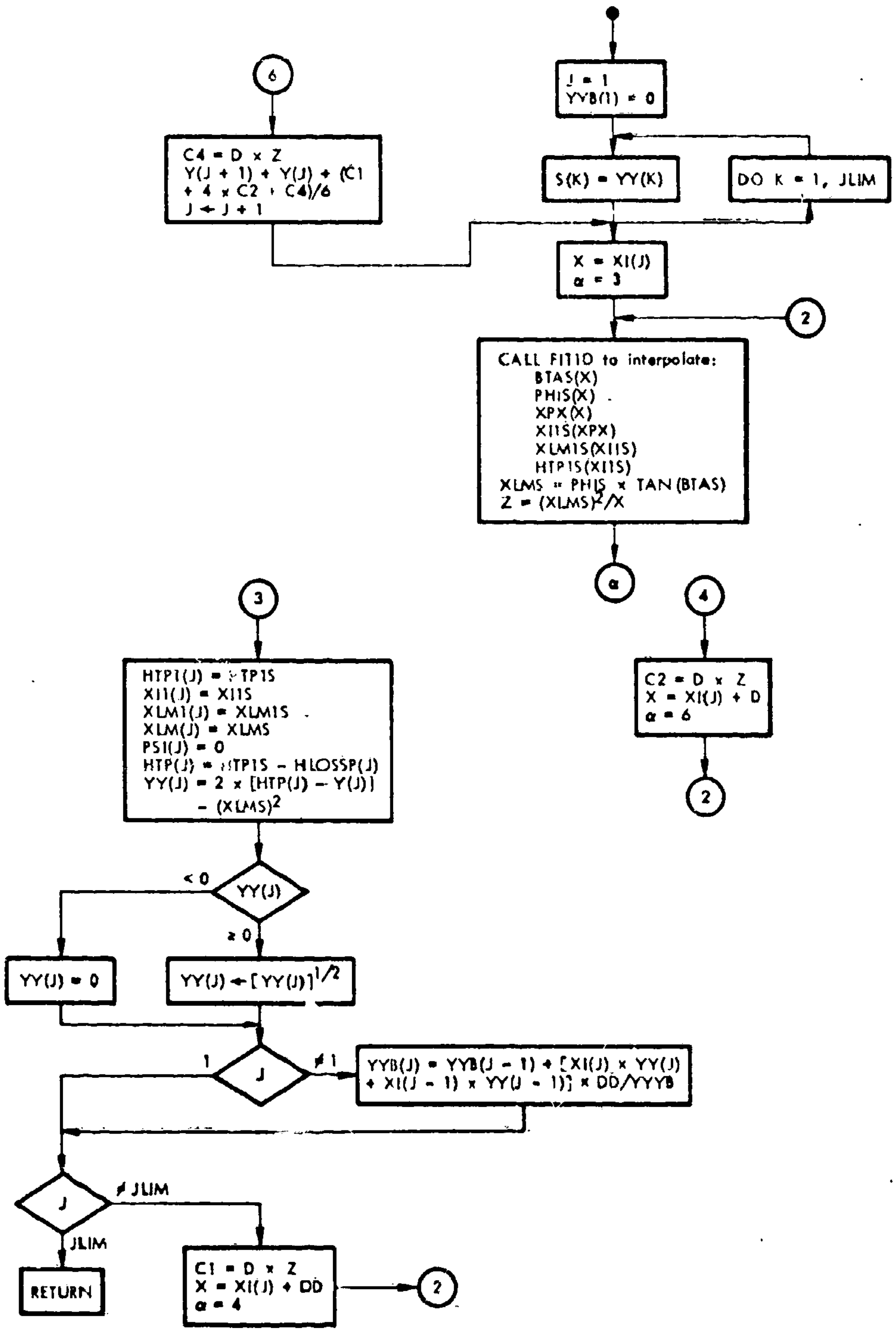
1. leaving whirl XLMS is computed from Eq. (3b);
2. design specification is BTAS (instead of PSIS);
3. additional interpolation PHIS is required [from previous solution PHI(K) with continuity satisfied (array S)].

RUNGK2 Variables (for remaining variables see RUNGK1)

BTAS	β_2
K	streamline index
PHIS	ϕ_2

RUNGK2 Array

S	previous solution ϕ_2



Flow Chart 7. Subroutine RUNGK2.

Subroutine LOSS

This subroutine estimates the new blade-element head-loss distribution, YHLOSS(J), based on flow solution for the blade row satisfying radial equilibrium and continuity requirements. Head losses are computed using either Eqs. (8) and (10), involving interpolations (FIT1D) Y at X, i.e., $(\theta/c)_2$ as function of D_{eq}, or using Eq. (10), involving interpolations (FIT2D) OMG(J) at DFAC(J), PPHFT(J). To obtain X and DFAC(J), using Eqs. (7a) and (7b), additional velocity triangle results [i.e., interpolations PHI1(J), angles BTA1(J), BTA(J), BTAP(J), relative whirl coefficients, XLM1P(J), XLMP(J), and dimensionless velocities V1UT(J), VUT(J), V1PUT(J), VPUT(J) are computed by the subroutine.

Blade-row type (rotor or stator) and head-loss type calculation are indicated by TYPNO and TYPLOS, respectively.

LOSS Variables

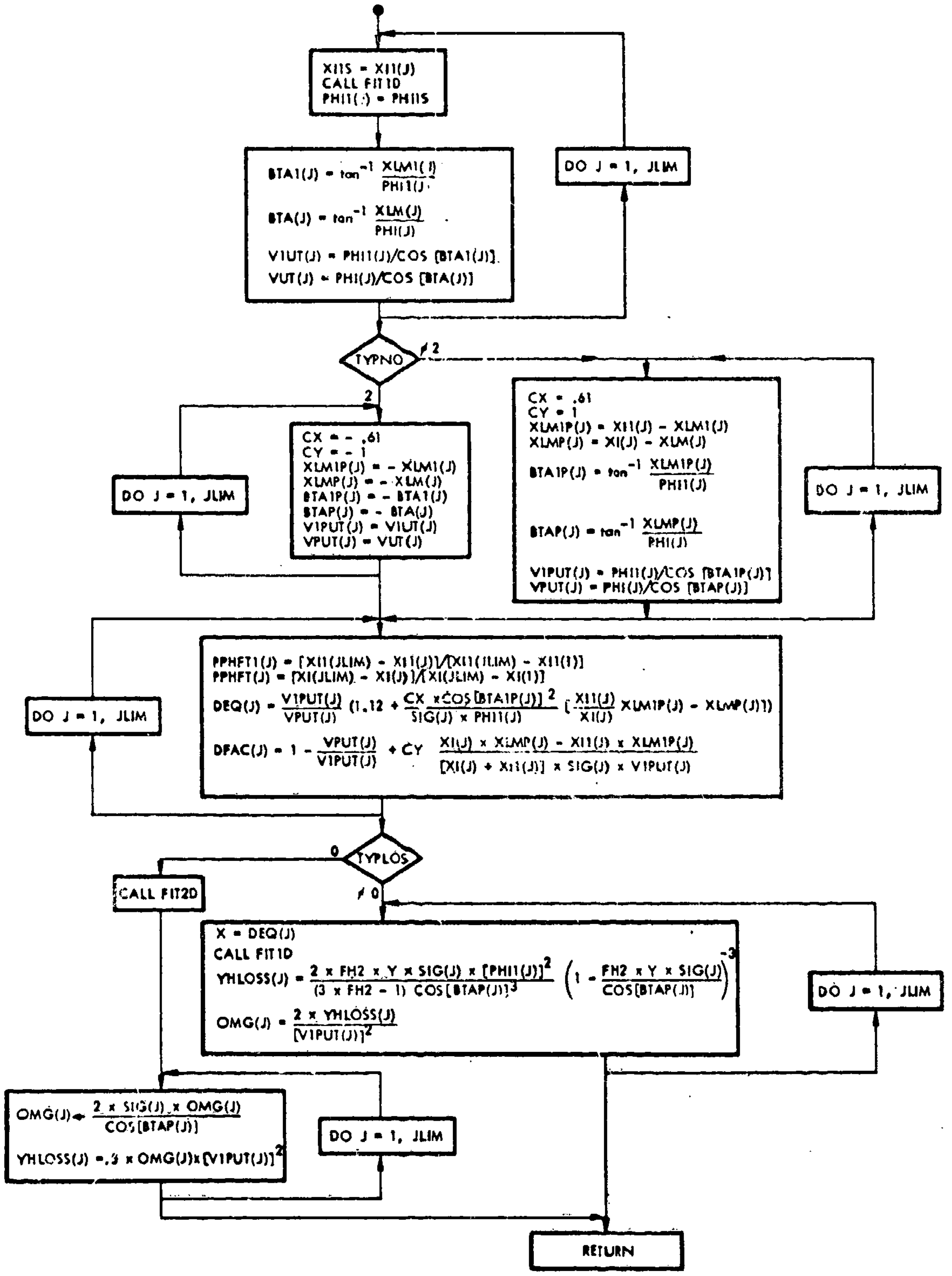
CX	coefficient in Eq. (7b)
CY	coefficient in Eq. (7a)
C3	intermediate result in evaluating Eqs. (8) and (10)
C4	intermediate result in evaluating Eqs. (8) and (10)
C5	intermediate result in evaluating Eqs. (8) and (10)
FH2	blade element wake shape factor
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
L	TYPNO
PHI1S	ϕ_1
TYPLOS	head-loss correlation table type indicator

TYPNO	blade-row type indicator
X	D_{eq}, or $(\xi_{1,t} - \xi_{1,h})$
XI1S	ξ_1
XX	$(\xi_{2,t} - \xi_{2,h})$
Y	$(\theta/c)_2$

LOSS Arrays

BTA	β_2
BTAP	β_2'
BTA1	β_1
BTA1P	β_1'
DEQ	D_{eq}
DEQB	reference table of D_{eq}
DFAC	diffusion factor, D
DFACB	reference table of D
PHI	ϕ_2
PHI1	ϕ_1
PHI1B	reference table of ϕ_1
OMG	$(\frac{\overline{\omega} \cos \beta_2'}{2\sigma})$, or $\overline{\omega}$
PPHFT	% Pass. Hgt. for blade-row exit station
PPHFTB	reference table of % Pass. Hgt.
PPHFT1	% Pass. Hgt. for blade-row inlet station
THACB	reference table of $(\theta/c)_2$
VPUT	V_2'/U_t
VUT	V_2/U_t
V1PUT	V_1'/U_t
V1UT	V_1/U_t

XI1	ξ_1
XI1B	reference table of ξ_1
XLM	λ_2
XLMP	λ_2'
XLM1	λ_1
XLM1P	λ_1'
YHLOSS	H_L^*



Flow Chart 8. Subroutine LOSS.

