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FORTRAN PROGRAM FOR CALCULATING VELOCITIES IN A MAGNIFIED REGION ON A BLADE-TO-BLADE STREAM SURFACE OF A TURBOMACHINE

by Theodore Katsanis and William D. McNally

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1969

ERRATA

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Page 45: Replace line 6 with

```
IF (NOBL.EQ.2) GO TO 95
IF (MBII.LT.1) MBII = 1000
IF (MBOO.GT.MMM) MBOO = -1000
GO TO 130
```

Page 46: The following lines should be inserted between statement 165 and the two calls on SPLINT:

```
IF (MBII.GE.1.AND.MBII.LE.MMM) MV(MBII) = MLE(3)
IF (MBOO.GE.1.AND.MBOO.LE.MMM) MV(MBOO) = CHORD(1) + MLE(1)
```

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ABSTRACT

A FORTRAN IV computer program was written to obtain a local detailed solution around a leading or trailing edge or in a slot region for compressible, subsonic, nonviscous flow on a blade-to-blade surface between turbomachine blades. This program allows a coarse-mesh solution for an entire blade-to-blade region to be magnified in a small rectangular region. The results include detailed surface velocities, velocity magnitude and direction, and stream-function values throughout the magnified region. The method is based on the stream function and uses the iterative solution of nonlinear finite-difference equations.

CONTENTS

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SUMMARY

A FORTRAN IV computer program was written to obtain a local detailed solution around a leading or trailing edge or in a slot region for compressible, subsonic, nonviscous flow on a blade-to-blade surface between turbomachine blades. This program allows a coarse-mesh solution for an entire blade-to-blade region to be magnified by a chosen magnification factor in a small rectangular region.

The program input requires information obtained from a less detailed solution from one of three other FORTRAN programs. These programs have been presented in NASA Technical Notes. The output includes detailed surface velocities, velocity magnitude and direction, and stream-function values throughout the magnified region.

The method is based on the stream function with the solution of the simultaneous, nonlinear, finite-difference equations being obtained by two major levels of iteration. The inner iteration consists of the solution of simultaneous linear equations by successive overrelaxation, using an estimated optimum overrelaxation factor. The outer iteration then changes the coefficient of the simultaneous equations to compensate for compressibility.

This report includes the FORTRAN IV computer program with an explanation of the equations involved, the method of solution, and the calculation of velocities. Numerical examples have been included to illustrate the use of the program and to show the results which are obtained.

INTRODUCTION

In the design of blade rows for turbines and compressors, it is desirable to obtain the velocity distribution through the passage and particularly over the blade surfaces. The authors have published computer programs (refs. 1 to 3) for obtaining this type of solution for single and tandem blade rows.

With these programs, however, it is not always possible to obtain sufficient detail on some critical parts of the blade surfaces. These programs give an approximate solution for velocities only at the mesh points of a finite-difference grid. Due to storage requirements on the computer, grid spacing may be too large to give the desired detail around small leading- or trailing-edge radii or within slot regions. And it is in these regions where geometry, and thus velocities, change most rapidly.

For these reasons a computer program has been written to obtain a solution on a fine mesh in a small part of the blade-to-blade region. The method used is similar to that used by Kramer (ref. 4). A small rectangular region of the solution obtained by either 2DCP (ref. 1), TURBLE (ref. 2), or TANDEM (ref. 3) can be magnified by a chosen factor using MAGNFY, the program described herein. The input and output are similar to 2DCP, TURBLE, and TANDEM, with additional input required. The additional input is obtained from the output of 2DCP, TURBLE, or TANDEM.

This report includes the FORTRAN IV computer program that was developed with explanation of the input required. An axial-flow turbine rotor slot and the tip of a mixed-flow impeller have been analyzed to illustrate the use of the program.

This report is organized so that the engineer desiring to use this program needs to read only the sections MATHEMATICAL ANALYSIS, NUMERICAL EXAMPLES, and DESCRIPTION OF INPUT AND OUTPUT. The necessary information of interest to a programmer is contained in the sections DESCRIPTION OF INPUT AND OUTPUT and PROGRAM PROCEDURE.

A MAGNFY source deck on tape is available from COSMIC (Computer Software Management and Information Center), Computer Center, University of Georgia, Athens, Georgia 30601. The program number is COSMIC number LEW-10789.

SYMBOLS

A coefficient matrix, (eq. (A7), ref. 1)

b stream-channel thickness normal to meridional streamline, meters

$\underline{k}$ constant vector, $\begin{pmatrix} k_1 \\ \cdot \\ \cdot \\ \cdot \\ k_n \end{pmatrix}$, (eq. (A7), ref. 1)

m meridional streamline distance, meters

R gas constant, joule/(kg)($^{\circ}$K)

r	radius from axis of rotation to meridional stream-channel mean line, meters
T	temperature, ^{o}K
u	stream function
W	fluid velocity relative to blade, meters/sec
w	mass flow per blade flowing through stream channel, kg/sec
β	angle between relative velocity vector and meridional plane, rad
γ	specific-heat ratio
θ	relative angular coordinate, rad
λ	prerotation $\left(rV_{\theta}\right)_{in}$, meters^2/sec
ρ	density, kg/meters^3
Ω	overrelaxation factor, (eq. (A8), ref. 1)
ω	rotational speed, rad/sec

Subscripts:

in	inlet or upstream
le	leading edge
m	component in direction of meridional streamline
te	trailing edge
θ	tangential component

Superscript:

'	absolute stagnation condition

MATHEMATICAL ANALYSIS

It is desired to determine the flow distribution over the leading or trailing edge of a turbomachine blade or through the slot of a tandem or slotted blade. The stream function is used for the analysis. The basic assumptions and equations are given in references 1 and 3. The only difference in this analysis from that of references 1 and 3 is in the boundary conditions. For the MAGNFY program, the value of the stream function must be given for the entire boundary of the region considered. These values are determined on a coarse mesh by 2DCP, TURBLE, or TANDEM. MAGNFY then interpolates these values to obtain boundary values of stream functions on a finer mesh. These boundary conditions determine a solution to the stream function (eq. (1), ref. 1). The numerical solution is determined by using finite-difference equations, as described in appendix A of references 1 and 3.

NUMERICAL EXAMPLES

Two numerical examples are given to illustrate the use of the program and to show the type of results which can be obtained. The first example is the slot region of a tandem axial-flow turbine rotor blade, and the other is the trailing edge of a mixed-flow impeller.

Leading Edge of Rear Blade of Tandem Blade Turbine Rotor

Flow about the leading edge of the rear blade of a tandem axial-flow turbine rotor blade (ref. 5) has been analyzed to illustrate the use of MAGNFY. The entire blade was first analyzed by using TANDEM with the mesh size shown in figure 1. Due to computer storage limitations, this was as fine a mesh as could be obtained with TANDEM. However, more detail was desired for velocities between adjacent mesh points on the leading edge of the tandem blade. Therefore, MAGNFY was used in order to reduce the mesh spacing in the region around the leading edge by a factor of 8, as shown in figure 2.

The input for this case is given in table I. This includes most of the input necessary

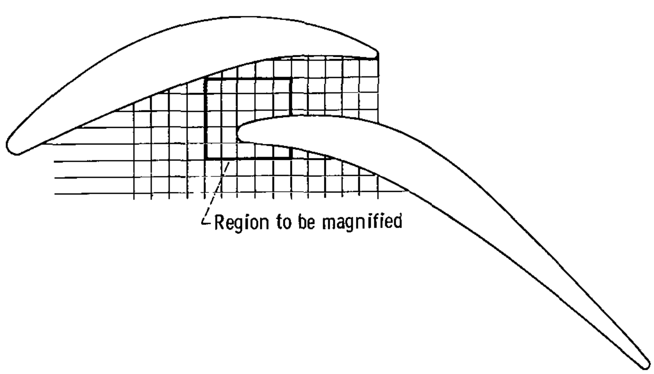


Figure 1. - Tandem axial turbine with region to be magnified.

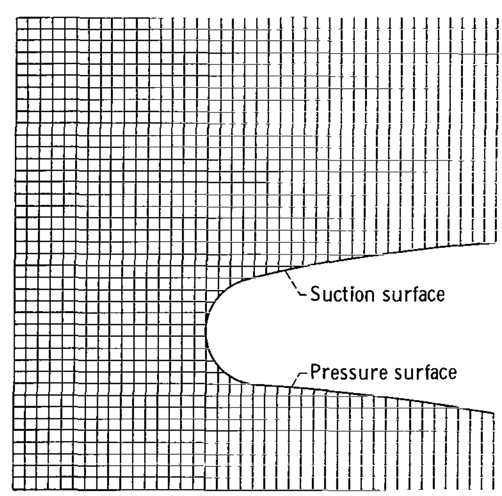


Figure 2. - Magnified region of figure 1 with reduced mesh size.

for TANDEM, in addition to the stream-function values on the vertical and horizontal boundaries of the magnified region. These stream-function values and their coordinates were obtained as output from the TANDEM program.

Blade-surface velocities from both TANDEM and MAGNFY are plotted in figure 3. The original velocities obtained by using the coarse mesh are denoted by circles in figure 3. The MAGNFY output is plotted as a solid line. As shown in figure 3, the velocity peak on the suction surface is much higher than indicated by the coarse-mesh solution. This illustrates the need for a finer grid in some parts of the solution region since the velocities denoted by circles do not define the velocity adequately.

The execution time for this example was 10 minutes on the direct-coupled IBM2-7094-7044 computer.

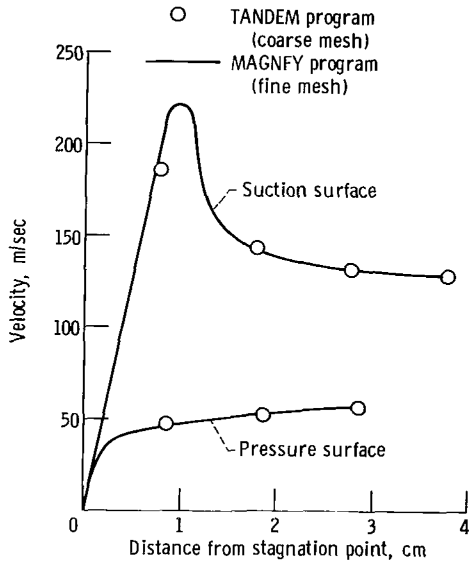


Figure 3. - Comparison of velocities from coarse-mesh and fine-mesh solutions.

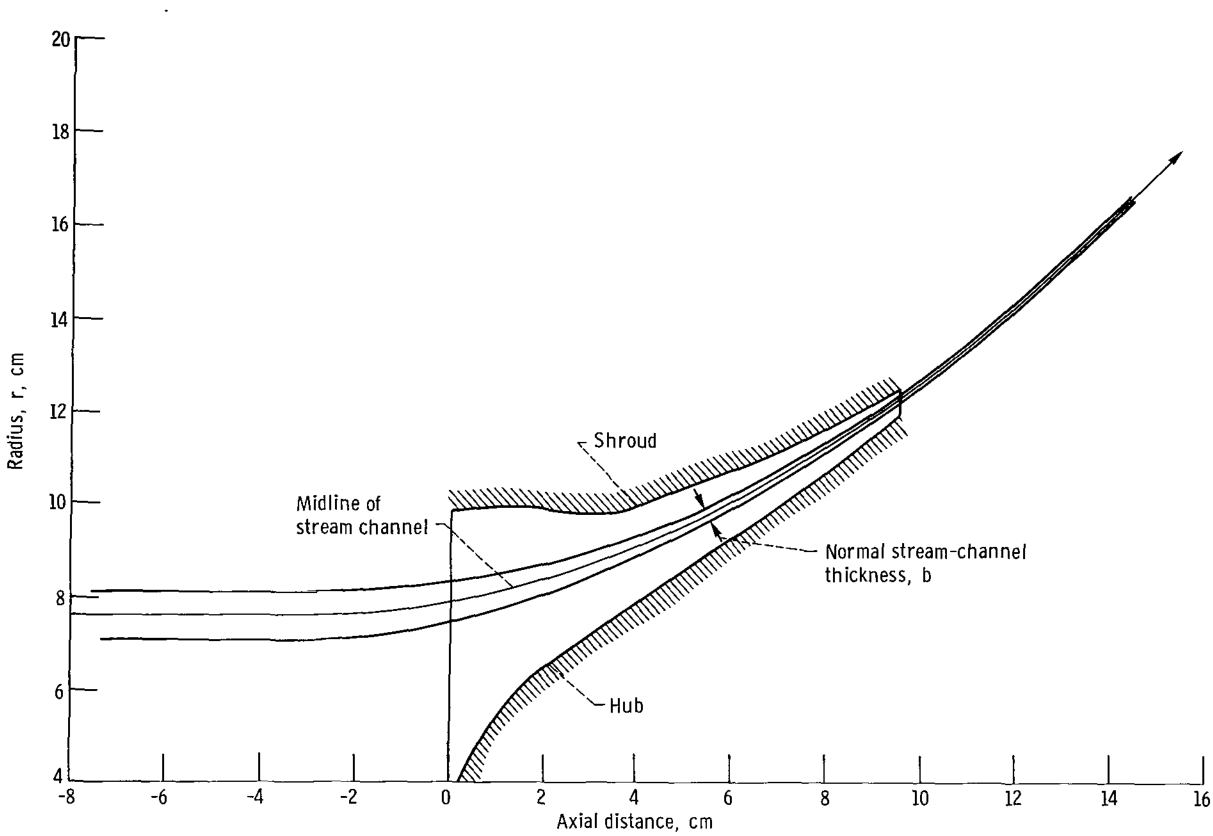
Trailing Edge of Mixed-Flow Impeller

Flow about the trailing edge of the main blade of a mixed-flow impeller with splitter blades (ref. 6) has also been analyzed using MAGNFY. The entire impeller was originally analyzed with TANDEM (ref. 3). The impeller profile (in the meridional plane) is shown in figure 4(a). Figure 4(b) shows the blade-to-blade region with the coarse mesh used in the TANDEM run. The region to be magnified about the trailing edge of the main blade is indicated by heavy lines in figure 4(b). MAGNFY was used to reduce the mesh

TABLE I. - MAGNFY INPUT FOR LEADING EDGE OF REAR BLADE OF TANDEM BLADE TURBINE ROTOR

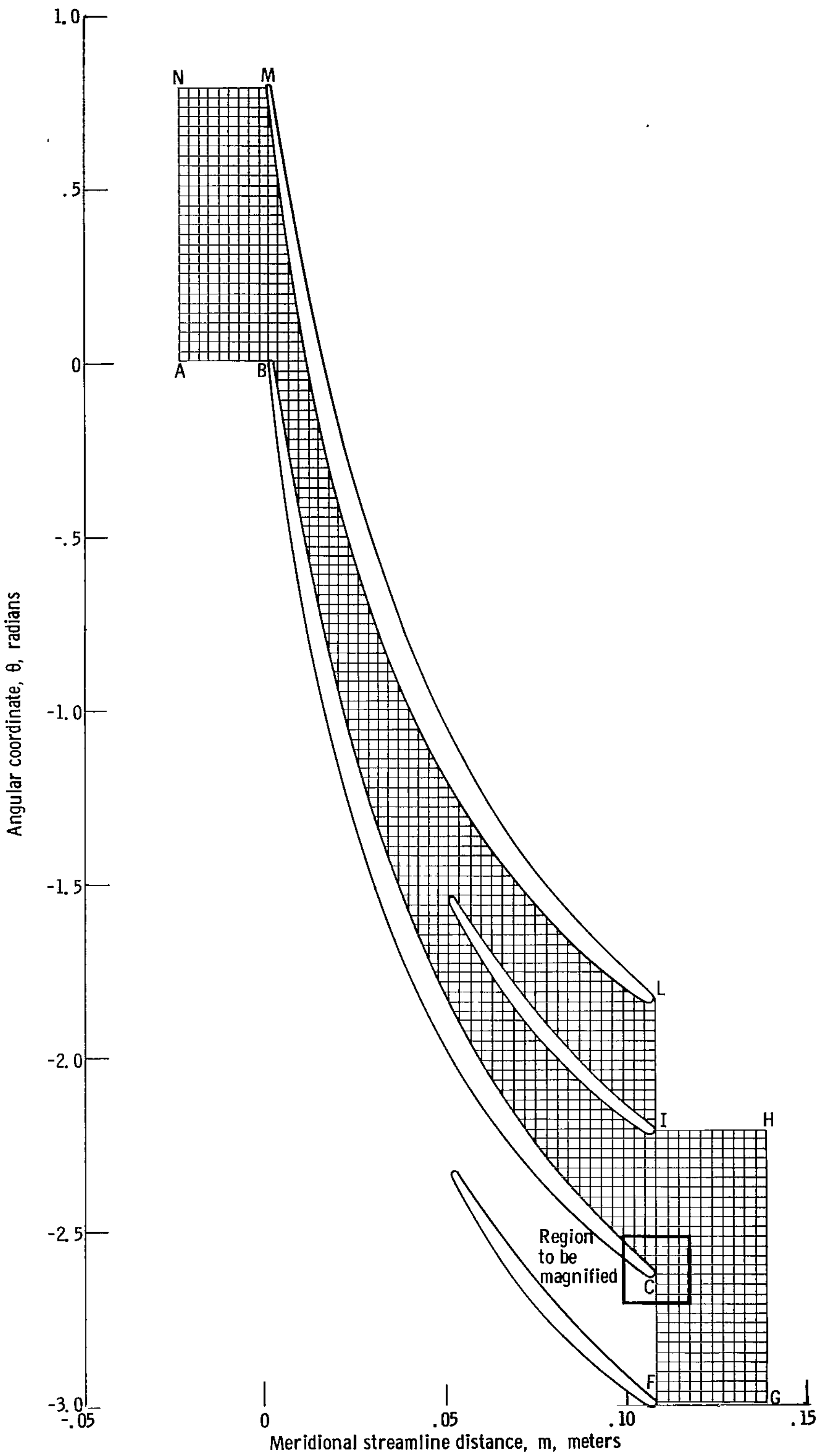
```
 SHIFTED TANDEM AXIAL TURBINE ROTOR - SMALL SLOT AREA
  NOBL
   2
  GAM             AR              TIP             RHOIP           WTFL            WTFLSP          OMEGA           ORF
1.4000000       287.05300       288.15000       1.2250000       0.2715000       0.6970000E-01   -0              1.7300000
  BETAI           BETAO           CHORDF          STGRF           CHORDR          STGRR           MLER            THLER
48.000000       -48.000000      0.2847000E-01   0.2133300E-01   0.3183000E-01   -0.5647000E-01  0.1773000E-01   0.2820000E-02
MBI  MBO MBI2 MBO2  MM  NBBI  NBL NRSP
10   32   24   49   58   20   76    2


 BLADE SURFACE 1  --  UPPER SURFACE - FRONT BLADE
   RI1             RO1             BETI1           BETO1           SPLNO1
 0.7620000E-03   0.3810000E-03   50.000000       -29.400000      7.0000000
   MSP1  ARRAY
-0               0.2570000E-02   0.7650000E-02   0.1527000E-01   0.2035000E-01   0.2543000E-01  -0
   THSP1  ARRAY
-0               0.9250000E-02   0.2118000E-01   0.2988000E-01   0.3020000E-01   0.2643000E-01  -0


 BLADE SURFACE 2  --  LOWER SURFACE - FRONT BLADE
   RI2             RO2             BETI2           BETO2           SPLNO2
 0.7620000E-03   0.3810000E-03   25.000000       -6.9000000      5.0000000
   MSP2  ARRAY
-0               0.7650000E-02   0.2035000E-01   0.2543000E-01  -0
   THSP2  ARRAY
-0               0.7140000E-02   0.2039000E-01   0.2094000E-01  -0


 BLADE SURFACE 3  --  UPPER SURFACE - REAR BLADE
   RI3             RO3             BETI3           BETO3           SPLNO3
 0.7620000E-03   0.3810000E-03   13.000000       -48.800000      5.0000000
   MSP3  ARRAY
-0               0.5160000E-02   0.1278000E-01   0.2294000E-01  -0
   THSP3  ARRAY
-0               0.4080000E-02  -0.2400000E-03  -0.2651000E-01  -0


 BLADE SURFACE 4  --  LOWER SURFACE - REAR BLADE
   RI4             RO4             BETI4           BETO4           SPLNO4
 0.7620000E-03   0.3810000E-03  -4.2000000      -42.500000      5.0000000
   MSP4  ARRAY
-0               0.5160000E-02   0.1278000E-01   0.2040000E-01  -0
   THSP4  ARRAY
-0              -0.4390000E-02  -0.1388000E-01  -0.2933000E-01  -0


   MR  ARRAY
-1.0000000       1.0000000
   RMSP  ARRAY
 0.3238500       0.3238500
   BESP  ARRAY
 0.1143000       0.1143000


 BLDAT  AANDK  ERSOR  STRFN  INTVL  SURVL
   1      1      2      2      2      3
```

```
 MBDYF  MBDYL   ITF    ITL   MAGFAC
  22     27     -1      4      8
   LAMBDA
27.587140


 KBDRY  NSP
   1      6
   BVIN  ARRAY
0.1519700E-01   0.1646400E-01   0.1773000E-01   0.1907200E-01   0.2041500E-01   0.2175700E-01
   UBVIN  ARRAY
-0.2562700      -0.2741800      -0.2883600      -0.2929900      -0.2920900      -0.2874300


 KBDRY  NSP
   2      6
   BVIN  ARRAY
0.1519700E-01   0.1646400E-01   0.1773000E-01   0.1907200E-01   0.2041500E-01   0.2175700E-01
   UBVIN  ARRAY
-0.1300000E-03  -0.1841000E-01  -0.3630000E-01  -0.5292000E-01  -0.6547000E-01  -0.7366000E-01


 KBDRY  NSP
   3      6
   BVIN  ARRAY
-0.4133700E-02  0               0.4133700E-02   0.8267400E-02   0.1240100E-01   0.1653500E-01
   UBVIN  ARRAY
-0.2562700      -0.2123600      -0.1671100      -0.1146800      -0.5821000E-01  -0.1300000E-03


 KBDRY  NSP
   4      2
   BVIN  ARRAY
-0.4133700E-02  -0.8230000E-03
   UBVIN  ARRAY
-0.2874300      -0.2567200


 KBDRY  NSP
   4      4
   BVIN  ARRAY
0.6708000E-02   0.8267400E-02   0.1240100E-01   0.1653500E-01
   UBVIN  ARRAY
-0.2567200      -0.2261100      -0.1478300      -0.7366000E-01
```



(a) Hub-shroud profile, showing meridional section of stream tube.

Figure 4. - Mixed-flow pump impeller.



(b) Blade-to-blade surface, showing coarse grid used in TANDEM program.

Figure 4. - Concluded.

