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FORTRAN PROGRAM FOR COMPUTING COORDINATES OF CIRCULAR ARC SINGLE AND TANDEM TURBOMACHINERY BLADE SECTIONS ON A PLANE

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16. Abstract

A FORTRAN IV program is presented which computes and plots coordinates for circular arc blade sections on a plane. Either single blade sections or tandem blade sections with up to 5 segments can be designed. Surfaces of blade segments consist of single circular arcs. The arrangement of segments on the plane is a function of the input parameters. These parameters are overall blade section quantities such as chord, camber, and solidity, as well as individual blade segment parameters such as chord, camber, gap between blade segments, overlap of segments, maximum thickness, and leading- and trailing-edge radii.

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SUMMARY

A FORTRAN IV computer program is presented which computes and plots coordinates for circular arc blade sections on a plane. Either single blade sections or tandem blades sections with up to 5 segments per blade section can be designed. Surfaces of blade segments consist of single circular arcs. The arrangement of blade segments with respect to each other (for tandem blades) depends on the input parameters that specify gap, overlap, and convergence between the segments.

Input is brief and can be altered rapidly. Input parameters describing the overall blade section include chord, camber, solidity, and inlet blade angle. Input to describe individual segments of the blade section include chord, camber, gap between adjacent segment and local segment, overlap of segments, maximum segment thickness, and radii of segment leading- and trailing-edge circles. Output consists of three main parts: (1) coordinates of individual segments suitable for making machine drawings, (2) geometrical input for companion blade-to-blade ideal flow programs, and (3) a Calcomp plot of the computed blade section in cascade at the input blade angle. All parts of the program except the plot routines are in general FORTRAN IV code and could be easily transferred to other IBM equipment. The plot routines, a short but important part of the output procedures, use a NASA Lewis code and would require recoding for use on other equipment.

This report includes a listing of the FORTRAN IV computer program, with an explanation of the input required and the output generated. Numerical examples are also included. Running times are about 1/4 minute per data set on IBM 7094 equipment. The report does not include derivation or explanation of the equations on which the program is based.

INTRODUCTION

Specialized airfoil shapes are needed for todays highly loaded, high-speed compressors and turbines to avoid choking and premature separation. Shapes under study include single segment airfoils, airfoils with slots, and multiple segment airfoils in a tandem arrangement.

Many of the single and tandem blade designs being studied have airfoil surfaces consisting of single circular arcs. The computation of geometry for such airfoils, particularly when placed in a tandem arrangement with controlled slot parameters, is complicated by the geometric calculations.

This report describes a computer program for generating coordinates for circular arc airfoil shapes. One blade section is designed for each set of input data. A blade section consists of one cut through a blade at a given radius from the axis of rotation. The blade section may be composed of just one segment, or it may be a tandem section with two to five segments. The arrangement of blade segments with respect to each other (for tandem blades) depends on input parameters that specify gap, overlap, and convergence between the segments. The program does not provide radial stacking of blade sections, since only one section is designed for each set of data.

Input is brief and can be prepared quickly. It consists entirely of geometric parameters describing the overall blade section and the individual blade segments. Output consists principally of blade coordinates usable in other programs for the study of ideal flow and boundary layer. Output also includes coordinates usable for drafting or machining, as well as a view of the blade in cascade in the form of a Calcomp plot.

One of the principal uses of such a program is in conjunction with other computer programs for the analytical study of the performance and flow through turbomachine blading. This program permits the user to quickly generate and visualize circular arc blade shapes. The procedures of references 1 to 4 are then used to calculate velocities and streamlines on blade-to-blade stream surfaces of selected designs. The program of reference 5 calculates boundary-layer parameters from known flow velocity distributions, and finally a program based on reference 6 calculates turbomachine losses from boundary-layer parameters at the blade trailing edge. These programs give the engineer the ability to investigate blade shapes by testing them analytically in a computer experiment.

This report includes a listing of the program and a description of its input and output. The development of equations for the program is lengthy and will not be included. Internal program variables are not defined unless they are part of the input or output. Numerical examples are included to illustrate typical input values and the form in which output is given.

SYMBOLS

C blade segment chord (fig. 3), ft; m

F ratio of gap at inlet of channel between blade segments to gap at outlet of channel (figs. 3 and 12)

G gap between blade segments (figs. 3 and 12), ft; m

L overlap between blade segments (figs. 3 and 12), ft; m

R radial coordinate direction (fig. 2)

R_b radius from axis of rotation to plane of blades (fig. 2), ft; m

RI leading-edge radius of blade segment (fig. 3), ft; m

RO trailing-edge radius of blade segment (fig. 3), ft; m

S blade-to-blade spacing on the cylindrical surface (figs. 1 and 2), ft; m

TC total chord of overall blade section (fig. 1), ft; m

TM maximum thickness of blade segment (fig. 3), ft; m

Z axial coordinate direction (figs. 2 and 3)

$\Delta\kappa$ overall blade section camber (fig. 3), deg

κ_{in} inlet blade angle with respect to Z axis (fig. 3), deg

θ tangential coordinate direction (fig. 2)

σ solidity (fig. 1), TC/S

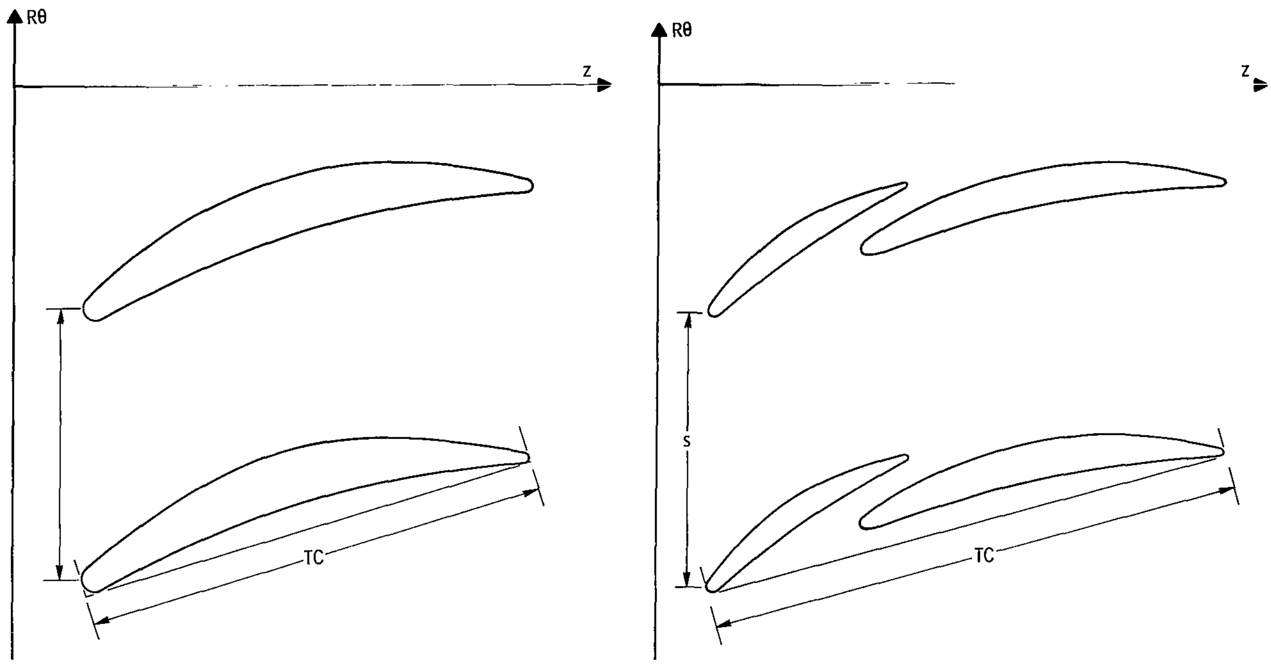
φ camber of individual blade segment (fig. 3), deg

GENERAL DESCRIPTION OF PROGRAM

Characteristics of the Program

From given inputs, the program calculates and plots coordinates of either a single blade section (see fig. 1(a)) or a tandem blade section (fig. 1(b)) with up to five segments per blade. (The plane of fig. 1 is the unwrapped cylindrical surface of fig. 2.)

All surfaces of the generated blade segments are single circular arcs tangent to leading- and trailing-edge circles. The radii of these arcs are a function of blade segment cambers, chords, and thicknesses, which in turn are functions of given input parameters. The position of the blade segments with respect to each other is also a function of the inputs.



(a) Single blade section.

(b) Tandem blade section.

Figure 1. - Computed blade sections.

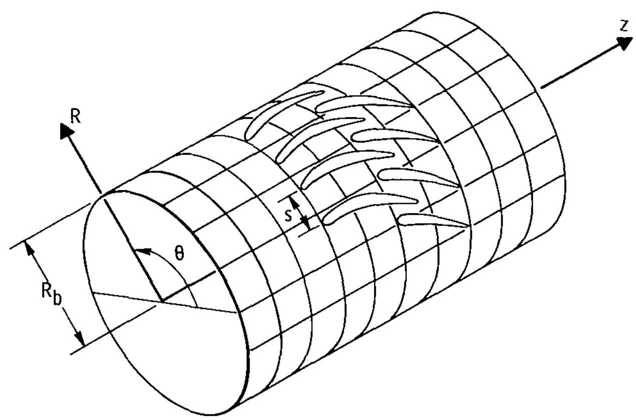


Figure 2. - Cylindrical surface of blade section.