Subroutine OUTPUT

This subroutine prints out the computed blade-element results for a blade row. Reaction, actual head-rise coefficient and hydraulic efficiency are computed from Eqs. (11), (12), and (13). Also loss parameter is computed for printout.

Subroutine MAVE is called to obtain mass-averaged results.

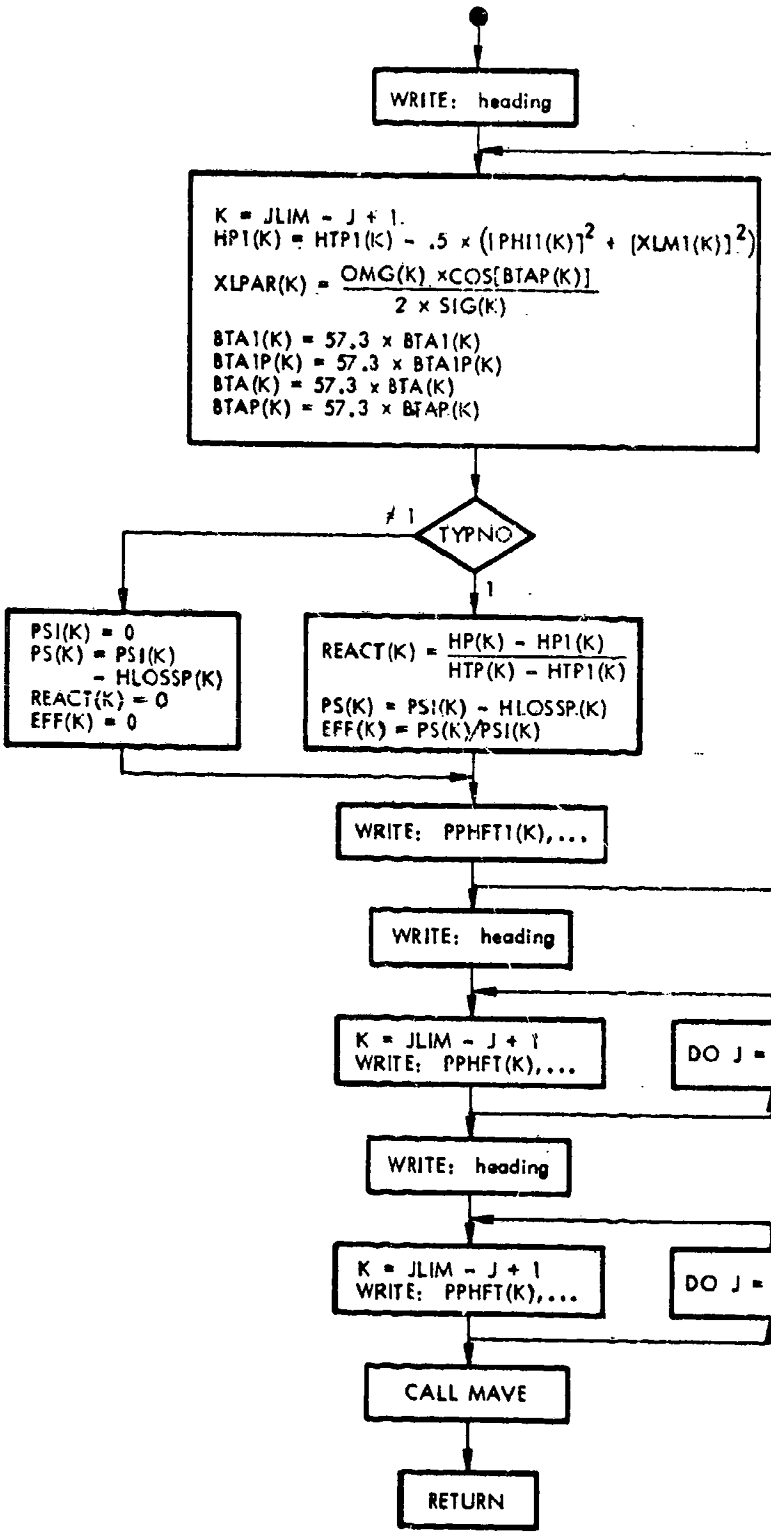
OUTPUT Variables

DD	one half the radial distance between streamlines leaving blade row
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
K	streamline index
TYPNO	blade-row type indicator

OUTPUT Arrays

BTA	β_2
BTAP	β'_2
BTA1	β_1
BTA1P	β'_1
DEQ	D_{eq}
DFAC	diffusion factor, D
EFF	η
HLOSSP	H^*_L
HP	h^*_2
HP1	h^*_1
HTP	H^*_2

HTP1	H_1^*
OMG	$\overline{\omega}$
PHI	ϕ_2
PHIBB	ν
PHI1	ϕ_1
PPHFT	% Pass. Hgt. at blade-row exit
PPHFT1	% Pass. Hgt. at blade-row inlet
PS	ψ
PSI	ψ_i
REACT	R
SIG	σ
XI	ξ_2
XI1	ξ_1
XLM	λ_2
XLM1	λ_1
XLPAR	$\frac{\overline{\omega} \cos \beta_2'}{2\sigma}$



Flow Chart 9. Subroutine OUTPUT.

Subroutine MAVE

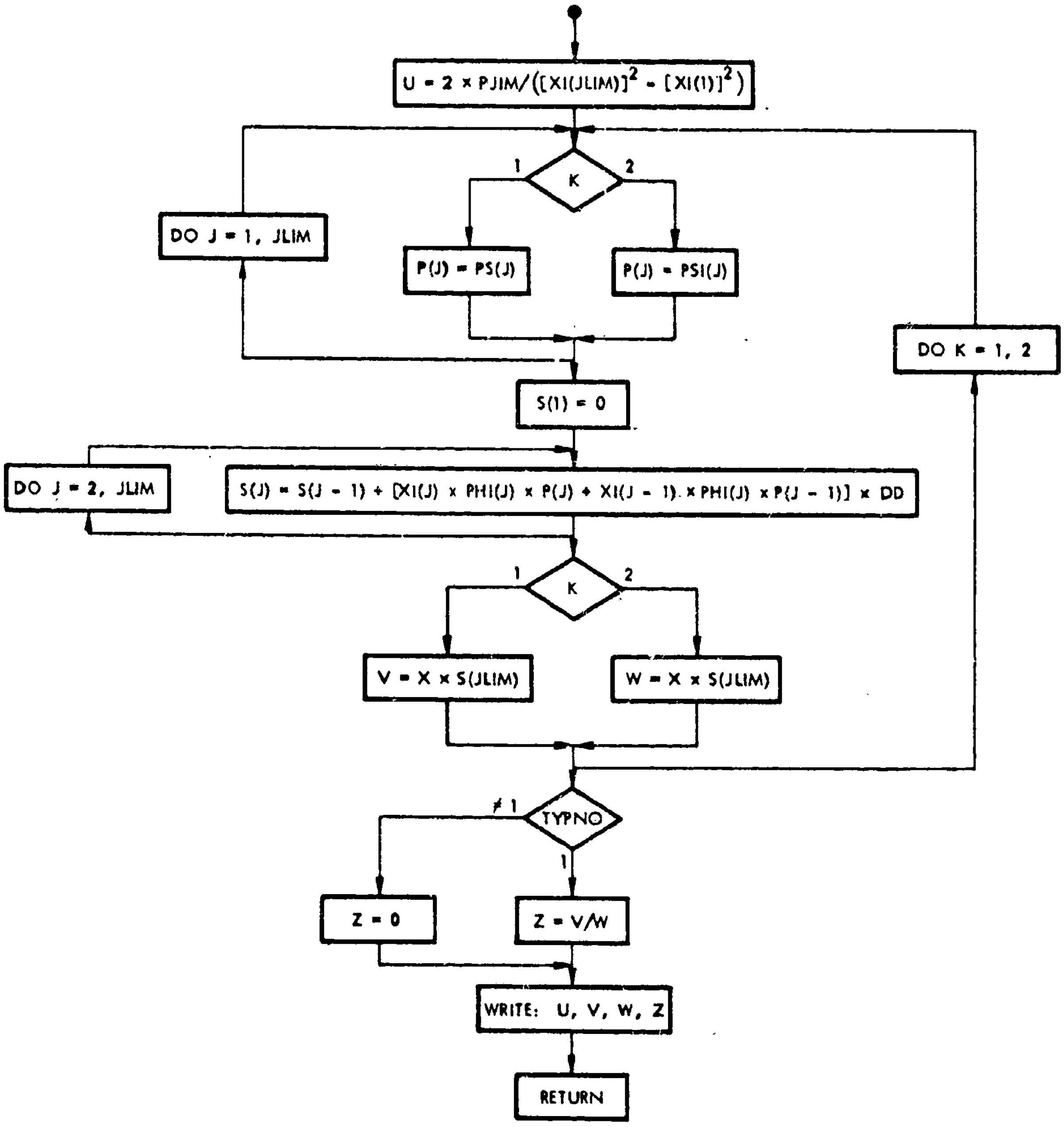
Local mass-averaged values of blade-element results across the annulus are obtained for actual head rise, ideal head rise, and hydraulic efficiency.

MAVE Variables

DD	one half the radial distance between streamlines leaving blade row
IOUT	printer reference number
J	streamline index
JLIM	number of streamlines, j_{lim}
K	branching index
PJLIM	machine nondimensional flow rate
TYPNO	blade-row type indicator
U	$\bar{\phi}_2$
V	$\bar{\psi}$
W	$\bar{\psi}_i$
X	1/PJLIM
Z	$\bar{\eta}$

MAVE Arrays

P	quantity to be mass-averaged
PHI	ϕ_2
PS	ψ
PSI	ψ_i
S	quadrature result
XI	ξ_2



Flow Chart 10. Subroutine MAVE.