TABLE II. - MAGNFY INPUT FOR TRAILING EDGE OF MIXED-FLOW IMPELLER

```
 MIXED FLOW IMPELLER (NASA TN D-1186) - TRAILING EDGE, MAIN BLADE
  NOBL
    2
  GAM            AR             TIP            RHOIP          WTFL             WTFLSP           OMEGA            ORF
 1.5C00000      1000.0000      1000000.0      1.0000000      0.3042000E-02    0.1351600E-02    796.00000        1.8440000
  BETAI          BETAO          CHORDF         STGRF          CHORDR           STGRR            MLER             THLER
-84.880000     -43.000000      0.1055500     -2.6290000      0.5664000E-01   -0.6649000        0.4891000E-01   -2.3434000
MBI  MBO MBI2 MBO2  MM  NBBI  NBL NRSP
10   47   28   47   57   28    8   18

 BLADE SURFACE 1  --  UPPER SURFACE - FRONT BLADE
  RI1            RO1            BETI1          BETO1          SPLNO1
 0.9140000E-03  0.1846000E-02 -80.000000     -49.000000      6.0000000
  MSP1  ARRAY
 0              0.1214000E-01  0.2651000E-01  0.4766000E-01  0.7360000E-01  0
  THSP1  ARRAY
 0             -0.6250000     -1.2330000     -1.8182000     -2.2750000      0

 BLADE SURFACE 2  --  LOWER SURFACE - FRONT BLADE
  RI2            RO2            BETI2          BETO2          SPLNO2
 0.9140000E-03  0.1846000E-02 -83.000000     -41.500000      6.0000000
  MSP2  ARRAY
 0              0.7880000E-02  0.2004000E-01  0.4006000E-01  0.6828000E-01  0
  THSP2  ARRAY
 0             -0.6310000     -1.2310000     -1.8206000     -2.2954000      0

 BLADE SURFACE 3  --  UPPER SURFACE - REAR BLADE
  RI3            RO3            BETI3          BETO3          SPLNO3
 0.1328000E-02  0.1753000E-02 -60.500000     -51.500000      6.0000000
  MSP3  ARRAY
 0              0.1307000E-01  0.2552000E-01  0.4172000E-01  0.5280000E-01  0
  THSP3  ARRAY
 0             -0.1670000     -0.3370000     -0.5262000     -0.6269000      0

 BLADE SURFACE 4  --  LOWER SURFACE - REAR BLADE
  RI4            RO4            BETI4          BETO4          SPLNO4
 0.1328000E-02  0.1753000E-02 -63.000000     -40.500000      5.0000000
  MSP4  ARRAY
 0              0.1073000E-01  0.2493000E-01  0.4172000E-01  0
  THSP4  ARRAY
 0             -0.2010000     -0.4070000     -0.5818000      0

  MR  ARRAY
-0.3124000E-01 -0.1514000E-01  0.2500000E-03  0.1065000E-01  0.1853000E-01  0.2651000E-01  0.3460000E-01  0.4281000E-01
 0.5115000E-01  0.5964000E-01  0.6828000E-01  0.7709000E-01  0.8607000E-01  0.9524000E-01  0.1046100      0.1141700
 0.1272600      0.1407300
  RMSP  ARRAY
 0.7586000E-01  0.7662000E-01  0.7874000E-01  0.8091000E-01  0.8294000E-01  0.8531000E-01  0.8802000E-01  0.9108000E-01
 0.9447000E-01  0.9820000E-01  0.1022800      0.1067400      0.1114600      0.1165600      0.1220000      0.1277800
 0.1360200      0.1448700
  BESP  ARRAY
 0.1053300E-01  0.1004500E-01  0.8724000E-02  0.7420000E-02  0.6316000E-02  0.5354000E-02  0.4532000E-02  0.3831000E-02
 0.3235000E-02  0.2728000E-02  0.2299000E-02  0.1936000E-02  0.1629000E-02  0.1370000E-02  0.1151000E-02  0.9790000E-03
 0.8250000E-03  0.7240000E-03
```

```
  BLDAT   AANDK   ERSOR   STRFN   INTVL   SURVL
    1       2       2       2       2       3


  MBDYF   MBDYL    ITF     ITL    MAGFAC
   44      50     -97     -90       5
    LAMBDA
-0.9835000E-02


  KBDRY   NSP
    1       7
    BVIN  ARRAY
 0.9660700E-01   0.9958800E-01   0.1025700       0.1055500       0.1085300       0.1115100       0.1144900
    UBVIN  ARRAY
-0.2089400      -0.1757100      -0.1440400      -0.1137000      -0.8342000E-01  -0.5251000E-01  -0.2076000E-01


  KBDRY   NSP
    2       7
    BVIN  ARRAY
 0.9660700E-01   0.9958800E-01   0.1025700       0.1055500       0.1085300       0.1115100       0.1144900
    UBVIN  ARRAY
 0.1517000E-01   0.4847000E-01   0.8207000E-01   0.1159000       0.1498600       0.1839400       0.2181900


  KBDRY   NSP
    3       6
    BVIN  ARRAY
-2.7208400      -2.6927900      -2.6647400      -2.6366900      -2.6086400      -2.5949900
    UBVIN  ARRAY
-0.2089400      -0.1676100      -0.1226400      -0.7412000E-01  -0.2446000E-01   0


  KBDRY   NSP
    3       2
    BVIN  ARRAY
-2.5380100      -2.5244900
    UBVIN  ARRAY
 0               0.1517000E-01


  KBDRY   NSP
    4       8
    BVIN  ARRAY
-2.7208400      -2.6927900      -2.6647400      -2.6366900      -2.6086400      -2.5805900      -2.5525400      -2.5244900
    UBVIN  ARRAY
-0.2077000E-01   0.1455000E-01   0.4942000E-01   0.8343000E-01   0.1166400       0.1499700       0.1837800       0.2181900
```

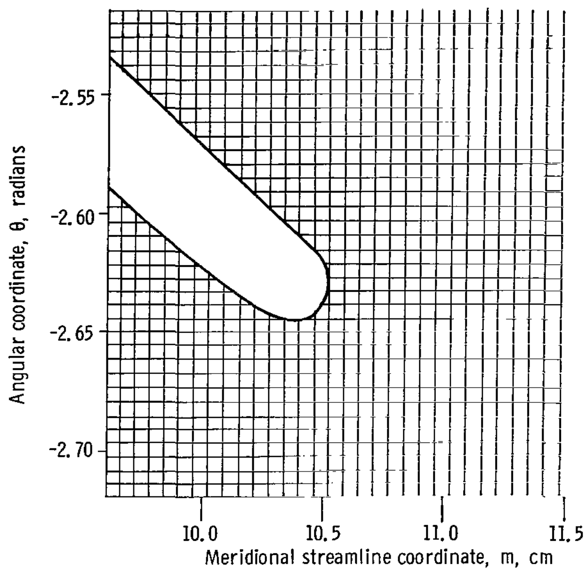


Figure 5. - Magnified region for mixed-flow impeller.

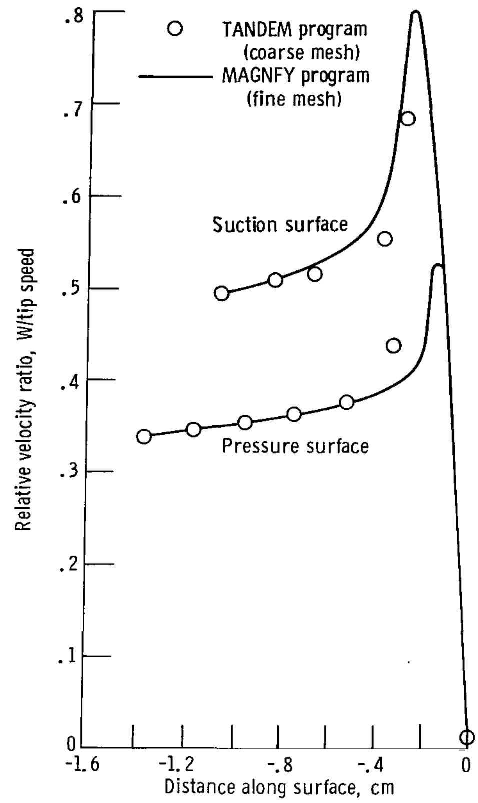


Figure 6. - Comparison of velocities near trailing edge of mixed-flow impeller.

size in this region by a factor of 5. The reduced mesh is shown in figure 5.

The input for this example is given in table II. It includes the original TANDEM input plus stream-function boundary values about the magnified region. These were obtained from the output of TANDEM. The process by which this input was obtained is explained later in the section Example of Preparing Input.

The blade-surface velocities from TANDEM and MAGNFY are plotted in figure 6. The velocities obtain by TANDEM (coarse mesh) are not accurate near the trailing-edge radius, and the magnitude of the peak is not shown accurately.

The execution time for this example was 2 minutes on the direct-coupled IBM2-7094-7044 computer.

DESCRIPTION OF INPUT AND OUTPUT

The computer program requires as input the same input as was used in either 2DCP (ref. 1), TURBLE (ref. 2), or TANDEM (ref. 3) plus the stream-function values along the boundary of the region to be magnified. These stream-function values are generally obtained from the output of either 2DCP, TURBLE, or TANDEM (refs. 1 to 3).

Output obtained from MAGNFY includes velocity magnitude and direction at all interior mesh points in the region, blade-surface velocities, and stream-function values throughout the region.

Instructions for Preparing Input

The first step in obtaining input for MAGNFY is to obtain the usual coarse-mesh solution from either 2DCP (ref. 1), TURBLE (ref. 2), or TANDEM (ref. 3). If TURBLE or TANDEM are used, their input forms part of the input for MAGNFY. If 2DCP is used, modifications must be made to its input to make it appropriate for MAGNFY. These modifications make the 2DCP input agree with input for TURBLE, and are explained in the following section.

The remainder of the input for MAGNFY (beyond the input for 2DCP, TURBLE, or TANDEM) consists of coordinates and stream-function values obtained from the output of one of these three programs. Figure 7 shows all the input for MAGNFY beyond that required for 2DCP, TURBLE, or TANDEM.

The boundary value input for MAGNFY could be determined from some method other than either 2DCP, TURBLE, or TANDEM. In this case the input which would ordinarily have been used with these programs must be determined as explained in references 1 or 2 (single blade) or reference 3 (tandem or slotted blade).

Modification of 2DCP Input

If the user desires to magnify a solution obtained with 2DCP, the 2DCP input must be rearranged as if it were to be run on TURBLE before it can be used with MAGNFY. Some of the 2DCP input variables have the same names as MAGNFY variables, but some

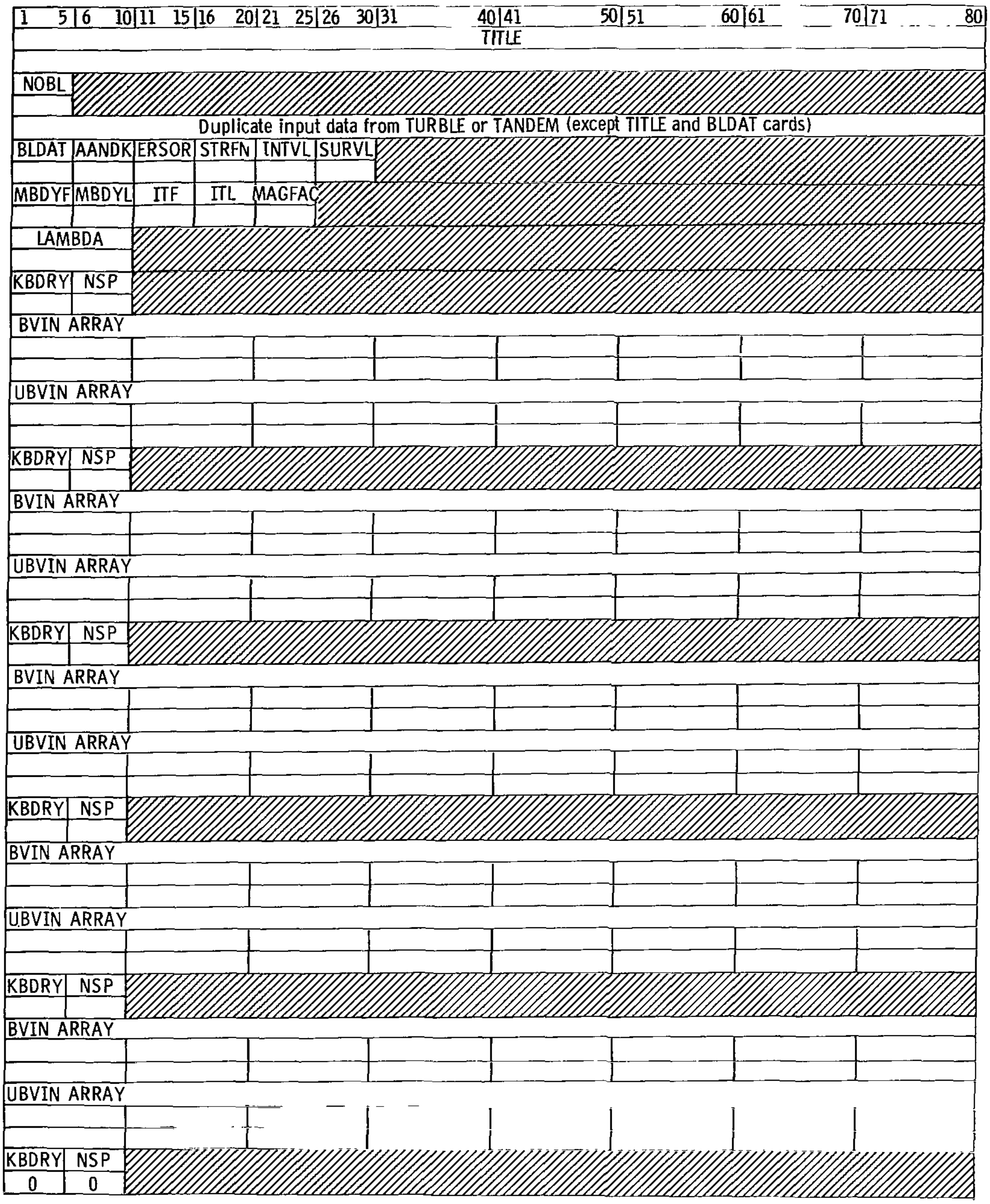


Figure 7. - Input form. Card column numbers appear at top.

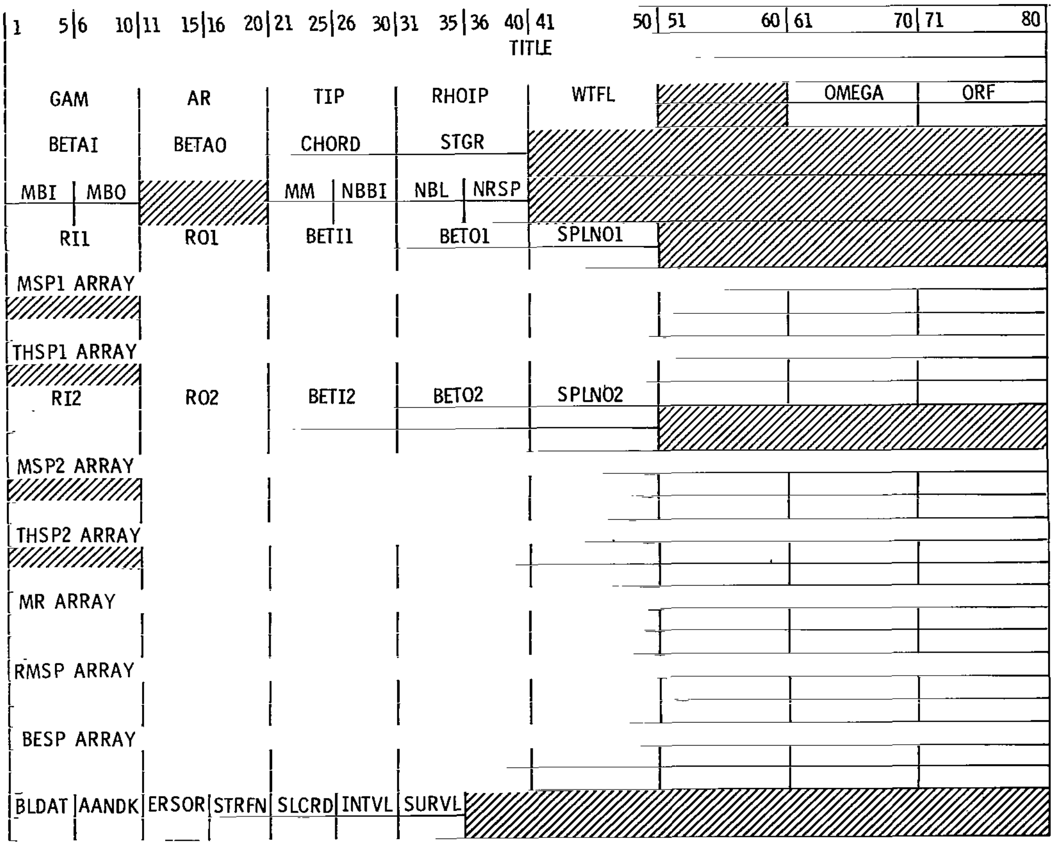


Figure 8. - Input form for TURBLE (ref. 2). Card column numbers appear at top.

do not. Table III lists the 2DCP and MAGNFY variables which have the same meaning but different names. Figure 8 and table III show the user how to rearrange his 2DCP input to make it compatible with MAGNFY. The first card of 2DCP input (the GAM card) must be modified for MAGNFY by shifting OMEGA and W 10 spaces to the right (see fig. 8). The second card should have the inlet and outlet flow angles (BETAI and BETAO) placed before CHORD and STGR. Also BETAI and BETAO have been redefined to be the flow angles at the leading and trailing edges, instead of at upstream and downstream boundaries. The third card contains information obtained from the fourth card for 2DCP. Once again, the position of variables on the card and the relation between 2DCP and MAGNFY variables can be seen from figure 8 and table III. The information on the third 2DCP card must be placed on two cards for MAGNFY. These cards are placed directly above the two sets of m- and θ-coordinates (MSP1, 2 and THSP1, 2) for the two blade surfaces. Each of these cards for MAGNFY contains inlet and outlet radii, tangency angles, and number of spline points for one of the two blade surfaces. Finally, the cards containing m- and θ-coordinates are unchanged between 2DCP and MAGNFY.

TABLE III. - 2DCP AND MAGNFY VARIABLES WITH SAME MEANING BUT DIFFERENT NAMES

2DCP variable	Corresponding MAGNFY variable
W	ORF
RI	RI1 and RI2
RO	RO1 and RO2
ALUI	BETI1
ALLI	BETI2
ALUO	BETO1
ALLO	BETO2
MXBI	MBI
MXBO	MBO
MX	MM
NUSP	SPLNO1 (real)
NLSP	SPLNO2 (real)
MU	MSP1
XSPU	THSP1
ML	MSP2
XSPL	THSP2

Choosing Magnified Region

The region where magnification is desired is usually located around a leading or trailing edge or about a tandem blade slot. Therefore, the region generally includes portions of both lower and upper blade surfaces. This is indicated by the heavily outlined region of figure 9 and by the similar region for the mixed-flow impeller example (fig. 4(b)). However, input must be given to MAGNFY as though the region was entirely located about the lower blade. (See the dashed portion of the region in fig. 9.) This condition, of course, results in a magnified region which is partially outside of the original 2DCP, TURBLE, or TANDEM region. In the case of the leading edge of the rear blade of a tandem blade, the magnified region may lie completely outside of the original TANDEM region. The region may contain at most one leading and one trailing edge.

The fact that the magnified region is restricted to the lower blade implies that, once it is drawn about the lower blade, no part of it may include any of the upper blade.

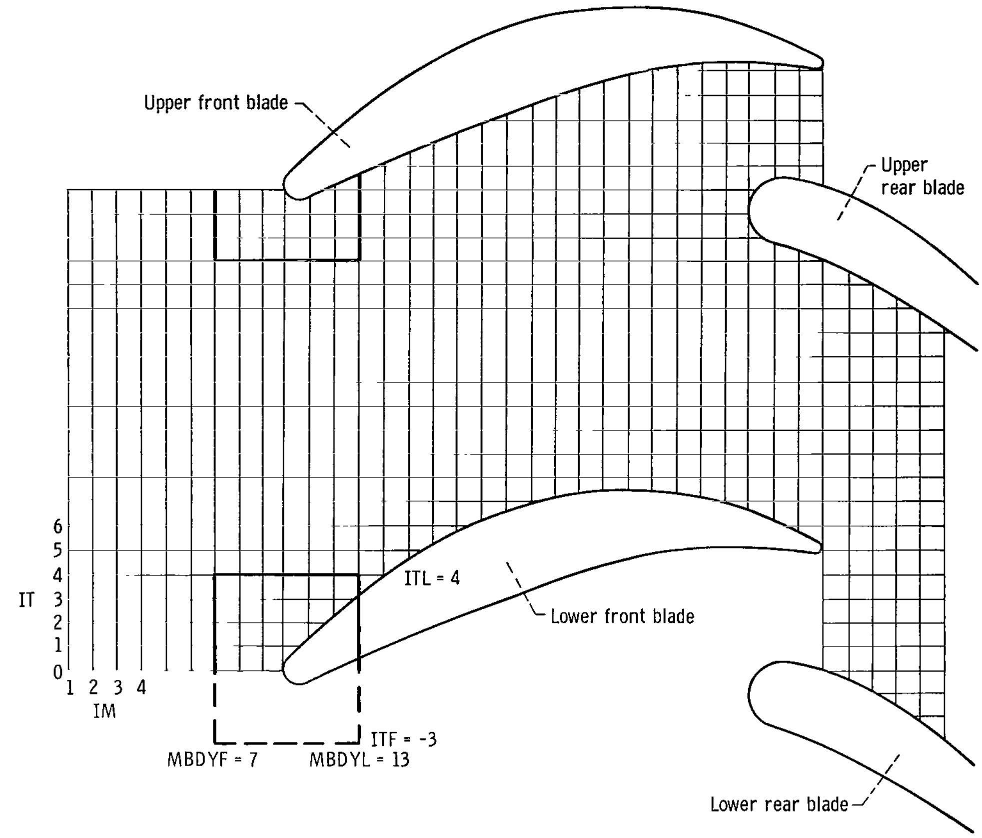


Figure 9. - Input variables defining magnified region.

Input

Only the additional input beyond that required for 2DCP, TURBLE, or TANDEM will be described in detail herein. All integers are in a five-column field and must be right adjusted. All numbers with a ten-column field are real numbers and must have a decimal point punched on the data card.

The first input data card (fig. 7) is a label card containing any desired identification label. The next card has either NOBL=1 (single blade) or NOBL=2 (tandem or slotted blade) in column 5. This is followed by the input data from either TURBLE or TANDEM, or modified input from 2DCP. This input consists of all the input cards from the first one starting with GAM up to the last geometry input card containing values of BESP. This input remains unchanged, except for the overrelaxation factor (ORF), which should be recalculated for the MAGNFY program; that is, it should be set equal to zero again for the initial MAGNFY run on a set of data.

The next input card has variables (BLDAT to SURVL) used to indicate what output is desired. These variables are used in the same way as in TURBLE or TANDEM, except for the ommission of SLCRD, which is not required in MAGNFY.

The remaining input variables (see fig. 7) are as follows:

MBDYF — index IM of vertical mesh line which is to be left boundary of magnified region (see fig. 9)

MBDYL — index IM of vertical mesh line which is to be right boundary of magnified region

ITF — index IT of horizontal mesh line which is to be lower boundary of magnified region (See previous section for explanation of how to choose magnified region.)

ITL — index IT of horizontal mesh line which is to be upper boundary of magnified region

MAGFAC — magnification factor (If MAGFAC = n, one mesh square of original coarse mesh will contain n^2 squares of smaller mesh.)

LAMBDA — value of prerotation λ at inlet (LAMBDA is given as part of the output for 2DCP, TURBLE, or TANDEM.)

KBDRY — indicates which boundary is referred to on input cards which follow it:
- KBDRY=1, lower boundary
- KBDRY=2, upper boundary
- KBDRY=3, left boundary
- KBDRY=4, right boundary

NSP — number of stream-function values given for a particular boundary on BVIN and UBVIN cards which follow it

BVIN — boundary coordinates (m or θ) for segment of boundary indicated by KBDRY (These coordinates should correspond to original coarse-mesh lines, except for possibly the first and last points, which could fall on a blade surface.)

UBVIN — stream-function values corresponding to BVIN

The variables from KBDRY to UBVIN are given for each segment of the boundary. After all boundary values are given for each segment of the four boundaries, one blank card (or a card with zeros for KBDRY and NSP) is added to signal the end of the input data for a particular case.

Example of Preparing Input

The second numerical example of this report (p. 5) dealt with solving for detailed

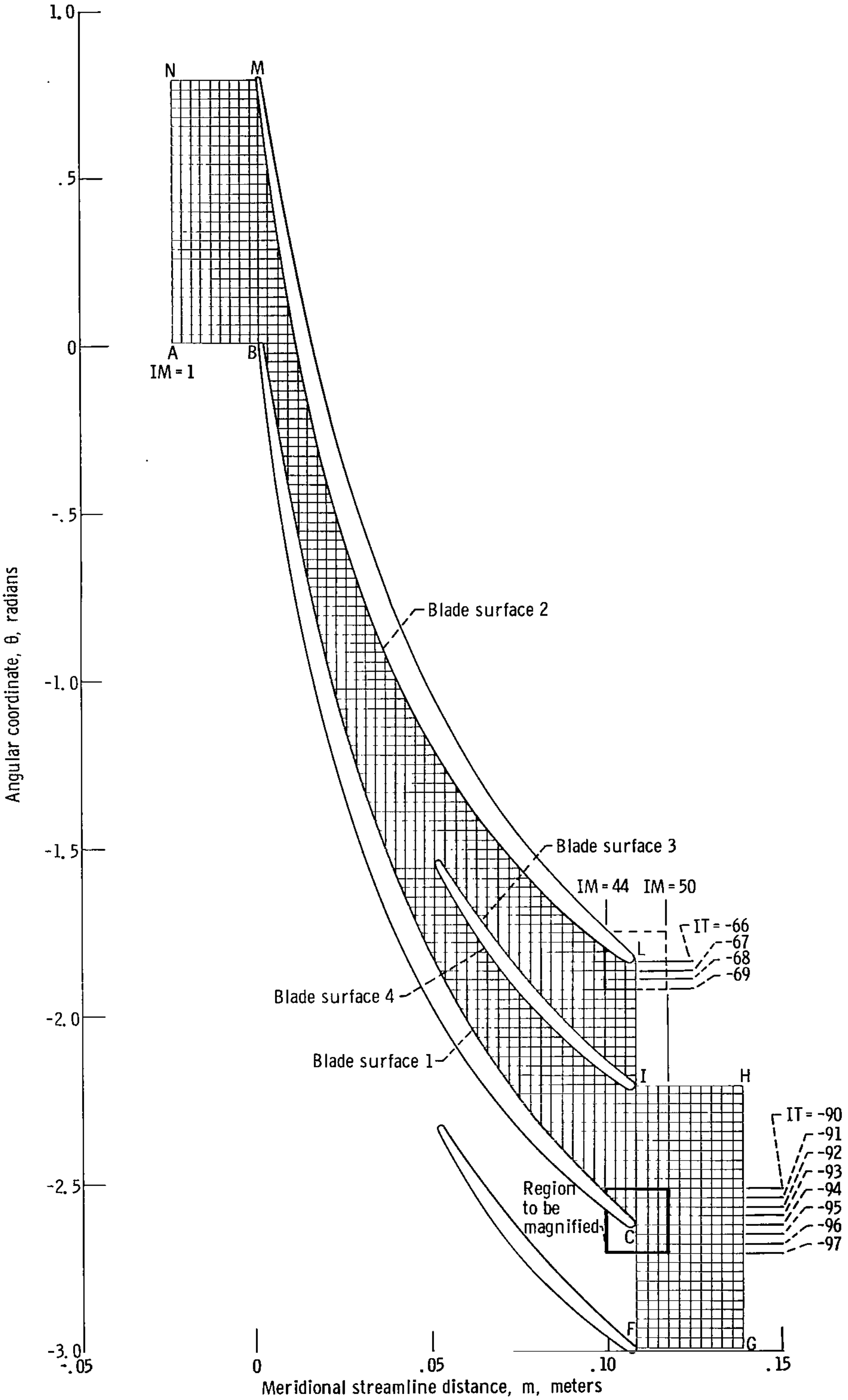


Figure 10. - Mixed-flow impeller, showing information for input example.

velocities about the trailing edge of the main blade of a mixed-flow impeller with splitter vanes (ref. 6). This section illustrates, in detail, how the additional MAGNFY input (beyond the normal TANDEM input) for that example was obtained. This input is given in table II.