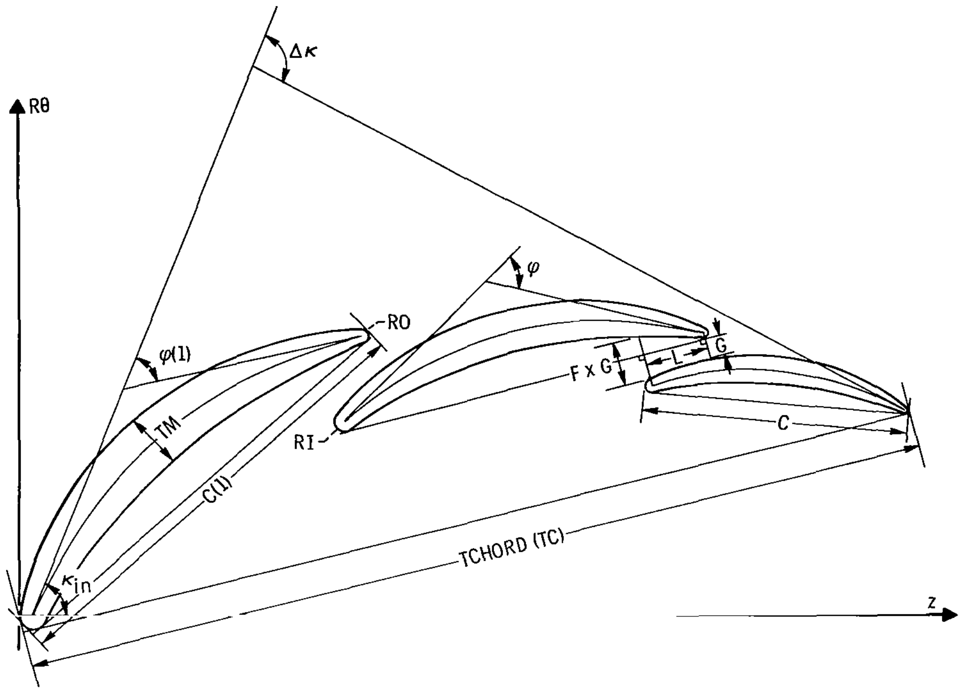


Figure 3. - Input variables.

The input parameters (fig. 3) describe both the overall blade section and the individual blade segments. The overall blade section is specified by a chord TC, camber $\Delta\kappa$, solidity $\sigma = TC/S$ (see fig. 1), inlet blade angle κ_{in}, and radius from axis of rotation to cylindrical surface R_b (see fig. 2). Individual blade segments are described by ratios of segment chord to the chord of the first blade segment $C/C(1)$, ratios of segment camber to first blade segment camber $\varphi/\varphi(1)$, and ratios of maximum thickness and leading-edge and trailing-edge radii of the segment to local segment chord TM/C, RI/C, and RO/C. Segments are related to each other by the gap between them (in the form of ratio to total chord, G/TC), their overlap (also a ratio, L/TC), and the convergence in the channel between them F. (The chord, camber, gap, overlap, and convergence inputs for the blade segments are not used when the blade section consists of only one segment.)

For a tandem blade (more than one segment), the program follows an iterative procedure in order to properly size the segments in relation to each other. From total camber $\Delta\kappa$ and total chord TC and the segment camber ratios $\varphi/\varphi(1)$ and chord ratios $C/C(1)$, initial estimates of segment cambers φ and chords C are calculated. Circular arc centerlines are fitted to these chords and cambers. The surfaces are also circular arcs that are tangent to leading- and trailing-edge circles, and meet the maximum thickness requirement. Finally, the segments are located with respect to each other. At this point the total camber formed from all estimated parameters is computed and checked against input total camber $\Delta\kappa$. Adjustments are made, and the entire procedure repeated until convergence is reached on total camber. After convergence, blade section coordinates and other output parameters are computed, and a plot of the blade section is made.

Output from the program consists of printed computer listings and a Calcomp plot. The computer listings are divided into two main parts: (1) surface coordinates of individual blade segments suitable for making machine drawings and (2) geometrical input for blade-to-blade ideal flow programs (refs. 1 to 4) or a boundary layer program (ref. 5). The Calcomp plot shows the generated blade row at the input blade angle. Two overall blades are plotted with the proper solidity in order to identify the flow passage.

The program is run at NASA Lewis on the IBM 7094-7044 direct coupled system with a 32 767 word core ($77777_{(8)}$). The total program storage requirement is $65403_{(8)}$ of which $31717_{(8)}$ is used in the storage of variables. The program runs in about 1/4 minute per data set on IBM 7094 equipment.

Limitations of the Program

The following are the principal limitations of the program:

(1) Blade sections are generated on a plane surface, rather than a conical or meridional flow surface which would be more closely alined with the streamline flow when there is significant streamline slope.

(2) Blade segment surfaces are single circular arcs. Multiple circular arcs or other types of variable geometry are not calculated by the program.

(3) Each set of input data generates only one blade section. The program does not provide radial stacking of blade sections after several sections have been run.

(4) The plotting portions of the program use routines that were developed at Lewis and would not be available or would need modification before they could be used on other machines. All other parts of the program, however, are in FORTRAN IV code, and could be easily transferred to other IBM equipment.

Use of Program

At Lewis, the program is being used to define blade sections for analytical parametric studies using the programs of references 1 to 6. The Calcomp plots allow preliminary screening of cascades formed by applying the input variables over a wide range.

Selected configurations are then examined analytically for ideal flow, boundary-layer development, and losses. Some of these sections are later selected for experimental study.

For applications in two-dimensional cascades or where radius does not change much across blade sections, output can be used for fabrication purposes.

NUMERICAL EXAMPLES

Two numerical examples are given which illustrate the use of the program. The first is a two-segment tandem blade section, and the second is a three-segment blade section with the front section acting as a slat. Both blade sections are designed for the same overall parameters which are listed in table I. The input for these two examples

TABLE I. - OVERALL DESIGN PARAMETERS

FOR TWO- AND THREE-SEGMENT

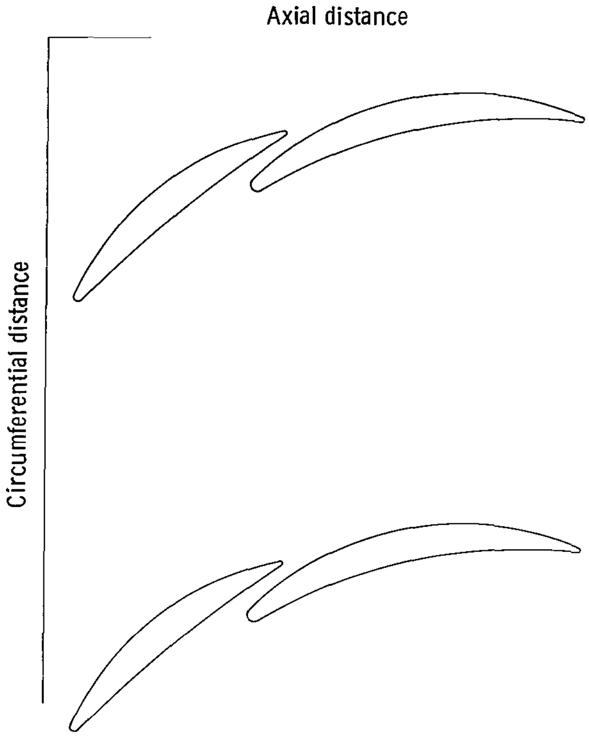
TANDEM BLADE SECTIONS

Total chord, TC, ft	0.18583
Solidity, σ	1.235
Overall camber, $\Delta\kappa$, deg	72.24
Inlet blade angle, κ_{in}, deg	56.53
Radius from axis or rotation, R_b, ft	0.77080

and the generated plots of blade shapes appear in figures 4 and 5. These examples illustrate typical values of input parameters for two- and three-segment blade sections. Sample output for the first example is discussed under OUTPUT.

INPUT

Figure 6 shows the placement of input variables on data cards. The first input card is for a title which identifies the data set and is printed on the output. The user may type whatever information he wishes in any of the first 72 columns of this card. The remaining cards are for input data. The input variables are defined in the next section. Further explanation of the proper preparation of input is contained in the section Typical Values and Limits of Input Variables.




```
EXAMPLE  -  TWO SECTION TANDEM BLADE

N       TCHORD     SOLID     DELR     KAPIN     RADIUS
2       0.18583    1.2350    72.240   56.530    0.77080

C/C(1) ARRAY
              1.25000

PHI/PHI(1) ARRAY
              1.56250

G/TC ARRAY
              0.02500

L/TC ARRAY
              0.10000

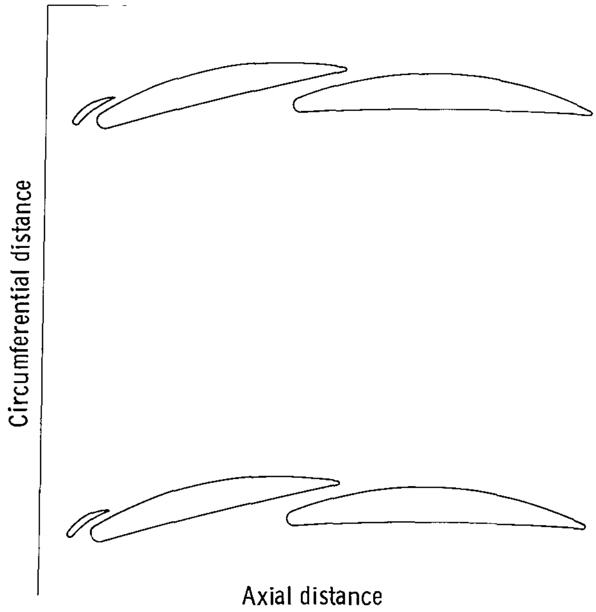
F ARRAY
              1.40000

TM/C ARRAY
     0.12000  0.10000

RI/C ARRAY
     0.01500  0.02000

RO/C ARRAY
     0.00800  0.00700
```

Figure 4. - Input and generated plot of two-section tandem blade example.




```
EXAMPLE  -  THREE SECTION TANDEM BLADE

N       TCHORD     SOLID     DELR     KAPIN     RADIUS
3       0.18583    1.2350    72.240   56.530    0.77080

C/C(1) ARRAY
              5.10000  6.00000

PHI/PHI(1) ARRAY
              0.50000  0.60000

G/TC ARRAY
              0.01250  0.02400

L/TC ARRAY
              0.04200  0.09700

F ARRAY
              1.20000  1.40000

TM/C ARRAY
     0.14000  0.12000  0.12000

RI/C ARRAY
     0.06000  0.03200  0.02500

RO/C ARRAY
     0.01000  0.00700  0.00700
```

Figure 5. - Input and generated plot of three-section tandem blade example.