Subroutine FIT1D

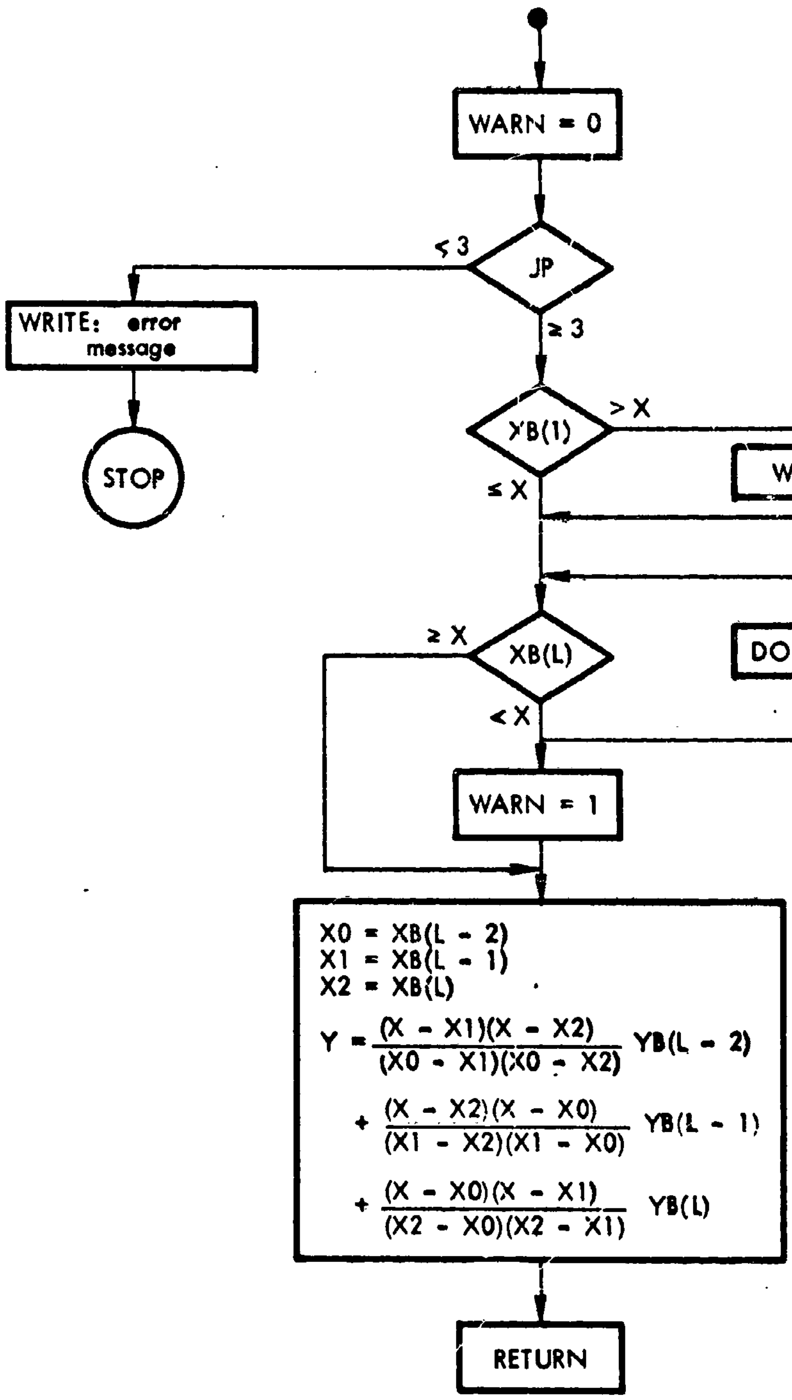
Interpolation for Y(X) is made based on 3-point Lagrange polynomials[8]. Reference data are tables YB, XB, where XB elements are monotone nondecreasing and JP is the number of point pairs (XB, YB). The interpolate X is bracketed (if possible) by three neighboring elements of XB. WARN = 1 indicates extrapolation of XB array.

FIT1D Variables

IOUT	printer reference number
J	streamline index
JP	number of point pairs (XB, YB)
L	streamline index
WARN	extrapolation indicator
X	interpolate
X0	XB value bracketing X
X1	XB value bracketing X
X2	XB value bracketing X
Y	interpolated answer at X

FIT1D Arrays

XB	reference data table
YB	reference data table



Flow Chart 11. Subroutine FIT1D.

Subroutine FIT2D

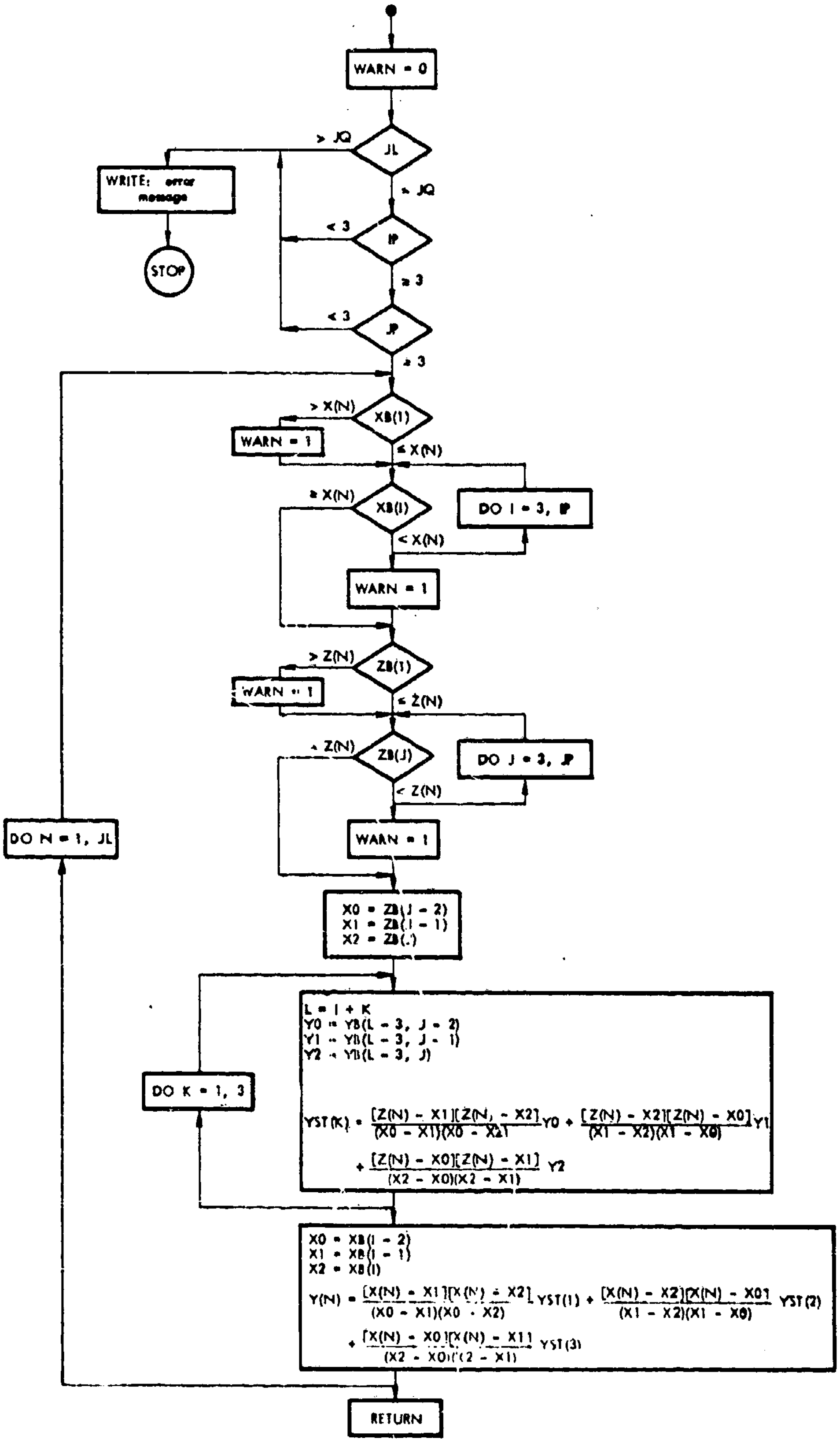
Interpolations for Y(X, Z) are made, JL in number, based on 3-point Lagrangian polynomials[8]. Similar procedures are used for bracketing and interpolating, and like restrictions are placed on elements of XB and ZB as in FIT1D. WARN = 1 indicates extrapolation of XB and/or ZB array.

FIT2D Variables

I	index
IOUT	printer reference number
IP	number of elements in XB array
J	index
JL	number of interpolations requested
JP	number of elements in ZB array
JQ	dimension size of Y array
K	index
L	index
M	index
N	interpolation index
WARN	extrapolation indicator
X0	XB or ZB value bracketing X or Z
X1	XB or ZB value bracketing X or Z
X2	XB or ZB value bracketing X or Z
Y0	YB element at bracket point (XB, ZB)
Y1	YB element at bracket point (XB, ZB)
Y2	YB element at bracket point (XB, ZB)

FIT2D Arrays

X	interpolate
XB	reference data table
Y	interpolated answer
YB	reference data table
YST	intermediate interpolated Y
Z	interpolate
ZB	reference data table



Flow Chart 12. Subroutine FIT2D.