MAGNFY is intended to be used by those who have run 2DCP, TURBLE, or TANDEM, and who desire a more detailed solution about some critical region on the blade. For the impeller example, that region is the trailing edge of the main blade as shown in figure 10. Notice that most of this region lies about blade surface 1, but that a portion of it is located at the end of blade surface 2. In most cases, the region to be analyzed will be divided in this way. However, input must be given to MAGNFY as though the region is entirely located about the lower blade. The way this is done is illustrated in the following paragraph.

The user should draw a magnified picture of the region for which a detailed solution is desired (fig. 11). This rectangular picture should extend three or four mesh lines (coarse mesh) in all directions from the point at which most detail is desired. The coarse mesh should be numbered with IM and IT grid line values. The ITV array of TURBLE or TANDEM can be used in the drawing of this sketch. The boundaries parallel to the IM axis are defined as boundaries 1 and 2 of this sketch, and those parallel to the IT axis as 3 and 4, as indicated in figure 11.

At this point, some of the input to MAGNFY can be obtained. The first and last values on the IM and IT axes are called MBDYF, MBDYL, ITF, and ITL. For the impeller example, these values are 44, 50, -97, and -90, respectively.

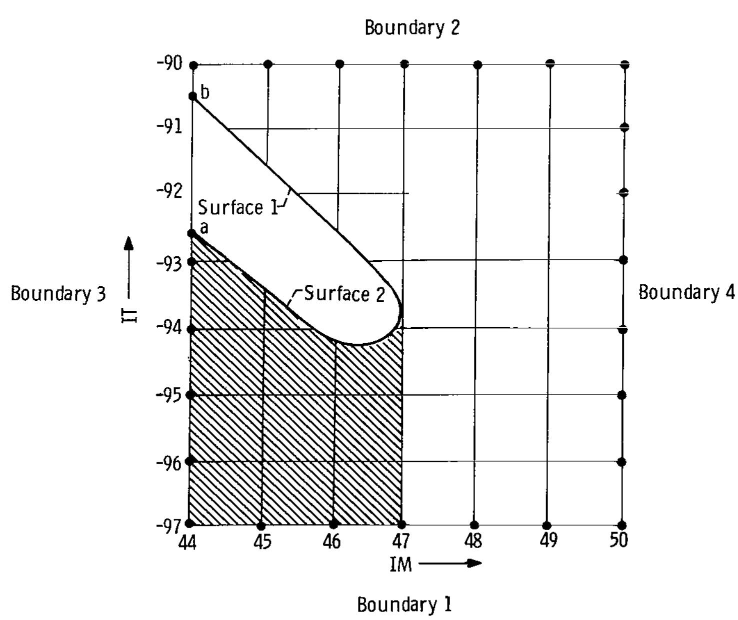


Figure 11. - Magnified region for input example.

MAGFAC can also be chosen at this time. A number between 5 and 8 is typical, and in this case 5 was used. MAGFAC must be chosen so that the resulting grid has less than 2000 mesh points in it.

LAMBDA is the next required input. It is obtained directly from the output of either 2DCP, TURBLE, or TANDEM.

The remainder of the MAGNFY input consists of geometrical (BVIN) and stream-function (UBVIN) boundary values for the coarse-mesh boundary points on the four boundaries of the magnified region (fig. 11). The boundaries 1 to 4 should be entered in order, giving values from left to right on boundaries 1 and 2 and from bottom to top on boundaries 3 and 4.

The blade surfaces always intersect some boundaries of the region. When this occurs, the resulting sections of boundaries should be entered separately. In this example, boundary 3 is divided into two parts. The first has six points (IT = -97 to IT = -93 plus the blade-surface point (point a), fig. 11). The second has two points (point b and IT = -90).

For each section of a boundary, four items of input are needed: KBDRY, NSP, the BVIN array, and the UBVIN array. KBDRY identifies by number the boundary for which data are given, and NSP is the number of points given on a section of that boundary. For the impeller example, NSP = 7 on boundaries 1 and 2; NSP = 6 and NSP = 2 on boundary 3; and NSP = 8 on boundary 4.

For boundaries 1 and 2, BVIN is obtained from the Stream Sheet Coordinates and Thickness Table for both TURBLE and TANDEM. A portion of the table for this example is reproduced in table IV. The meridional coordinates for BVIN from IM = 44 to IM = 50 are circled.

TABLE IV. - STREAM SHEET COORDINATES AND THICKNESS TABLE

IM	M	R	SAL	B	DB/DM
1	-0.24455E-01	0.76028E-01	0.38990E-01	0.10422E-01	-0.25197E-01
2	-0.21738E-01	0.76152E-01	0.52336E-01	0.10342E-01	-0.33504E-01
3	-0.19021E-01	0.76314E-01	0.67178E-01	0.10239E-01	-0.42743E-01
4	-0.16303E-01	0.76519E-01	0.83516E-01	0.10109E-01	-0.52913E-01
5	-0.13586E-01	0.76769E-01	0.10100	0.99507E-02	-0.63772E-01
39	0.81702E-01	0.10914	0.52474	0.17711E-02	-0.34060E-01
40	0.84683E-01	0.11071	0.53430	0.16727E-02	-0.31962E-01
41	0.87664E-01	0.11233	0.54631	0.15804E-02	-0.29980E-01
42	0.90645E-01	0.11397	0.55690	0.14938E-02	-0.28176E-01
43	0.93626E-01	0.11564	0.56553	0.14122E-02	-0.26560E-01
44	0.96607E-01	0.11734	0.57246	0.13352E-02	-0.25103E-01
45	0.99588E-01	0.11906	0.57954	0.12626E-02	-0.23590E-01
46	0.10257	0.12080	0.58712	0.11947E-02	-0.21979E-01
47	0.10555	0.12256	0.59514	0.11317E-02	-0.20275E-01
48	0.10853	0.12434	0.60279	0.10739E-02	-0.18520E-01
49	0.11151	0.12615	0.60980	0.10213E-02	-0.16728E-01
50	0.11449	0.12798	0.61617	0.97415E-03	-0.14901E-01
51	0.11747	0.12983	0.62238	0.93233E-03	-0.13193E-01
52	0.12046	0.13169	0.62878	0.89527E-03	-0.11706E-01
53	0.12344	0.13357	0.63535	0.86232E-03	-0.10440E-01
54	0.12642	0.13548	0.64210	0.83281E-03	-0.93952E-02
55	0.12940	0.13740	0.64879	0.80611E-03	-0.85392E-02

TABLE V. - THETA COORDINATES OF

HORIZONTAL MESH LINES

IT	THETA
-107	-3.00134
-106	-2.97329
-105	-2.94524
-104	-2.91719
-103	-2.88914
-102	-2.86109
-101	-2.83304
-100	-2.80499
-99	-2.77694
-98	-2.74889
-97	-2.72084
-96	-2.69279
-95	-2.66474
-94	-2.63669
-93	-2.60864
-92	-2.58059
-91	-2.55254
-90	-2.52449
-89	-2.49644
-88	-2.46839
-87	-2.44034
-86	-2.41229
-85	-2.38424
-84	-2.35619

If a blade surface passes through boundary 1 or 2 (it does not in this example), the BVIN for the point of intersection of the blade and boundary is obtained from the MH array (m-coordinates of intersections of horizontal mesh lines with blade given as output from 2DCP, TANDEM, or TURBLE) for the blade surface involved.

For boundaries 3 and 4, BVIN is obtained from the table of Theta Coordinates of Horizontal Mesh Lines for both TURBLE and TANDEM. A portion of this table for this example is reproduced in table V. The tangential coordinates for BVIN from IT = -97 to IT = -90 are circled.

If a blade surface passes through boundary 3 or 4, the BVIN for the point of intersection of the blade and boundary is obtained from the TV array (θ-coordinates of blade at vertical mesh lines) for the blade surface involved. In the example, blade surfaces 1 and 2 pass through boundary 3. A portion of the TV array output from TANDEM for surfaces 1 and 2 is given in table VI. The m-coordinate corresponding to IM = 44 is circled along with the θ values, called TV, where the IM = 44 mesh line meets surfaces 1 and 2. The θ for blade surface 2 (or 4 on the rear blade of a tandem blade) must always have PITCH subtracted from it to bring it down on the same blade as surface 1 (or 3).

TABLE VI. - EXAMPLE OF TV ARRAY OUTPUT FROM TANDEM

FOR BLADE SURFACES 1 AND 2

BLADE DATA AT INTERSECTIONS OF VERTICAL MESH LINES WITH BLADES

	BLADE SURFACE 1		BLADE SURFACE 2	
M	TV	DTDMV	TV	DTDMV
0	0	0.10000E 11	0.78540	-0.10000E 11
0.27172E-02	-0.62034E-01	-69.7931	0.52933	-85.1682
0.54344E-02	-0.24292	-63.4793	0.31771	-71.3544
0.81517F-02	-0.40773	-57.9565	0.13743	-62.0849
0.10869E-01	-0.55860	-53.2247	-0.21730E-01	-55.2224
0.81702E-01	-2.37840	-11.8861	-1.66869	-10.7007
0.84683E-01	-2.41299	-11.3360	-1.69985	-10.2016
0.87664E-01	-2.44605	-10.8536	-1.72952	-9.70233
0.90645E-01	-2.47777	-10.4388	-1.75770	-9.20294
0.93626E-01	-2.50836	-10.0916	-1.78439	-8.70342
0.96607F-01	-2.53801	-9.81206	-1.80959	-8.20376
0.99588E-01	-2.56692	-9.60010	-1.83330	-7.70396
0.10257	-2.59531	-9.45574	-1.85548	-6.36166
0.10555	-2.62900	-0.10000E 11	-1.84360	0.10000E 11

All values of UBVIN are obtained from the table Stream-Function Values. A portion of that table for the example has been reproduced in table VII. The boundary values for the region of figure 11 have been circled in table VII, and the following paragraph explains how they were obtained.

The table of stream-function values gives u along vertical mesh lines from blade to blade. Each mesh line is listed separately, and if a second blade intersects the mesh line, the two parts of the mesh line are listed separately. On each part the IT of the first mesh point on the line above blade surface 1 or 3 is listed as IT1 in table VII. With this information, the proper boundary values for the region can be obtained.

Values in the shaded portion of the region of figure 11 must be obtained from the blade above, as shown in figure 10.

Along boundary 1 in the example it is desired to obtain u at IT = -97 for IM = 44 to 50. However, for IM = 44 to IM = 47, u must be obtained from the blade above the region in the figure (see fig. 10). Since NBBI (the number of horizontal mesh lines between AB and MN) is 28 in this example, u must be obtained at IT = -97 + 28 = -69 for these values of IM.

For IM = 44, ITL = -76 for the upper section of this vertical mesh line. Therefore, the eighth value in the row (0.79106) is the u for IT = -69. To reduce it to correspond to IT = -97, the stream-function period (1.0) is subtracted. The input value used is thus 0.79106 - 1.0000 = -0.20894. Likewise, for IM = 45, IT1 = -77; and the ninth value (0.82429) corresponds to IT = -69. Reducing this by 1.0 gives -0.17571, the value used as input.

TABLE VII. - STREAM-FUNCTION VALUE TABLE

IM = 42 IT1 = -74	0.56370215	0.59089224	0.62004882	0.65130834	0.68482589	0.72076356	0.75924806	0.80028503	0.84364127	0.88884238
	0.93554489	0.98355945								
IM = 43 IT1 = -89	0.01338000	0.04592191	0.08012446	0.11625171	0.15459124	0.19547091	0.23926882	0.28639312	0.33717524	0.39157937
	0.44875421	0.50737296								
IM = 43 IT1 = -75	0.56540487	0.59254353	0.62132733	0.65190407	0.68445893	0.71922223	0.75647087	0.79649328	0.83945329	0.88507573
	0.93239887	0.98098022								
IM = 44 IT1 = -90	0.01517114	0.04746477	0.08105000	0.11617973	0.15312202	0.19218484	0.23374939	0.27831270	0.32652676	0.37915015
	0.43659545	0.49739579								
IM = 44 IT1 = -76	0.56548788	0.59293610	0.62166080	0.65180898	0.68355786	0.71713170	0.75282977	0.79106461	0.83238629	0.87736242
	0.92588085	0.97554200								
IM = 45 IT1 = -91	0.01624954	0.04847043	0.08163682	0.11599385	0.15177523	0.18923291	0.22866775	0.27047658	0.31523652	0.36386504
	0.41787726	0.47931882	0.54605063							
IM = 45 IT1 = -77	0.56370431	0.59194452	0.62101315	0.65109950	0.68237852	0.71504194	0.74932828	0.78557044	0.82428847	0.86637111
	0.91331481	0.96643321								
IM = 46 IT1 = -92	0.01692258	0.04918601	0.08207236	0.11586361	0.15076017	0.18695513	0.22466160	0.26413777	0.30573007	0.34996708
	0.39781557	0.45154771	0.51836125							
IM = 46 IT1 = -78	0.55961629	0.58938974	0.61925767	0.64969136	0.68091226	0.71309783	0.74643017	0.78112448	0.81747350	0.85595778
	0.89759777	0.94536442								
IM = 47 IT1 = -93	0.01894281	0.05020627	0.08260356	0.11589979	0.15012404	0.18537962	0.22180108	0.25954640	0.29880205	0.33979683
	0.38282271	0.42824350	0.47632948	0.52582654						
IM = 47 IT1 = -79	0.55809889	0.58508012	0.61643707	0.64747123	0.67901288	0.71115961	0.74405468	0.77785022	0.81270609	0.84879535
	0.88629808	0.92530244	0.96512271	1.00002798						
IM = 48 IT1 = -107	-0.42029791	-0.38789126	-0.35575397	-0.32350658	-0.29100066	-0.25809307	-0.22464573	-0.19053367	-0.15565266	-0.11993713
	-0.08341560	-0.04537519	-0.00981174	0.02372140	0.05218717	0.08351019	0.11620351	0.14986151	0.18441523	0.21990840
	0.25642654	0.29407255	0.33295587	0.37317996	0.41480967	0.45776550	0.50148795	0.54395759		
IM = 49 IT1 = -107	-0.39479662	-0.36041694	-0.32688116	-0.29360276	-0.26029523	-0.22677304	-0.19289698	-0.15856233	-0.12370409	-0.08831833
	-0.05251244	-0.01560652	0.01871358	0.05240273	0.08420596	0.11663655	0.14989388	0.18393930	0.21877056	0.25442570
	0.29096157	0.32843728	0.36689877	0.40635552	0.44673426	0.48777796	0.52884319	0.56860353		
IM = 50 IT1 = -107	-0.36652284	-0.33123814	-0.29679292	-0.26274382	-0.22881144	-0.19480821	-0.16060171	-0.12610277	-0.09126864	-0.05611859
	-0.02076425	0.01454852	0.04942065	0.08343153	0.11663859	0.14997184	0.18378516	0.21819571	0.25326142	0.28902949
	0.32554135	0.36282565	0.40088454	0.43967149	0.47905274	0.51874412	0.55822743	0.59672115		
IM = 51 IT1 = -107	-0.33620130	-0.30048737	-0.26548242	-0.23089461	-0.19649943	-0.16213188	-0.12767380	-0.09304883	-0.05822450	-0.02322172
	0.01187199	0.04589337	0.08162532	0.11590057	0.14980716	0.18375354	0.21801195	0.25272756	0.28798253	0.32382912
	0.36029924	0.39740183	0.43511284	0.47335853	0.51199066	0.55075540	0.58927225	0.62707399		
IM = 52 IT1 = -107	-0.30426541	-0.26834252	-0.23299874	-0.19804831	-0.16332335	-0.12868846	-0.09404254	-0.05931953	-0.02449090	0.01042976
	0.04538360	0.08027114	0.11497962	0.14944728	0.18374881	0.21809705	0.25268143	0.28763186	0.32303160	0.35893158
	0.39535650	0.43230306	0.46973339	0.50756428	0.54565387	0.58379085	0.62169896	0.65908255		

After line 47, the region of figure 11 is normal, and values at IT = -97 are desired. Since IT1 = -107 for IM = 48 to 50, the 11th value in these rows corresponds to IT = -97.

Boundary 2 is easier for this example than boundary 1. At all values of IM, u is desired for IT = -90. At IM = 44, IT = -90 corresponds to the first value in the row, which is 0.01517. For IM = 50, we need the 18th value (-107 + 17 = -90), which is 0.21819.

On boundary 3, values of u are desired from mesh line 44. For the first section of the boundary, values must once again be obtained from the periodic blade above. IT = -97 to -93 is the desired range. Adding NBBI = 28 gives IT = -69 to -65. The values corresponding to these IT's are circled in table VII (0.79106 to 0.97554). Subtracting 1.0 from each of these gives -0.20894 to -0.02446. For the final point on the blade surface (point a), u = 0 is used.

The upper part of boundary 3 has two points. The first is again u = 0. The second, for IM = 44, is IT = -90. This point is the first stream-function value given for line 44, which is 0.01517.

Boundary 4 corresponds to IM = 50. Values are required from IT = -97 to IT = -90. Since IT1 = -107, the 11th to 18th values are desired. These are circled in table VII (-0.02076 to 0.21819).

After the final set of boundary values is given for boundary 4, a final data card must be given with zero for KBDRY and NSP. This signals the end of the data for MAGNFY.

Output

Generally, the MAGNFY output is similar to the 2DCP, TURBLE, or TANDEM output, but for the finer mesh. In MAGNFY the vertical mesh lines are numbered with IM = 1 for the left boundary to IM = MMM for the right boundary. The horizontal mesh lines are numbered with IT = 1 for the lower boundary to IT = ITMAX for the upper boundary.

Sample output is given in table VIII for the first example. Since the complete output would be lengthy and is similar to that for 2DCP, TURBLE, or TANDEM, the only output reproduced here is that which differs from the output of these three programs. The main part of table VIII is the stream-function values (UBV) and values of ρ times the component of W normal to the boundary (RWBV) along the vertical and horizontal boundaries for the finer mesh. This main part is followed by a table of calculated program constants. The variable names are all defined in the section Main Dictionary.

TABLE VIII. - EXAMPLE OF MAGNFY OUTPUT

STREAM FUNCTION AND RHO*W-SUB-THETA ON HORIZONTAL BOUNDARIES

M	LOWER HORIZONTAL BOUNDARY UBV	RWBV	UPPER HORIZONTAL BOUNDARY UBV	RWBV
0.96607E-01	-0.20894	-25.8414	0.15170E-01	-25.3671
0.97203E-01	-0.20220	-25.9841	0.21810E-01	-25.6806
0.97799E-01	-0.19550	-26.0991	0.28460E-01	-26.0027
0.98395E-01	-0.18884	-26.1856	0.35119E-01	-26.3336
0.98992E-01	-0.18225	-26.2423	0.41788E-01	-26.6735

STREAM FUNCTION AND RHO*W-SUB-M ON VERTICAL BOUNDARIES

THETA	LEFT VERTICAL BOUNDARY UBV	RWBV	RIGHT VERTICAL BOUNDARY UBV	RWBV
-2.72084	-0.20894	34.8187	-0.20770E-01	30.8383
-2.71523	-0.20090	35.1925	-0.13689E-01	30.8007
-2.70962	-0.19276	35.6345	-0.66120E-02	30.7562
-2.70401	-0.18451	36.1446	0.45354E-03	30.7049
-2.69840	-0.17613	36.7226	0.75065E-02	30.6467

CALCULATED PROGRAM CONSTANTS

PITCH	HT	HM1	HM2	HM3
0.7853982	0.5609987E-02	0.5434444E-03	0.5962105E-03	0.5962105E-03

MBII	MBOO	MMM	ITMAX
-79	16	31	36

NUMBER OF INTERIOR MESH POINTS = 870

SURFACE BOUNDARY VALUES

SURFACE	BV
1	0.
2	0.
3	-0.44431
4	-0.44431

Error Conditions

The error conditions are as follows:

(1) SPLINT USED FOR EXTRAPOLATION

EXTRAPOLATED VALUE = X.XXX

SPLINT is normally used for interpolation, but may be used for extrapolation in some cases. When this occurs, the above message is printed, as well as the input and output of SPLINT. Calculations proceed normally after this printout.

(2) BLCD CALL NO. XX

M COORDINATE IS NOT WITHIN BLADE

This message is printed by subroutine BLCD if the m-coordinate given this subroutine as input is not within the bounds of the blade surface for which BLCD is called. The value of m and the blade-surface number are also printed when this happens. This condition may be caused by an error in the integer input items for the program.

The location of the error in the main program is given by means of BLCD CALL NO. XX, which corresponds to locations noted by comment cards at each MHORIZ, ROOT, and BLCD call in the program.

(3) ROOT CALL NO. XX

ROOT HAS FAILED TO CONVERGE IN 1000 ITERATIONS

This message is printed by subroutine ROOT if a root cannot be located. The input to ROOT is also printed. The user should thoroughly check the input to the main program.

The location of the error in the main program is given by means of ROOT CALL NO. XX, which corresponds to locations noted by comment cards at each MHORIZ and ROOT call in the program.

(4) DENSTY CALL NO. XX

NER(1) = XX

RHO*W IS X.XXXX TIMES THE MAXIMUM VALUE FOR RHO*W

This message is printed if the value of ρW at some mesh point is so large that there is no solution for the values of ρ and W. This indicates a locally supersonic condition, which can be eliminated by decreasing WTFL in the original 2DCP, TURBLE, or TANDEM run to obtain new input boundary values for MAGNFY.

If RHO*W is too large, MAGNFY still attempts to calculate a solution. This often permits an approximate solution to be obtained which is valid at all the subsonic points in the region. In other cases, the value of W is reduced at some of the points in question during later iterations, resulting in a valid final solution for these points. The program counts the number of times supersonic flow has been located at any point during a given run (NER(1)). When NER(1) = 50, the program is stopped.

The location of the error in the main program is given by means of DENSTY CALL NO. XX, which corresponds to locations noted by comments cards at each DENSTY call in the program.

(5) THE USER HAS FAILED TO SPECIFY WHICH TYPE OF INPUT HE IS USING

The first card of input after the title card specifies whether a single or tandem blade is being considered. There must be a 1 or a 2 in column 5 of this card.

(6) MMM GT 100, OR ITMAX GT 50

This is printed if MMM > 100 or if ITMAX > 50. In this case either MAGFAC should be reduced, or a smaller region chosen.

(7) ONE OF THE MH ARRAYS IS TOO LARGE

This is printed if there are more than 100 intersections of horizontal mesh lines with any blade surface. In this case MAGFAC should be reduced, or a smaller region chosen.

(8) THE NUMBER OF INTERIOR MESH POINTS EXCEEDS 2000
This is printed if there are more than the allowable number of finite-difference grid points. Either MAGFAC must be reduced, or a smaller region must be chosen.

(9) SEARCH CANNOT FIND M IN THE MH ARRAY
If this is printed, the value of m and the blade-surface number are also printed. The user should thoroughly check the input to the main program.

PROGRAM PROCEDURE

The program is segmented into seven main parts - the subroutines INPUT, PRECAL, COEF, SOR, SLAX, TANG, and VELOCY, called by the main program MAGNFY. In addition there are several other subroutines. All the subroutines and their relation are shown in figure 12. All information which must be transmitted between the seven main subroutines is placed in COMMON.