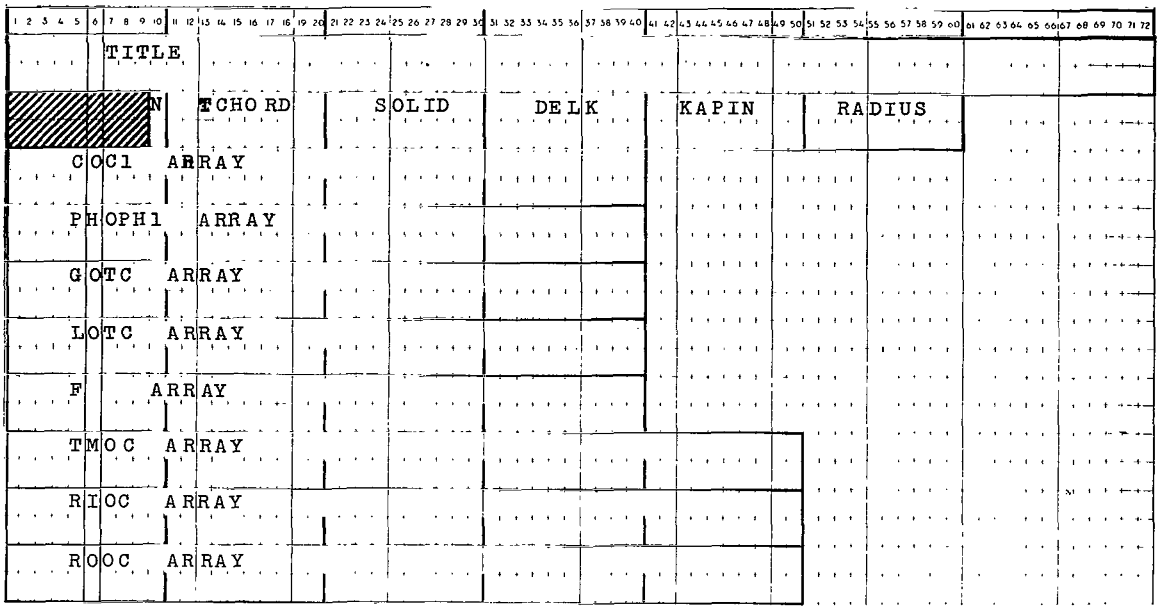


Figure 6. - Input data form.

Input Variables

Schematic representations of these variables appear in figures 1 to 3. After the title card, the following input variables are given:

N — integer number (1 to 5) of blade segments comprising the blade section; equals 1 when designing a single, circular-arc blade section; must occupy column 10 of the data card (fig. 6)

TCHORD — total chord of the overall N-segment tandem blade section TC, ft; m

SOLID — solidity of the blade row, σ, that is, total chord divided by blade spacing TC/S. (Solidity is only used in the plotting part of the program to produce a duplicate blade on the plot.)

DELK — total camber of the overall blade sections, $\Delta\kappa$, deg

KAPIN — blade inlet angle or angle between tangent to mean camber line at leading edge of first blade segment and the Z axis, κ_{in}, deg

RADIUS — radius from axis of rotation to cylindrical blade plane R_b, ft; m (RADIUS is only used to convert tangential coordinates, $R\theta$, in feet or meters, to radians for input to the ideal flow programs, refs. 1 to 4.)

Each of the following arrays has N - 1 entries. If N = 1, a blank card should be given for each of these 5 arrays.

COC1 array of ratios of chords of blade segments 2 to N to the chord of the first segment, C/C(1)

PHOPH1 array of ratios of cambers of blade segments 2 to N to the camber of the first segment, $\varphi/\varphi(1)$

GOTC array of ratios of gaps between blade segments to the total chord of the overall blade section, G/TC

LOTC array of ratios of overlap between blade segments to the total chord of the overall blade section, L/TC

F array of channel convergences between blade segments, F (F is the ratio of the gap at the channel inlet to the gap at the channel outlet.)

Each of the arrays below has N entries, one for each of the blade segments:

TMOC array of ratios of maximum blade segment thickness to chord of the individual blade segments, TM/C

RIOC array of ratios of leading-edge radius to chord of the individual blade segments, RI/C

ROOC array of ratios of trailing-edge radius to chord of the individual blade segments, RO/C

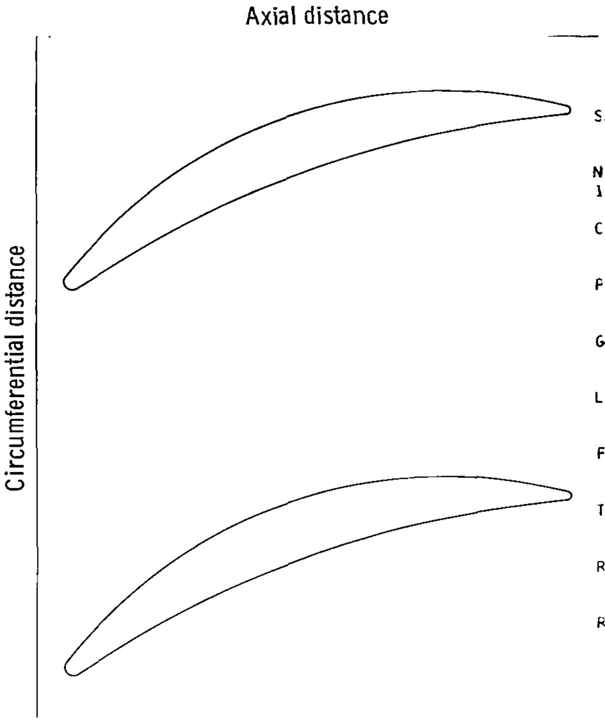
Typical Values and Limits of Input Variables

Ranges of typical values are given in this section for the input variables. Limits are also given beyond which unreasonable blade sections (and hence errors in the program) will occur.

N, the number of blade sections, can be any integer from 1 to 5. For typical tandem blades, N is usually 2 or 3. To design a single blade section, N is set equal to 1, and blank cards are used for the COC1, PHOPH1, GOTC, LOTC, and F arrays (Fig. 7 is the input and the corresponding output plot of a single blade section.) Since N is an integer, it must be right shifted on the data card; that is, it must occupy column 10 (see fig. 5).

TCHORD can be any positive value.

SOLID can also be any positive value; the range from 0.5 to 2.0 is typical.




```
SAMPLE BLADE WITH A SINGLE SEGMENT

N       TCHCRD      SOLID      DELK       KAPIN      RADIUS
1       0.15200     1.3000     50.000     45.000     0.62500

C/C(1) ARRAY
                -0.

PHI/PHI(1) ARRAY
                -0.

G/TC ARRAY
                -0.

L/TC ARRAY
                -0.

F ARRAY
                -0.

TM/C ARRAY
        0.11000

RI/C ARRAY
        0.01500

RO/C ARRAY
        0.00800
```

Figure 7. - Input and generated plot of blade section with single segment.

DELK, the overall chamber, must be a positive number or zero. Values as high as the 180^{o} will run, but the range from 5^{o} to 120^{o} is typical. If DELK has a small value (from 0^{o} to 10^{o}) the program will not converge to an answer if other parameters such as segment camber, gap, overlap, and convergence are not physically compatible with DELK.

KAPIN, the blade inlet angle, can be positive, negative, or zero. Values between the limits of -90^{o} to 90^{o} are allowable, but the range from -30^{o} to 70^{o} is typical.

RADIUS can be any positive value.

TCHORD and RADIUS are the only inputs with units of length; units should be the same on these two variables. Generally either feet or meters are used so that output can be used with the ideal flow programs (refs. 1 to 4). This is not required, however, and any units of length are acceptable. Units on all output coordinates will always correspond to what was used on these two input quantities.

COC1 can be any positive value. The range from 0.1 to 10.0 is typical.

PHOPH1 can be any positive or negative value, or zero. Values from 0 to 3.0 are most common. To obtain a very straight front segment, PHOPH1 should contain very large values. To obtain a very straight aft segment, PHOPH1 should be near or equal to zero for that segment.

GOTC can be any positive value from zero to about 0.5 depending on other inputs such as segment cambers, overlaps, and convergences. The range from 0.01 to 0.04 is typical.

LOTC can have positive or negative values, or be zero. Typical values are contained in the range from 0.1 to -0.05. Values above 0.4 or below -0.2 will generally cause errors and prevent the program from running.

F can have positive values from zero to about 10.0. The range from 0.9 (diverging passage) to 1.5 (converging passage) is most typical. When F = 1.0, the capture area of the passage between blade segments is equal to the exit area of the passage.

TMOC is allowed positive values from zero to about 0.8. Values in the range from 0.1 to 0.2 are most typical. Elements of TMOC must be at all times at least twice as large as the corresponding elements of RIOC and ROOC in order for the program to run. (If TMOC equals zero, RIOC and ROOC must also be zero for that blade segment.)

RIOC and ROOC may have positive values from zero to about 0.4. Most values are in the range 0.01 to 0.1. Corresponding elements of RIOC and ROOC do not have to equal each other. (RIOC may only equal zero if the corresponding element of ROOC also equals zero. ROOC, on the other hand, may equal zero at any time, regardless of the values in RIOC.)

Example of Adjustment of Inputs in Design Process

The program is used here to design a two-segment tandem blade section. Given the overall blade section parameters, an initial selection is made for the other input variables. These variables are subsequently changed (twice in this example) until a final blade section is accepted.

Changes are made after inspection of the machine plots which accompany the computer output. They are made to obtain a blade section which appears to have a good flow path while satisfying the overall blade parameters. These iterations on input variables also illustrate the effect of the different input parameters on the final blade shape.