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APPENDIX A

Fortran Computer Program Listing

```
C
C
C     MAIN PROGRAM
C     ************
C
C
C
      COMMON
     1JLIM,D,IIN,IOUT,KP,LP,YHLOSS(11),YS(3),YSIG(11),
     2YXI(11),XI(11),XI1B(11),PSIBB(11),XLM1B(11),HTP1(11),
     3HLOSSP(11),PSI(11),XI1(11),XLM(11),DFAC(11),EPS(3),
     4HP(11),HTP(11),HTP1B(11),P(11),PHI(11),PHIBB(11),
     5BTA(11),PHI1B(11),PHI1BB(11),SIG(11),XLM1(11),PHI1(11)
      COMMON OMGB(12,6)
      DIMENSION
     1Y(11),BTAP(11),BTA1(11),BTA1P(11),DFACB(12),OMG(11),
     2THACB(12), PPHFT(11),PPHFT1(11),PPHFTB(6),XLMP(11),
     3XLM1P(11),VUT(11),V1UT(11),V1PUT(11),VPUT(11),YYB(11),
     4DEQ(11),DEQB(12)
C
C
C         INPUT LIMIT PARAMETERS AND CALCULATE INLET STATION
C         FLOW CONDITIONS
C               SET UP TABLES OF RADIUS VALUES AND ZERO WHIRL
C               ITERPOLATE FOR TABLES OF RADIAL DISTRIBUTIONS
C.              OF FLOW COEFFICIENT,TOTAL HEAD; CALCULATE
C               TABLE STREAM FCN. DISTRIBUTION
C
      IIN=1
      IOUT=3
      JQ=11
      JPX=3
      XEPS=0
      P(1)=0
      PHIBB(1)=0
      READ(IIN,1)X,TPHI,THL
      JLIM=X
      WRITE(IOUT,20)
      WRITE(IOUT,21)X,TPHI,THL
      READ(IIN,1)X
      KLIM=X
      READ(IIN,1)(XI(K),PHI(K),HTP(K),K=1,KLIM)
      WRITE(IOUT,22)
      WRITE(IOUT,23)
      WRITE(IOUT,24)   (XI(K),PHI(K),HTP(K),K=1,KLIM)
      XI1B(1)=XI(1)
      XI1B(JLIM)=XI(KLIM)
      XLM1B(1)=0
      XLM1B(JLIM)=0
      XJ=JLIM-1
      D=(XI(KLIM)-XI(1))/XJ
      DD=.5*D
      KK=XJ
```

```
      DO 2 K=2,KK
      XI1B(K)=XI1B(K-1)+D
    2 XLM1B(K)=0
      DO 60 K=1,JLIM
      X=XI1B(K)
      CALL FIT1D(X,XX,XI,PHI,KLIM,WARN,IOUT)
      PHI1B(K)=XX
      CALL FIT1D(X,XX,XI,HTP,KLIM,WARN,IOUT)
   60 HTP1B(K)=XX
      DO 61 K=2,JLIM
   61 P(K)=P(K-1)+(XI1B(K)*PHI1B(K)+XI1B(K-1)*PHI1B(K-1))*DD
      PHIBBS=2.*P(JLIM)/(XI1B(JLIM)*XI1B(JLIM)-XI1B(1)*XI1B
     1(1))
      PJLIM=P(JLIM)
      WRITE(IOUT,240)PHIBBS
      DO 62 K=1,JLIM
   62 PHI1BB(K)=P(K)/PJLIM
C
C
C        IDENTIFY FIRST BLADE ROW
C
      READ(IIN,1)STANO,TYPNO,TYPLOS
      TIFLOS=0
  202 IF(TYPNO-1.)27,26,27
   26 WRITE(IOUT,25)STANO
      GO TO 209
   27 WRITE(IOUT,29)STANO
C
C
C        INPUT LOSS TABLES,BLADE ROW DESIGN CONDITION TABLES
C
  209 IF(TIFLOS)203,200,203
  203 IF(TYPLOS)288,28,288
  200 IF(TYPLOS)312,301,312
  301 READ(IIN,1) X,XX
      KLIMP=X
      LLIMP=XX
      DO 601 LL=1,KLIMP
  601 READ(IIN,1) DFACB(LL),(PPHFTB(LJ),OMGB(LL,LJ),LJ=1,
     1LLIMP)
   28 WRITE(IOUT,42)
      WRITE(IOUT,43)
      WRITE(IOUT,44)(PPHFTB(J),J=1,LLIMP)
      DO 445 J=1,KLIMP
  445 WRITE(IOUT,45)  DFACB(J),(OMGB(J,K),K=1,LLIMP)
      GO TO 201
  312 READ(IIN,1)X
      KLIMP=X
      READ(IIN,1)(DEQB(LL),THACB(LL),LL=1,KLIMP)
  288 WRITE(IOUT,42)
      WRITE(IOUT,430)(DEQB(LL),LL=1,KLIMP)
      WRITE(IOUT,431)(THACB(LL),LL=1,KLIMP)
  201 READ(IIN,1)X
      KLIM=X
      READ(IIN,1)(YXI(K),Y(K),YSIG(K),K=1,KLIM)
      IF(TYPNO-1.)48.59,48
```

```
   59 WRITE(IOUT,46)
      GO TO 49
   48 WRITE(IOUT,51)
   49 WRITE(IOUT,47)(YXI(K),Y(K),YSIG(K),K=1,KLIM)
C
C
C         COMPUTE BLADE ROW DESIGN CONDITIONS AND INITIALIZED
C         LEAVING FLOW CONDITIONS
C              COMPUTE STREAMLINE RADII AND AVERAGE FLOW
C              COEFFICIENT
C              INTERPOLATE STREAMLINE DESIGN CONDITIONS,
C              INITIALIZE STREAMLINE FLOW COEFFICIENTS,LOSSES
C              AND STREAM FCN. VALUES
C
      D=(YXI(KLIM)-YXI(1))/XJ
      DD=.5*D
      XI(JLIM)=YXI(KLIM)
      XI(1)=YXI(1)
      DO 65 J=2,KK
   65 XI(J)=XI(J-1)+D
      XPHI=2.*PJLIM/(XI(JLIM)*XI(JLIM)-XI(1)*XI(1))
      DO 66 J=1,JLIM
      X=XI(J)
      CALL FIT1D(X,XX,YXI,Y, KLIM,WARN,IOUT)
      IF(TYPNO-1.)63,64,63
   64 PSI(J)=XX
      GO TO 67
   63 BTA(J)=XX/57.3
   67 CALL FIT1D(X,XX,YXI,YSIG,KLIM,WARN,IOUT)
      SIG(J)=XX
      PHI(J)=XPHI
   66 HLOSSP(J)=0
      DO 666 J=2,JLIM
  666 PHIBB(J)=PHIBB(J-1)+(XI(J)*PHI(J)+XI(J-1)*PHI(J-1))*
     1DD/PJLIM
C
C
C         RADIAL EQUILIBRIUM SOLUTION FOR BLADE ROW LEAVING
C         FLOW WITH EXISTING LOSS DISTRIBUTION
C              PREPARE FOR RADIAL EQUILIBRIUM SOLUTION,
C              INITIALIZE LOSS LOOP INDEX AND RADIAL EQUIL.
C              ITERATION SOLUTION COUNTER
C              COMPUTE BEST EST. STATIC HEAD HP(1) VALUE AT
C              INNER CASING STREAMLINE
C              ITERATE RADIAL EQUILIBRIUM SOLUTION WITH
C              EXISTING LOSSES AND VARYING HP(1) UNTIL CONT.
C              REQUIREMENT IS SATISFIED (15 OR LESS TRIES)
C              COMPUTE RADIAL EQUILIBRIUM SOLUTION(ROTOR OR
C              STATOR) AND COMPUTE STREAM FCN. ERROR AT OUTER
C              CASING STREAMLINE (3 OR LESS TRIES)
C              IMPROVE HP(1)EST. FOR ZERO STREAM FCN. ERROR
C              BASED ON THE 3 PRECEDING RADIAL EQUILIRIUM AND
C              STREAM FCN. ERROR SOLUTIONS
C              COMPUTE FINAL BEST RADIAL EQUILIBRIUM SOLUTION
C              WITH CONTINUITY CONDITION UNSATISFIED
C
```

```
      IF(TYPNO-1.)70,69,70
   69 A =(PSI(1)+XLM1B(1)*XI1B(1))/XI(1)
      A=HTP1B(1)+PSI(1)-.5*A*A
   70 KNCT=0
      DO 302 LOK=1,25
      LLK=LOK
      EPSP=.1
      IF(TYPNO-1.)170,169,170
  169 HP(1)=A-HLOSSP(1)-EPSP-.5*PHI(1)*PHI(1)
      GO TO 171
  170 HP(1)=HTP1B(1)-HLOSSP(1)-EPSP-.5*PHI(1)*PHI(1)/
     1(COS(BTA(1))*COS(BTA(1)))
  171 DO 30 KN=1,5
      KNCT=KNCT+1
      DO 31 K=1,3
      IF(TYPNO-1.)72,71,72
   72 CALL RUNGK2( YYB,DD, PJLIM)
      GO TO 73
   71 CALL RUNGK1( YYB,DD,PJLIM)
   73 EPS(K)=  YYB(JLIM)-1.
      IF(ABS(EPS(K))-TPHI)40,41,41
   41 YS(K)=HP(1)
   31 HP(1)=HP(1)+EPSP
      EPSP=.04
      CALL FIT1D(XEPS,YHP,EPS,YS,JPX,WARN,IOUT)
   30 HP(1)=YHP-EPSP
      HP(1)=HP(1)+EPSP
      WRITE(IOUT,50)EPS,YS
      IF(TYPNO-1.)82,81,82
   82 CALL RUNGK2( YYB,DD,PJLIM)
      GO TO 140
   81 CALL RUNGK1( YYB,DD,PJLIM)
  140 WRITE(IOUT,85)LOK,(YYB(J),J=1,JLIM)
C
C
C          COMPUTE LOSSES AND REVISE LOSS DISTRIBUTION
C                CHECK FOR ANNULUS STALL--IFSTALL HAS OCCURRED
C                THEN BRANCH TO READ IN NEXT PROBLEM IN INPUT
C                LOAD
C
   40 YYB(JLIM)=1
      DO 418 J=1,JLIM
      IF(PHI(J)) 83,83,418
   83 WRITE(IOUT,84)
      GO TO 404
  418 PHIBB(J)=YYB(J)
      CALL LOSS(BTAP,BTA1,BTA1P,DFACB,OMG,PPHFT,PPHFT1,PPHFT
     1B,XLMP,XLM1P, VUT,V1UT,V1PUT,VPUT,TYPNO,KLIMP,LLIMP,DE
     2Q,DEQB,THACB,TYPLOS,JQ)
      DO 400 I=1,JLIM
      IF(ABS(HLOSSP(I)-YHLOSS(I))-THL)400,401,401
  400 CONTINUE
      GO TO 403
```

2

2 OF 2

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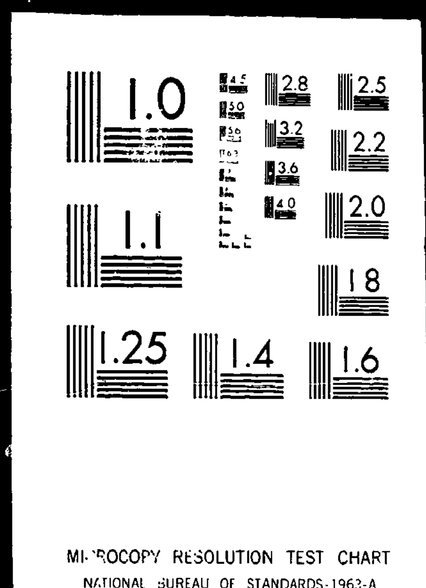

```
401 GO TO(511,511,512,514),LOK
    GO TO 514
511 XJOE=.5
    GO TO 410
512 XJOE=.65
    GO TO 410
514 XJOE=1.
    IF(LOK-25)410,303,303
410 DO 302 I=1,JLIM
302 HLOSSP(I)=HLOSSP(I)+XJOE*(YHLOSS(I)-HLOSSP(I))
303 WRITE(IOUT,599) (HLOSSP(I),YHLOSS(I),I=1,JLIM)
C
C
C        COMPUTE ADDITIONAL RESULTS AND PRINT ANSWERS
C
403 WRITE(IOUT,52)LLK,KNCT
    CALL OUTPUT(PPHFT1,PPHFT,BTA1,BTA1P,DD, BTAP,OMG,DEQ,
   1TYPNO,PJLIM)
C
C
C        READ NEXT PROBLEM AND TRANSFER LEAVING FLOW RESULTS
C        (IF NECESSARY) AS INPUT TO NEXT BLADE ROW
C
404 READ(IIN,1)YSTANO, TYPNO,TIFLOS,TYPLOS
    IF(YSTANO)405,406,405
406 STOP
405 IF(STANO-YSTANO)407,202,407
407 STANO=YSTANO
    DO 408 I=1,JLIM
    XI1B(I)=XI(I)
    XLM1B(I)=XLM(I)
    PHI1B(I)=PHI(I)
    HTP1B(I)=HTP(I)
408 PHI1BB(I)=PHIBB(I)
    GO TO 202
C
  1 FORMAT(10F7.0)
 20 FORMAT(1H1,' INPUT DATA')
 21 FORMAT(  /'     JLIM=',F9.0,'  CONT. TOLER.=',F9.4,
   1'  LOSS TOLER.=',F9.4)
 22 FORMAT(  /'      INLET')
 23 FORMAT(  /5X,'R/RT',6X,'PHI',2X,'HD COEF'/   )
 24 FORMAT(3F9.4)
 25 FORMAT(1H1,'      STA. NO. (ROTOR ROW)=',F9.0)
 29 FORMAT(1H1,'      STA. NO. (STATOR)=',F9.0)
 42 FORMAT(  /5X,'LOSS COEF.  TABLE')
 43 FORMAT(  /16X,'PERCENT PASSAGE HEIGHT FROM TIP')
 44 FORMAT(  /4X,' DFAC',10F9.2)
 45 FORMAT(13F9.4)
 46 FORMAT(  /'     DESIGN CONDITIONS: R2/RT        PSI1',
   1'  SOLIDITY'/  )
 47 FORMAT(19X,F9.3,F12.3,F10.3)
 50 FORMAT(1H1,6F14.6,' CONT. FAILED')
```