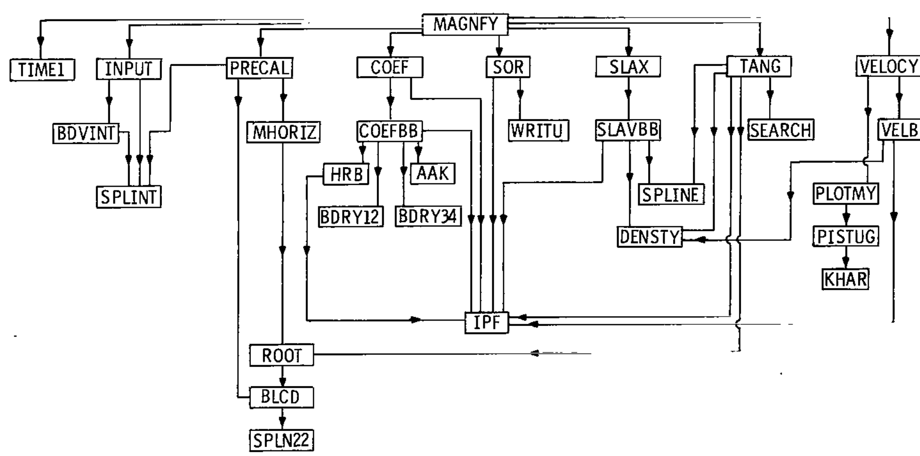


Figure 12. - Calling relation of subroutines.

Although most subroutines have been changed from those in TANDEM (ref. 3), the subroutine names have not been changed. Even with the rather extensive revisions made in some subroutines, the general descriptions of the subroutines in reference 3 still apply with minor differences, except for INPUT and PRECAL. Therefore, the only subroutines described here are INPUT and PRECAL, plus two new subroutines, WRITU and BDVINT.

Most of the subroutines in MAGNFY use the same set of variables. And most of these variables are the same as those used in TANDEM. These variables are all defined in the Main Dictionary (p. 32). The subroutines using these variables are described prior to the Main Dictionary or in reference 3. The remaining subroutines are described after

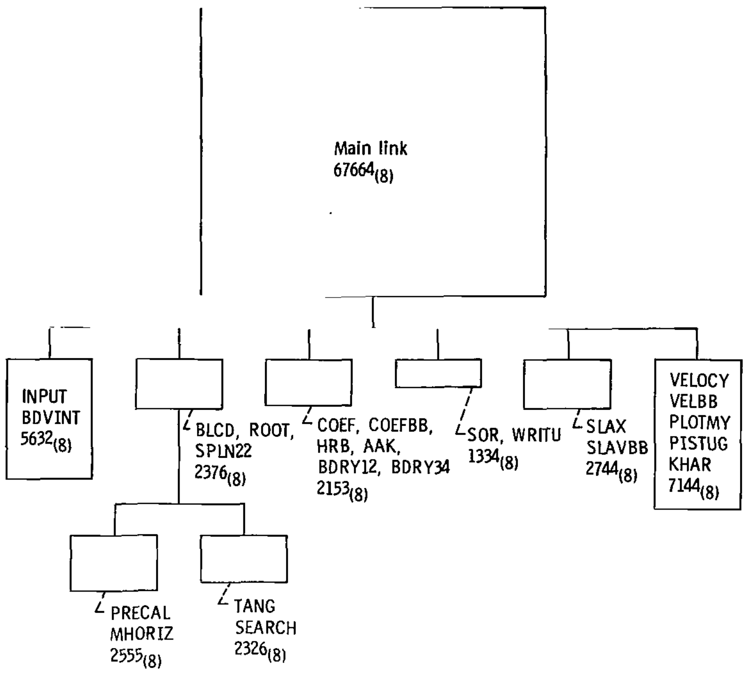


Figure 13. - Arrangement for overlay, showing octal storage requirements.

the Main Dictionary or in reference 3, and variables are defined with each subroutine.

The program can handle as many as 2000 mesh points on the IBM 2-7094-7044 direct-coupled system with a 32 768-word core. To provide for the handling of 2000 mesh points an overlay arrangement is used, as shown in figure 13. All subroutines not shown are in the main link. The total program storage requirement is $74044_{(8)}$ of which $53364_{(8)}$ is in COMMON blocks which are stored in the main link. The system storage requirement for our computer is $2764_{(8)}$ and unused storage is $750_{(8)}$. If there is a storage problem on the user's computer, the maximum number of mesh points should be reduced. The following program changes are required to change the maximum number of mesh points:

(1) Change the dimension of A, U, K, and RHO in the COMMON/AUKRHO statement to the maximum allowable number of mesh points. This statement occurs in most subroutines.

(2) In subroutine INPUT change the number of values of K and RHO to be initialized (the bound on the DO loop near statement 240).

(3) In subroutine PRECAL change the statement following statement 210 and format statement 1130 to reflect the maximum allowable number of mesh points. The statement following statement 210 will cause the program to stop if there are too many mesh points.

(4) Change the dimensions of W, RWM, and BETA in SLAX, SLAVBB, TANG, VELOCY, and VELBB.

(5) If the number of mesh points is reduced below 1600, the EQUIVALENCE state-

ments in SLAX, SLAVBB, TANG, VELOCY, and VELBB must be changed.

The first segment of the program is INPUT. This subroutine reads all input data cards, calculates constants, and initializes arrays. It also uses SPLINE interpolation on the input boundary values to obtain boundary values on the fine mesh. The next subroutine is PRECAL, which calculates all quantities that remain constant for a single problem. INPUT and PRECAL are each called once for a given problem. The remaining subroutines are each called once for each outer iteration. The subroutine COEF calculates the entries of the matrix A and the vector $\underline{k}$ of equation (A7) (ref. 1). These coefficients must be recalculated for each outer iteration. On the first outer iteration subroutine SOR estimates an optimum overrelaxation parameter Ω on the first call if it is not given as input. The same value of Ω is used for each outer iteration. SOR then finds the linear solution to equation (A7) (ref. 1) with fixed coefficients by successive overrelaxation. Then subroutine SLAX calculates ρW_m. Subroutine TANG calculates ρW_θ, and then ρW and β throughout the region. Finally, the subroutine VELOCY calculates density ρ and velocity W throughout the region and on the blade surfaces, and plots the surface velocities.

Conventions Used in Program

In general, the same conventions are used in MAGNFY as were used in the TANDEM program (ref. 3). In addition the lower, upper, left, and right boundaries of the magnified region are numbered 1, 2, 3, and 4, respectively. Also, the lower and upper boundaries of the region must sometimes be considered as blade surfaces by the program. In these cases they are numbered 5 and 6, respectively.

Labeled COMMON Blocks

The labeled COMMON blocks are organized the same as for TANDEM (ref. 3), except for the omission of /SLA/.

Subroutine INPUT

Read and print first part of input. - The program first reads the input cards which are the same as those for TURBLE or TANDEM, or were modified from 2DCP. A description of this input is given in reference 1, 2, or 3. All the input data are printed as they are read in.

Fill in dummy second blade for single-blade case. - When there is only one blade, the arrays for the second blade (surfaces 3 and 4) are filled in with the data for the first blade.

Calculate large mesh arrays. - The large mesh spacing and MV array are calculated first so that the RMI and RMO arrays can be calculated.

Transfer blade coordinates for tandem blade when necessary. - If a leading-edge region is being analyzed, it is always considered to be on the rear blade. Hence, if it is the leading edge of the first blade of a tandem or slotted blade, the arrays for the rear blade are filled with the data for the front blade. Similar considerations hold for a trailing-edge region, since it is always considered to be on the front blade.

Calculate constants. - Geometrical and miscellaneous constants are calculated.

Calculate fine-mesh m-coordinates. - The final MV array for the fine mesh can now be calculated.

Read boundary values and interpolate for fine mesh. - Each set of coarse-mesh boundary value data is read. Then interpolated stream-function values for the fine mesh are calculated and printed.

Subroutine PRECAL

The calculation of λ and other constants in PRECAL is no longer necessary in MAGNFY, since λ is given as input and the other constants are not used in the calculation. The remainder of the description of PRECAL in reference 3 is still valid.

Subroutine WRITU

WRITU prints the value of the stream function along a given vertical line between blades or boundaries. A label is printed with the value of IM for the mesh line and the value of IT(IT1) for the first printed stream-function value.

Main Dictionary

The Main Dictionary applies to the previously discussed subroutines.

A — array of coefficients of u (i.e., elements of a_{ij} of matrix A in eq. (A7) of ref. 1)

A12, A34	a_{12}, a_{34} in eq. (A2) of ref. 1
AA	temporary variable in BLCD
AAA	array used for temporary storage
AANDK	input variable
AATEMP	temporary location for AANDK in SOR
ANS	result of calls on ROOT in TANG and DENSTY in SLAVBB and VELBB
AR	input variable (from 2DCP, TURBLE, or TANDEM)
AZ	a_0 in eq. (A2) of ref. 1
B	array containing stream-channel thickness b at the four points adjacent to a point for which AAK is called
B12, B34	b_{12}, b_{34} in eq. (A2) of ref. 1
BB	temporary variable in BLCD
BE	array of values of b at vertical mesh lines
BEH	array of values of b where horizontal mesh lines meet the four blade surfaces
BESP	input variable (from 2DCP, TURBLE, or TANDEM)
BETA	array of values of β at interior mesh points
BETAH(BETAV)	array of values of β where horizontal (vertical) mesh lines meet the four blade surfaces
BETAI(BETAO)	input variable (from 2DCP, TURBLE, or TANDEM)
BETI(BETO)	array of angles at tangent points of leading- (trailing-) edge radii with the four blade surfaces (see input BETI1, 2, 3, 4 and BETO1, 2, 3, 4)
BLDAT	input variable
BV	array of stream-function boundary values on the four blade surfaces
BVIN	input variable
BZ	stream-channel thickness b_0 at point for which AAK is called

CDMBIT(CDMBOT)	temporary grid locations along meridional axis in INPUT
CHANGE	change in value of stream function at a particular point during an iteration of SOR
CHORD	array containing the meridional chord distances of each of the four blade surfaces (see input CHORDF and CHORDR)
CMM	temporary variable in BLCD
CP	specific heat at constant pressure, c_p
CPTIP	$2c_pT'_{in}$
DBDM	array of slopes at vertical mesh lines of spline curve for stream-channel thickness
DIST	meridional distance in SEARCH from a blade leading edge to where a horizontal mesh line meets a blade surface
DMLR	tolerance for mesh points near a boundary in the m-direction (If a mesh point is closer than DMLR to a boundary, the point is considered to be on the boundary.)
DTDM	$d\theta/dm$ along a blade surface in BLCD
DTDMH(DTDMV)	array of $d\theta/dm$ where horizontal (vertical) mesh lines meet the four blade surfaces
DTLR	tolerance in θ-direction (see DMLR)
DUDM	array of derivatives of stream function $\partial u/\partial m$ along horizontal mesh lines in meridional direction
DUDT	array of derivatives of stream function $\partial u/\partial \theta$ along vertical mesh lines in θ-direction
EM	array of second derivatives of spline curves for each blade surface, calculated by SPLN22 in BLCD
EMK, EMKM1	temporary variables for EM in BLCD
ERROR	maximum absolute value of change in u at any point for an overrelaxation (SOR) iteration
ERSOR	input variable
EXPON	$1/(\gamma - 1)$
FIRST	initial value of some index
GAM	input variable (from 2DCP, TURBLE, or TANDEM)

H	array containing mesh spacing h between the point for which AAK is called and the four points adjacent to it
HM1	mesh spacing in m-direction from upstream boundary through front blade
HM2	mesh spacing in m-direction for overlapping portion of front and rear blades, or between blades for nonoverlapping case
HM3	mesh spacing in m-direction through rear blade to downstream boundary
HT	mesh spacing in θ-direction from blade to blade
I	temporary integer variable in INPUT, PRECAL, SLAX, and SEARCH
IEND	integer variable set equal to 1 when final convergence to a solution is reached in the outer iterations on a given set of data
IH	array containing current number of intersections of horizontal mesh lines with each of the four blade surfaces as intersections are located
IHS	integer variable in BDRY34 and TANG for counting intersections of horizontal mesh lines with blade surfaces
IM	index of mesh line in the meridional direction (m-direction)
IM1(IMT)	integer variable in TANG indicating vertical mesh line index of the first (final) point in region of a horizontal mesh line
IM2	IM1 + 1
IMS	array containing total number of intersections of horizontal mesh lines with each of the four blade surfaces
IMSL	temporary variable in PRECAL
IMSS	temporary variable in PRECAL, VELOCY, and VELBB
IMTM1	IMT - 1
INF	variable in PRECAL indicating when an infinite slope is located at a blade leading or trailing edge in a call on BLCD
INIT	array used to indicate whether BLCD has been called previously on a given blade surface
INTVL	input variable
IP	index of mesh point

IP1, IP2, IP3, IP4	value of IP at the four points adjacent to the mesh point under consideration
IPL(IPU)	value of IP where a vertical mesh line meets a lower (upper) surface or boundary
IPLM1(IPUP1)	value of IP on a vertical mesh line adjacent to a lower (upper) surface in VELBB
IS	integer variable in SEARCH for indicating where a horizontal mesh line intersects a blade surface
IT	index of mesh line in θ-direction
ITF(ITL)	input variable
ITER	outer iteration counter
ITMAX	maximum value of IT in magnified mesh region
ITOR	value of IT at origin of coordinates at leading edge of front blade
ITV	array of horizontal mesh line indexes (IT) corresponding to itersections of vertical mesh lines with blade surfaces (ITV(IM, SURF) is the IT value for the mesh point in the region on vertical mesh line IM which is closest to blade surface SURF. If ITV $\leq$ 1, the value is adjusted to 1 for a lower surface or 2 for an upper surface. If ITV $\geq$ ITMAX, the value is adjusted to ITMAX - 1 for a lower surface or ITMAX for an upper surface. If a vertical line does not intersect a blade surface, its value of ITV(IM, SURF) is equal to -10 000. For the lower boundary (SURF = 5), ITV = 2; and for the upper boundary (SURF = 6), ITV = ITMAX - 1.)
ITVL(ITVU)	ITV of lower (upper) blade surface on a given vertical mesh line
ITVM1(ITVP1)	ITV of a blade surface in COEFBB for vertical mesh line to left (right) of the line under consideration
IV	array containing the value of IP at the base of each vertical mesh line
J	temporary integer variable in INPUT
K	array of constants; the vector $\underline{k}$ in eq. (A7) of ref. 1
KA	integer array indicating which of the four points surrounding a mesh point lie on a boundary

KAK	real array giving boundary values of points surrounding a mesh point next to a boundary
KBDRY	input variable
KK	integer counter in BLCD
KKK	array containing information used in plotting subroutine PLOTMY
LAMBDA	input variable
LAST	final value of some index
LER	array indicating location of error messages printed by program
LMAX	maximum value of u_i^{m+1}/u_i^m for eq. (B2) of ref. 7
LOWER	integer variable representing one of lower blade surfaces, 2 or 4
M	meridional coordinate, meters
MAGFAC	input variable
MB1, MB2	temporary vertical grid line locations along meridional axis
MBDYF, MBDYL	input variable
MBI	input variable (from 2DCP, TURBLE, or TANDEM)
MBI2	input variable (from TANDEM)
MBII	number of vertical mesh lines from left boundary to leading edge of a blade in the magnified region (If region surrounds trailing edge of rear blade of a tandem blade, MBII = 1000.)
MBIIM1	MBII - 1
MBIIP1	MBII + 1
MBIT, MBOT	temporary grid locations along meriodional axis
MBO	input variable (from 2DCP, TURBLE, or TANDEM)
MBO2	input variable (from TANDEM)
MBOO	number of vertical lines from left boundary to trailing edge of a blade in the magnified region (If region surrounds leading edge of front blade of a tandem blade, MBOO = -1000.)
MBOOM1	MBOO - 1
MBOOP1	MBOO + 1
MH	array of m-coordinates of intersections of horizontal mesh lines with the four blade surfaces

MLE	array of m-coordinates of leading edges of the four blade surfaces (see input MLE2)
MM	input variable (from 2DCP, TURBLE, or TANDEM)
MMM	number of vertical mesh lines from the left to right boundaries of the magnified region
MMMM1	MMM - 1
MMLE	temporary meridional distance in BLCD
MMMSP	temporary meridional distance in BLCD
MR	input variable (from 2DCP, TURBLE, or TANDEM)
MRTS	integer switch in PRECAL indicating when infinite derivatives would be encountered in a call on MHORIZ
MSP	array of m-coordinates of spline points for each blade surface measured from its leading edge (see input MSP1, 2, 3, 4)
MSPMM	temporary meridional distance in BLCD
MV	array of m-coordinates of vertical mesh lines
NBBI	input variable (from 2DCP, TURBLE, or TANDEM)
NBL	number of blades
NER	array indicating number of times certain error messages are printed by program
NIP	number of interior mesh points
NOBL	input variable
NP1, NP2	integer counters in VELOCY indicating number of plotted blade-surface velocities
NRSP	input variable (from 2DCP, TURBLE, or TANDEM)
NSP	input variable
NSPI	array containing number of spline points on each of the four blade surfaces (see input SPLNO1, 2, 3, 4)
NSPM1	NSP - 1
OMEGA	input variable (from 2DCP, TURBLE, or TANDEM)
ORF	input variable (from 2DCP, TURBLE, or TANDEM)
ORFOPT	upper bound for optimum Ω from eqs. (B1) and (B2) of ref. 7

ORFTEM	temporary storage for ORFOPT
P	array containing information used in the plotting subroutine, PLOTMY
PITCH	θ-coordinate from blade to blade, 2π/NBL
R	array of densities ρ at the four points adjacent to a point for which AAK is called
RATIO	value of u_i^{m+1}/u_i^m for use in eqs. (B2) and (B3) of ref. 7
RBV	array of densities ρ on the four boundaries of the magnified region
RELER	maximum relative change in density at surface mesh points between two outer iterations
RHO	array of densities ρ at interior mesh points
RHOB	temporary storage in VELBB for a value of ρ on a blade surface
RHOHB	array of densities ρ at horizontal mesh line intersections with the four blade surfaces
RHOIP	input variable (from 2DCP, TURBLE, or TANDEM)
RHOVB	array of densities ρ at vertical mesh line intersections with the four blade surfaces
RI(RO)	array of leading- (trailing-) edge radii on the four blade surfaces (see input RI1, 2, 3, 4 and RO1, 2, 3, 4)
RM	array of r-coordinates of the mean stream surface radii at vertical mesh lines
RMDTL2(RMDTU2)	$\left[r(d\theta/dm)\right]^2$ at vertical mesh line intersections on lower (upper) blade surfaces
RMH	array of r-coordinates of the stream surface radii where horizontal mesh lines meet the four blade surfaces
RMI(RMO)	array of r-coordinates of mean stream surface radii at the inlet (outlet) of the four blade surfaces
RMM	temporary meridional distance in BLCD
RMSP	input variable (from 2DCP, TURBLE, or TANDEM)
RW	value of ρW of a mesh point
RWBV	array of ρ times the velocity component normal to the boundary of the magnified region

RWM — array of ρW_m where vertical mesh lines intersect the four blade surfaces

RWT — array of ρW_θ where horizontal mesh lines intersect the four blade surfaces

RWMBV — value of ρW_m at a mesh point along the lower or upper boundary of the magnified region

RZ — density ρ_0 at point for which AAK is called

S — meridional distance between two adjacent blade-surface spline points in BLCD

S1(ST) — blade-surface number at the beginning (end) of a horizontal mesh line in TANG

SAL — array of values of $\sin \alpha = dr/dm$ at each vertical mesh line

SIGN — integer constant in BLCD

SPLNO — number of input spline points on a blade surface

SPM — array of m-coordinates along a horizontal mesh line in TANG

SRW — integer code variable that will cause certain subroutines to write out useful data for debugging:

SRW = 13, SPLINE will write input and output data.
SRW = 16, SPLINT will write input and output data.
SRW = 18, SPLN22 will write input and output data.
SRW = 21, ROOT will write input and successive estimates of the root to which it is converging.

STGR — array of θ-coordinates of center of each trailing-edge radius with respect to center of its leading-edge radius (see input STGRF and STGRR)

STRFN — input variable

SURF — integer variable referring to each of the four blade surfaces, the lower boundary (5), or the upper boundary (6)

SURVL — input variable

T1, T2 — elapsed time in clock pulses (1/60 sec)

TBI — $\tan \beta_{le}$

TBO — $\tan \beta_{te}$

TGROG — $2\gamma R/(\gamma + 1)$

TH	array in INPUT; also single variable in PRECAL and TANG containing θ-coordinates from leading edge of front blade to a horizontal mesh line
THETA	θ-coordinate of a point along a blade surface in BLCD
THK, THKM1	temporary variables in BLCD
THLE	array of θ-coordinates from origin of front blade to leading edge of each blade surface (see input THLE2)
THSP	array of θ-coordinates of spline points for each blade surface measured from its leading edge (see input, THSP1, 2, 3, 4)
TIME	elapsed time in minutes
TIP	input variable (from 2DCP, TURBLE, or TANDEM)
TSP	array of θ-coordinates of points along a vertical mesh line in SLAVBB
TV	array of θ-coordinates where vertical mesh lines meet the four blade surfaces
TWL	$2\omega\lambda$
TWLMR	$2\omega\lambda - (\omega r)^2$
TWW	$2\omega/w$
U	array of stream-function values at each mesh point, or of eigenvector associated with calculation of ORFOPT
UBV	array of values of stream function u at mesh points on boundary of magnified region
UBVIN	input variable
UNEW	new value of stream-function estimate at a single point calculated by eq. (7) of ref. 1
UPPER	integer variable representing one of the upper blade surfaces, 1 or 3
USP	array of values of stream function along a vertical or horizontal mesh line, including boundary points
W	array of relative velocities W at unknown mesh points, also used for storing ρW
WCR	critical velocity on a blade surface

WMB — array of ρW_m where vertical mesh lines intersect the four blade surfaces

WTB — array of ρW_θ where horizontal mesh lines intersect the four blade surfaces

WTFL — input variable (from 2DCP, TURBLE, or TANDEM)

WTFLSP — input variable (from TANDEM)

WWCRM — array, ratio of blade-surface velocity (based on meridional components) to critical velocity

WWCRT — array, ratio of blade-surface velocity (based on tangential components) to critical velocity