The blade section to be designed has the overall blade parameters listed in table II. In order to obtain an initial picture of a blade section meeting these specifications, gen-

TABLE II. - OVERALL DESIGN PARAMETERS FOR TWO-SEGMENT TANDEM BLADE SECTION

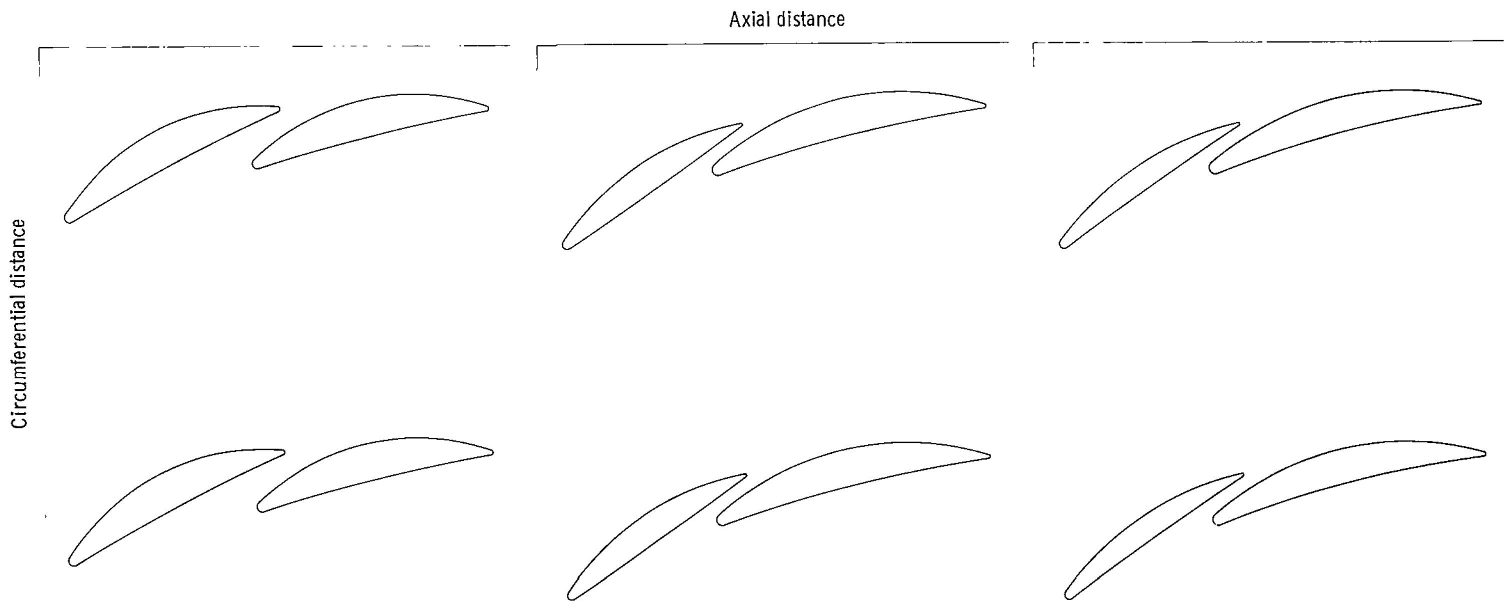
Total chord, TC, ft	0.192
Solidity, σ	1.3
Overall camber, $\Delta\kappa$, deg	50.0
Inlet blade angle, κ_{in}, deg	45.0
Radius of rotation, R_b, ft	0.625

TABLE III. - VARIABLE INPUT PARAMETERS FOR TWO-SEGMENT TANDEM BLADE SECTION

Run	Ratio of segment chord to chord of first blade segment, C/C(1)	Ratio of segment chamber to first blade segment chamber, $\varphi/\varphi(1)$	Ratio of gap to total chord, G/TC	Ratio of overlap to total chord, L/TC	Ratio of gap at channel inlet to gap at channel outlet, F	Ratio of maximum thickness to local segment chord, TM/C	Ratio of leading-edge radius to local segment chord, RI/C	Ratio of trailing-edge radius to local segment chord, RO/C
1	1.0	1.0	0.05	0.10	1.5	0.15	0.02	0.01
						.15	.02	.01
2	1.3	1.6	0.03	----	1.1	0.13	----	0.007
						.13	----	.007
3	---	---	----	----	1.2	0.11	----	-----
						.12	----	-----

eral initial values of the other input parameters were chosen and run. These values are listed in table III (run 1). The resulting blade section is shown in figure 8(a).

Changes made after an initial run on the program are entirely based on the user's experience and his concept of the final desired blade shape. For this example we wanted more chord and camber to be concentrated in the rear blade segment; so, in run 2, C/C(1) was increased from 1.0 to 1.3, and φ/φ (1) from 1.0 to 1.6. The channel gap was also decreased (G/TC = 0.05 to 0.03), as well as the channel convergence between blade segments (F = 1.5 to 1.1) in order to bring the segments closer together. Finally the blade thicknesses TM/C and the outlet radii RO/C were reduced. The blade section resulting from run 2 (table III) is pictured in figure 8(b). From experience it appeared that this blade section was still thicker than desired and that its channel needed more convergence. Appropriate changes were made for run 3 (table III), and the final blade section is shown in figure 8(c). This section was accepted for further analysis by the ideal flow programs (refs. 1 to 4).



(a) Run 1. (b) Run 2. (c) Run 3.

Figure 8. - Blade plots for subsequent design runs of two-segment tandem blade section.

OUTPUT

Output from the program consists of two principal parts: a computer listing with printed tables of output variables and a Calcomp plot that pictures schematically the generated blade.

A sample computer listing for the two-section tandem blade example is given in table IV. In this table some sections of the output have been abbreviated because they were too long. In all cases output labels agree with program variable names which are defined in the next section.

TABLE IV. - SAMPLE OUTPUT FOR TWO-SECTION TANDEM BLADE EXAMPLE

```
EXAMPLE  -  TWO SECTION TANDEM BLADE

N       TCHORD      SOLID      DELK      KAPIN      RADIUS
2       0.18583     1.2350     72.240    56.530     0.77080

C/C(1) ARRAY
                 1.25000

PHI/PHI(1) ARRAY
                 1.56250

G/TC ARRAY
                 0.02500

L/TC ARRAY
                 0.10000

F ARRAY
                 1.40000

TM/L ARRAY
        0.12000  0.10000

RI/L ARRAY
        0.01500  0.02000

RO/L ARRAY
        0.00800  0.00700



OVERALL BLADE PARAMETERS
    N       TCHORD      PITCH      SOLID      DELK      KAPIN      GAMB      THETB     XOB       YOB
    2       0.18583     0.15047    1.2350     72.240    56.5300    19.6196   0.1820    0.17413   [illegible]


BLADE SEGMENT NO.  1

   CHORD     RI        RO        THETA
  0.09334   0.00140   0.00075   0.41051

   XI        YI        XO        YO        XCM       YCM
  0.00140   0.00140   0.09259   0.00075   0.04534   0.00803

   X1        Y1        X2        Y2        GAM       GAMR
  0.        -0.       0.09334   -0.       0.        0.

   PHIS      RS        HS        BS        KIS       KOS
 56.52347   0.09737   0.04570   0.08373  27.48966  29.03381

   PHIC      RC        HC        BC        KIC       KOC
 34.70861   0.15287   0.04595   0.14483  16.94380  17.76481

   PHIP      RP        HP        BP        KIP       KOP
 12.24054   0.42659   0.04701   0.42416   6.11793   6.12261

   XX        YS        YP        NDEL = 47
  0.        0.00225  -0.00016
  0.00200   0.00328   0.00006
  0.00400   0.00426   0.00026
  0.00600   0.00518   0.00046
  0.00800   0.00604   0.00065
  0.01000   0.00686   0.00083
  0.01200   0.00762   0.00100
  0.01400   0.00833   0.00116
```

TABLE IV. - Continued. SAMPLE OUTPUT FOR TWO-SECTION TANDEM BLADE EXAMPLE

0.01600	C.C0900	0.00131
0.C1800	0.00961	0.00145
C.02000	C.01018	0.00158
C.C2200	C.01071	0.CC170
C.02400	C.01119	0.00182
C.0260C	C.01162	0.00192
C.C2800	C.C1201	0.C0201
C.03000	0.01236	0.C0210
C.03200	C.C1267	0.00217
C.03400	C.01293	0.C0224
C.03600	C.01315	0.00230
0.C3800	C.C1333	0.00234
C.04000	C.01347	0.00238
C.C4200	0.01357	0.00241
C.04400	C.01362	0.00243
C.0460C	C.C1364	0.00244
C.C4600	C.01361	0.00244
C.05CC0	0.C1354	0.00243
C.C52C0	C.01343	0.00241
C.C5400	C.01328	0.CC238
C.05600	0.01309	0.00234
C.C580C	C.C1286	0.C0230
C.C6000	C.C1258	0.00224
C.C62C0	0.C1226	0.CC217
0.06400	C.C1190	0.00210
C.C6600	0.C1150	0.00201
C.C680C	C.01105	C.00192
C.C7CC0	0.01055	0.00182
C.C7200	C.C10C2	0.CC171
C.C7400	0.00943	0.CC158
C.C76CC	0.C0880	0.00145
C.C7800	C.CC812	0.00131
C.C8C00	C.CC739	0.00116
0.C8200	0.00662	0.00100
C.C8400	C.0C579	0.00083
C.C86CC	C.C049C	C.00C65
C.C8800	C.C0397	0.0CC46
C.C9C00	C.C0297	0.C0027
0.C9200	C.00192	0.0CC06

BLADE SEGMENT NO. 2

CHORD	RI	RO	THETA			
C.11667	C.00233	0.C0C82	0.76547			
XI	YI	XO	YC	XCM	YCM	
0.00233	C.CC233	0.11586	0.00082	0.05386	0.01522	
X1	Y1	X2	Y2	GAM	GAMR	
C.C7C86	C.C0825	C.17448	0.06189	27.36919	27.36919	
PHIS	RS	HS	BS	KIS	KOS	
7C.04290	C.10C49	0.C5669	0.07939	33.62912	36.41378	
PHIC	RC	HC	BC	KIC	KOC	
54.2322C	C.12454	0.C5761	0.10927	26.35063	27.88157	
PHIP	RP	HP	BP	KIP	KOP	
37.66516	0.17337	0.C5922	0.16391	18.89117	18.97399	
G	GA	GAOC	L	F	FA	SINC
C.00465	C.00463	0.04960	0.01858	1.40000	1.40619	-9.55789

NDEL = 24

XX	YS	YP
0.	C.00357	-C.00096
C.005C0	C.C0678	C.C0C77
C.01000	C.C0959	C.C0233
C.015C0	C.01204	0.C0373
C.C20C0	C.01416	0.00497
C.C25C0	0.01597	0.00605
C.C3C00	C.01748	0.00698
C.03500	C.C1872	0.00776

COMPLTED INPUT FOR IDEAL FLOW PROGRAMS

BLADE	MCHORD	STGR	RSTGR	RI	RO	MLE	THLE	RTHLE	MTE	THTE	RTHTE
1	0.C7284	0.C7474	0.05761	0.00140	0.00075	0.	0.0C000	0.00000	0.07284	0.07474	0.05761
2	0.11442	0.02924	0.02254	0.00233	0.00082	0.06054	0.C5137	0.03960	0.17496	0.08062	0.06214

BLADE	BETIS	BETOS	BETIP	BETCP	MCL	THCL	RTHCL	MCT	THCT	RTHCT
1	67.07586	10.55239	45.70413	33.46359	0.00140	0.0000C	C.00000	0.07209	0.07474	0.05761
2	45.84613	-24.19677	31.10818	-6.75698	0.06287	0.05137	0.03960	0.17415	0.08062	0.06214