2

```
 51 FORMAT(  /'     DESIGN CONDITIONS: R2/RT  BETA2(DEG)',
   1'  SOLIDITY'/ )
 52 FORMAT( //' NO. LOSS ITERATIONS=',I3,5X,
   1'NO. CONTINUITY ITERATIONS=',I3,//)
 84 FORMAT(' STALLED FLOW-ABORT')
 85 FORMAT(' LOSS LOOP=',I3,' FINAL BEST EST STR FCN=',11F
   17.4)
240 FORMAT(/' INLET  FLOW COEF=',F7.3)
430 FORMAT( /5X,'DEQB=',12F9.3)
431 FORMAT         ( /5X,'THACB=',12F9.3)
599 FORMAT(/  ,' LOSS FAILED',10F7.4)
    END
```

```
C
C
      SUBROUTINE RUNGK1
C     *****************
C
C
C
C
     1(YYB,DD,YYYB)
      COMMON
     1JLIM,D,IIN,IOUT,KP,LP,YHLOSS(11),YS(3),YSIG(11),
     2YXI(11),XI(11),XI1B(11),PSIBB(11),XLM1B(11),HTP1(11),
     3HLOSSP(11),PSI(11),XI1(11),XLM(11),DFAC(11),EPS(3),
     4 Y(11),HTP(11),HTP1B(11),P(11), YY(11),PHIBB(11),
     5BTA(11),PHI1B(11),PHI1BB(11),SIG(11),XLM1(11),PHI1(11)
      COMMON OMGB(12,6)
      DIMENSION YYB(11)
C
C
C         INTEGRATION OF RADIAL EQUIL. D.E. BY RUNGE-KUTTA
C         PROCEDURE AND DETERMINATION OF ROTOR LEAVING FLOW
C         COEFFICIENT AND STREAM FCN. DISTRIBUTIONS(HUB-TIP)
C         START VALUE IS HUB STREAMLINE STATIC HEAD(Y(J=1))
C
C                INITIALIZE STREAMLINE NUMBER(AT HUB) AND SET
C                BEGINNING STREAM FCN. VALUE
C                SET WORKING RADIUS(X) FOR RUNGE-KUTTA SOLUTION
C                CORRESPONDING TO STREAMLINE RADIUS IN ROTOR
C                LEAVING FLOW
C
      J=1
      YYB(1)=0
    1 X=XI(J)
      N=1
C
C                INTERPOLATE SPECIFIED WORK COEFFICIENT AND
C                EXISTING STREAM FCN. DISTRIBUTIONS AT RADIUS X
C
    2 CALL FIT1D(X,PSIS,XI,PSI,JLIM,WARN,IOUT)
      CALL FIT1D(X,XPX,XI,PHIBB,JLIM,WARN,IOUT)
C
C                INTERPOLATE ENTERING STREAMLINE RADIUS AT
C                DETERMINED STREAM FCN. VALUE
C
      CALL FIT1D(XPX,XI1S,PHI1BB,XI1B,JLIM,WARN,IOUT)
C
C                INTERPOLATE ENTERING WHIRL AND TOTAL HEAD
C                AT DETERMINED ENTERING FLOW STREAMLINE RADIUS
C
      CALL FIT1D(XI1S,XLM1S,XI1B,XLM1B,JLIM,WARN,IOUT)
      CALL FIT1D(XI1S,HTP1S,XI1B,HTP1B,JLIM,WARN,IOUT)
```

```
C
C              COMPUTE LEAVING WHIRL AND DIFF. COEFFICIENT(Z)
C              CORRESPONDING TO RADIUS X
C
      XLMS=(PSIS+XI1S*XLM1S)/X
      Z=XLMS*XLMS/X
      GO TO(3,4,6),N
C
C              SAVE ENTERING FLOW STREAMLINE DATA,COMPUTE NEW
C              LEAVING FLOW STREAMLINE FLOW COEF. AND STR.FCN
C
    3 HTP1(J)=HTP1S
      XI1(J)=XI1S
      XLM1(J)=XLM1S
      XLM(J)=XLMS
      HTP(J)=HTP1S+PSIS-HLOSSP(J)
   10 YY(J)=      2.*(HTP(J) -Y(J))-XLMS*XLMS
      IF(YY(J))20,21,21
   20 YY(J)=0
      GO TO 22
   21 YY(J)=SQRT(YY(J))
   22 IF(J-1)24,23,24
   24 YYB(J)=YYB(J-1)+(XI(J)*YY(J)+XI(J-1)*YY(J-1))*DD/YYYB
C
C              CHECK FOR OUTER CASING STREAMLINE(JLIM)
C              COMPUTE COEFFICIENTS AND INCREMENT X PER RUNGE
C              -KUTTA METHOD
C
   23 IF(J-JLIM)11,7,11
   11 C1=D*Z
      X=XI(J)+DD
      N=2
      GO TO 2
    4 C2=D*Z
      X=XI(J)+D
      N=3
      GO TO 2
    6 C4=D*Z
C
C              COMPUTE STREAMLINE STATIC HEAD VALUE. INCRE-
C              MENT STREAMLINE NUMBER
C
      Y(J+1)=Y(J)+(C1+4.*C2+C4)/6.
    8 J=J+1
      GO TO 1
    7 RETURN
      END
```

```
C
C
      SUBROUTINE RUNGK2
C     *****************
C
C
C
     1(YYB,DD,YYYB)
      COMMON
     1JLIM,D,IIN,IOUT,KP,LP,YHLOSS(11),YS(3),YSIG(11),
     2YXI(11),XI(11),XI1B(11),PSIBB(11),XLM1B(11),HTP1(11),
     3HLOSSP(11),PSI(11),XI1(11),XLM(11),DFAC(11),EPS(3),
     4 Y(11),HTP(11),HTP1B(11),P(11), YY(11),PHIBB(11),
     5BTA(11),PHI1B(11),PHI1BB(11),SIG(11),XLM1(11),PHI1(11)
      COMMON OMGB(12,6)
      DIMENSION YYB(11),S(11)
C
C
C         INTEGRATION OF RADIAL EQUIL. D.E. BY RUNGE-KUTTA
C         PROCEDURE AND DETERMINATION OF STATOR LEAVING FLOW
C         COEFFICIENT AND STREAM FCN. DISTRIBUTIONS(INNER-
C         OUTER CASING)
C         START VALUE IS INNER CASING STREAMLINE STATIC HEAD
C
C                 INITIALIZE STREAMLINE NUMBER(AT INNER CASING)
C                 AND SET BEGINNING STREAM FCN. VALUE
C
      J=1
      YYB(1)=0
C
C                 SAVE EXISTING FLOW COEFFICIENT DISTRIBUTION
C                 SET WORKING RADIUS(X) FOR RUNGE-KUTTA SOLUTION
C                 CORRESPONDING TO STREAMLINE RADIUS IN STATOR
C                 LEAVING FLOW
C
      DO 30 K=1,JLIM
   30 S(K)=YY(K)
    1 X=XI(J)
      N=1
C
C                 INTERPOLATE SPECIFIED LEAVING FLOW ANGLE ,AND
C                 EXISTING LEAVING FLOW COEFFICIENT AND STREAM
C                 FCN. DISTRIBUTIONS AT RADIUS X
C
    2 CALL FIT1D(X,BTAS,XI,BTA,JLIM,WARN,IOUT)
      CALL FIT1D(X,PHIS,XI,S,JLIM,WARN,IOUT)
      CALL FIT1D(X,XPX,XI,PHIBB,JLIM,WARN,IOUT)
C
C                 INTERPOLATE ENTERING STREAMLINE RADIUS AT
C                 DETERMINED STREAM FCN. VALUE
C
      CALL FIT1D(XPX,XI1S,PHI1BB,XI1B, JLIM,WARN,IOUT)
```

```
C
C           INTERPOLATE ENTERING WHIRL AND TOTAL HEAD AT
C           DETERMINED ENTERING FLOW STREAMLINE RADIUS
C
      CALL FIT1D(XI1S,XLM1S,XI1B,XLM1B,JLIM,WARN,IOUT)
      CALL FIT1D(XI1S,HTP1S,XI1B,HTP1B,JLIM,WARN,IOUT)
C
C           COMPUTE LEAVING WHIRL AND DIFF. COEFFICIENT(Z)
C           CORRESPONDING TO RADIUS X
C
      XLMS=PHIS*TAN(BTAS)
      Z=XLMS*XLMS/X
      GO TO(3,4,6),N
C
C           SAVE ENTERING FLOW STREAMLINE DATA,COMPUTE NEW
C           LEAVING FLOW STREAMLINE FLOW COEF. AND STR.FCN
C
    3 HTP1(J)=HTP1S
      XI1(J)=XI1S
      XLM1(J)=XLM1S
      XLM(J)=XLMS
      PSI(J)=0
      HTP(J)=HTP1S     -HLOSSP(J)
   10 YY(J)=     2.*(HTP(J) -Y(J))-XLMS*XLMS
      IF(YY(J))20,21,21
   20 YY(J)=0
      GO TO 22
   21 YY(J)=SQRT(YY(J))
   22 IF(J-1)24,23,24
   24 YYB(J)=YYB(J-1)+(XI(J)*YY(J)+XI(J-1)*YY(J-1))*DD/YYYB
C
C           CHECK FOR OUTER CASING STREAMLINE(JLIM)
C           COMPUTE COEFFICIENTS AND INCREMENT X PER RUNGE
C           -KUTTA METHOD
C
   23 IF(J-JLIM)11,7,11
   11 C1=D*Z
      X=XI(J)+DD
      N=2
      GO TO 2
    4 C2=D*Z
      X=XI(J)+D
      N=3
      GO TO 2
    6 C4=D*Z
C
C           COMPUTE STREAMLINE STATIC HEAD VALUE. INCRE-
C           MENT STREAMLINE NUMBER
C
      Y(J+1)=Y(J)+(C1+4.*C2+C4)/6.
    8 J=J+1
      GO TO 1
    7 RETURN
      END
```

```
C
C
      SUBROUTINE LOSS
C     ***************
C
C
C
     1(BTAP,BTA1,BTA1P,DFACB,OMG,PPHFT,PPHFT1,PPHFTB
     2,XLMP,XLM1P, VUT,V1UT,V1PUT,VPUT,TYPNO,KLIMP,LLIMP,DEQ
     3,DEQB,THACB,TYPLOS,JQ)
      COMMON
     1JLIM,D,IIN,IOUT,KP,LP,YHLOSS(11),YS(3),YSIG(11),
     2YXI(11),XI(11),XI1B(11),PSIBB(11),XLM1B(11),HTP1(11),
     3HLOSSP(11),PSI(11),XI1(11),XLM(11),DFAC(11),EPS(3),
     4HP(11),HTP(11),HTP1B(11),P(11),PHI(11),PHIBB(11),
     5BTA(11),PHI1B(11),PHI1BB(11),SIG(11),XLM1(11),PHI1(11)
      COMMON OMGB(12,6)
      DIMENSION BTAP(1),BTA1(1),BTA1P(1),DFACB(1),OMG(1),
     1PPHFT(1),PPHFT1(1),PPHFTB(1),XLMP(1),XLM1P(1),VUT(1),
     2 VPUT(1),DEQ(1),DEQB(1),THACB(1),V1UT(1),V1PUT(1)
C
C
C         DETERMINATION OF LOSS DISTRIBUTION(HUB-TIP,ROTOR OR
C         STATOR) USING DEQ OR D-FACTOR CALCULATION AND COR-
C         RESPONDING TABLE REFERENCE LOSS CORRELATION
C
C                INTERPOLATE ENTERING STREAMLINE FLOW COEFFI-
C                CIENTS. COMPUTE BLADE ROW ENTERING AND LEAVING
C                STREAMLINE ABSOLUTE FLOW ANGLES AND DIMENSION-
C                LESS VELOCITIES
C
      DO 1 J=1,JLIM
      XI1S=XI1(J)
      CALL FIT1D(XI1S,PHI1S,XI1B,PHI1B,JLIM,WARN,IOUT)
      PHI1(J)=PHI1S
      BTA1(J)=ATAN2(XLM1(J),PHI1(J))
      BTA(J)=ATAN2(XLM(J),PHI(J))
      V1UT(J)=PHI1(J)/COS(BTA1(J))
    1 VUT(J)=PHI(J)/COS(BTA(J))
C
C                CHECK FOR STATOR(2) OR ROTOR ROW
C                COMPUTE ENTERING AND LEAVING STREAMLINE REL.
C                FLOW ANGLES AND DIMENSIONLESS VELOCITIES(STA-
C                TOR OR ROTOR)
C
      L=TYPNO
      IF(L-2)5,3,5
    3 DO 30 J=1,JLIM
      CX=-.61
      CY=-1
      XLM1P(J)=-XLM1(J)
      XLMP(J)=-XLM(J)
      BTA1P(J)=-BTA1(J)
      BTAP(J)=-BTA(J)
      V1PUT(J)=V1UT(J)
   30 VPUT(J)=VUT(J)
```

```
      GO TO 31
    5 DO 4 J=1,JLIM
      CX=+.61
      CY=1
      XLM1P(J)=XI1(J)-XLM1(J)
      XLMP(J)=XI(J)-XLM(J)
      BTA1P(J)=ATAN2(XLM1P(J),PHI1(J))
      BTAP(J)=ATAN2(XLMP(J),PHI(J))
      V1PUT(J)=PHI1(J)/COS(BTA1P(J))
    4 VPUT(J)=PHI(J)/COS(BTAP(J))
C
C              COMPUTE ENTERING AND LEAVING STREAMLINE PER-
C              CENT PASSAGE HEIGHT(FROM OUTER CASING) , DEQ
C              AND D-FAC VALUES FROM VELOCITY TRIANGLES AND
C              BLADE ROW SOLIDITY DISTRIBUTION(STATOR OR RO-
C              TOR)
C
   31 X=XI1(JLIM)-XI1(1)
      XX=XI(JLIM)-XI(1)
      DO 2 J=1,JLIM