XDOWN — array of m-coordinates where surface velocities are plotted

YACROS — array of surface velocities to be plotted

Program Listing for Subroutines Using Main Dictionary

```
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /GEOMIN/ CHORD(4),STGR(4),MLE(4),THLE(4),RMI(4),RMO(4),
     1RI(4),RO(4),BETI(4),BETO(4),NSPI(4),MSP(50,4),THSP(50,4)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      COMMON /BLCDCM/ EM(50,4),INIT(4)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      CALL TIME1(T1)
   10 IEND = -1
      ITER = 0
      DO 20 SURF=1,4
   20 INIT(SURF) = 0
      CALL INPUT
      CALL PRECAL
   30 CALL COEF
      CALL SOR
      CALL TIME1(T2)
      TIME= (T2-T1)/3600.
      WRITE(6,1000) TIME
```

```
      CALL SLAX
      CALL TANG
      CALL VELOCY
      CALL TIME1(T2)
      TIME= (T2-T1)/3600.
      WRITE(6,1000) TIME
      IF (IEND) 30,30,10
 1000 FORMAT (8HLTIME = ,F7.4,5H MIN.)
      END
```

```
      SUBROUTINE INPUT
C
C   INPUT READS AND PRINTS ALL INPUT DATA CARDS AND CALCULATES HORIZONTAL
C   MESH SPACING (MV ARRAY)
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /GEOMIN/ CHORD(4),STGR(4),MLE(4),THLE(4),RMI(4),RMO(4),
     1RI(4),RO(4),BETI(4),BETO(4),NSPI(4),MSP(50,4),THSP(50,4)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      DIMENSION BVIN(100),UBVIN(100),TH(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
C
C   READ AND WRITE INPUT DATA
C
      WRITE(6,1000)
      READ (5,1100)
      WRITE(6,1100)
      READ (5,1010) NOBL
      WRITE(6,1110) NOBL
      IF (NOBL.EQ.1.OR.NOBL.EQ.2) GO TO 10
      WRITE (6,1120)
      STOP
C   OLD TURBLE (2DCP) OR TANDEM DATA
   10 IF (NOBL.EQ.1) WRITE(6,1130)
      IF (NOBL.EQ.2) WRITE(6,1140)
      READ (5,1030) GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF
      WRITE(6,1040) GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF
      IF (NOBL.EQ.1) WRITE(6,1150)
      IF (NOBL.EQ.2) WRITE(6,1160)
      READ(5,1030) BETAI,BETAO,CHORD(1),STGR(1),CHORD(3),STGR(3),
     1MLE(3),THLE(3)
      WRITE(6,1040)BETAI,BETAO,CHORD(1),STGR(1),CHORD(3),STGR(3),
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```
     1MLE(3),THLE(3)
      IF (NOBL.EQ.1) WRITE(6,1170)
      IF (NOBL.EQ.2) WRITE(6,1180)
      READ (5,1010) MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP
      WRITE(6,1010) MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP
      DO 20 J=1,4
      IF (NOBL.EQ.1.AND.J.EQ.3) GO TO 30
      IF (J.EQ.1) WRITE(6,1190)
      IF (J.EQ.2) WRITE(6,1200)
      IF (J.EQ.3) WRITE(6,1210)
      IF (J.EQ.4) WRITE(6,1220)
      WRITE(6,1230) J,J,J,J,J
      READ (5,1030) RI(J),RO(J),BETI(J),BETO(J),SPLNO
      WRITE(6,1040) RI(J),RO(J),BETI(J),BETO(J),SPLNO
      NSPI(J)= SPLNO
      NSP= NSPI(J)
      WRITE(6,1240) J
      READ (5,1030) (MSP(I,J),I=1,NSP)
      WRITE(6,1040) (MSP(I,J),I=1,NSP)
      WRITE(6,1250) J
      READ (5,1030) (THSP(I,J),I=1,NSP)
   20 WRITE(6,1040) (THSP(I,J),I=1,NSP)
   30 WRITE(6,1260)
      READ (5,1030) (MR(I),I=1,NRSP)
      WRITE(6,1040) (MR(I),I=1,NRSP)
      WRITE(6,1270)
      READ (5,1030) (RMSP(I),I=1,NRSP)
      WRITE(6,1040) (RMSP(I),I=1,NRSP)
      WRITE(6,1280)
      READ (5,1030) (BESP(I),I=1,NRSP)
      WRITE(6,1040) (BESP(I),I=1,NRSP)
C  NEW MAGNFY DATA
      WRITE(6,1290)
      READ (5,1010) BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL
      WRITE(6,1020) BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL
      WRITE(6,1300)
      READ (5,1010) MBDYF,MBDYL,ITF,ITL,MAGFAC
      WRITE(6,1020) MBDYF,MBDYL,ITF,ITL,MAGFAC
      WRITE(6,1310)
      READ (5,1030) LAMBDA
      WRITE(6,1040) LAMBDA
      MLE(1) = 0.
      THLE(1) = 0.
C
C  FOR SINGLE BLADE CASE, FILL IN DUMMY TANDEM BLADE
C
      IF (NOBL.EQ.2) GO TO 60
      WTFLSP= 0.
      CHORD(3) = CHORD(1)
      STGR(3) = STGR(1)
      MLE(3) = 0.
      THLE(3)= 0.
      MBI2= MBI
      MBO2= MBO
      RI(3)= RI(1)
      RI(4)= RI(2)
      RO(3)= RO(1)
      RO(4)= RO(2)
      BETI(3)= BETI(1)
```

```
      BETI(4)= BETI(2)
      BETO(3)= BETO(1)
      BETO(4)= BETO(2)
      NSPI(3)= NSPI(1)
      NSPI(4)= NSPI(2)
      NSP= NSPI(3)
      DO 40 I=1,NSP
      MSP(I,3)= MSP(I,1)
   40 THSP(I,3)= THSP(I,1)
      NSP= NSPI(4)
      DO 50 I=1,NSP
      MSP(I,4)= MSP(I,2)
   50 THSP(I,4)= THSP(I,2)
C
C  CALCULATE LARGE MESH SPACING
C
   60 HM1 = CHORD(1)/FLOAT(MBO-MBI)
      IF (MBO.GT.MBI2 .AND. MBI.NE.MBI2) HM1= MLE(3)/FLOAT(MBI2-MBI)
      HM2= 1.E30
      IF (MBI2.NE.MBO) HM2= (CHORD(1)-MLE(3))/FLOAT(MBO-MBI2)
      HM3 = CHORD(3)/FLOAT(MBO2-MBI2)
      IF (MBO.GT.MBI2 .AND. MBO.NE.MBO2) HM3= (CHORD(3)+MLE(3)-CHORD(1))
     1/FLOAT(MBO2-MBO)
      PITCH= 2.*3.1415927/FLOAT(NBL)
      HT = PITCH/FLOAT(NBBI)
C
C     CALCULATE LARGE MESH MV ARRAY, AND RMI,RMO,AND BV ARRAYS
C
      MBOT= MIN0(MBO,MBI2)
      CDMBOT= AMIN1(CHORD(1),MLE(3))
      DO 70 IM=1,MBOT
   70 MV(IM)= FLOAT(IM-MBI)*HM1
      MBIT= MAX0(MBO,MBI2)
      CDMBIT= AMAX1(CHORD(1),MLE(3))
      DO 80 IM=MBOT,MBIT
   80 MV(IM)= CDMBOT+FLOAT(IM-MBOT)*HM2
      DO 90 IM=MBIT,MM
   90 MV(IM)= CDMBIT+FLOAT(IM-MBIT)*HM3
      CALL SPLINT (MR,RMSP,NRSP,MV,MM,RM,SAL)
      RMI(1)= RM(MBI)
      RMI(2)= RM(MBI)
      RMI(3)= RM(MBI2)
      RMI(4)= RM(MBI2)
      RMO(1)= RM(MBO)
      RMO(2)= RM(MBO)
      RMO(3)= RM(MBO2)
      RMO(4)= RM(MBO2)
      BV(1)= 0.
      BV(2)= 0.
      BV(3)= -WTFLSP/WTFL
      BV(4)= BV(3)
C
C     CALCULATE GEOMETRICAL CONSTANTS
C
      MBII= (MBI2-MBDYF)*MAGFAC+1
      MBOO= (MBO-MBDYF)*MAGFAC+1
      MMM= (MBDYL-MBDYF)*MAGFAC+1
      ITMAX= (ITL-ITF)*MAGFAC+1
```

```
      HM1= HM1/FLOAT(MAGFAC)
      HM2= HM2/FLOAT(MAGFAC)
      HM3= HM3/FLOAT(MAGFAC)
      HT = HT/FLOAT(MAGFAC)
      ITOR= -ITF*MAGFAC+1
      IF (NOBL.EQ.1) GO TO 130
C
C  FOR TANDEM BLADE CASE, IF REGION SURROUNDS LEADING EDGE OF
C  FRONT BLADE, STORE BLADE SURFACES 1 AND 2 INTO 3 AND 4
C
      IF (MBDYF.GE.MBI.OR.MBDYL.LE.MBI) GO TO 110
      IF (ITF.GE.0.OR.ITL.LE.0) GO TO 110
      MBII= (MBI-MBDYF)*MAGFAC+1
      MBOO= -1000
      HM2 = HM1
      HM3 = HM1
      CHORD(3) = CHORD(1)
      STGR(3) = STGR(1)
      MLE(3) = MLE(1)
      THLE(3) = THLE(1)
      DO 100 J=1,2
      RI(J+2) = RI(J)
      RO(J+2) = RO(J)
      BETI(J+2) = BETI(J)
      BETO(J+2) = BETO(J)
      RMI(J+2) = RMI(J)
      RMO(J+2) = RMO(J)
      BV(J+2) = BV(J)
      NSPI(J+2) = NSPI(J)
      NSP = NSPI(J)
      DO 100 I=1,NSP
      MSP(I,J+2) = MSP(I,J)
  100 THSP(I,J+2) = THSP(I,J)
C
C  FOR TANDEM BLADE CASE, IF REGION SURROUNDS TRAILING EDGE OF
C  REAR BLADE, STORE BLADE SURFACES 3 AND 4 INTO 1 AND 2
C
  110 IF (MBDYF.GE.MBO2.OR.MBDYL.LE.MBO2) GO TO 130
      IF (FLOAT(ITF*MAGFAC)*HT.GE.THLE(3)+STGR(3).OR.FLOAT(ITL*MAGFAC)*
     1HT.LE.THLE(3)+STGR(3)) GO TO 130
      MBII= 1000
      MBOO= (MBO2-MBDYF)*MAGFAC+1
      HM1 = HM3
      HM2 = HM3
      CHORD(1) = CHORD(3)
      STGR(1) = STGR(3)
      MLE(1) = MLE(3)
      THLE(1) = THLE(3)
      DO 120 J=3,4
      RI(J-2) = RI(J)
      RO(J-2) = RO(J)
      BETI(J-2) = BETI(J)
      BETO(J-2) = BETO(J)
      RMI(J-2) = RMI(J)
      RMO(J-2) = RMO(J)
      BV(J-2) = BV(J)
```

```
      NSPI(J-2) = NSPI(J)
      NSP = NSPI(J)
      DO 120 I=1,NSP
      MSP(I,J-2) = MSP(I,J)
  120 THSP(I,J-2) = THSP(I,J)
C
C     CALCULATE MISCELLANEOUS CONSTANTS
C
  130 CHORD(2) = CHORD(1)
      CHORD(4) = CHORD(3)
      STGR(2) = STGR(1)
      STGR(4) = STGR(3)
      MLE(2) = MLE(1)
      MLE(4) = MLE(3)
      THLE(2) = THLE(1)
      THLE(4) = THLE(3)
      DTLR= HT/1000.
      DMLR= AMIN1(HM1,HM2,HM3)/1000.
      MBIIM1= MBII-1
      MBIIP1= MBII+1
      MBOOM1= MBOO-1
      MBOOP1= MBOO+1
      MMMM1= MMM-1
      NER(1) = 0
      CP= AR/(GAM-1.)*GAM
      EXPON= 1./(GAM-1.)
      TWW= 2.*OMEGA/WTFL
      CPTIP= 2.*CP*TIP
      TGROG= 2.*GAM*AR/(GAM+1.)
C
C     CALCULATE FINE MESH MV ARRAY
C
      MV(1)= MV(MBDYF)
      MBOT= MINO(MBII,MBOO)
      MBOT= MAXO(MBOT,1)
      DO 140 IM=1,MBOT
  140 MV(IM)= MV(1)+FLOAT(IM-1)*HM1
      MBIT= MAXO(MBII,MBOO)
      MBIT= MINO(MBIT,MMM)
      DO 150 IM=MBOT,MBIT
  150 MV(IM)= MV(MBOT)+FLOAT(IM-MBOT)*HM2
      DO 160 IM=MBIT,MMM
  160 MV(IM)= MV(MBIT)+FLOAT(IM-MBIT)*HM3
      DO 165 IM=1,MMM
  165 IF (ABS(MV(IM)).LT.DMLR) MV(IM)=0.
      CALL SPLINT(MR,RMSP,NRSP,MV,MMM,RM,SAL)
      CALL SPLINT(MR,BESP,NRSP,MV,MMM,BE,DBDM)
C
C  FINISH READING NEW MAGNFY INPUT DATA
C  READ, COMPUTE, AND STORE BOUNDARY VALUES
C
      DO 170 I=1,100
      DO 170 J=1,4
      UBV(I,J) = 0.
  170 RWBV(I,J) = 0.
  180 READ(5,1010) KBDRY,NSP
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      IF (KBDRY.EQ.0) GO TO 210
      WRITE(6,1320)
      WRITE(6,1020) KBDRY,NSP
      WRITE(6,1330)
      READ (5,1030) (BVIN(I),I=1,NSP)
      WRITE(6,1040) (BVIN(I),I=1,NSP)
      WRITE(6,1340)
      READ (5,1030) (UBVIN(I),I=1,NSP)
      WRITE(6,1040) (UBVIN(I),I=1,NSP)
      IF (KBDRY.EQ.3 .OR. KBDRY.EQ.4) GO TO 190
      CALL BDVINT(BVIN,UBVIN,NSP,MV,KBDRY,DMLR,MMM)
      GO TO 180
  190 DO 200 IT=1,ITMAX
  200 TH(IT)= FLOAT(IT-ITOR)*HT
      CALL BDVINT(BVIN,UBVIN,NSP,TH,KBDRY,DTLR,ITMAX)
      GO TO 180
  210 DO 220 KBDRY=1,2
      DO 220 IM=1,MMM
  220 RWBV(IM,KBDRY) = -RWBV(IM,KBDRY)*WTFL/BE(IM)
      DO 230 KBDRY=3,4
      DO 230 IT=1,ITMAX
  230 RWBV(IT,KBDRY) = RWBV(IT,KBDRY)*WTFL/BE(IM)/RM(IM)
      IF(BLDAT.GT.0) WRITE (6,1350) (MV(IM),UBV(IM,1),RWBV(IM,1),
     1UBV(IM,2),RWBV(IM,2),IM=1,MMM)
      IF(BLDAT.GT.0) WRITE (6,1360) (TH(IT),UBV(IT,3),RWBV(IT,3),
     1UBV(IT,4),RWBV(IT,4),IT=1,ITMAX)
C
C      INITIALIZE ARRAYS
C
      DO 240 I=1,2000
      U(I) = 1.
      K(I)= 0.
  240 RHO(I)= RHOIP
      DO 250 IM=1,100
      DO 250 SURF=1,4
      RHOHB(IM,SURF)= RHOIP
      RHOVB(IM,SURF)= RHOIP
      RBV(IM,SURF) = RHOIP
  250 ITV(IM,SURF) = -10000
      DO 260 IM=1,100
      ITV(IM,5)= 2
  260 ITV(IM,6)= ITMAX-1
      IF (MMM.LE.100.AND.ITMAX.LE.100) RETURN
      WRITE (6,1370)
      STOP
C
C  FORMAT STATEMENTS
C
 1000 FORMAT (1H1)
 1010 FORMAT (16I5)
 1020 FORMAT (1X,16I7)
 1030 FORMAT (8F10.5)
 1040 FORMAT (1X,8G16.7)
 1100 FORMAT (80H
     1                                     )
 1110 FORMAT (7X,4HNOBL/7X,I3)
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 1120 FORMAT (29H1 NOBL HAS NOT BEEN SPECIFIED)
 1130 FORMAT (7X,3HGAM,14X,2HAR,13X,3HTIP,12X,5HRHOIP,12X,4HWTFL,27X,
     15HOMEGA,12X,3HORF)
 1140 FORMAT (7X,3HGAM,14X,2HAR,13X,3HTIP,12X,5HRHOIP,12X,4HWTFL,11X,6HW
     1TFLSP,10X,5HOMEGA,12X,3HORF)
 1150 FORMAT (6X,5HBETAI,10X,5HBETAO,11X,5HCHORD,12X,4HSTGR)
 1160 FORMAT (6X,5HBETAI,10X,5HBETAO,11X,6HCHORDF,11X,5HSTGRF,10X,
     16HCHORDR,10X,5HSTGRR,12X,4HMLER,11X,5HTHLER)
 1170 FORMAT (4X,8HMBI   MBO,12X,18HMM   NBBI   NBL NRSP)
 1180 FORMAT (41H    MBI   MBO MBI2 MBO2   MM    NBBI    NBL NRSP)
 1190 FORMAT (53HL     BLADE SURFACE 1  --  UPPER SURFACE - FRONT BLADE)
 1200 FORMAT (53HL     BLADE SURFACE 2  --  LOWER SURFACE - FRONT BLADE)
 1210 FORMAT (52HL     BLADE SURFACE 3  --  UPPER SURFACE - REAR BLADE)
 1220 FORMAT (52HL     BLADE SURFACE 4  --  LOWER SURFACE - REAR BLADE)
 1230 FORMAT (7X,2HRI,I1,12X,2HRO,I1,12X,4HBETI,I1,11X,4HBETO,I1,11X,5HS
     1PLNO,I1)
 1240 FORMAT (7X,3HMSP,I1,2X,5HARRAY)
 1250 FORMAT (7X,4HTHSP,I1,2X,5HARRAY)
 1260 FORMAT (16HL         MR   ARRAY)
 1270 FORMAT (7X,11HRMSP   ARRAY)
 1280 FORMAT (7X,11HBESP   ARRAY)
 1290 FORMAT (45HL     BLDAT  AANDK   ERSOR   STRFN   INTVL   SURVL)
 1300 FORMAT (39HL     MBDYF  MBDYL    ITF     ITL    MAGFAC)
 1310 FORMAT (7X,6HLAMBDA)
 1320 FORMAT (15HL     KBDRY  NSP)
 1330 FORMAT (7X,11HBVIN   ARRAY)
 1340 FORMAT (7X,12HUBVIN   ARRAY)
 1350 FORMAT (1H1,7X,60HSTREAM FUNCTION AND RHO*W-SUB-THETA ON HORIZONTA
     1L BOUNDARIES//19X,55HLOWER HORIZONTAL BOUNDARY      UPPER HORIZONTA
     2L BOUNDARY/8X,1HM,6X,2(7X,3HUBV,12X,4HRWBV,4X)/(1X,5G15.5))
 1360 FORMAT (1H1,7X,54HSTREAM FUNCTION AND RHO*W-SUB-M ON VERTICAL BOUN
     1DARIES//20X,52HLEFT VERTICAL BOUNDARY        RIGHT VERTICAL BOUNDAR
     2Y/6X,5HTHETA,4X,2(7X,3HUBV,12X,4HRWBV,4X)/(1X,5G15.5))
 1370 FORMAT (28H1 MMM GT 100 OR ITMAX GT 100)
      END



      SUBROUTINE PRECAL
C
C  PRECAL CALCULATES ALL REQUIRED FIXED CONSTANTS
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      EXTERNAL BL1,BL2,BL3,BL4
```

```
C
C   CALCULATE TV, ITV, IV, DTDMV AND BETAV ARRAYS
C
C   TV, ITV, DTDMV AND BETAV ON BLADES
      SRW = 0
      MBIT = MAXO(1,(MBI-MBDYF)*MAGFAC+1)
      MBOT = MINO(MMM,MBOO)
      IF (MBOT.LF.MBIT) GO TO 20
      DO 10 IM=MBIT,MBOT
      LER(2) = 1
C     BLCD CALL NO. 1
      CALL BL1(MV(IM),TV(IM,1),DTDMV(IM,1),INF)
      ITV(IM,1)= INT((TV(IM,1)+DTLR)/HT)+ITOR
      IF(TV(IM,1).GT.-DTLR)ITV(IM,1)=ITV(IM,1)+1
      ITV(IM,1) = MINO(ITV(IM,1),ITMAX)
      ITV(IM,1) = MAXO(ITV(IM,1),2)
      BETAV(IM,1)=ATAN(DTDMV(IM,1)*RM(IM))*57.295779
      LER(2) = 2
C     BLCD CALL NO. 2
      CALL BL2(MV(IM),TV(IM,2),DTDMV(IM,2),INF)
      ITV(IM,2)=INT((TV(IM,2)-DTLR)/HT)+ITOR
      IF(TV(IM,2).LT.DTLR)ITV(IM,2)=ITV(IM,2)-1
      ITV(IM,2) = MAXO(ITV(IM,2),1)
      ITV(IM,2) = MINO(ITV(IM,2),ITMAX-1)
   10 BETAV(IM,2)=ATAN(DTDMV(IM,2)*RM(IM))*57.295779
   20 MBIT = MAXO(1,MBII)
      MBOT = MINO(MMM,(MBO2-MBDYF)*MAGFAC+1)
      IF (MBIT.GT.MBOT) GO TO 40
      DO 30 IM=MBIT,MBOT
      LER(2) = 3
C     BLCD CALL NO. 3
      CALL BL3(MV(IM),TV(IM,3),DTDMV(IM,3),INF)
      ITV(IM,3)= INT((TV(IM,3)+DTLR)/HT)+ITOR
      IF(TV(IM,3).GT.-DTLR)ITV(IM,3)=ITV(IM,3)+1
      ITV(IM,3) = MINO(ITV(IM,3),ITMAX)
      ITV(IM,3) = MAXO(ITV(IM,3),2)
      BETAV(IM,3)= ATAN(DTDMV(IM,3)*RM(IM))*57.295779
      LER(2) = 4
C     BLCD CALL NO. 4
      CALL BL4(MV(IM),TV(IM,4),DTDMV(IM,4),INF)
      ITV(IM,4)=INT((TV(IM,4)-DTLR)/HT)+ITOR
      IF(TV(IM,4).LT.DTLR)ITV(IM,4)=ITV(IM,4)-1
      ITV(IM,4) = MAXO(ITV(IM,4),1)
      ITV(IM,4) = MINO(ITV(IM,4),ITMAX-1)
   30 BETAV(IM,4)= ATAN(DTDMV(IM,4)*RM(IM))*57.295779
C   IV ARRAY
   40 IV(1) = 0
      IV(2)=1
      MBOT = MINO(MBIIM1,MBOO)
      IF(MBOT.LT.2) GO TO 60
      DO 50 IM=2,MBOT
      IV(IM+1) = IV(IM)+ITV(IM,2)-ITV(IM,1)+ITMAX-1
   50 IF (ITV(IM,1).EQ.-10000) IV(IM+1)=IV(IM+1)-1
   60 MBIT = MAXO(2,MBII)
      MBOT = MINO(MMMM1,MBOO)
      IF(MBIT.GT.MBOT)GO TO 80
      DO 70 IM=MBIT,MBOT
   70 IV(IM+1)= IV(IM)+ITV(IM,4)+ITV(IM,2)-ITV(IM,3)-ITV(IM,1)+ITMAX
   80 MBIT = MAXO(2,MBOOP1)
      MBOT = MINO(MMMM1,MBIIM1)
```

```
      IF(MBIT.GT.MBOT) GO TO 100
      DO 90 IM= MBIT,MBOT
   90 IV(IM+1)= IV(IM)+ITMAX-2
  100 MBIT = MAXO(MBII,MBOOP1)
      IF(MBIT.GT.MMMM1)GO TO 120
      DO 110 IM=MBIT,MMMM1
      IV(IM+1)=IV(IM)+ITV(IM,4)-ITV(IM,3)+ITMAX-1
  110 IF (ITV(IM,3).EQ.-10000) IV(IM+1)=IV(IM+1)-1
  120 NIP= IV(MMM)-1
      WRITE (6,1020) PITCH,HT,HM1,HM2,HM3
      WRITE (6,1030) MBII,MBOO,MMM,ITMAX,NIP
      WRITE (6,1040) (SURF,BV(SURF),SURF=1,4)
      IF(BLDAT.LE.0) GO TO 140
      MBIT = MAXO(1,(MBI-MBDYF)*MAGFAC+1)
      MBOT = MINO(MMM,MBOO)
      WRITE (6,1050)
      DO 130 SURF = 1,3,2
      I = SURF+1
      IF (MBIT.LE.MBOT) WRITE(6,1060) SURF,I,(MV(IM),TV(IM,SURF),DTDMV(I
     1M,SURF),TV(IM,I),DTDMV(IM,I),IM=MBIT,MBOT)
      MBIT = MAXO(1,MBII)
  130 MBOT = MINO(MMM,(MBO2-MBDYF)*MAGFAC+1)
      WRITE(6,1070)(IM,MV(IM),RM(IM),SAL(IM),BE(IM),DBDM(IM),IM=1,MMM)
      WRITE(6,1080) (IM,IV(IM),(ITV(IM,SURF),SURF=1,4),IM=1,MMM)
C
C  CALCULATE MH AND DTDMH ARRAYS.
C
  140 IMS(1)=0
      MRTS = 0
      MBIT = MAXO(1,(MBI-MBDYF)*MAGFAC+1)
      MBOT = MINO(MMM,MBOO)
      LER(2) = 5
C     BLCD AND ROOT (VIA MHORIZ) CALL NO. 5
      CALL MHORIZ(MV,ITV(1,1),BL1,MBIT,MBOT,ITOR,HT,DTLR,0,IMS(1),
     1MH(1,1),DTDMH(1,1),MRTS)
      IF(ITV(MBOO,1)-ITV(MBOO,2).NE.2) GO TO 150
      IMSL = IMS(1)+1
      MH(IMSL,1)= MV(MBOO)
      DTDMH(IMSL,1)= -1.E10
      IMS(1)= IMSL
  150 IMS(2)=0
      MRTS = 0
      LER(2) = 6
C     BLCD AND ROOT (VIA MHORIZ) CALL NO. 6
      CALL MHORIZ(MV,ITV(1,2),BL2,MBIT,MBOT,ITOR,HT,DTLR,1,IMS(2),
     1MH(1,2),DTDMH(1,2),MRTS)
      IMS(3)=0
      IF(ITV(MBII,3)-ITV(MBII,4).NE.2) GO TO 160
      MRTS = 1
      IMS(3)=1
      MH(1,3)= MV(MBII)
      DTDMH(1,3)=1.E10
  160 MBIT = MAXO(1,MBII)
      MBOT = MINO(MMM,(MBO2-MBDYF)*MAGFAC+1)
      LER(2) = 7
C     BLCD AND ROOT (VIA MHORIZ) CALL NO. 7
      CALL MHORIZ(MV,ITV(1,3),BL3,MBIT,MBOT,ITOR,HT,DTLR,0,IMS(3),
     1MH(1,3),DTDMH(1,3),MRTS)
      IMS(4)=0
      IF (ITV(MBII,3)-ITV(MBII,4).EQ.2) MRTS=1
```

```
      LER(2) = 8
C     BLCD AND ROOT (VIA MHORIZ) CALL NO. 8
      CALL MHORIZ(MV,ITV(1,4),BL4,MBIT,MBOT,ITOR,HT,DTLR,1,IMS(4),
     1MH(1,4),DTDMH(1,4),MRTS)
      I = MAXO(IMS(1),IMS(2),IMS(3),IMS(4))
      IF (I.LE.100) GO TO 170
      WRITE(6,1090) I
      STOP
C
C     CALCULATE RMH, BEH, AND BETAH ARRAYS
C
  170 IF (BLDAT.GT.0) WRITE(6,1100)
      DO 190 SURF=1,4
      CALL SPLINT(MR,RMSP,NRSP,MH(1,SURF),IMS(SURF),RMH(1,SURF),AAA)
      CALL SPLINT(MR,BESP,NRSP,MH(1,SURF),IMS(SURF),BEH(1,SURF),AAA)
      IMSS= IMS(SURF)
      IF (IMSS.LT.1) GO TO 190
      DO 180 IHS=1,IMSS
  180 BETAH(IHS,SURF)= ATAN(DTDMH(IHS,SURF)*RMH(IHS,SURF))*57.295779
      IF (BLDAT.GT.0) WRITE(6,1110) SURF,(MH(IM,SURF),RMH(IM,SURF),
     1BEH(IM,SURF),BETAH(IM,SURF),DTDMH(IM,SURF),IM=1,IMSS)
  190 CONTINUE
      IF (BLDAT.LE.0) GO TO 210
      WRITE (6,1120)
      DO 200 IT=1,ITMAX
      TH = FLOAT(IT-ITOR)*HT
  200 WRITE (6,1010) IT,TH
  210 WRITE (6,1000)
      IF (NIP.LE.2000) RETURN
      WRITE (6,1130)
      STOP
 1000 FORMAT (1H1)
 1010 FORMAT (4X,I4,G16.5)
 1020 FORMAT (1H1////5X,28HCALCULATED PROGRAM CONSTANTS//5X,5HPITCH,
     113X,2HHT,13X,3HHM1,13X,3HHM2,13X,3HHM3/1X,5G16.7)
 1030 FORMAT (/5X,4HMBII,10X,4HMBOO,10X,3HMMM,10X,5HITMAX/3X,I5,9X,I5,
     19X,I5,9X,I5///5X,33HNUMBER OF INTERIOR MESH PUINTS = ,I5)
 1040 FORMAT (//////5X,23HSURFACE BOUNDARY VALUES//5X,7HSURFACE,7X,2HBV/
     1(5X,I4,4X,F10.5))
 1050 FORMAT (1H1,6X,62HBLADE DATA AT INTERSECTIONS OF VERTICAL MESH LIN
     1ES WITH BLADES)
 1060 FORMAT (1HL,22X,13HBLADE SURFACE,I2,15X,13HBLADE SURFACE,I2/7X,
     11HM,14X,2HTV,11X,5HDTDMV,12X,2HTV,11X,5HDTDMV/(5G15.5))
 1070 FORMAT (1H1,13X,44HSTREAM SHEET COORDINATES AND THICKNESS TABLL/
     12X,2HIM,7X,1HM,14X,1HR,13X,3HSAL,13X,1HB,12X,5HDB/DM/
     2(1X,I3,5G15.5))
 1080 FORMAT (4H1 IM,9X,8HIV ARRAY,32X,9HITV ARRAY/38X,5HBLADE/37X,7HSUR
     1FACE,3X,1H1,5X,1H2,5X,1H3,5X,1H4/39X,3HNO./(1X,I3,5X,I10,25X,
     24(I4,2X)))
 1090 FORMAT (35H1 ONE OF THE MH ARRAYS IS TOO LARGE/7HLIT HAS,I5,
     18H  POINTS)
 1100 FORMAT (67H1M COORDINATES OF INTERSECTIONS OF HORIZONTAL MESH LINE
     1S WITH BLADE)
 1110 FORMAT (25HLMH ARRAY - BLADE SURFACE,I2//15X,2HMH,19X,3HRMH,19X,
     1   3HBEH,18X,5HBETAH,17X,5HDTDMH/(5G22.4))
 1120 FORMAT (43H1THETA COORDINATES OF HORIZONTAL MESH LINES//6X,2HIT,
     15X,5HTHETA)
 1130 FORMAT (48H THE NUMBER OF INTERIOR MESH POINTS EXCEEDS 2000)
      END
```

```
      SUBROUTINE COEF
C
C  COEF CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANTS, K,
C  AT ALL UNKNOWN MESH POINTS FOR THE ENTIRE REGION
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),IH(4),RZ,BZ
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
C  INITIALIZE ARRAYS
      ITER = ITER+1
      IH(1) = MAXO(0,ITV(2,1)-ITV(1,1))
      IH(2) = MAXO(0,ITV(1,2)-ITV(2,2))
      IH(3) = MAXO(0,ITV(2,3)-ITV(1,3))
      IH(4) = MAXO(0,ITV(1,4)-ITV(2,4))
      IF(ITV(MBII,3)-ITV(MBII,4).EQ.2) IH(3) = 1
C  INCOMPRESSIBLE CASE
      IF(GAM.NE.1.5.OR.AR.NE.1000..OR.TIP.NE.1.E6) GO TO 10
      IEND = 0
      GO TO 20
C  ADJUSTMENT OF PRINTING CONTROL VARIABLES
   10 IF(ITER.NE.1.AND.ITER.NE.2) GO TO 20
      AANDK = AANDK-1
      ERSOR = ERSOR-1
      STRFN = STRFN-1
      INTVL = INTVL-1
      SURVL = SURVL-1
   20 IF(IEND.NE.0) GO TO 30
      AANDK = AANDK+2
      ERSOR = ERSOR+2
      STRFN = STRFN+2
      INTVL = INTVL+2
      SURVL = SURVL+2
C
C  CALL COEFBB THROUGHOUT THE REGION
C
C  FRONT BLADE
   30 MBOT = MINO(MBIIM1,MBOO)
      IF (MBOT.LT.2) GO TO 50
      DO 40 IM=2,MBOT
      CALL COEFBB (IM,5,2)
   40 CALL COEFBB (IM,1,6)
C  OVERLAP REGION
   50 MBIT = MAXO(2,MBII)
      MBOT = MINO(MMMM1,MBOO)
      IF (MBIT.GT.MBOT) GO TO 70
      DO 60 IM=MBIT,MBOT
      CALL COEFBB (IM,5,4)
```