TABLE IV. - Concluded. SAMPLE OUTPUT FOR TWO-SECTION TANDEM BLADE EXAMPLE

BLADE SEGMENT NO. 1

MSPS	THSPS	RTHSPS	MSPP	THSPP	RTHSPP
-0.00022	-0.00031	-0.00024	0.00132	-0.00272	-0.00210
0.00066	0.00237	0.00183	0.00272	-0.00085	-0.00065
0.00158	0.00500	0.00386	0.00413	0.00101	0.00078
0.00254	0.00758	0.00584	0.00554	0.00286	0.00221
0.00353	0.01010	0.00778	0.00696	0.00471	0.00363
0.00455	0.01256	0.00968	0.00839	0.00654	0.00504
0.00561	0.01498	0.01155	0.00983	0.00836	0.00644
0.00669	0.01735	0.01337	0.01126	0.01017	0.00784
0.00781	0.01966	0.01516	0.01271	0.01198	0.00923
0.00896	0.02193	0.01691	0.01416	0.01377	0.01062
0.01014	0.02416	0.01862	0.01562	0.01556	0.01199
0.01134	0.02634	0.02030	0.01708	0.01733	0.01336
0.01258	0.02847	0.02194	0.01855	0.01910	0.01472
0.01384	0.03056	0.02355	0.02003	0.02086	0.01608
0.01514	0.03260	0.02513	0.02151	0.02260	0.01742
0.01646	0.03460	0.02667	0.02300	0.02434	0.01876
0.01780	0.03656	0.02818	0.02449	0.02607	0.02010
0.01918	0.03848	0.02966	0.02599	0.02779	0.02142
0.02058	0.04035	0.03110	0.02749	0.02950	0.02274
0.02200	0.04219	0.03252	0.02901	0.03120	0.02405
0.02346	0.04398	0.03390	0.03052	0.03289	0.02535
0.02494	0.04573	0.03525	0.03205	0.03457	0.02665
0.02644	0.04744	0.03656	0.03358	0.03625	0.02794
0.02798	0.04910	0.03785	0.03511	0.03791	0.02922
0.02953	0.05073	0.03910	0.03665	0.03956	0.03049
0.03112	0.05232	0.04033	0.03820	0.04121	0.03176
0.03273	0.05386	0.04152	0.03975	0.04284	0.03302
0.03437	0.05536	0.04268	0.04131	0.04447	0.03427
0.03603	0.05683	0.04380	0.04288	0.04608	0.03552
0.03772	0.05825	0.04490	0.04445	0.04769	0.03676
0.03944	0.05962	0.04596	0.04603	0.04929	0.03799
0.04118	0.06096	0.04699	0.04761	0.05087	0.03921
0.04295	0.06225	0.04798	0.04920	0.05245	0.04043
0.04475	0.06350	0.04895	0.05079	0.05402	0.04164
0.04658	0.06471	0.04987	0.05239	0.05558	0.04284
0.04843	0.06587	0.05077	0.05400	0.05713	0.04404
0.05032	0.06698	0.05163	0.05561	0.05867	0.04522
0.05223	0.06805	0.05245	0.05723	0.06020	0.04640
0.05416	0.06907	0.05324	0.05886	0.06173	0.04758
0.05615	0.07005	0.05399	0.06049	0.06324	0.04874
0.05816	0.07097	0.05471	0.06213	0.06474	0.04990
0.06019	0.07185	0.05538	0.06377	0.06623	0.05105
0.06226	0.07267	0.05602	0.06542	0.06772	0.05220
0.06437	0.07344	0.05661	0.06707	0.06919	0.05333
0.06650	0.07416	0.05716	0.06874	0.07066	0.05446
0.06868	0.07482	0.05767	0.07040	0.07211	0.05559
0.07089	0.07542	0.05814	0.07208	0.07356	0.05670

BLADE SEGMENT NO. 2

MSPS	THSPS	RTHSPS	MSPP	THSPP	RTHSPP
-0.00021	0.00093	0.00072	0.00075	-0.00482	-0.00372
0.00400	0.00637	0.00491	0.00527	-0.00125	-0.00097
0.00829	0.01130	0.00871	0.00983	0.00210	0.00162
0.01266	0.01578	0.01216	0.01442	0.00525	0.00404
0.01710	0.01984	0.01529	0.01904	0.00819	0.00631
0.02160	0.02351	0.01812	0.02370	0.01094	0.00843
0.02617	0.02681	0.02066	0.02839	0.01349	0.01040

Output Variables

The first page of output contains a copy of the input to the program. These variables are defined in the Input Variables section on page 9.

The next page of output lists some overall blade section parameters, some of which are repetitions from the input list. The others are defined as follows:

PITCH blade-to-blade spacing S in the θ direction or ratio of total chord to solidity TC/σ (fig. 1), ft; m

GAMB angle between chord line of first blade segment and chord line of overall blade section (fig. 9), deg

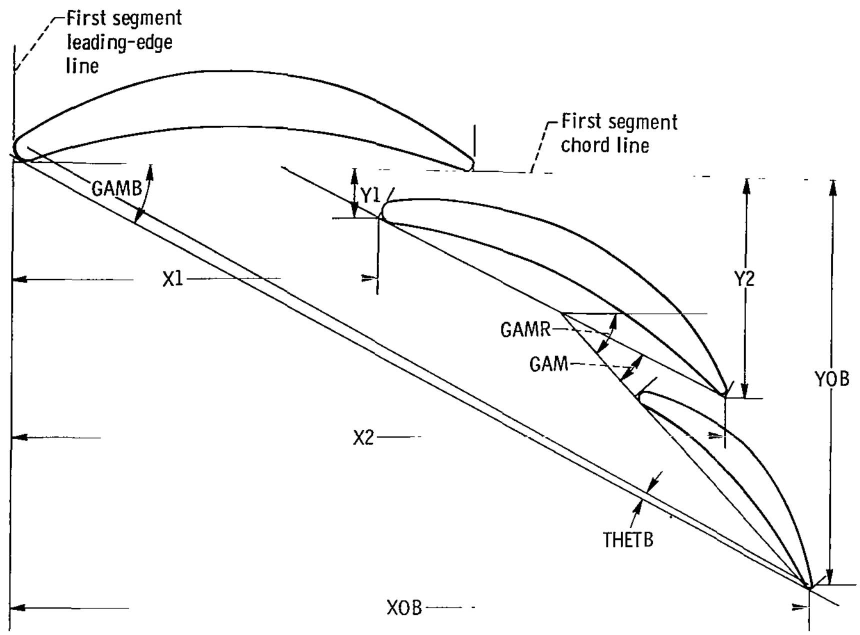


Figure 9. - Output variables for overall blade section.

THETB — angle between chord line of overall blade section and a line joining leading-edge circle center of first blade segment and trailing-edge circle center of final blade segment (see fig. 9); positive if RI(1) > RO(N) and negative if RI(1) < RO(N), deg

XOB(YOB) — distance from first segment leading-edge line (first segment chord line) to circle center at trailing edge of final blade segment (fig. 9), ft; m

Following the overall blade parameters are lists of parameters for each of the individual blade segments:

CHORD — chord length of blade segment, that is, distance from leading-edge point to trailing-edge point (fig. 10), ft; m

RI(RO) — leading- (trailing-) edge radius of blade segment (fig. 10), ft; m

THETA — angle between chord line of blade segment and a line joining leading- and trailing-edge circle centers (fig. 10); positive if RI > RO, and negative if RI < RO, deg

XI(YI) — distance between leading-edge line (chord line) of blade segment and center of leading-edge circle (fig. 10), ft; m

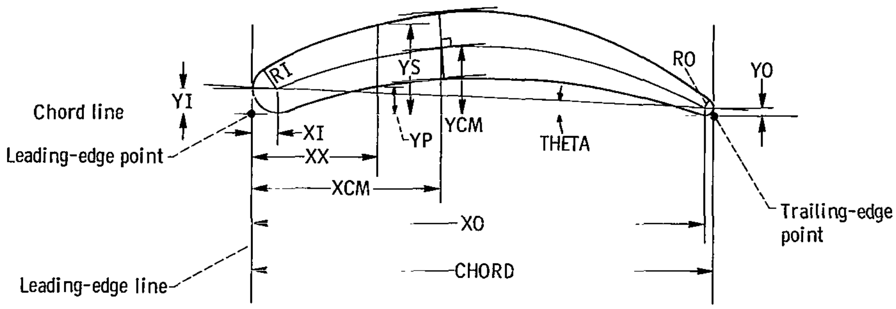
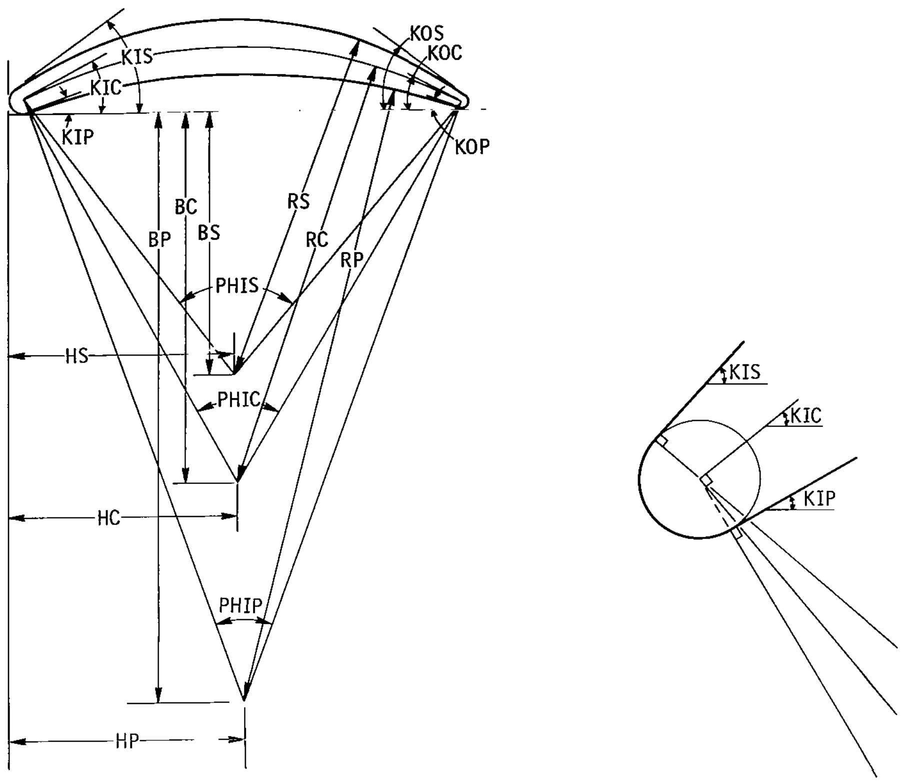


Figure 10. - Output variables for individual blade segment.