      PPHFT1(J)=(XI1(JLIM)-XI1(J))/X
      PPHFT(J)=(XI(JLIM)-XI(J))/XX
      DEQ(J)=V1PUT(J)/VPUT(J)*(1.12+CX*COS(BTA1P(J))*
     1COS(BTA1P(J))*((XI1(J)*XLM1P(J)/XI(J))-XLMP(J))/
     2(SIG(J)*PHI1(J)))
    2 DFAC(J)=1.-VPUT(J)/V1PUT(J)-CY*(XI(J)*XLMP(J)-XI1(J)*
     1XLM1P(J))/((XI(J)+XI1(J))*SIG(J)*V1PUT(J))
C
C              CHECK TYPLOS(=0,D-FAC CALC.). COMPUTE DIMEN-
C              SIONLESS HEAD LOSS AND LOSS COEFFICIENT VALUES
C              PER STREAMLINE(STATOR OR ROTOR) AS FCN.(DEQ,
C              OR D-FAC AND PERCENT PASSAGE HEIGHT)
C
      IF(TYPLOS)20,21,20
   20 FH2=1.08
      C4=2./(3.*FH2-1.)
      DO 7 J=1,JLIM
      X=DEQ(J)
      CALLFIT1D(X,Y,DEQB,THACB,KLIMP,WARN,IOUT)
      C3=SIG(J)*Y*FH2/COS(BTAP(J))
      C5=PHI1(J)/COS(BTAP(J))
      YHLOSS(J)=C3*C4*C5*C5/((1.-C3)**3)
    7 OMG(J)=2.*YHLOSS(J)/(V1PUT(J)*V1PUT(J))
      RETURN
   21 CALL FIT2D(DFAC,OMG,PPHFT,DFACB,OMGB,PPHFTB,KLIMP,
     1 LLIMP,JLIM,JQ,WARN,IOUT)
      DO 6 J=1,JLIM
      OMG(J)=2.*SIG(J)*OMG(J)/COS(BTAP(J))
    6 YHLOSS(J)=.5*OMG(J)* V1PUT(J)*V1PUT(J)
      RETURN
      END
```

```
C
C
      SUBROUTINE OUTPUT
C     *****************
C
C
C
     1(PPHFT1,PPHFT,BTA1,BTA1P,ωD,BTAP,OMG,DEQ,TYPNO,PJLIM)
      COMMON
     1JLIM,D,IIN,IOUT,KP,LP,YHLOSS(11),YS(3),YSIG(11),
     2YXI(11),XI(11),XI1B(11),PSIBB(11),XLM1B(11),HTP1(11),
     3HLOSSP(11),PSI(11),XI1(11),XLM(11),DFAC(11),EPS(3),
     4HP(11),HTP(11),HTP1B(11),P(11),PHI(11),PHIBB(11),
     5BTA(11),PHI1B(11),PHI1BB(11),SIG(11),XLM1(11),PHI1(11)
      COMMON OMGB(12,6)
      DIMENSION PPHFT1(1),PPHFT(1),OMG(1),BTA1P(1),BTAP(1)
     1,DEQ(1),PS(11),HP1(11),XLPAR(11),REACT(11),EFF(11),
     2BTA1(11)
C
C
C         PRINTOUT OF COMPUTED RESULTS
C
C               COMPUTE ADDITIONAL STREAMLINE RESULTS AND
C               CONVERT ANGLES TO UNITS OF DEG.(REACTION
C               AND EFFICIENCY FOR STATOR ROW=0)
C
      WRITE(IOUT,1)
      DO 3 J=1,JLIM
      K=JLIM-J+1
      XLPAR(K)=OMG(K)*COS(BTAP(K))/(2.*SIG(K))
      BTA1(K)=57.3*BTA1(K)
      BTA1P(K)=57.3*BTA1P(K)
      BTA(K)=57.3*BTA(K)
      BTAP(K)=57.3*BTAP(K)
      HP1(K)=HTP1(K)-.5*(PHI1(K)*PHI1(K)+XLM1(K)*XLM1(K))
      IF(TYPNO-1.)20,21,20
   21 REACT(K)=(HP(K)-HP1(K))/(HTP(K)-HTP1(K))
      PS(K)=PSI(K)-HLOSSP(K)
      EFF(K)=PS(K)/PSI(K)
      GO TO 3
   20 PSI(K)=0
      EFF(K)=0
      REACT(K)=0
      PS(K)=PSI(K)-HLOSSP(K)
C
C               PRINT OUT STREAMLINE RESULTS FOR FLOW
C               ENTERING BLADE ROW
C               PRINT OUT STREAMLINE RESULTS FOR FLOW
C               LEAVING BLADE ROW
C
    3 WRITE(IOUT,2)PPHFT1(K),XI1(K),PHI1(K),XLM1(K),BTA1(K),
     1BTA1P(K),HTP1(K), PHIBB(K)
      WRITE(IOUT,10)
```

```
      DO 11 J=1,JLIM
      K=JLIM-J+1
   11 WRITE(IOUT,12)PPHFT(K),XI(K),PHI(K),XLM(K),BTA(K),
     1BTAP(K),HTP(K),HP(K),PHIBB(K)
      WRITE(IOUT,13)
      DO 14 J=1,JLIM
      K=JLIM-J+1
   14 WRITE(IOUT,15)PPHFT(K),XI(K),PS(K),PSI(K),REACT(K),EFF
     1(K),HLOSSP(K),OMG(K),XLPAR(K),DFAC(K),DEQ(K)
C
C             CALL SUBROUTINE MAVE TO COMPUTE AND PRINT OUT
C             MASS-AVERAGED RESULTS
C
      CALL MAVE(PS,TYPNO,DD,PJLIM)
      CONTINUE
      RETURN
C
    1 FORMAT(  /' %PASS HT FR TIP   R1/RT   PHI1   LAMDA1',
     1'   BTA1(DEG)    BTA1P    HTP1   STR FCN'/  )
    2 FORMAT(F16.3,3F7.3,F11.2,F8.2,F7.3,F9.3)
   10 FORMAT(  /18X,'R2/RT   PHI2   LAMDA2   BTA2(DEG)    ',
     1'BTA2P    HTP2     HP2   STR FCN'/ )
   12 FORMAT(F16.3,3F7.3,F11.2,F8.2,2F7.3,F9.3)
   13 FORMAT(  /18X,'R2/RT     PSI    PSII    REACTION    EFF',
     1 '   HLOSSP   OMEGAB   LOSS PARAM   DFAC    DEQ'/ )
   15 FORMAT(F16.3,3F7.3,F11.3,F8.3,F7.4,F8.4,F12.4,2F6.3)
      END
```

```
C
C
      SUBROUTINE MAVE
C     ***************
C
C
C
     1(PS,TYPNO,DD,PJLIM)
      COMMON
     1JLIM,D,IIN,IOUT,KP,LP,YHLOSS(11),YS(3),YSIG(11),
     2YXI(11),XI(11),XI1B(11),PSIBB(11),XLM1B(11),HTP1(11),
     3HLOSSP(11),PSI(11),XI1(11),XLM(11),DFAC(11),EPS(3),
     4HP(11),HTP(11),HTP1B(11),Y(11),PHI(11),PHIBB(11),
     5BTA(11),PHI1B(11),PHI1BB(11),SIG(11),XLM1(11),PHI1(11)
      COMMON OMGB(12,6)
      DIMENSION PS(1),S(11),P(11)
C
C
C         COMPUTION OF MASS-AVERAGED VALUES FOR FLOW LEAVING
C         A BLADE ROW
C
      X=1./PJLIM
      U=2.*PJLIM/(XI(JLIM)*XI(JLIM)-XI(1)*XI(1))
      DO 5 K=1,2
C
C                TRANSFER ARRAYS TO P-ARRAY
C
      DO 1 J=1,JLIM
      GO TO (3,4),K
    3 P(J)=PS(J)
      GO TO 1
    4 P(J)=PSI(J)
    1 CONTINUE
C
C                COMPUTE P-ARRAY INTEGRAL(FROM INNER TO OUTER
C                CASING) AT COMPUTING STATION FOR FLOW LEAVING
C                BLADE ROW
C
      S(1)=0
      DO 6 J=2,JLIM
    6 S(J)=S(J-1)+(XI(J)*PHI(J)*P(J)+XI(J-1)*PHI(J-1)*P(J-1))*DD
C
C                FORM MASS-AVERAGED FLOW COEFFICIENT, ACTUAL
C                AND IDEAL HEAD-RISE COEFFICIENTS
C
      GO TO (8,9),K
    8 V=X*S(JLIM)
      GO TO 5
    9 W=X*S(JLIM)
    5 CONTINUE
```

```
C
C             COMPUTE HYDRAULIC EFFICIENCY FOR BLADE ROW
C             (=0 FOR STATOR ROW)
C             WRITE OUT COMPUTED MASS-AVERAGED RESULTS
C
      IF(TYPNO-1.)11,12,11
   11 Z=0.
      GO TO 13
   12 Z=V/W
   13 WRITE(IOUT,10)U,V,W,Z
      RETURN
C
   10 FORMAT(/ ' MASS-AVERAGED: PHI2=',F7.3,'  PSI=',F7.3,
     1'   PSII=',F7.3,'  EFF=',F7.3)
      END
```

```
C
C
      SUBROUTINE FIT1D
C     ****************
C
C
C
     1(X,Y,XB,YB,JP,WARN,IOUT)
      REAL XB( 1),YB( 1)
C
C
C         3-POINT LAGRANGIAN INTERPOLATION FOR Y=FCN(X) FROM
C         DATA TABLES XB,YB. XB-ARRAY VALUES ARE ARBITRARILY
C         SPACED, MONOTONE NON-DECREASING. JP IS GIVEN NUMBER
C         OF XB- OR YB-ARRAY ELEMENTS
C
C                CHECK COMPATIBILITY OF JP VALUE WITH LAGRANGE
C                FORMULA REQUIREMENTS
C
      WARN=0
   14 IF(JP-3)12,15,15
   12 WRITE(IOUT,500)JP
      STOP
C
C                BRACKET INTERPOLATE X WITH THREE NEIGHBORING
C                XB-ARRAY VALUES(WARN=1 INDICATES EXTRAPOLATION
C                OUTSIDE OF RANGE OF XB-ARRAY)
C
   15 IF(XB(1)-X)16,16,17
   17 WARN=1
   16 DO 1 J=3,JP
      L=J
      IF(X-XB(L))2,2,1
    1 CONTINUE
      WARN=1
C
C                COMPUTE INTERPOLATED Y USING LAGRANGE FORMULA
C
    2 X0=XB(L-2)
      X1=XB(L-1)
      X2=XB(L)
      Y=(X-X1)*(X-X2)*YB(L-2)/((X0-X1)*(X0-X2))+(X-X2)*
     1(X-X0)*YB(L-1)/((X1-X2)*(X1-X0))+(X-X0)*(X-X1)*YB(L)/
     2((X2-X0)*(X2-X1))
      RETURN
C
  500 FORMAT(10X,' INCORRECT ARRAY SIZE IN FIT1D, JP=',I2)
      END
```

```
C.
C
      SUBROUTINE FIT2D
C     ****************
C
C
C
     1(X,Y,Z,XB,YB,ZB,IP,JP,JL,JQ,WARN,IOUT)
      DIMENSION X(1),Y(1),Z(1),YST(3),XB(1),ZB(1),YB(12,1)
C
C
C          3-POINT LAGRANGIAN INTERPOLATION FOR Y=FCN(X,Z)
C          FROM DATA TABLES XB,YB,ZB. XB-AND ZB-ARRAY VALUES
C          ARE ARBITRARILY SPACED, MONOTONE NON-DECREASING.
C          IP,JP ARE NUMBER OF ELEMENTS IN XB,ZB ARRAYS,RE-
C          SPECTIVELY. JQ IS DIMENSION SIZE OF Y-ARRAY.
C          JL IS NUMBER OF INTERPOLATIONS Y REQUESTED FOR
C          INTERPOLATE PAIRS(X,Z)
C
C                 CHECK COMPATIBILITY OF JL WITH Y-ARRAY DIMEN-
C                 SION (JQ)
C                 CHECK COMPATIBILITY OF IP,JP VALUES WITH
C                 LAGRANGE FORMULA REQUIREMENTS
C
      WARN=0
      IF(JL-JQ)20,20,15
   20 IF(IP-3)15,10,10
   10 IF(JP-3)15,12,12
   15 WRITE(IOUT ,500)IP,JP,JL
      STOP
   12 DO 6 N=1,JL
C
C                 BRACKET INTERPOLATES X,Z EACH WITH THREE
C                 NEIGHBORING XB-AND ZB-ARRAY VALUES(WARN=1
C                 INDICATES EXTRAPOLATION OUTSIDE RANGE OF XB-
C                 AND/OR ZB-ARRAY)
C
      IF(XB(1)-X(N))16,16,17
   17 WARN=1
   16 DO 1 M=3,IP
      I=M
      IF(X(N)-XB(I))2,2,1
    1 CONTINUE
      WARN=1
    2 IF(ZB(1)-Z(N))18,18,19
   19 WARN=1
   18 DO 3 M=3,JP
      J=M
      IF(Z(N)-ZB(J))4,4,3
    3 CONTINUE
      WARN=1
    4 X0=ZB(J-2)
      X1=ZB(J-1)
      X2=ZB(J)
```

```
C
C           COMPUTE INTERPOLATED YST(3-TIMES) AND Y USING
C           LAGRANGE FORMULA
C
      DO 5 K=1,3
      L=I+K
      Y0=YB(L-3,J-2)
      Y1=YB(L-3,J-1)
      Y2=YB(L-3,J)
    5 YST(K)=(Z(N)-X1)*(Z(N)-X2)*Y0/((X0-X1)*(X0-X2))
     1+(Z(N)-X2)*(Z(N)-X0)*Y1/((X1-X2)*(X1-X0))
     2+(Z(N)-X0)*(Z(N)-X1)*Y2/((X2-X0)*(X2-X1))
      X0=XB(I-2)
      X1=XB(I-1)
      X2=XB(I)
    6 Y(N)=(X(N)-X1)*(X(N)-X2)*YST(1)/((X0-X1)*(X0-X2))
     1+(X(N)-X2)*(X(N)-X0)*YST(2)/((X1-X2)*(X1-X0))
     2+(X(N)-X0)*(X(N)-X1)*YST(3)/((X2-X0)*(X2-X1))
      RETURN
C
  500 FORMAT(10X,' INCORRECT ARRAY SIZE IN FIT2D, IP=',I2,
     1' JP=',I2,' JL=',I2)
      END
```