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      CALL COEFBB (IM,3,2)
   60 CALL COEFBB (IM,1,6)
      GO TO 90
C   NON-OVERLAP REGION
   70 MBIT = MAXO(2,MBOOP1)
      MBOT = MINO(MBIIM1,MMMM1)
      IF (MBIT.GT.MBOT) GO TO 90
      DO 80 IM=MBIT,MBOT
   80 CALL COEFBB (IM,5,6)
C   REAR BLADE
   90 MBIT = MAXO(MBII,MBOOP1)
      IF (MBIT.GT.MMMM1) GO TO 110
      DO 100 IM=MBIT,MMMM1
      CALL COEFBB (IM,5,4)
  100 CALL COEFBB (IM,3,6)
C
C   SPECIAL CASES - POINTS J OR C ARE MESH POINTS
C
C   POINT J
  110 IF (ITV(MBII,3)-ITV(MBII,4).NE.2) GO TO 120
      IT = ITV(MBII,4)+1
      IP = IPF(MBIIM1,IT)
      K(IP) = K(IP)+A(IP,4)*BV(4)
      A(IP,4) = 0.
C   POINT C
  120 IF(ITV(MBOO,1)-ITV(MBOO,2).NE.2) RETURN
      IT = ITV(MBOO,2)+1
      IP = IPF(MBOOP1,IT)
      A(IP,3) = 0.
      RETURN
      END




      SUBROUTINE COEFBB(IM,UPPER,LOWER)
C
C   COEFBB CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANTS, K
C   ALONG ALL VERTICAL MESH LINES WHICH INTERSECT BLADES
C
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),IH(4),RZ,BZ
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLF,MR,MSP,MV,MVIM1
      IF(ITV(IM,UPPER).GT.ITV(IM,LOWER)) RETURN
      ITVU= MAXO(ITV(IM,UPPER),2)
      ITVL= MINO(ITV(IM,LOWER),ITMAX-1)
      IF (ITVU.GT.ITVL) RETURN
```

```
      IT= ITVU-1
      IPU= IPF(IM,ITVU)
      IPL= IPU+ITVL-ITVU
      DO 80 IP=IPU,IPL
      IT= IT+1
      CALL HRB (IM,IT,IP)
      DO 10 I=1,4
      KAK(I)= 0.
   10 KA(I)= 0
C
C  FIX HRB VALUES FOR CASES WHERE MESH LINES INTERSECT BLADES
C  OR BOUNDARIES
C
      IF (IT.NE.2) GO TO 20
      KAK(1)= UBV(IM,1)
      KA(1)= 1
   20 IF (IT.NE.ITMAX-1) GO TO 30
      KAK(2)= UBV(IM,2)
      KA(2)= 1
   30 IF (IM.NE.2) GO TO 40
      KAK(3)= UBV(IT,3)
      KA(3)= 1
   40 IF (IM.NE.MMMM1) GO TO 50
      KAK(4)= UBV(IT,4)
      KA(4)= 1
   50 IF (IT.EQ.ITVU.AND.UPPER.NE.5) CALL BDRY12(1,IM,IT,UPPER)
      IF (IT.EQ.ITVL.AND.LOWER.NE.6) CALL BDRY12(2,IM,IT,LOWER)
      ITVM1= ITV(IM-1,UPPER)
      ITVP1= ITV(IM+1,UPPER)
      IF (ITV(IM,UPPER).EQ.-10000) GO TO 55
      IF (IT.LT.ITVM1) CALL BDRY34(3,IM,UPPER)
      IF (IT.LT.ITVP1) CALL BDRY34(4,IM,UPPER)
   55 ITVM1= ITV(IM-1,LOWER)
      ITVP1= ITV(IM+1,LOWER)
      IF (ITVM1.EQ.-10000) GO TO 60
      IF (IM.EQ.MBII.AND.LOWER.EQ.4) GO TO 60
      IF (IT.GT.ITVM1) CALL BDRY34(3,IM,LOWER)
   60 IF (ITVP1.EQ.-10000) GO TO 70
      IF (IM.EQ.MBOO.AND.LOWER.EQ.2) GO TO 70
      IF (IT.GT.ITVP1) CALL BDRY34(4,IM,LOWER)
C
C  COMPUTE A AND K COEFFICIENTS
C
   70 CALL AAK(IM,IP)
      DO 80 I=1,4
      K(IP)= K(IP)+KAK(I)*A(IP,I)
   80 IF (KA(I).EQ.1) A(IP,I)=0.
      RETURN
      END
```

```
      SUBROUTINE HRB(IM,IT,IP)
C
C  HRB CALCULATES MESH SPACING, H, DENSITIES, RZ AND R, AT GIVEN AND
C  ADJACENT POINTS, AND STREAM SHEET THICKNESSES, BZ AND B, AT GIVEN
C  AND ADJACENT POINTS
C
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),IH(4),RZ,BZ
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      H(1)= HT*RM(IM)
      H(2)= HT*RM(IM)
      H(3)= MV(IM) - MV(IM-1)
      H(4) = MV(IM+1)-MV(IM)
      RZ = RHO(IP)
      IP3 = IPF(IM-1,IT)
      IP4 = IPF(IM+1,IT)
      R(1)= RHO(IP-1)
      IF (IT.EQ.2) R(1)= RBV(IM,1)
      R(2)= RHO(IP+1)
      IF (IT.EQ.ITMAX-1) R(2)= RBV(IM,2)
      R(3)= RHO(IP3)
      IF (IM.EQ.2) R(3)= RBV(IT,3)
      R(4)= RHO(IP4)
      IF (IM.EQ.MMMM1) R(4)= RBV(IT,4)
      BZ= BE(IM)
      B(3)= BE(IM-1)
      B(4)= BE(IM+1)
      RETURN
      END
```

```
      SUBROUTINE AAK(IM,IP)
C
C  AAK CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANT, K,
C  AT A SINGLE MESH POINT
C
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),IH(4),RZ,BZ
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
```

```
      A12= 2./H(1)/H(2)
      A34= 2./H(3)/H(4)
      AZ= A12+A34
      B12= (R(2)-R(1))/RZ/(H(1)+H(2))
      B34= (B(4)*R(4)-B(3)*R(3))/BZ/RZ/(H(3)+H(4))-SAL(IM)/RM(IM)
      A(IP,1) = (2./H(1)+B12)/AZ/(H(1)+H(2))
      A(IP,2) = A12/AZ-A(IP,1)
      A(IP,3) = (2./H(3)+B34)/AZ/(H(3)+H(4))
      A(IP,4) = A34/AZ-A(IP,3)
      K(IP) = -TWW*BZ*RZ*SAL(IM)/AZ
      RETURN
      END



      SUBROUTINE BDRY12(I,IM,IT,SURF)
C
C  BDRY12 CORRECTS VALUES COMPUTED BY HRB WHEN A VERTICAL MESH LINE
C  INTERSECTS A BLADE
C
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),IH(4),RZ,BZ
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      H(I) = ABS(FLOAT(IT-ITOR)*HT-TV(IM,SURF))*RM(IM)
      R(I)= RHOVB(IM,SURF)
      KAK(I)=BV(SURF)
      KA(I)=1
      RETURN
      END



      SUBROUTINE BDRY34(I,IM,SURF)
C
C  BDRY34 CORRECTS VALUES COMPUTED BY HRB WHEN A HORIZONTAL MESH LINE
C  INTERSECTS A BLADE
C
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),IH(4),RZ,BZ
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
```

```
      IH(SURF)=IH(SURF)+1
      IHS=IH(SURF)
      H(I)=ABS(MV(IM)-MH(IHS,SURF))
      R(I)=RHOHB(IHS,SURF)
      B(I)=BEH(IHS,SURF)
      KAK(I)=BV(SURF)
      KA(I)=1
      RETURN
      END



      SUBROUTINE SOR
C
C  SOR SOLVES THE SET OF SIMULTANEOUS EQUATIONS FOR THE STREAM FUNCTION
C  USING THE METHOD OF SUCCESSIVE OVER-RELAXATION
C
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      AATEMP = AANDK
      IF (ORF.GE.2.) ORF=0.
      IF(ORF.GT.1.) GO TO 20
      ORF = 1.
      ORFOPT = 2.
   10 ORFTEM = ORFOPT
      LMAX = 0.
   20 IF(AATEMP.GT.0) WRITE(6,1010)
      ERROR = 0.
C
C  SOLVE MATRIX EQUATION BY SOR, OR CALCULATE OPTIMUM OVERRELAXATION
C  FACTOR
C
      DO 50 IM=2,MMMM1
      IF(AATEMP.GT.0) WRITE(6,1020)IM
      IPU = IV(IM)
      IPL= IV(IM+1)-1
      IT= 1
      DO 50 IP=IPU,IPL
      IF(IPU.GT.IPL) GO TO 50
      IT= IT+1
      IF(IT.GT.ITV(IM,4).AND.IT.LE.ITV(IM,3)) IT=IT+ITV(IM,3)-
     1MAX0(ITV(IM,4),1)-1
      IF(IT.GT.ITV(IM,2).AND.IT.LE.ITV(IM,1)) IT=IT+ITV(IM,1)-
     1MAX0(ITV(IM,2),1)-1
```

```
      IP1= IP-1
      IP2= IP+1
      IP3= IPF(IM-1,IT)
      IP4= IPF(IM+1,IT)
      IF(IM.EQ.2) IP3 = 0
      IF(IM.EQ.MMMM1) IP4 = 0
      IF(ORF.GT.1.) GO TO 30
C  CALCULATE NEW ESTIMATE FOR LMAX
      UNEW = A(IP,1)*U(IP1)+A(IP,2)*U(IP2)+A(IP,3)*U(IP3)+A(IP,4)*U(IP4)
      IF (UNEW.LT.1.E-25) U(IP) = 0.
      IF (U(IP).EQ.0.) GO TO 40
      RATIO = UNEW/U(IP)
      LMAX= AMAX1(RATIO,LMAX)
      U(IP) = UNEW
      GO TO 40
C  CALCULATE NEW ESTIMATE FOR STREAM FUNCTION BY SOR
   30 CHANGE = ORF*(K(IP)-U(IP)+A(IP,1)*U(IP1)+A(IP,2)*U(IP2)+A(IP,3)*
     1U(IP3)+A(IP,4)*U(IP4))
      ERROR= AMAX1(ERROR,ABS(CHANGE))
      U(IP) = U(IP)+CHANGE
   40 IF(AATEMP.LE.0) GO TO 50
      WRITE (6,1030) IT,IP,IP1,IP2,IP3,IP4,(A(IP,I),I=1,4),K(IP)
   50 CONTINUE
      AATEMP = 0
      IF(ORF.GT.1.) GO TO 60
      ORFOPT = 2./(1.+SQRT(ABS(1.-LMAX)))
      WRITE (6,1040) ORFOPT
      IF (ORFTEM-ORFOPT.GT..00001.OR.ORFOPT.GT.1.999) GO TO 10
      WRITE (6,1000)
      ORF = ORFOPT
      GO TO 20
   60 IF(ERSOR.GT.0) WRITE(6,1050) ERROR
      IF(ERROR.GT..000001) GO TO 20
      IF(STRFN.LE.0) RETURN
C
C  PRINT STREAM FUNCTION VALUES FOR THIS ITERATION
C
      WRITE (6,1060)
      IPL = 0
      MBOT = MINO(MBIIM1,MBCO)
      IF (MBOT.LT.2) GO TO 80
      DO 70 IM=2,MBOT
      CALL WRITU(IM,5,2,IPL)
   70 CALL WRITU(IM,1,6,IPL)
   80 MBIT = MAXO(2,MBII)
      MBOT = MINO(MMMM1,MBOO)
      IF (MBIT.GT.MBOT) GO TO 100
      DO 90 IM=MBIT,MBOT
      CALL WRITU(IM,5,4,IPL)
      CALL WRITU(IM,3,2,IPL)
   90 CALL WRITU(IM,1,6,IPL)
      GO TO 120
  100 MBIT = MAXO(2,MBOOP1)
      MBOT = MINO(MBIIM1,MMMM1)
      IF (MBIT.GT.MBOT) GO TO 120
      DO 110 IM=MBIT,MBOT
  110 CALL WRITU(IM,5,6,IPL)
  120 MBIT = MAXO(MBII,MBOOP1)
```

```
      IF (MBIT.GT.MMMM1) RETURN
      DO 130 IM=MBIT,MMMM1
      CALL WRITU(IM,5,4,IPL)
  130 CALL WRITU(IM,3,6,IPL)
      RETURN
 1000 FORMAT (1H1)
 1010 FORMAT (82H1  IT   IP    IP1    IP2    IP3    IP4     A(1)        A(2)
     1     A(3)       A(4)         K)
 1020 FORMAT(5H IM =,I4)
 1030 FORMAT(1X,I4,5I6,5F10.5)
 1040 FORMAT(24H ESTIMATED OPTIMUM ORF =,F9.6)
 1050 FORMAT(8H ERROR =,F11.8)
 1060 FORMAT(1H1,10X,22HSTREAM FUNCTION VALUES)
      END
```

```
      SUBROUTINE WRITU(IM,UPPER,LOWER,IPL)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      ITVU = MAX0(ITV(IM,UPPER),2)
      ITVL = MIN0(ITV(IM,LOWER),ITMAX-1)
      IF(ITVU.GT.ITVL) RETURN
      IPU = IPL+1
      IPL = IPU+ITVL-ITVU
      WRITE(6,1000) IM,ITVU
      WRITE(6,1010) (U(IP),IP=IPU,IPL)
      RETURN
 1000 FORMAT(5H IM =,I3,10X,5HIT1 =,I3)
 1010 FORMAT (2X,10F13.8)
      END
```

```
      SUBROUTINE SLAX
C
C  SLAX CALLS SUBROUTINES TO CALCULATE RHO*W-SUB-M THROUGHOUT THE REGION
C  AND ON THE BLADE SURFACES, AND TO CALCULATE AND PLOT THE
C  STREAMLINE LOCATIONS
C
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
```

```
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      DIMENSION W(2000),RWM(2000),BETA(2000),WMB(100,4),WTB(100,4),
     1XDOWN(800),YACROS(800),TSL(400),TSP(100),USP(100),DUDT(100)
      EQUIVALENCE (A(1,1),W(1)),(A(1,2),RWM(1)),(A(1,3),BETA(1)),
     1(A(1,4),WMB(1)),(A(401,4),WTB(1)),(A(801,4),XDOWN(1)),
     2(K(1),YACROS(1)),(K(801),TSP(1)),
     3(K(901),USP(1)),(K(1001),DUDT(1))
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
C
C     CALL SLAVBB THROUGHOUT REGION
C
      DO 10 I=1,4
      DO 10 IM=1,100
      WMB(IM,I) = 0.
   10 WTB(IM,I) = 0.
      MBOT = MINO(MBIIM1,MBOO)
      IF (MBOT.LT.2) GO TO 30
      DO 20 IM=2,MBOT
      CALL SLAVBB(IM,5,2)
   20 CALL SLAVBB(IM,1,6)
   30 MBIT = MAXO(2,MBII)
      MBOT = MINO(MMMM1,MBOO)
      IF (MBIT.GT.MBOT) GO TO 50
      DO 40 IM=MBIT,MBOT
      CALL SLAVBB(IM,5,4)
      CALL SLAVBB(IM,3,2)
   40 CALL SLAVBB(IM,1,6)
      GO TO 70
   50 MBIT = MAXO(2,MBOOP1)
      MBOT = MINO(MBIIM1,MMMM1)
      IF (MBIT.GT.MBOT) GO TO 70
      DO 60 IM=MBIT,MBOT
   60 CALL SLAVBB(IM,5,6)
   70 MBIT = MAXO(MBII,MBOOP1)
      IF (MBIT.GT.MMMM1) RETURN
      DO 80 IM=MBIT,MMMM1
      CALL SLAVBB(IM,5,4)
   80 CALL SLAVBB(IM,3,6)
      RETURN
      END
```

```
      SUBROUTINE SLAVBB(IM,UPPER,LOWER)
C
C  SLAVBB CALCULATES RHO*W-SUB-M ALONG VERTICAL MESH LINES
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      DIMENSION W(2000),RWM(2000),BETA(2000),WMB(100,4),WTB(100,4),
     1XDOWN(800),YACROS(800),TSL(400),TSP(100),USP(100),DUDT(100)
      EQUIVALENCE (A(1,1),W(1)),(A(1,2),RWM(1)),(A(1,3),BETA(1)),
     1(A(1,4),WMB(1)),(A(401,4),WTB(1)),(A(801,4),XDOWN(1)),
     2(K(1),YACROS(1)),(K(801),TSP(1)),
     3(K(901),USP(1)),(K(1001),DUDT(1))
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      ITVU= MAX0(ITV(IM,UPPER),2)
      ITVL= MIN0(ITV(IM,LOWER),ITMAX-1)
      NSP= ITVL-ITVU+3
      IF(NSP.LT.3) RETURN
      TSP(1)= FLOAT(1-ITOR)*HT
      IF(ITV(IM,UPPER).LT.2.OR.UPPER.EQ.5) GO TO 10
      IF (TV(IM,UPPER).LT.TSP(1)) GO TO 10
      TSP(1)= TV(IM,UPPER)
      USP(1)= BV(UPPER)
      GO TO 20
   10 USP(1)= UBV(IM,1)
   20 TSP(NSP)= FLOAT(ITMAX-ITOR)*HT
      IF(ITV(IM,LOWER).GE.ITMAX.OR.LOWER.EQ.6) GO TO 30
      IF (TV(IM,LOWER).GE.TSP(NSP)) GO TO 30
      TSP(NSP)= TV(IM,LOWER)
      USP(NSP)= BV(LOWER)
      GO TO 40
   30 USP(NSP)= UBV(IM,2)
   40 NSPM1= NSP-1
      IT= 2
      IP= IPF(IM,ITVU)
      IPU= IP
   50 IF(IT.GT.NSPM1) GO TO 60
      TSP(IT)= FLOAT(IT-2+ITVU-ITOR)*HT
      USP(IT)= U(IP)
      IT= IT+1
      IP= IP+1
      GO TO 50
C
C  CALCULATE RHO*W-SUB-M IN THE REGION, AND RHO*W AT VERTICAL
C  MESH LINE INTERSECTIONS ON THE BLADE SURFACES, OR RHO
C  ON THE HORIZONTAL BOUNDARIES
C
   60 CALL SPLINE(TSP,USP,NSP,DUDT,AAA)
```