XO(YO)	distance between leading-edge line (chord line) of blade segment and center of trailing-edge circle (see fig. 10), ft; m
XCM(YCM)	distance between leading-edge line (chord line) of blade segment and point on mean camber line at which slopes of both blade surfaces are equal to slope of mean camber line (fig. 10), ft; m
X1(Y1)	distance between leading-edge line (chord line) of first segment and leading-edge point of local segment (fig. 9), ft; m
X2(Y2)	distance between leading-edge line (chord line) of first segment and trailing-edge point of local segment (fig. 9), ft; m
GAM	angle between chord line of local blade segment and chord line of previous blade segment (fig. 9), deg
GAMR	angle between chord line of local blade segment and chord line of first blade segment (fig. 9), deg
PHIC(PHIS, PHIP)	overall camber of local blade segment mean camber line (suction surface, pressure surface) from a line through leading-edge circle center to a line through trailing-edge circle center (fig. 11(a)), deg
RC(RS, RP)	radius of curvature of local blade segment mean camber line (suction surface, pressure surface) (fig. 11(a)), ft; m
HC(HS, HP)	distance from leading-edge line of blade segment to center of curvature of mean camber line (suction surface, pressure surface) of blade segment (fig. 11(a)), ft; m
BC(BS, BP)	distance from chord line of blade segment to center of curvature of mean camber line (suction surface, pressure surface) of blade segment (fig. 11(a)); negative when PHIC(PHIS, PHIP) is negative



(a) Entire blade segment.

(b) Enlarged leading edge.

Figure 11. - Continuation of output variables for individual blade segment.

When PHOPH1, and thus PHIC, of a segment equals 0, RC and BC are set to 999.99999.

KIC(KOC) angle between chord line of blade segment and tangent to mean camber line at the center of leading-edge (trailing-edge) circle (see fig. 11), deg

KIS(KOS) angle between chord line of blade segment and tangent to suction surface at leading-edge (trailing-edge) transition point (see fig. 11), deg

KIP(KOP) angle between chord line of blade segment and tangent to pressure surface at leading-edge (trailing-edge) transition point (see fig. 11), deg

KIC(KIS, KIP) and KOC(KOS, KOP) are defined positive as shown in figure 11 for a centerline or surface which has positive camber. They will be negative for a surface with negative camber.

G gap between trailing edge of previous blade segment and suction surface of local blade segment (fig. 12); measured perpendicular to the chord line of previous blade segment along line passing through trailing-edge circle center of the previous blade segment, ft; m

GA actual gap between trailing edge of previous blade segment and suction surface of local blade segment (fig. 12); measured perpendicular to suction surface of local blade segment along line passing through trailing-edge circle center of previous blade segment, ft; m

GAOC ratio of GA to CHORD of previous blade segment (fig. 12)

L distance between gap G at trailing edge of previous blade segment and gap (F×G) at leading edge of local blade segment (fig. 12), ft; m

F ratio of gap F×G at leading edge of local blade segment to gap G at trailing edge of previous blade segment (fig. 12) F×G is measured perpendicular to chord line of previous blade segment along a line passing through leading edge circle center of local blade segment

FA ratio of actual gap FA×GA at leading edge of local blade segment to actual gap GA at trailing edge of previous blade segment (fig. 12) (Actual gap FA×GA is measured perpendicular to a line (A-A in fig. 12) which bisects the tangents to the suction surface of the local blade segment and the pressure surface of the previous blade segment where the line FA×GA meets these surfaces. The line containing FA×GA passes through the leading-edge circle center of the local blade segment.)

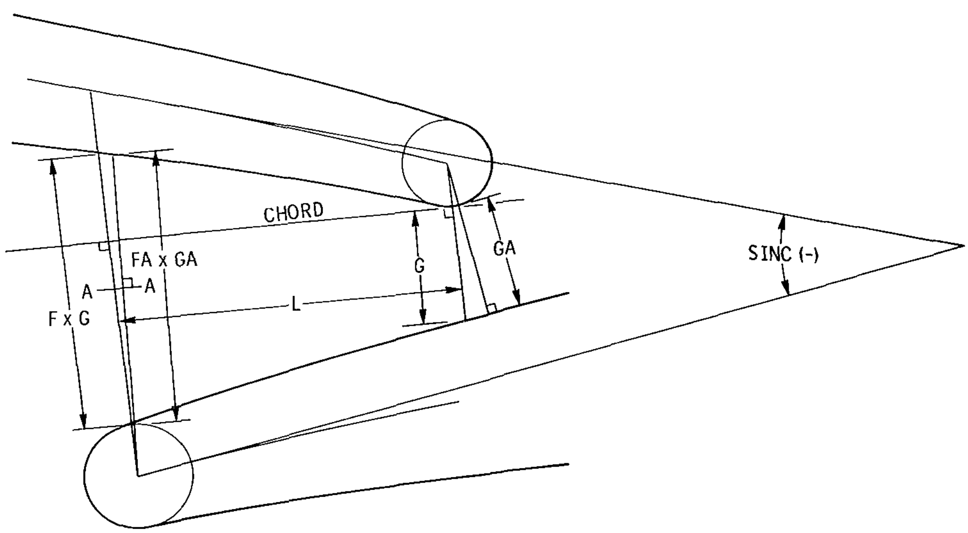


Figure 12. - Input and output variables in overlap region.

SINC angle between tangents to mean camber lines of local blade segment and previous blade segment at points of intersection with line containing FXG (see fig. 12), deg (SINC is a measure of the incidence of the average blade-to-blade flow on the leading edge of the local blade segment. SINC is negative as shown in figure 12 since the mean flow would have negative incidence in this blade orientation.)

XX array of distances (parallel to blade segment chord line) between leading-edge line of blade segment and points at which blade surface coordinates (YS and YP) are given (fig. 10), ft; m

YS(YP) array of perpendicular distances from chord line of blade segment to points on suction (pressure) surface of the segment (fig. 10), ft; m

NDEL number of blade coordinate points (XX and YS, XX and YP) along suction or pressure surfaces of local blade segment.

For blades with normal levels of positive camber, some values of YP at inlet and outlet may be negative. These are points on the pressure or suction surface circular arcs that occur prior to the leading-edge radius or after the trailing-edge radius (fig. 13).

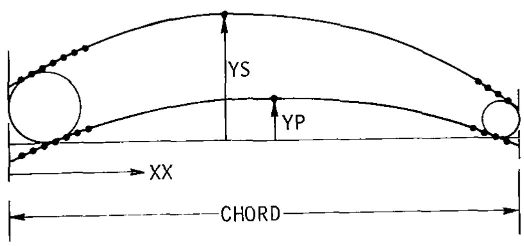


Figure 13. - Blade surface coordinate points.

For a blade with small positive camber, or with negative camber, many values of YP (and sometimes YS) can be negative (fig. 14).

Following the blade coordinates for each of the blade segments are output parameters that serve as inputs for the ideal flow programs. These programs are reported in references 1 to 4. They compute ideal flow on an axisymmetric blade-to-blade surface of a single or tandem bladed turbomachine in either subsonic or mildly transonic flow.

To obtain input to be used in the ideal flow programs, the flat plane in which the blade section lies is assumed to be wrapped about a cylinder of radius equal to the input parameter, (RADIUS, R_b, in fig. 2). This cylinder serves as the axisymmetric blade-to-blade surface required for the input of geometry to the ideal flow programs.

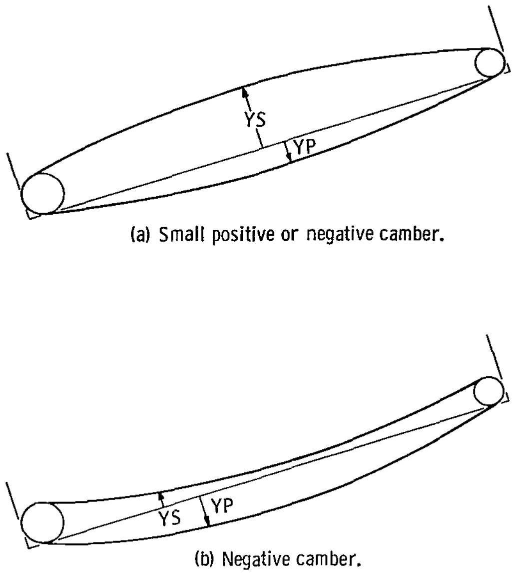


Figure 14. - Example blade sections with negative surface coordinate points.

Specific output quantities which are required as geometric input parameters in the ideal flow programs are defined in the following:

MCHORD	chord lengths of blade segments in Z direction (figs. 15 and 16), ft; m
STGR	angular θ coordinates of trailing edges of blade segments with respect to leading edges of blade segments (figs. 15 and 16), rad
RSTGR	angular distances of trailing edges of blade segments from leading edges of blade segments (figs. 15 and 16), ft; m
RI(RO)	leading-edge (trailing-edge) radii of the blade segments (figs. 10 and 16), ft; m
MLE(MTE)	distances in Z-direction from leading edge of first blade segment to leading (trailing) edges of other blade segments (fig. 15), ft; m
THLE(THTE)	angular θ coordinates of leading (trailing) edges of blade segments with respect to leading edge of first blade segment (fig. 15), rad
RTHLE(RTHTE)	angular distances of leading (trailing) edges of blade segments with respect to leading edge of first blade segment (fig. 15), ft; m
BETIS(BETOS)	angles with respect to Z-direction at tangent points of leading- (trailing) edge radii with suction surfaces of blade segments (fig. 16), deg

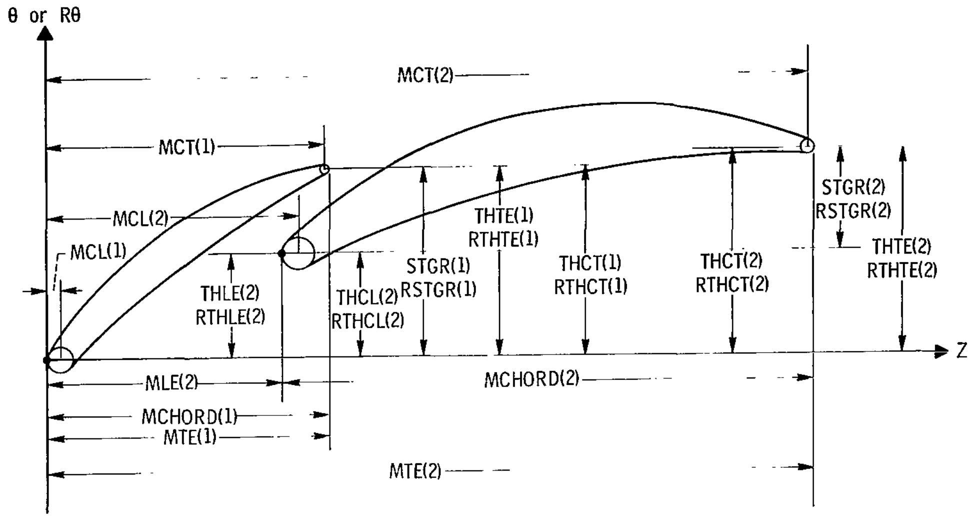


Figure 15. - Blade section output variables used for plots and ideal flow programs (refs. 1 to 4).