APPENDIX B

Listing of Example Data Load

The input data cards for an example design[9] of a single-stage pump are listed below. Each line represents a card, and the card type (as denoted in the section "Input Load Description") is indicated at the left of each line. Two design specifications are given for the rotor to illustrate the parametric capability discussed in the section "Computer Program Capability and Utilization." As mentioned previously, all input is read under 10F7.0 format for simplicity and the decimal point must be defined either explicitly or by format convention. Reassignment as integer variables is done in the program where appropriate.

CARD TYPE										
1	7.	.001	.001							
2	3.									
3	.8	.49	.5	.9	.49	.5	1.0	.49	.5	
4a	1.	1.	0.							
5a	7.	5.								
6a	0.	0.	0.	.25	0.	.50	0.	.75	0.	1.
6a	0.									
6a	.2	0.	.0072	.25	.0049	.50	.001	.75	.001	1.
6a	.0023									
6a	.4	0.	.0182	.25	.0125	.50	.002	.75	.003	1.
6a	.005									
6a	.5	0.	.0269	.25	.019	.50	.0028	.75	.0041	1.
6a	.007									
6a	.6	0.	.0378	.25	.0271	.50	.0041	.75	.0065	1.
6a	.0105									
6a	.7	0.	.0503	.25	.038	.50	.0061	.75	.01	1.
6a	.0155									
6a	.8	0.	.0648	.25	.0508	.50	.009	.75	.014	1.
6a	.0218									
7a	7.									
8a	.8	.433	.875	.833	.433	.84	.867	.433	.807	.9
8a	.433	.778	.933	.456	.751	.967	.478	.724	1.	.498
8a	.7									
4b	1.	1.	1.	0.						
7a	7.									
8a	.8	.437	1.250	.833	.433	1.2	.867	.426	1.152	.9
8a	.427	1.111	.933	.456	1.071	.967	.481	1.035	1.	.498
8a	1.									
4b	2.	2.	.0	.0						
5a	7.	3.								
6a	.0	.0	.003	.5	.003	1.	.003			
6a	.2	.0	.004	.5	.004	1.	.004			
6a	.4	.0	.008	.5	.008	1.	.008			
6a	.5	.0	.0125	.5	.0125	1.	.0125			
6a	.6	.0	.017	.5	.017	1.	.017			
6a	.7	.0	.0275	.5	.0275	1.	.0275			
6a	.8	.0	.0425	.5	.0425	1.	.0425			
7b	3.									
8b	.8	.0	1.25	.9	.0	1.111	1.	.0	1.	
9	(Blank card)									

Listing of Example Computer Program Output

INPUT DATA

JLIM= 7. CONT. TOLER.= 0.0010 LOSS TOLER.= 0.0010

INLET

R/RT	PHI	HD COEF
0.8000	0.4900	0.5000
0.9000	0.4900	0.5000
1.0000	0.4900	0.5000

INLET FLOW COEF= 0.490

STA. NO. (ROTOR ROW)= 1.