```
      IPL= IP-1
      IT= 2
      IP= IPU
   70 IF(IP.GT.IPL) GO TO 80
      RWM(IP)= DUDT(IT)*WTFL/BE(IM)/RM(IM)
      IP= IP+1
      IT= IT+1
      GO TO 70
   80 IF(ITV(IM,UPPER).LT.2.OR.UPPER.EQ.5) GO TO 90
      IF (TV(IM,UPPER).LT.FLOAT(1-ITOR)*HT) GO TO 90
C  UPPER BLADE SURFACE
      WMB(IM,UPPER)= DUDT(1)*WTFL/BE(IM)/RM(IM)
      RMDTU2 = (RM(IM)*DTDMV(IM,UPPER))**2
      IF(RMDTU2.GT.10000.) WMB(IM,UPPER)=0.
      WMB(IM,UPPER) = ABS(WMB(IM,UPPER))*SQRT(1.+RMDTU2)
      GO TO 100
C  LOWER BOUNDARY
   90 RWMBV = DUDT(1)*WTFL/BE(IM)/RM(IM)
      RW= SQRT(RWBV(IM,1)**2+RWMBV**2)
      TWLMR= 2.*OMEGA*LAMBDA-(OMEGA*RM(IM))**2
      LER(1) = 1
C     DENSTY CALL NO. 1
      CALL DENSTY(RW,RBV(IM,1),ANS,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP)
  100 IF(ITV(IM,LOWER).GE.ITMAX.OR.LOWER.EQ.6) GO TO 110
      IF (TV(IM,LOWER).GE.FLOAT(ITMAX-ITOR)*HT) GO TO 110
C  LOWER BLADE SURFACE
      WMB(IM,LOWER)= DUDT(NSP)*WTFL/BE(IM)/RM(IM)
      RMDTL2 = (RM(IM)*DTDMV(IM,LOWER))**2
      IF(RMDTL2.GT.10000.) WMB(IM,LOWER)=0.
      WMB(IM,LOWER) = ABS(WMB(IM,LOWER))*SQRT(1.+RMDTL2)
      RETURN
C  UPPER BOUNDARY
  110 RWMBV = DUDT(NSP)*WTFL/BE(IM)/RM(IM)
      RW= SQRT(RWBV(IM,2)**2+RWMBV**2)
      TWLMR= 2.*OMEGA*LAMBDA-(OMEGA*RM(IM))**2
      LER(1) = 2
C     DENSTY CALL NO. 2
      CALL DENSTY(RW,RBV(IM,2),ANS,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP)
      RETURN
      END
```

```
      SUBROUTINE TANG
C
C  TANG CALCULATES RHO*W-SUB-THETA AND THEN RHO*W THROUGHOUT THE REGION
C  AND ON THE BLADE SURFACES, AND CALCULATES THE VELOCITY ANGLE, BETA,
C  THROUGHOUT THE REGION
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
```

```
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROC,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      DIMENSION SPM(100),USP(100),DUDM(100)
      DIMENSION W(2000),RWM(2000),BETA(2000),WMB(100,4),WTB(100,4),
     1XDOWN(800),YACROS(800)
      EQUIVALENCE (A(1,1),W(1)),(A(1,2),RWM(1)),(A(1,3),BETA(1)),
     1(A(1,4),WMB(1)),(A(401,4),WTB(1)),(A(801,4),XDOWN(1)),
     2(K(1),YACROS(1))
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      EXTERNAL BL1,BL2,BL3,BL4
C
C  PERFORM CALCULATIONS ALONG ONE HORIZONTAL LINE AT A TIME
C
      IT= 2
   10 IF (IT.EQ.ITMAX) RETURN
C
C     ON GIVEN HORIZONTAL MESH LINE, FIND FIRST POINT IN THE REGION
C
      IF (MBII.LE.1.AND.(IT.LE.ITV(1,4).OR.(IT.GE.ITV(1,3).AND.
     1IT.LE.ITV(1,2)).OR.IT.GE.ITV(1,1))) GO TO 50
      IF (MBII.GE.2.AND.(MBOO.LT.0.OR.IT.LE.ITV(1,2).OR.
     1IT.GE.ITV(1,1))) GO TO 50
      IM = 1
   20 IM= IM+1
      IF (IM.GE.MMM) GO TO 180
      DO 30 SURF=1,3,2
      IF (IM.GT.MBOO.AND.SURF.EQ.1) GO TO 30
      IF (IM.LE.MBII.AND.SURF.EQ.3) GO TO 30
      IF (IT.GE.ITV(IM,SURF).AND.IT.LT.ITV(IM-1,SURF))  GO TO 60
   30 CONTINUE
      SURF = 1
      IF (IM.EQ.MBOOP1.AND.IT.EQ.ITV(MBOO,1)-1.AND.
     1ITV(MBOO,1)-ITV(MBOO,2).EQ.2) GO TO 60
      DO 40 SURF=2,4,2
      IF (IM.GT.MBOO.AND.SURF.EQ.2) GO TO 40
      IF (IM.LE.MBII.AND.SURF.EQ.4) GO TO 40
      IF (IT.LE.ITV(IM,SURF).AND.IT.GT.ITV(IM-1,SURF)) GO TO 60
   40 CONTINUE
      GO TO 20
C
C     FIRST POINT IS ON LEFT BOUNDARY
C
   50 S1 = 0
      IM1 = 1
      IM= 2
      SPM(1)= MV(1)
      USP(1)= UBV(IT,3)
      GO TO 70
C
C     FIRST POINT IS ON A BLADE SURFACE
C
   60 S1= SURF
```

```
      IM1= IM-1
      IM2= IM
      TH= FLOAT(IT-ITOR)*HT
      MVIM1 = MV(IM1)
      IF (IM.EQ.MBIIP1.AND.(SURF.EQ.3.OR.SURF.EQ.4)) MVIM1=
     1MVIM1+(MV(IM2)-MVIM1)/1000.
      LER(2) = 9
C     BLCD (VIA ROOT) CALL NO. 9
      IF (S1.EQ.1.AND.IM1.NE.MBOO) CALL ROOT(MVIM1,MV(IM2),TH,BL1,
     1DTLR,ANS,AAA)
      LER(2) = 10
C     BLCD (VIA ROOT) CALL NO. 10
      IF (S1.EQ.2) CALL ROOT(MVIM1,MV(IM2),TH,BL2,DTLR,ANS,AAA)
      LER(2) = 11
C     BLCD (VIA ROOT) CALL NO. 11
      IF (S1.EQ.3) CALL ROOT(MVIM1,MV(IM2),TH,BL3,DTLR,ANS,AAA)
      LER(2) = 12
C     BLCD (VIA ROOT) CALL NO. 12
      IF (S1.EQ.4) CALL ROOT(MVIM1,MV(IM2),TH,BL4,DTLR,ANS,AAA)
      IF (S1.EQ.1.AND.IM1.EQ.MBOO) ANS=MV(MBOO)
      SPM(IM1)= ANS
      USP(IM1)= BV(S1)
C
C     MOVE ALONG HORIZONTAL MESH LINE UNTIL END OF REGION IS REACHED
C
   70 DO 80 SURF=1,3,2
      IF (IM.GT.MBOO.AND.SURF.EQ.1) GO TO 80
      IF (IM.LE.MBII.AND.SURF.EQ.3) GO TO 80
      IF (ITV(IM-1,SURF).EQ.-10000) GO TO 80
      IF (IT.LT.ITV(IM,SURF).AND.IT.GE.ITV(IM-1,SURF)) GO TO 110
   80 CONTINUE
      SURF = 3
      IF (IM.EQ.MBII.AND.IT.EQ.ITV(MBII,3)-1.AND.
     1ITV(MBII,3)-ITV(MBII,4).EQ.2) GO TO 110
      DO 90 SURF=2,4,2
      IF (IM.GT.MBOO.AND.SURF.EQ.2) GO TO 90
      IF (IM.LE.MBII.AND.SURF.EQ.4) GO TO 90
      IF (IT.GT.ITV(IM,SURF).AND.IT.LE.ITV(IM-1,SURF)) GO TO 110
   90 CONTINUE
      SPM(IM)= MV(IM)
      IP= IPF(IM,IT)
      USP(IM)= U(IP)
      IF (IM.EQ.MMM) GO TO 100
      IM= IM+1
      GO TO 70
C
C     FINAL POINT IS ON RIGHT BOUNDARY
C
  100 ST = 0
      IMT = MMM
      USP(IMT) = UBV(IT,4)
      GO TO 120
C
C     FINAL POINT IS ON A BLADE SURFACE
C
  110 ST= SURF
      IMT= IM
      IMTM1= IMT-1
      TH= FLOAT(IT-ITOR)*HT
      MVIM1 = MV(IMTM1)
```

```
      IF ((IMTM1.EQ.MBII).AND.(ST.EQ.3.OR.ST.EQ.4).AND.(ITV(MBII,3)-
     1   ITV(MBII,4).EQ.2)) MVIM1 = MVIM1+(MV(IMT)-MVIM1)/1000.
      LER(2) = 13
C     BLCD (VIA ROOT) CALL NO. 13
      IF (ST.EQ.1) CALL ROOT(MVIM1,MV(IMT),TH,BL1,DTLR,ANS,AAA)
      LER(2) = 14
C     BLCD (VIA ROOT) CALL NO. 14
      IF (ST.EQ.2) CALL ROOT(MVIM1,MV(IMT),TH,BL2,DTLR,ANS,AAA)
      LER(2) = 15
C     BLCD (VIA ROOT) CALL NO. 15
      IF (ST.EQ.3.AND.IMT.NE.MBII) CALL ROOT(MVIM1,MV(IMT),TH,BL3,
     1DTLR,ANS,AAA)
      LER(2) = 16
C     BLCD (VIA ROOT) CALL NO. 16
      IF (ST.EQ.4) CALL ROOT(MVIM1,MV(IMT),TH,BL4,DTLR,ANS,AAA)
      IF (ST.EQ.3.AND.IMT.EQ.MBII) ANS=MV(MBII)
      SPM(IMT)= ANS
      USP(IMT)= BV(ST)
C
C     CALCULATE RHO*W-SUB-THETA AND THEN RHO*W AND BETA IN THE REGION
C
  120 NSP= IMT-IM1+1
      CALL SPLINE(SPM(IM1),USP(IM1),NSP,DUDM(IM1),AAA(IM1))
      FIRST= 2
      IF (IM1.NE.1) FIRST=IM2
      LAST=MMMM1
      IF (IMT.NE.MMM) LAST=IMTM1
      IF (FIRST.GT.LAST) GO TO 140
      DO 130 I=FIRST,LAST
      RWT = -DUDM(I)*WTFL/BE(I)
      IP = IPF(I,IT)
      W(IP)= SQRT(RWT**2+RWM(IP)**2)
  130 BETA(IP)= ATAN(RWT/RWM(IP))*57.295779
C
C  CALCULATE RHO*W ON THE BLADE SURFACES, OR RHO ON VERTICAL BOUNDARIES
C
  140 IF (S1.EQ.0) GO TO 150
      CALL SEARCH (SPM(IM1),S1,IHS)
      ANS= -DUDM(IM1)*WTFL/BEH(IHS,S1)
      WTB(IHS,S1)= ABS(ANS)*SQRT(1.+1./(RMH(IHS,S1)*DTDMH(IHS,S1))**2)
      GO TO 160
  150 RWT= -DUDM(1)*WTFL/BE(1)
      RW= SQRT(RWT**2+RWBV(IT,3)**2)
      TWLMR= 2.*OMEGA*LAMBDA-(OMEGA*RM(1))**2
      LER(1) = 3
C     DENSTY CALL NO. 3
      CALL DENSTY(RW,RBV(IT,3),ANS,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP)
  160 IF (ST.EQ.0) GO TO 170
      CALL SEARCH(SPM(IMT),ST,IHS)
      ANS= -DUDM(IMT)*WTFL/BEH(IHS,ST)
      WTB(IHS,ST)= ABS(ANS)*SQRT(1.+1./(RMH(IHS,ST)*DTDMH(IHS,ST))**2)
      GO TO 20
  170 RWT= -DUDM(MMM)*WTFL/BE(MMM)
      RW= SQRT(RWT**2+RWBV(IT,4)**2)
      TWLMR= 2.*OMEGA*LAMBDA-(OMEGA*RM(MMM))**2
      LER(1) = 4
C     DENSTY CALL NO. 4
      CALL DENSTY (RW,RBV(IT,4),ANS,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP)
  180 IT= IT+1
      GO TO 10
      END
```

```
      SUBROUTINE SEARCH (DIST,SURF,IS)
C
C  SEARCH LOCATES THE POSITION OF A GIVEN VALUE OF M IN THE MH ARRAY
C
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      DO 10 I=1,100
      IF (ABS(MH(I,SURF)-DIST).GT.DMLR) GO TO 10
      IS = I
      RETURN
   10 CONTINUE
      WRITE (6,1000) DIST,SURF
      STOP
 1000 FORMAT (38HL SEARCH CANNOT FIND M IN THE MH ARRAY/7H DIST =,G14.6,
     110X,6HSURF =,G14.6)
      END



      SUBROUTINE VELOCY
C
C  VELOCY CALLS SUBROUTINES TO CALCULATE DENSITIES AND VELOCITIES
C  THROUGHOUT THE REGION AND ON THE BLADE SURFACES, AND IT PLOTS
C  THE SURFACE VELOCITIES
C
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      DIMENSION KKK(18)
      DIMENSION W(2000),RWM(2000),BETA(2000),WMB(100,4),WTB(100,4),
     1XDOWN(800),YACROS(800)
      EQUIVALENCE (A(1,1),W(1)),(A(1,2),RWM(1)),(A(1,3),BETA(1)),
     1(A(1,4),WMB(1)),(A(401,4),WTB(1)),(A(801,4),XDOWN(1)),
     2(K(1),YACROS(1))
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      DATA KKK(4)/1H*/,KKK(6)/1HO/,KKK(8)/1H=/,KKK(10)/1H(/,
     1KKK(12)/1H+/,KKK(14)/1HX/,KKK(16)/1H$/,KKK(18)/1H)/
C
C     CALL VELBB AND VELSUR THROUGHOUT THE REGION
C
```

```
      MBOT = MINO(MBIIM1,MBOO)
      IF (MBOT.LT.2) GO TO 20
      DO 10 IM=2,MBOT
      CALL VELBB(IM,5,2)
   10 CALL VELBB(IM,1,6)
   20 MBIT = MAXO(2,MBII)
      MBOT = MINO(MMMM1,MBOO)
      IF (MBIT.GT.MBOT) GO TO 40
      DO 30 IM=MBIT,MBOT
      CALL VELBB(IM,5,4)
      CALL VELBB(IM,3,2)
   30 CALL VELBB(IM,1,6)
      GO TO 60
   40 MBIT = MAXO(2,MBOOP1)
      MBOT = MINO(MBIIM1,MMMM1)
      IF (MBIT.GT.MBOT) GO TO 60
      DO 50 IM=MBIT,MBOT
   50 CALL VELBB(IM,5,6)
   60 MBIT = MAXO(MBII,MBOOP1)
      IF (MBIT.GT.MMMM1) GO TO 80
      DO 70 IM=MBIT,MMMM1
      CALL VELBB(IM,5,4)
   70 CALL VELBB(IM,3,6)
   80 CALL VELSUR
C
C     PREPARE INPUT ARRAYS FOR PLOT OF VELOCITIES
C
      NP2= 0
C  SURFACES 1 TO 4 - TANGENTIAL COMPONENTS
      DO 110 SURF=1,4
      NP1= NP2
      IMSS= IMS(SURF)
      IF (IMSS.LT.1) GO TO 100
      DO 90 IHS=1,IMSS
      IF(WTB(IHS,SURF).EQ.0.) GO TO 90
      IF (ABS(DTDMH(IHS,SURF)*RMH(IHS,SURF)).LT..57735) GO TO 90
      NP1= NP1+1
      YACROS(NP1)= WTB(IHS,SURF)
      XDOWN(NP1)= MH(IHS,SURF)
   90 CONTINUE
  100 KKK(2*SURF+1)= NP1-NP2
  110 NP2= NP1
C  SURFACES 1 AND 2 - MERIDIONAL COMPONENTS
      DO 140 SURF=1,2
      NP1= NP2
      MBOT = MINO(MBOOM1,MMMM1)
      IF(2.GT.MBOT) GO TO 130
      DO 120 IM=2,MBOT
      IF(WMB(IM,SURF).EQ.0.) GO TO 120
      IF (ABS(DTDMV(IM,SURF)*RM(IM)).GT.1.7321) GO TO 120
      NP1= NP1+1
      YACROS(NP1)= WMB(IM,SURF)
      XDOWN(NP1)= MV(IM)
  120 CONTINUE
  130 KKK(2*SURF+9) = NP1-NP2
  140 NP2= NP1
C  SURFACES 3 AND 4 - MERIDIONAL COMPONENTS
      DO 170 SURF=3,4
      NP1= NP2
      MBIT = MAXO(MBIIP1,2)
```

```
      IF(MBIT.GT.MMMM1) GO TO 160
      DO 150 IM=MBIT,MMMM1
      IF(WMB(IM,SURF).EQ.0.) GO TO 150
      IF (ABS(DTDMV(IM,SURF)*RM(IM)).GT.1.7321) GO TO 150
      NP1= NP1+1
      YACROS(NP1)= WMB(IM,SURF)
      XDOWN(NP1)= MV(IM)
  150 CONTINUE
  160 KKK(2*SURF+9) = NP1-NP2
  170 NP2= NP1
C
C     PLOT VELOCITIES
C
      KKK(1)= 1
      KKK(2)= 8
      P= 5.
      WRITE(6,1000)
      CALL PLOTMY(XDOWN,YACROS,KKK,P)
      WRITE(6,1010)
      RETURN
 1000 FORMAT(2HPT,50X,24HBLADE SURFACE VELOCITIES)
 1010 FORMAT (2HPL,37X,63HVELOCITY(W) VS. MERIDIONAL STREAMLINE DISTANCE
     1(M) DOWN THE PAGE  /2HPL/
     22HPL,50X,50H+ - BLADE SURFACE 1, BASED ON MERIDIONAL COMPONENT/
     32HPL,50X,50H* - BLADE SURFACE 1, BASED ON TANGENTIAL COMPONENT/
     42HPL,50X,50HX - BLADE SURFACE 2, BASED ON MERIDIONAL COMPONENT/
     52HPL,50X,50HO - BLADE SURFACE 2, BASED ON TANGENTIAL COMPONENT/
     62HPL,50X,50H$ - BLADE SURFACE 3, BASED ON MERIDIONAL COMPONENT/
     72HPL,50X,50H= - BLADE SURFACE 3, BASED ON TANGENTIAL COMPONENT/
     82HPL,50X,50H) - BLADE SURFACE 4, BASED ON MERIDIONAL COMPONENT/
     92HPL,50X,50H( - BLADE SURFACE 4, BASED ON TANGENTIAL COMPONENT)
      END
```

```
      SUBROUTINE VELBB(IM,UPPER,LOWER)
C
C  VEL CALCULATES DENSITIES AND VELOCITIES FROM THE PRODUCT OF
C  DENSITY TIMES VELOCITY
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /AUKRHO/ A(2000,4),U(2000),K(2000),RHO(2000)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /RHOS/ RHOHB(100,4),RHOVB(100,4),RBV(100,4)
      DIMENSION WWCRM(100,4),WWCRT(100,4)
      DIMENSION W(2000),RWM(2000),BETA(2000),WMB(100,4),WTB(100,4),
     1XDOWN(800),YACROS(800)
      EQUIVALENCE (A(1,1),W(1)),(A(1,2),RWM(1)),(A(1,3),BETA(1)),
     1(A(1,4),WMB(1)),(A(401,4),WTB(1)),(A(801,4),XDOWN(1)),
```

```
     2(K(1),YACROS(1))
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
C
C     VELBB CALCULATES ALONG VERTICAL MESH LINES FROM BLADE TO BLADE
C
      IF (IM.NE.2.OR.UPPER.NE.5) GO TO 10
      IF(INTVL.GT.0) WRITE(6,1000)
      RELER = 0.
   10 ITVU =MAX0(ITV(IM,UPPER),2)
      ITVL = MIN0(ITV(IM,LOWER),ITMAX-1)
      IPUP1 = IPF(IM,ITVU)
      IPLM1  = IPF(IM,ITVL)
      TWLMR= 2.*OMEGA*LAMBDA-(OMEGA*RM(IM))**2
      WCR= SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))
      IF (ITVL.LT.ITVU) GO TO 30
C     ALONG THE LINE BETWEEN BLADES
      DO 20 IP= IPUP1,IPLM1
      LER(1) = 5
C     DENSTY CALL NO. 5
      CALL DENSTY(W(IP),RHO(IP),ANS,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP)
   20 W(IP)= ANS
      IF (INTVL.LE.0) GO TO 30
      WRITE(6,1010) IM,(W(IP),BETA(IP),IP=IPUP1,IPLM1)
C     ON THE UPPER SURFACE, IF IT IS A BLADE
   30 IF (UPPER.EQ.5) GO TO 40
      IF (ITV(IM,UPPER).LT.2) WMB(IM,UPPER) = 0.
      RHOB= RHOVB(IM,UPPER)
      LER(1) = 6
C     DENSTY CALL NO. 6
      CALL DENSTY(WMB(IM,UPPER),RHOVB(IM,UPPER),ANS,TWLMR,CPTIP,EXPON,
     1RHOIP,GAM,AR,TIP)
      WMB(IM,UPPER)= ANS
      WWCRM(IM,UPPER)= WMB(IM,UPPER)/WCR
      RELER= AMAX1(RELER,ABS((RHOB-RHOVB(IM,UPPER)) / RHOVB(IM,UPPER)))
C     ON THE LOWER SURFACE, IF IT IS A BLADE
   40 IF (LOWER.EQ.6) RETURN
      IF (ITV(IM,LOWER).GT.ITMAX-1) WMB(IM,LOWER) = 0.
      RHOB= RHOVB(IM,LOWER)
      LER(1) = 7
C     DENSTY CALL NO. 7
      CALL DENSTY(WMB(IM,LOWER),RHOVB(IM,LOWER),ANS,TWLMR,CPTIP,EXPON,
     1RHOIP,GAM,AR,TIP)
      WMB(IM,LOWER)= ANS
      WWCRM(IM,LOWER)= WMB(IM,LOWER)/WCR
      RELER= AMAX1(RELER,ABS((RHOB-RHOVB(IM,LOWER)) / RHOVB(IM,LOWER)))
      RETURN
C
C     VELSUR CALCULATES ALONG A BLADE SURFACE
C
      ENTRY VELSUR
      DO 60 SURF=1,4
      IMSS = IMS(SURF)
      IF (IMSS.EQ.0) GO TO 60
      DO 50 IHS=1,IMSS
      TWLMR= 2.*OMEGA*LAMBDA-(OMEGA*RMH(IHS,SURF))**2
      WCR= SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))
      RHOB= RHOHB(IHS,SURF)
      LER(1) = 8
```

```
C     DENSTY CALL NO. 8
      CALL DENSTY(WTB(IHS,SURF),RHOHB(IHS,SURF),ANS,TWLMR,CPTIP,EXPON,
     1RHOIP,GAM,AR,TIP)
      WTB(IHS,SURF)= ANS
      WWCRT(IHS,SURF)= WTB(IHS,SURF)/WCR
   50 RELER= AMAX1(RELER,ABS((RHOB-RHOHB(IHS,SURF)) / RHOHB(IHS,SURF)))
   60 CONTINUE
      IF (RELER.LT..001) IEND=IEND+1
      WRITE(6,1020) ITER,RELER
      MARK = 0
C
C  WRITE ALL BLADE SURFACE VELOCITIES
C
      IF (SURVL.LE.0) RETURN
      WRITE(6,1030)
      MBOT = MINO(MMMM1,MBOO)
      IF(MBOT.LT.2) GO TO 70
      WRITE(6,1040)
      WRITE(6,1050) (MV(IM),WMB(IM,1),BETAV(IM,1),WWCRM(IM,1),WMB(IM,2),
     1BETAV(IM,2),WWCRM(IM,2),IM=2,MBOT)
   70 MBIT = MAXO(2,MBII)
      IF(MBIT.GT.MMMM1) GO TO 80
      WRITE(6,1060)
      WRITE(6,1050) (MV(IM),WMB(IM,3),BETAV(IM,3),WWCRM(IM,3),WMB(IM,4),
     1BETAV(IM,4),WWCRM(IM,4),IM=MBIT,MMMM1)
   80 WRITE(6,1070)
      DO 90 SURF=1,4
      IMSS = IMS(SURF)
      IF (IMSS.EQ.0) GO TO 90
      WRITE(6,1080) SURF
      WRITE(6,1090) (MH(IHS,SURF),WTB(IHS,SURF),BETAH(IHS,SURF),WWCRT
     1(IHS,SURF),IHS=1,IMSS)
   90 CONTINUE
      RETURN
 1000 FORMAT(1H1///40X,34HVELOCITIES AT INTERIOR MESH POINTS//)
 1010 FORMAT(1HL,3HIM=,I3,5(24H   VELOCITY   ANGLE(DEG))/
     1(5X,5(G15.4,F9.2)))
 1020 FORMAT(14HLITERATION NO.,I3,3X,36HMAXIMUM RELATIVE CHANGE IN DENSI
     1TY =,G11.4)
 1030 FORMAT(1H1///16X,1H*,25X,49HSURFACE VELOCITIES BASED ON MERIDIONA
     1L COMPONENTS,36X,1H*)
 1040 FORMAT(16X,1H*,53X,1H*,56X,1H*/16X,1H*,19X,15HBLADE SURFACE 1,19X,
     11H*,20X,15HBLADE SURFACE 2,21X,1H*/7X,1HM,8X,1H*,2(3X,8HVELOCITY,
     13X,10HANGLE(DEG),5X,5HW/WCR,19X,1H*,3X))
 1050 FORMAT(1H ,G13.4,3H  *,G12.4,F9.2,G15.4,17X,1H*,3X,G12.4,F9.2,G15.
     14,17X,1H*)
 1060 FORMAT(///16X,1H*,19X,15HBLADE SURFACE 3,19X,1H*,20X,15HBLADE SURF
     1ACE 4,21X,1H*/7X,1HM,8X,1H*,2(3X,8HVELOCITY,3X,10HANGLE(DEG),5X,
     15HW/WCR,19X,1H*,3X))
 1070 FORMAT(1H1///3X,49HSURFACE VELOCITIES BASED ON TANGENTIAL COMPONE
     1NTS)
 1080 FORMAT(//22X,15HBLADE SURFACE  ,I1/7X,1HM,10X,8HVELOCITY,3X,10HANG
     1LE(DEG),3X,5HW/WCR)
 1090 FORMAT(1H ,2G13.4,F9.2,G15.4)
      END
```