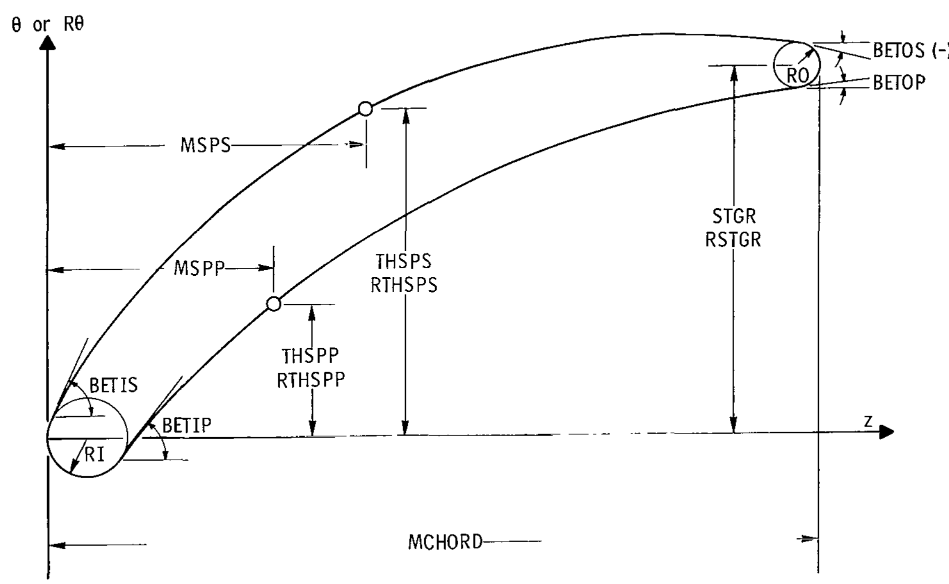


Figure 16. - Blade segment output variables used for plots and ideal flow programs (refs. 1 to 4).

BETIP(BETOP) angles with respect to Z-direction at tangent points of leading- (trailing) edge radii with pressure surfaces of blade segments (fig. 16), deg

MCL(MCT) distance in Z-direction from leading edge of first blade segment to centers of leading-edge (trailing-edge) circles of blade segments (fig. 15), ft; m

THCL(THCT) angular θ coordinates of centers of leading-edge (trailing-edge) circles with respect to leading edge of first blade segment (fig. 15), rad

RTHCL(RTHCT) angular distances of centers of leading-edge (trailing-edge) circles with respect to leading edge of first blade segment (fig. 15), ft; m

The preceding variables are followed by the coordinates of suction and pressure surfaces of the individual blade segments. These coordinates are given with respect to axes in the Z-direction passing through the leading-edge circle centers of each of the segments.

MSPS(MSPP) array of distances in Z-direction between leading edges of individual blade segments and points on the suction (pressure) surface at which blade coordinates (THSPS and THSPP) are given as output (fig. 16), ft; m

THSPS(THSPP) array of angular θ coordinates from a line in the Z direction through the leading edge circle center of each segment, to points on the suction (pressure) surface of the segment (fig. 16), rad

RTHSPS(RTHSPP) array of distances (RADIUS × THSPS(THSPP)) corresponding to THSPS(THSPP) (fig. 16), ft; m

Output Blade Plots

The Calcomp plot portion of the output shows the blade as it would appear in cascade at a given solidity and inlet blade angle. The plot is very helpful in evaluating the blade visually; the user can see immediately whether the shape resulting from the program agrees with his concept.

The complete Calcomp plot for the two-section tandem blade example is shown in figure 17. All plots have the same format as this one. To the left of the plot are printed the complete input and some selected output variables. The input variables on the Calcomp plot and in the program are related as follows: C/C(1) = COC1, PHI/PHI(1) = PHOPH1, etc. For the output, PHI are the blade segment cambers, PHIC. The blades

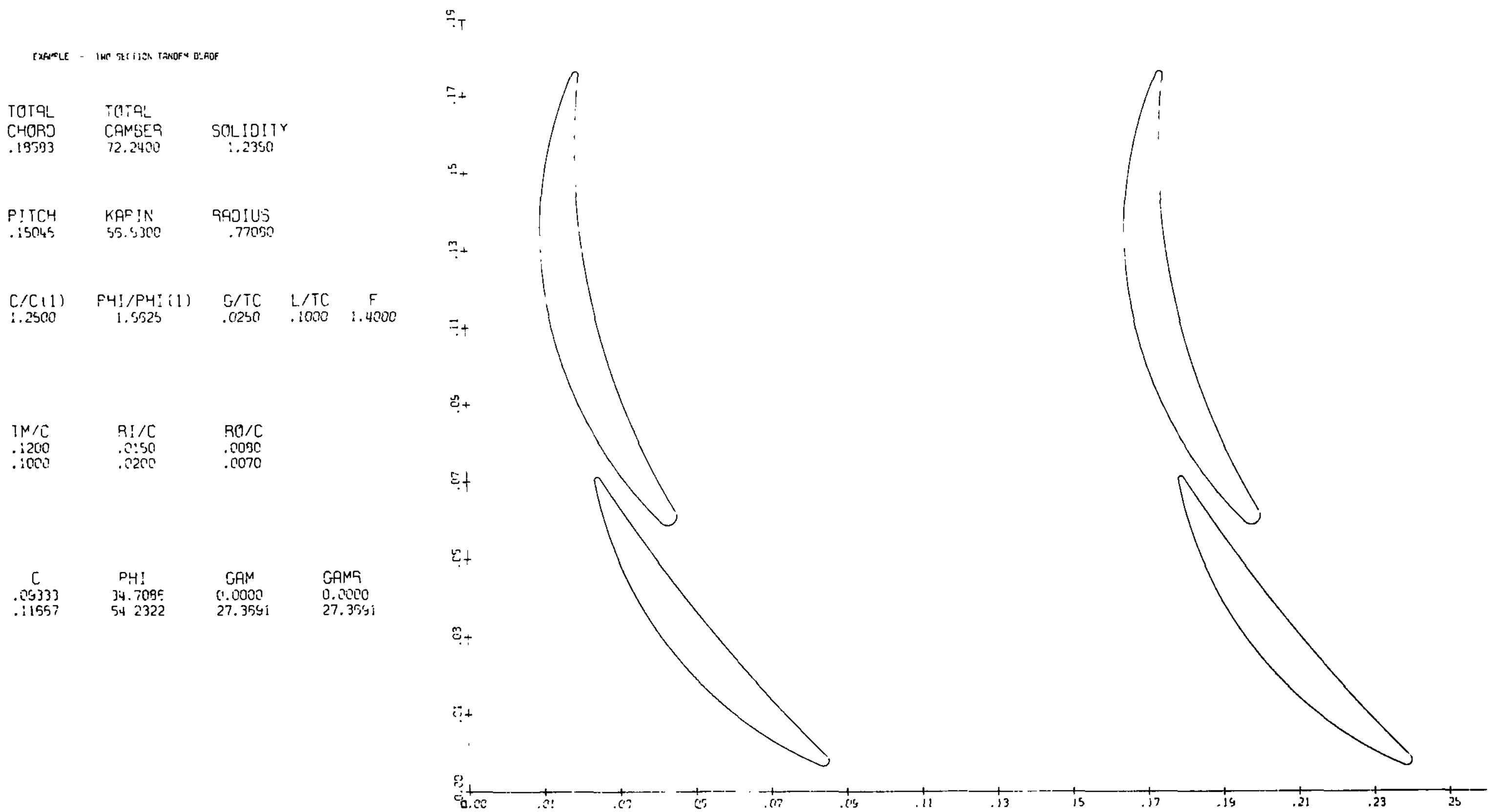


Figure 17. - Full Calcomp plot for two-section tandem blade example.

are drawn in a position corresponding to the blade angle, KAPIN. The Z-axis is normal to the sides of the Calcomp page. The blade is not positioned at (0, 0) and its origin has no set position in relation the plotted axis. So the plot is only useful for visual examination of the blade.

The portion of the program which generates the Calcomp plot is coded specifically for the NASA Lewis system and would not work elsewhere. However, the program is written with the plotting code at the end. A programmer at another installation could easily substitute a code to obtain a plot based on the requirements of his own system.

The coordinates for plotting are calculated and arranged in the PLOTT subroutine. (See COMPLETE PROGRAM LISTING.) Down to statement 310 of this routine the blade coordinates have been stored into two arrays: XDOWN and YACROS. The number of points on each blade segment have been stored into the array, NPNTS. After statement 310, the section of code labelled PREPARE KKK AND P AND CALL CALPLT prepares special variables for a call on the CALPLT routine which is internal to the Lewis system. The subroutine CALTIT, which writes the input and output to the left of the plot, also uses special Lewis routines. Finally, the statement DECK CALPLT calls in the CALPLT routine which does the plotting. So from statement 310 of the PLOTT routine to the end of the coding, changes would have to be made by a programmer to get plotting on another system.

Error Conditions

Several error messages are given by the program under certain conditions. This section lists the error messages and explains what to do if they are encountered.