LOSS COEF. TABLE

PERCENT PASSAGE HEIGHT FROM TIP

DFAC	0.0	0.25	0.50	0.75	1.00
0.0	0.0	0.0	0.0	0.0	0.0
0.2000	0.0072	0.0049	0.0010	0.0010	0.0023
0.4000	0.0182	0.0125	0.0020	0.0030	0.0050
0.5000	0.0269	0.0190	0.0028	0.0041	0.0070
0.6000	0.0378	0.0271	0.0041	0.0065	0.0105
0.7000	0.0503	0.0380	0.0061	0.0100	0.0155
0.8000	0.0648	0.0508	0.0090	0.0140	0.0218

DESIGN CONDITIONS:

R2/RT	PSII	SOLIDITY
0.800	0.433	[illegible]
0.833	0.433	0.840
0.867	0.433	0.807
0.900	0.433	0.778
0.933	0.456	0.751
0.967	0.478	0.724
1.000	0.498	0.700

NO. LOSS ITERATIONS= 6 NO. CONTINUITY ITERATIONS= 12

%PASS HT FR TIP	R1/RT	PHI1	LAMDA1	BTA1(DEG)	BTA1P	HTP1	STR FCN
0.0	1.000	0.490	0.0	0.0	63.90	0.500	1.000
0.155	0.969	0.490	0.0	0.0	63.18	0.500	0.831
0.315	0.937	0.490	0.0	0.0	62.40	0.500	0.663
0.483	0.903	0.490	0.0	0.0	61.53	0.500	0.490
0.658	0.868	0.490	0.0	0.0	60.57	0.500	0.318
0.831	0.834	0.490	0.0	0.0	59.56	0.500	0.154
1.000	0.800	0.490	0.0	0.0	58.52	0.500	0.0

	R2/RT	PHI2	LAMDA2	BTA2(DEG)	BTA2P	HTP2	HP2	STR FCN
0.0	1.000	0.454	0.498	47.68	47.91	0.931	0.705	1.000
0.167	0.967	0.455	0.494	47.38	46.09	0.922	0.696	0.831
0.333	0.933	0.482	0.489	45.38	42.66	0.924	0.688	0.663
0.500	0.900	0.515	0.481	43.07	39.15	0.928	0.679	0.490
0.667	0.867	0.517	0.500	44.01	35.36	0.929	0.670	0.318
0.833	0.833	0.504	0.520	45.90	31.92	0.922	0.660	0.154
1.000	0.800	0.495	0.541	47.55	27.59	0.918	0.649	0.0

	R2/RT	PSI	PSII	REACTION	EFF	HLOSSP	OMEGAB	LOSS PARAM	DFAC	DEQ
0.0	1.000	0.431	0.498	0.753	0.866	0.0665	0.1084	0.0519	0.712	2.126
0.167	0.967	0.422	0.478	0.750	0.883	0.0559	0.0960	0.0460	0.713	2.143
0.333	0.933	0.424	0.456	0.727	0.929	0.0326	0.0586	0.0287	0.692	2.090
0.500	0.900	0.428	0.433	0.700	0.987	0.0055	0.0104	0.0052	0.659	2.009
0.667	0.867	0.429	0.433	0.677	0.990	0.0042	0.0084	0.0042	0.676	2.055
0.833	0.833	0.422	0.433	0.664	0.974	0.0111	0.0237	0.0120	0.707	2.149
1.000	0.800	0.418	0.433	0.643	0.965	0.0153	0.0346	0.0175	0.734	2.233

MASS-AVERAGED: PHI2= 0.490 PSI= 0.425 PSII= 0.450 EFF= 0.944

STA. NO. (ROTOR ROW)= 1.

LOSS COEF. TABLE

PERCENT PASSAGE HEIGHT FROM TIP

DFAC	0.0	0.25	0.50	0.75	1.00
0.0	0.0	0.0	0.0	0.0	0.0
0.2000	0.0072	0.0049	0.0010	0.0010	0.0023
0.4000	0.0182	0.0125	0.0020	0.0030	0.0050
0.5000	0.0269	0.0190	0.0028	0.0041	0.0070
0.6000	0.0378	0.0271	0.0041	0.0065	0.0105
0.7000	0.0503	0.0380	0.0061	0.0100	0.0155
0.8000	0.0648	0.0508	0.0090	0.0140	0.0218

DESIGN CONDITIONS:

R2/RT	PSII	SOLIDITY
0.800	0.437	1.250
0.833	0.433	1.200
0.867	0.426	1.152
0.900	0.427	1.111
0.933	0.456	1.071
0.967	0.481	1.035
1.000	0.498	1.000

NO. LOSS ITERATIONS= 7 NO. CONTINUITY ITERATIONS= 14

%PASS HT FR TIP	R1/RT	PHI1	LAMDA1	BTA1(DEG)	BTA1P	HTP1	STR.FCN
0.0	1.000	0.490	0.0	0.0	63.90	0.500	1.000
0.152	0.970	0.490	0.0	0.0	63.20	0.500	0.835
0.311	0.938	0.490	0.0	0.0	62.42	0.500	0.666
0.480	0.904	0.490	0.0	0.0	61.55	0.500	0.493
0.654	0.869	0.490	0.0	0.0	60.59	0.500	0.321
0.828	0.834	0.490	0.0	0.0	59.58	0.500	0.156
1.000	0.800	0.490	0.0	0.0	58.52	0.500	0.0

	R2/RT	PHI2	LAMDA2	BTA2(DEG)	BTA2P	HTP2	HP2	STR FCN
0.0	1.000	0.436	0.498	48.82	49.04	0.921	0.702	1.000
0.167	0.967	0.454	0.497	47.63	45.97	0.920	0.694	0.835
0.333	0.933	0.486	0.489	45.17	42.44	0.925	0.685	0.666
0.500	0.900	0.514	0.474	42.71	39.62	0.922	0.677	0.493
0.667	0.867	0.517	0.492	43.57	35.97	0.923	0.668	0.321
0.833	0.833	0.509	0.520	45.60	31.66	0.923	0.658	0.156
1.000	0.800	0.503	0.546	47.36	26.77	0.922	0.646	0.0

	R2/RT	PSI	PSII	REACTION	EFF	HLOSSP	OMEGAB	LOSS PARAM	DFAC	DEQ
0.0	1.000	0.421	0.498	0.765	0.846	0.0768	0.1250	0.0410	0.627	2.077
0.167	0.967	0.420	0.481	0.747	0.874	0.0604	0.1029	0.0346	0.623	2.069
0.333	0.933	0.423	0.456	0.722	0.927	0.0334	0.0597	0.0206	0.597	1.999
0.500	0.900	0.422	0.427	0.704	0.987	0.0054	0.0102	0.0035	0.562	1.915
0.667	0.867	0.423	0.426	0.682	0.992	0.0036	0.0072	0.0025	0.576	1.952
0.833	0.833	0.423	0.433	0.658	0.976	0.0104	0.0222	0.0079	0.607	2.037
1.000	0.800	0.422	0.437	0.631	0.966	0.0148	0.0335	0.0120	0.632	2.112

MASS-AVERAGED: PHI2= 0.490 PSI= 0.422 PSII= 0.448 EFF= 0.941

STA. NO. (STATOR)= 2.

LOSS COEF. TABLE

PERCENT PASSAGE HEIGHT FROM TIP

DFAC	0.0	0.50	1.00
0.0	0.0030	0.0030	0.0030
0.2000	0.0040	0.0040	0.0040
0.4000	0.0080	0.0080	0.0080
0.5000	0.0125	0.0125	0.0125
0.6000	0.0170	0.0170	0.0170
0.7000	0.0275	0.0275	0.0275
0.8000	0.0425	0.0425	0.0425

DESIGN CONDITIONS:

R2/RT	BETA2(DEG)	SOLIDITY
0.800	0.0	1.250
0.900	0.0	1.111
1.000	0.0	1.000

NO. LOSS ITERATIONS= 5 NO. CONTINUITY ITERATIONS= 10

%PASS HT FR TIP	R1/RT	PHI1	LAMDA1	BTA1(DEG)	BTA1P	HTP1	STR FCN
0.0	1.000	0.436	0.498	48.82	-48.82	0.921	1.000
0.184	0.963	0.457	0.497	47.38	-47.38	0.921	0.818
0.357	0.929	0.492	0.485	44.60	-44.60	0.923	0.641
0.521	0.896	0.515	0.476	42.75	-42.75	0.922	0.471
0.680	0.864	0.516	0.494	43.75	-43.75	0.923	0.307
0.840	0.832	0.509	0.521	45.67	-45.67	0.923	0.150
1.000	0.800	0.503	0.546	47.36	-47.36	0.922	0.0

	R2/RT	PHI2	LAMDA2	BTA2(DEG)	BTA2P	HTP2	HP2	STR FCN
0.0	1.000	0.492	0.0	0.0	0.0	0.912	0.792	1.000
0.167	0.967	0.490	0.0	0.0	0.0	0.912	0.792	0.818
0.333	0.933	0.493	0.0	0.0	0.0	0.913	0.792	0.641
0.500	0.900	0.491	0.0	0.0	0.0	0.912	0.792	0.471
0.667	0.867	0.491	0.0	0.0	0.0	0.912	0.792	0.307
0.833	0.833	0.487	0.0	0.0	0.0	0.910	0.792	0.150
1.000	0.800	0.482	0.0	0.0	0.0	0.908	0.792	0.0

	R2/RT	PSI	PSII	REACTION	EFF	HLOSSP	OMEGAB	LOSS PARAM	DFAC	DEQ
0.0	1.000	-0.009	0.0	0.0	0.0	0.0087	0.0397	0.0198	0.633	1.915
0.167	0.967	-0.009	0.0	0.0	0.0	0.0092	0.0403	0.0195	0.630	1.947
0.333	0.933	-0.009	0.0	0.0	0.0	0.0092	0.0385	0.0180	0.612	1.964
0.500	0.900	-0.009	0.0	0.0	0.0	0.0095	0.0385	0.0173	0.604	1.988
0.667	0.867	-0.011	0.0	0.0	0.0	0.0106	0.0415	0.0180	0.612	2.014
0.833	0.833	-0.012	0.0	0.0	0.0	0.0123	0.0465	0.0194	0.628	2.052
1.000	0.800	-0.014	0.0	0.0	0.0	0.0143	0.0524	0.0210	0.645	2.099

MASS-AVERAGED: PHI2= 0.490 PSI= -0.010 PSII= 0.0 EFF= 0.0

END

DATE

FILMED

FEB 16 1971