```
      SUBROUTINE BLCD
C
C  BLCD CALCULATES BLADE THETA COORDINATE AS A FUNCTION OF M
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      COMMON /INP/ GAM,AR,TIP,RHOIP,WTFL,WTFLSP,OMEGA,ORF,BETAI,BETAO,
     1NOBL,MBI,MBO,MBI2,MBO2,MM,NBBI,NBL,NRSP,MBDYF,MBDYL,ITF,ITL,
     2BLDAT,AANDK,ERSOR,STRFN,INTVL,SURVL,MAGFAC,
     3MR(50),RMSP(50),BESP(50)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      COMMON /GEOMIN/ CHORD(4),STGR(4),MLE(4),THLE(4),RMI(4),RMO(4),
     1RI(4),RO(4),BETI(4),BETO(4),NSPI(4),MSP(50,4),THSP(50,4)
      COMMON /BLCDCM/ EM(50,4),INIT(4)
      ENTRY  BL1(M,THETA,DTDM,INF)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      REAL M,MMLE,MSPMM,MMMSP
      SURF= 1
      SIGN= 1.
      GO TO 10
      ENTRY  BL2(M,THETA,DTDM,INF)
      SURF= 2
      SIGN= -1.
      GO TO 10
      ENTRY  BL3(M,THETA,DTDM,INF)
      SURF= 3
      SIGN= 1.
      GO TO 10
      ENTRY  BL4(M,THETA,DTDM,INF)
      SURF= 4
      SIGN= -1.
   10 INF= 0
      NSP= NSPI(SURF)
      IF (INIT(SURF).EQ.13) GO TO 30
      INIT(SURF)= 13
C
C  INITIAL CALCULATION OF FIRST AND LAST SPLINE POINTS ON BLADE
C
      AA = BETI(SURF)/57.295779
      AA = SIN(AA)
      MSP(1,SURF) =  RI(SURF)*(1.-SIGN*AA)
      BB = SQRT(1.-AA**2)
      THSP(1,SURF) = SIGN*BB*RI(SURF)/RMI(SURF)
      BETI(SURF) = AA/BB/RMI(SURF)
      AA = BETO(SURF)/57.295779
      AA = SIN(AA)
      MSP(NSP,SURF) = CHORD(SURF)-RO(SURF)*(1.+SIGN*AA)
      BB = SQRT(1.-AA**2)
      THSP(NSP,SURF) = STGR(SURF)+SIGN*BB*RO(SURF)/RMO(SURF)
      BETO(SURF) = AA/BB/RMO(SURF)
      DO 20 IA=1,NSP
      MSP(IA,SURF)= MSP(IA,SURF)+MLE(SURF)
   20 THSP(IA,SURF)= THSP(IA,SURF)+THLE(SURF)
      CALL SPLN22(MSP(1,SURF),THSP(1,SURF),BETI(SURF),BETO(SURF),NSP,
```

```
     1AAA,EM(1,SURF))
      IF (BLDAT.LE.0) GO TO 30
      IF (SRW.EQ.0) WRITE(6,1000)
      SRW = 1
      WRITE(6,1010) SURF
      WRITE (6,1020) (MSP(IA,SURF),THSP(IA,SURF),AAA(IA),EM(IA,SURF),
     1IA=1,NSP)
C
C  BLADE COORDINATE CALCULATION
C
   30 KK = 2
      IF (M.GT.MSP(1,SURF)) GO TO 50
C
C  AT LEADING EDGE RADIUS
C
      MMLE= M-MLE(SURF)
      IF (MMLE.LT.-DMLR) GO TO 90
      MMLE= AMAX1(0.,MMLE)
      THETA= SQRT(MMLE*(2.*RI(SURF)-MMLE))*SIGN
      IF (THETA.EQ.0.) GO TO 40
      RMM= RI(SURF)-MMLE
      DTDM= RMM/THETA/RMI(SURF)
      THETA= THETA/RMI(SURF)+THLE(SURF)
      RETURN
   40 INF= 1
      DTDM = 1.E10*SIGN
      THETA= THLE(SURF)
      RETURN
C
C  ALONG SPLINE CURVE
C
   50 IF (M.LE.MSP(KK,SURF)) GO TO 60
      IF (KK.GE.NSP) GO TO 70
      KK = KK+1
      GO TO 50
   60 S= MSP(KK,SURF)-MSP(KK-1,SURF)
      EMKM1= EM(KK-1,SURF)
      EMK= EM(KK,SURF)
      MSPMM= MSP(KK,SURF)-M
      MMMSP= M-MSP(KK-1,SURF)
      THK= THSP(KK,SURF)/S
      THKM1= THSP(KK-1,SURF)/S
      THETA= EMKM1*MSPMM**3/6./S + EMK*MMMSP**3/6./S + (THK-EMK*S/6.)*
     1 MMMSP + (THKM1-EMKM1*S/6.)*MSPMM
      DTDM= -EMKM1*MSPMM**2/2./S + EMK*MMMSP**2/2./S + THK-THKM1-(EMK-
     1 EMKM1)*S/6.
      RETURN
C
C  AT TRAILING EDGE RADIUS
C
   70 CMM= CHORD(SURF)+MLE(SURF)-M
      IF (CMM.LT.-DMLR) GO TO 90
      CMM= AMAX1(0.,CMM)
      THETA= SQRT(CMM*(2.*RO(SURF)-CMM))*SIGN
      IF (THETA.EQ.0.) GO TO 80
      RMM= RO(SURF)-CMM
      DTDM = -RMM/THETA/RMO(SURF)
      THETA = STGR(SURF)+THETA/RMO(SURF)+THLE(SURF)
      RETURN
   80 INF= 1
```

```
      DTDM = -1.E10*SIGN
      THETA= THLE(SURF)+STGR(SURF)
      RETURN
C
C  ERROR RETURN
C
   90 WRITE (6,1030) LER(2),M,SURF
      STOP
 1000 FORMAT (1H1,13X,27HBLADE DATA AT SPLINE POINTS)
 1010 FORMAT(1HL,17X,16HBLADE    SURFACE,I4)
 1020 FORMAT (7X ,1HM,10X,5HTHETA,10X,10HDERIVATIVE,5X,10H2ND DERIV. /
     1(4G15.5))
 1030 FORMAT (14HLBLCD CALL NO.,I3/33H M COORDINATE IS NOT WITHIN BLADE/
     14H M =,G14.6,10X,6HSURF =,G14.6)
      END
```

```
      FUNCTION IPF(IM,IT)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      IPF= IV(IM)+IT-2
      IF(IT.LE.ITV(IM,4)) RETURN
      IF(IT.LE.ITV(IM,2).AND.IM.LT.MBII) RETURN
      IF(IM.GE.MINO(MBII,MBOOP1)) GO TO 10
      IF (ITV(IM,1).EQ.-10000) RETURN
      IPF= IPF-ITV(IM,1) + ITV(IM,2)+1
      RETURN
   10 IF(IM.GT.MAXO(MBIIM1,MBOO)) GO TO 20
      IF(IM.GT.MBOO) RETURN
      IPF= IPF-ITV(IM,3)+ITV(IM,4)+1
      IF(IT.LT.ITV(IM,1)) RETURN
      IPF= IPF-ITV(IM,1)+ITV(IM,2)+1
      RETURN
   20 IF (ITV(IM,3).EQ.-10000) RETURN
      IPF= IPF-ITV(IM,3)+ITV(IM,4)+1
      RETURN
      END
```

Subroutine BDVINT

BDVINT calculates interpolated values of the stream function along either a vertical or a horizontal boundary for the fine mesh. The interpolation is based on a cubic spline curve (ref. 8) using the stream-function values at the original coarse-mesh points.

The input arguments for BDVINT are as follows:

BVIN — input array from main program (see DESCRIPTION OF INPUT AND OUTPUT)

UBVIN	input array from main program (see DESCRIPTION OF INPUT AND OUTPUT)
NSP	given number of stream-function values on the coarse mesh
MVTH	array of either m(MV) or θ(TH) coordinates for the fine mesh
KBDRY	input variable (see DESCRIPTION OF INPUT AND OUTPUT)
DLR	tolerance, either DMLR or DTLR
MMMITX	total number of fine mesh lines, either MMM or ITMAX

The internal variables for BDVINT are as follows:

BVINT	array of values of m or θ where interpolated stream-function values are desired
IM	index of mesh line
IM1	value of IM for first point in region
IM2	IM1 + 1
IMT	value of IM for last point in region
NSPINT	number of interpolated values of stream function
RWBV	array of interpolated values of either $\partial u/\partial m$ or $\partial u/\partial \theta$
UBV	array of interpolated stream-function values

```
      SUBROUTINE BDVINT(BVIN,UBVIN,NSP,MVTH,KBDRY,DLR,MMMITX)
      COMMON /CALCON/ MBII,MBOO,MMM,MBIIM1,MBIIP1,MBOOM1,MBOOP1,MMMM1,
     1HM1,HM2,HM3,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,
     2LAMBDA,TWL,ITOR,ITMAX,NIP,IMS(4),BV(4),MV(100),IV(101),
     3UBV(100,4),RWBV(100,4),ITV(100,6),TV(100,4),DTDMV(100,4),
     4BETAV(100,4),MH(100,4),DTDMH(100,4),BETAH(100,4),RMH(100,4),
     5BEH(100,4),RM(100),BE(100),DBDM(100),SAL(100),AAA(100)
      DIMENSION BVINT(100),BVIN(100),UBVIN(100),MVTH(100)
      REAL MVTH
      DO 10 IM=2,MMMITX
      IF (MVTH(IM).GT.BVIN(1)+DLR) GO TO 20
   10 CONTINUE
      IM = MMMITX
   20 IM1 = IM-1
      BVINT(IM1) = BVIN(1)
      IM2 = IM
      DO 30 IM=IM2,MMMITX
      IF (MVTH(IM).GT.BVIN(NSP)-DLR) GO TO 40
   30 BVINT(IM) = MVTH(IM)
      IM = MMMITX
   40 IMT=IM
      BVINT(IMT) = BVIN(NSP)
      NSPINT= IMT-IM1+1
      CALL SPLINT(BVIN,UBVIN,NSP,BVINT(IM1),NSPINT,UBV(IM1,KBDRY),RWBV(I
     1M1,KBDRY))
      RETURN
      END
```

Program Listing of Remaining Subroutines

The remaining subroutines are described in reference 3. The description applies even though the subroutines have been revised.

```
      SUBROUTINE MHORIZ(MV,ITV,BL,MBI,MBO,ITO,HT,DTLR,KODE,J,MH,DTDMH,
     1MRTS)
C
C   MHORIZ CALCULATES M COORDINATES OF INTERSECTIONS OF ALL HORIZONTAL
C   MESH LINES WITH A BLADE SURFACE
C   KODE = 0 FOR UPPER BLADE SURFACE
C   KODE = 1 FOR LOWER BLADE SURFACE
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      DIMENSION MV(100),ITV(100),MH(100),DTDMH(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SURVL,AATEMP,SURF,
     1FIRST,UPPER,S1,ST,SRW
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSP,MV,MVIM1
      REAL MVIM
      EXTERNAL BL
      IF (MBI.GE.MBO) RETURN
      IM= MBI
   10 ITIND= 0
   20 IF (ITV(IM+1)-ITV(IM)-ITIND) 30,40,50
   30 J= J+1
      TI= FLOAT(ITV(IM+1)-ITO-ITIND+KODE)*HT
      ITIND= ITIND-1
      MVIM = MV(IM)
      IF (MRTS.EQ.1) MVIM = MVIM+(MV(IM+1)-MVIM)/1000.
      CALL ROOT (MVIM,MV(IM+1),TI,BL,DTLR,MH(J),DTDMH(J))
      GO TO 20
   40 IM= IM+1
      MRTS = 0
      IF (IM.EQ.MBO) RETURN
      GO TO 10
   50 J= J+1
      TI= FLOAT(ITV(IM)-ITO+ITIND+KODE)*HT
      ITIND= ITIND+1
      MVIM = MV(IM)
      IF (MRTS.EQ.1) MVIM = MVIM+(MV(IM+1)-MVIM)/1000.
      CALL ROOT(MVIM  ,MV(IM+1),TI,BL,DTLR,MH(J),DTDMH(J))
      GO TO 20
      END
```

```
      SUBROUTINE DENSTY(RHOW,RHO,VEL,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP)
C
C  DENSTY CALCULATES DENSITY AND VELOCITY FROM THE WEIGHT FLOW PARAMETER
C  DENSITY TIMES VELOCITY
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      VEL = RHOW/RHO
      IF (VEL.NE.0.) GO TO 10
      RHO = RHOIP
      RETURN
   10 TTIP = 1.-(VEL**2+TWLMR)/CPTIP
      IF(TTIP.LT.0.) GO TO 30
      TEMP = TTIP**(EXPON-1.)
      RHOT = RHOIP*TEMP*TTIP
      RHOWP = -VEL**2/GAM*RHOIP/AR*TEMP/TIP+RHOT
      IF(RHOWP.LE.0.) GO TO 30
      VELNEW = VEL+(RHOW-RHOT*VEL)/RHOWP
      IF(ABS(VELNEW-VEL)/VELNEW.LT..0001) GO TO 20
      VEL = VELNEW
      GO TO 10
   20 VEL = VELNEW
      RHO = RHOW/VEL
      RETURN
   30 TGROG = 2.*GAM*AR/(GAM+1.)
      VEL = SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))
      RHO = RHOIP*(1.-(VEL**2+TWLMR)/CPTIP)**EXPON
      RWMORW = RHOW/RHO/VEL
      NER(1) = NER(1)+1
      WRITE (6,1000) LER(1),NER(1),RWMORW
      IF (NER(1).EQ.50) STOP
      RETURN
 1000 FORMAT (16HLDENSTY CALL NO.,I3/9H NER(1) =,I3/10H RHO*W IS ,F7.4,
     134H TIMES THE MAXIMUM VALUE FOR RHO*W)
      END
```

```
      SUBROUTINE ROOT(A,B,Y,FUNCT,TOLERY,X,DFX)
C
C  ROOT FINDS A ROOT FOR (FUNCT MINUS Y) IN THE INTERVAL (A,B)
C
      COMMON SRW,ITER,IEND,LER(2),NER(1)
      INTEGER SRW
      IF (SRW.EQ.21) WRITE(6,1000) A,B,Y,TOLERY
      TOLERX= (B-A)/1000.
      AB2= (A+B)/2.
      I= 0
      X= A
   10 CALL FUNCT(X,FX,DFX,INF)
      IF (SRW.EQ.21) WRITE(6,1010) I,X,FX,DFX,INF
      IF (ABS(Y-FX).LT.TOLERY) RETURN
      IF (I.GE.1000) GO TO 30
      I= I+1
      IF (INF.NE.0 .OR. DFX.EQ.0.) GO TO 20
      X= (Y-FX)/DFX+X
      IF (X.GE.A .AND. X.LE.B) GO TO 10
      X = A+TOLERX*FLOAT(I)
```

```
      IF(I.EQ.1) X = B
      GO TO 10
   20 IF (X.LT.AB2) X=X+TOLERX
      IF (X.GE.AB2) X=X-TOLERX
      GO TO 10
   30 WRITE(6,1020) LER(2),A,B,Y
      STOP
 1000 FORMAT (32H1INPUT ARGUMENTS FOR ROOT -- A =G13.5,3X,3HB =,G13.5,
     13X,3HY =,G13.5,3X,8HTOLERY =,G13.5/17H  ITER. NO.      X,17X,
     22HFX,15X,3HDFX,10X,3HINF)
 1010 FORMAT (5X,I3,G16.5,2G18.5,I6)
 1020 FORMAT (14HLROOT CALL NO.,I3/47H ROOT HAS FAILED TO CONVERGE IN 10
     100 ITERATIONS/4H A =,G14.6,10X,3HB =,G14.6,10X,3HY =,G14.6)
      END
```

```
      SUBROUTINE SPLINE (X,Y,N,SLOPE,EM)
C
C  SPLINE CALCULATES FIRST AND SECOND DERIVATIVES AT SPLINE POINTS
C  END CONDITION - SECOND DERIVATIVES ARE THE SAME AT END POINT AND
C  ADJACENT POINT
C
      COMMON Q/BOX/S(100),A(100),B(100),C(100),F(100),W(100),SB(100),
     1G(200)
      DIMENSION X(N),Y(N),EM(N),SLOPE(N)
      INTEGER Q
      DO 10 I=2,N
   10 S(I)=X(I)-X(I-1)
      NO=N-1
      IF(NO.LT.2) GO TO 30
      DO 20 I=2,NO
      A(I)=S(I)/6.
      B(I)=(S(I)+S(I+1))/3.
      C(I)=S(I+1)/6.
   20 F(I)=(Y(I+1)-Y(I))/S(I+1)-(Y(I)-Y(I-1))/S(I)
   30 A(N) = -.5
      B(1)=1.
      B(N)=1.
      C(1) = -.5
      F(1)=0.
      F(N)=0.
      W(1)=B(1)
      SB(1)=C(1)/W(1)
      G(1)=0.
      DO 40 I=2,N
      W(I)=B(I)-A(I)*SB(I-1)
      SB(I)=C(I)/W(I)
   40 G(I)=(F(I)-A(I)*G(I-1))/W(I)
      EM(N)=G(N)
      DO 50 I=2,N
      K=N+1-I
```

```
   50 EM(K)=G(K)-SB(K)*EM(K+1)
      SLOPE(1)=-S(2)/6.*(2.*EM(1)+EM(2))+(Y(2)-Y(1))/S(2)
      DO 60 I=2,N
   60 SLOPE(I)=S(I)/6.*(2.*EM(I)+EM(I-1))+(Y(I)-Y(I-1))/S(I)
      IF (Q.EQ.13) WRITE (6,1000) N,(X(I),Y(I),SLOPE(I),EM(I),I=1,N)
      RETURN
 1000 FORMAT (2X,15HNO. OF POINTS =,I3/10X,1HX,19X,1HY,19X,5HSLOPE,15X,
     12HEM/(4F20.8))
      END
```

```
      SUBROUTINE SPLN22 (X,Y,Y1P,YNP,N,SLOPE,EM)
C
C  SPLN22 CALCULATES FIRST AND SECOND DERIVATIVES AT SPLINE POINTS
C  END CONDITION - DERIVATIVES SPECIFIED AT END POINTS
C
      COMMON Q/BOX/S(100),A(100),B(100),C(100),F(100),W(100),SB(100),
     1G(200)
      DIMENSION X(N),Y(N),EM(N),SLOPE(N)
      INTEGER Q
      DO 10 I=2,N
   10 S(I)=X(I)-X(I-1)
      NO=N-1
      IF(NO.LT.2) GO TO 30
      DO 20 I=2,NO
      A(I)=S(I)/6.
      B(I)=(S(I)+S(I+1))/3.
      C(I)=S(I+1)/6.
   20 F(I)=(Y(I+1)-Y(I))/S(I+1)-(Y(I)-Y(I-1))/S(I)
   30 A(N) = S(N)/6.
      B(1)=S(2)/3.
      B(N) = S(N)/3.
      C(1)=S(2)/6.
      F(1)=(Y(2)-Y(1))/S(2)-Y1P
      F(N) = YNP-(Y(N)-Y(N-1))/S(N)
      W(1)=B(1)
      SB(1)=C(1)/W(1)
      G(1)=F(1)/W(1)
      DO 40 I=2,N
      W(I)=B(I)-A(I)*SB(I-1)
      SB(I)=C(I)/W(I)
   40 G(I)=(F(I)-A(I)*G(I-1))/W(I)
      EM(N)=G(N)
      DO 50 I=2,N
      K=N+1-I
   50 EM(K)=G(K)-SB(K)*EM(K+1)
      SLOPE(1)=-S(2)/6.*(2.*EM(1)+EM(2))+(Y(2)-Y(1))/S(2)
      DO 60 I=2,N
   60 SLOPE(I)=S(I)/6.*(2.*EM(I)+EM(I-1))+(Y(I)-Y(I-1))/S(I)
      IF (Q.EQ.18) WRITE (6,1000) N,(X(I),Y(I),SLOPE(I),EM(I),I=1,N)
      RETURN
 1000 FORMAT (2X,15HNO. OF POINTS =,I3/10X,1HX,19X,1HY,19X,5HSLOPE,15X,
     12HEM/(4F20.8))
      END
```

```
      SUBROUTINE SPLINT (X,Y,N,Z,MAX,YINT,DYDX)
C
C   SPLINT CALCULATES INTERPOLATED POINTS AND DERIVATIVES FOR
C   A SPLINE CURVE
C   END CONDITION - SECOND DERIVATIVES ARE THE SAME AT END POINT AND
C   ADJACENT POINT
C
      COMMON Q/BOX/S(100),A(100),B(100),C(100),F(100),W(100),SB(100),
     1G(100),EM(100)
      DIMENSION   X(N),Y(N),Z(MAX),YINT(MAX),DYDX(MAX)
      INTEGER Q
      IF(MAX.LE.0) RETURN
      III = Q
      DO 10 I=2,N
   10 S(I)=X(I)-X(I-1)
      NO=N-1
      IF(NO.LT.2) GO TO 30
      DO 20 I=2,NO
      A(I)=S(I)/6.0
      B(I)=(S(I)+S(I+1))/3.0
      C(I)=S(I+1)/6.0
   20 F(I)=(Y(I+1)-Y(I))/S(I+1)-(Y(I)-Y(I-1))/S(I)
   30 A(N) = -.5
      B(1)=1.0
      B(N)=1.0
      C(1) = -.5
      F(1)=0.0
      F(N)=0.0
      W(1)=B(1)
      SB(1)=C(1)/W(1)
      G(1)=0.0
      DO 40 I=2,N
      W(I)=B(I)-A(I)*SB(I-1)
      SB(I)=C(I)/W(I)
   40 G(I)=(F(I)-A(I)*G(I-1))/W(I)
      EM(N)=G(N)
      DO 50 I=2,N
      K=N+1-I
   50 EM(K)=G(K)-SB(K)*EM(K+1)
      DO 140 I=1,MAX
      K=2
      IF(Z(I)-X(1)) 70,60,90
   60 YINT(I)=Y(1)
      GO TO 130
   70 IF(Z(I).GE.(1.1*X(1)-.1*X(2))) GO TO 120
      WRITE (6,1000) Z(I)
      Q = 16
      GO TO 120
   80 K=N
      IF(Z(I).LE.(1.1*X(N)-.1*X(N-1))) GO TO 120
      WRITE (6,1000) Z(I)
      Q = 16
      GO TO 120
   90 IF(Z(I)-X(K)) 120,100,110
```

```
  100 YINT(I)=Y(K)
      GO TO 130
  110 K=K+1
      IF(K-N) 90,90,80
  120 YINT(I) = EM(K-1)*(X(K)-Z(I))**3/6./S(K)+EM(K)*(Z(I)-X(K-1))**3/6.
     1/S(K)+(Y(K)/S(K)-EM(K)*S(K)/6.)*(Z(I)-X(K-1))+(Y(K-1)/S(K)-EM(K-1)
     2*S(K)/6.)*(X(K)-Z(I))
  130 DYDX(I)=-EM(K-1)*(X(K)-Z(I))**2/2.0/S(K)+EM(K)*(X(K-1)-Z(I))**2/2.
     10/S(K)+(Y(K)-Y(K-1))/S(K)-(EM(K)-EM(K-1))*S(K)/6.0
  140 CONTINUE
      MXA = MAXO(N,MAX)
      IF(Q.EQ.16) WRITE(6,1010) N,MAX,(X(I),Y(I),Z(I),YINT(I),DYDX(I),
     1I=1,MXA)
      Q = III
      RETURN
 1000 FORMAT (54H SPLINT USED FOR EXTRAPOLATION.  EXTRAPOLATED VALUE = ,
     1G14.6)
 1010 FORMAT (2X,21HNO. OF POINTS GIVEN =,I3,30H, NO. OF INTERPOLATED PO
     1INTS =,I3/10X,1HX,19X,1HY,16X,11HX-INTERPOL.,9X,11HY-INTERPOL.,
     28X,14HDYDX-INTERPOL./(5E20.8))
      END
```

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 12, 1968,
126-15-02-31-22.

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