(1) MAX THICKNESS OF SOME SEGMENT IS LESS THAN LEADING OR TRAILING EDGE THICKNESS OF THAT SEGMENT

This message is printed if either of the following conditions is found on any of the blade segments

$$\mathrm{TMOC} < 2.0 \times \mathrm{RIOC}$$

$$\mathrm{TMOC} < 2.0 \times \mathrm{ROOC}$$

The blade segments must be at least as thick as their leading- or trailing-edge thicknesses.

(2) THE SUM OF ONE PLUS THE VALUES IN THE PHOPH1 ARRAY MUST BE GREATER THAN 0.1

This message is only printed when negative input values are used in PHOPH1 and the sum of these input values is less than -0. 9. When excessive negative cambers are used, the program cannot converge on its iterations to calculate individual blade segment cambers. (A negative input to PHOPH1 implies that the first blade segment will have positive camber, and the segment corresponding to the negative PHOPH1 will have negative camber. This situation is permitted in the program, but is physically unrealistic. So the error message eliminates long iterations on bad data.)

(3) PROCEDURE FOR SIZING OF BLADE CAMBERS HAS NOT CONVERGED IN 25 ITERATIONS

The program initially calculates blade segment cambers and then corrects these cambers in an iteration process until an overall blade camber of DELK is obtained. Usually four or five iterations are required to reach a specified tolerance. The error message is given if convergence is not obtained in 25 iterations. This error is generally due to the fact that specified inputs are not geometrically compatible. This condition is most likely to occur when DELK is small (0° to 10°).

In addition to the programmed error messages, computer errors (such as square root of negative number) are likely to occur if input values are beyond recommended limits. Limits within which computer errors are not likely are summarized.

$$1 \leq N \leq 5$$

$$TCHORD > 0.$$

$$SOLID > 0.$$

$$0. \leq DELK \leq 180.$$

$$-90. \leq KAPIN \leq 90.$$

$$RADIUS > 0.$$

$$COC1 > 0.$$

$$-1000. \leq PHOPH1 \leq 1000.$$

$$0. \leq GOTC \leq 0.5$$

$$-0.2 \leq LOTC \leq 0.4$$

$$0.. \leq F \leq 10.$$

$$0. \leq TMOC \leq 0.8$$

$$0. \leq RIOC \leq 0.4$$

$$0. \leq ROOC \leq 0.4$$

COMPLETE PROGRAM LISTING

```
$IBJOB
$IBFTC CATBP
      COMMON/INPUT/N,TCHORD,SOLID,DELK,KAPIN,RADIUS,COC1(5),PHOPH1(5),
     1GOTC(5),LOTC(5),F(5),TMOC(5),RIOC(5),ROOC(5),TITLE(12)
      COMMON/OUTPUT/CHORD(5),GAM(5),GAMR(5),PHIC(5),PITCH
      COMMON/CLPLOT/XPEN,YPEN,NX,NY,IPEN,XLABEL(10),YLABEL(10)
      COMMON/COM1/RI(5),RO(5),THETA(5),XI(5),YI(5),XC(5),YC(5),
     1XCM(5),YCM(5),X1(5),Y1(5),X2(5),Y2(5),SLS(5),SLP(5),XSM(5),YSM(5),
     1XPM(5),YPM(5),KCM(5),G(5),GA(5),GAOC(5),L(5),FA(5),SINC(5),
     1RC(5),HC(5),BC(5),KIC(5),KOC(5),RS(5),HS(5),BS(5),KIS(5),KOS(5),
     1PHIS(5),RP(5),HP(5),BP(5),KIP(5),KOP(5),PHIP(5),TM(5),XR(5),YR(5),
     1XG(5),YG(5),NDEL(5),XX(5,100),YS(5,100),YP(5,100)
      COMMON/COM2/GAMS,MCHORD(5),RSTGR(5),STGR(5),MLE(5),RTHLE(5),
     1THLE(5),MTE(5),RTHTE(5),THTE(5),MCL(5),RTHCL(5),THCL(5),MCT(5),
     1RTHCT(5),THCT(5),BETIS(5),BETOS(5),BETIP(5),BETOP(5),MSPS(5,100),
     1RTHSPS(5,100),THSPS(5,100),MSPP(5,100),RTHSPP(5,100),THSPP(5,100)
      REAL L,LOTC,NEWC,KIC,KOC,KIS,KOS,KIP,KOP,KCM,
     1KGS1,KGS2,KGP1,KGP2,KGSI,KAPIN
      REAL MLE,MTE,MCL,MCT,MCHORD,MSPS,MSPP
   10 CALL BLDCRD
      CALL IFINPT
      CALL PLOTT
      GO TO 10
      END
```

```
$IBFTC BLDCR
      SUBROUTINE BLDCRD
      COMMON/INPUT/N,TCHORD,SOLID,DELK,KAPIN,RADIUS,COC1(5),PHOPH1(5),
     1GOTC(5),LOTC(5),F(5),TMOC(5),RIOC(5),ROOC(5),TITLE(12)
      COMMON/OUTPUT/CHORD(5),GAM(5),GAMR(5),PHIC(5),PITCH
      COMMON/COM1/RI(5),RO(5),THETA(5),XI(5),YI(5),XC(5),YO(5),
     1XCM(5),YCM(5),X1(5),Y1(5),X2(5),Y2(5),SLS(5),SLP(5),XSM(5),YSM(5),
     1XPM(5),YPM(5),KCM(5),G(5),GA(5),GAOC(5),L(5),FA(5),SINC(5),
```

```
     1RC(5),HC(5),BC(5),KIC(5),KOC(5),RS(5),HS(5),BS(5),KIS(5),KOS(5),
     1PHIS(5),RP(5),HP(5),BP(5),KIP(5),KOP(5),PHIP(5),TM(5),XR(5),YR(5),
     1XG(5),YG(5),NDEL(5),XX(5,100),YS(5,100),YP(5,100)
      REAL L,LOTC,NEWC,KIC,KOC,KIS,KOS,KIP,KOP,KCM,LC,
     1KGS1,KGS2,KGP1,KGP2,KGSI,KAPIN
C
C   READ AND PRINT INPUT
C
   10 WRITE(6,1000)
      READ (5,1250) (TITLE(I),I=1,12)
      WRITE(6,1260) (TITLE(I),I=1,12)
      READ (5,1020) N,TCHORD,SOLID,DELK,KAPIN,RADIUS
      WRITE(6,1030) N,TCHORD,SOLID,DELK,KAPIN,RADIUS
      READ (5,1010) (COC1(J),J=2,N)
      WRITE(6,1040) (COC1(J),J=2,N)
      READ (5,1010) (PHOPH1(J),J=2,N)
      WRITE(6,1050) (PHOPH1(J),J=2,N)
      READ (5,1010) (GOTC(J),J=2,N)
      WRITE(6,1060) (GOTC(J),J=2,N)
      READ (5,1010) (LOTC(J),J=2,N)
      WRITE(6,1070) (LOTC(J),J=2,N)
      READ (5,1010) (F(J),J=2,N)
      WRITE(6,1080) (F(J),J=2,N)
      READ (5,1010) (TMOC(J),J=1,N)
      WRITE(6,1090) (TMOC(J),J=1,N)
      READ (5,1010) (RIOC(J),J=1,N)
      WRITE(6,1100) (RIOC(J),J=1,N)
      READ (5,1010) (ROOC(J),J=1,N)
      WRITE(6,1110) (ROOC(J),J=1,N)
C
C   INITIAL VALUES OF CAMBER AND CHORD
C
      DELK = DELK/57.295779
      PITCH= TCHORD/SOLID
      SUMC= 0.
      SUML= 0.
      SUMPHI= 0.
      PHOPH1(1)= 1.0
      IF (N.EQ.1) GO TO 30
      DO 20 J=2,N
      SUML= SUML+LOTC(J)
      SUMC= SUMC+COC1(J)
   20 SUMPHI= SUMPHI+PHOPH1(J)
   30 FACTOR= 1./(1.-DELK**2/24.)
      SUML= FACTOR+SUML
      SUMC= 1.+SUMC
      SUMPHI= 1.+SUMPHI
      IF (SUMPHI.GT..1) GO TO 40
      WRITE(6,1270)
      GO TO 10
   40 CHORD(1)= TCHORD*SUML/SUMC
      PHIC(1)= DELK/SUMPHI
      IF (N.EQ.1) GO TO 60
      DO 50 J=2,N
      PHIC(J) = PHIC(1)*PHOPH1(J)
   50 CHORD(J)= CHORD(1)*COC1(J)
C
C   SIZING OF OTHER BLADE SEGMENT DIMENSIONS
C
   60 ITER = 1
      IF (N.EQ.1) GO TO 80
      DO 70 J=2,N
```

```
      L(J)= LOTC(J)*TCHORD
   70 G(J)= GOTC(J)*TCHORD
   80 DO 90 J=1,N
      TM(J)= TMOC(J)*CHORD(J)
      RI(J)= RIOC(J)*CHORD(J)
      RO(J) = ROOC(J)*CHORD(J)
      IF (2.*RI(J).LE.TM(J).AND.2.*RO(J).LE.TM(J)) GO TO 90
      WRITE(6,1120)
      GO TO 10
   90 CONTINUE
C
C  SEGMENT CENTER LINE CALCULATIONS
C
      DO 100 J=1,N
      XI(J) = RI(J)
      YI(J) = RI(J)
      XO(J) = CHORD(J)-RO(J)
      YO(J) = RO(J)
      ARG=(YI(J)-YO(J))/(XI(J)-XO(J))
  100 THETA(J)= -ATAN(ARG)
  110 DO 130 J=1,N
      KIC(J) =  PHIC(J)/2.-THETA(J)
      KOC(J) = -PHIC(J)/2.-THETA(J)
      IF (ABS(PHIC(J)).LT..0001) GO TO 120
      BC(J)= (XI(J)**2+YI(J)**2-XO(J)**2-YO(J)**2-2.*(XI(J)-XO(J))*(XI
     1(J)+YI(J)*TAN(KIC(J))))/2./(YO(J)-YI(J)+(XI(J)-XO(J))*TAN(KIC(J)))
      HC(J)= -XI(J)-(YI(J)+BC(J))*TAN(KIC(J))
      RC(J)= SQRT((XI(J)+HC(J))**2+(YI(J)+BC(J))**2)
      GO TO 130
  120 BC(J)= 999.99999
      IF (PHIC(J).LT.0.) BC(J)= -BC(J)
      HC(J)= -CHORD(J)/2.
      RC(J)= 999.99999
  130 CONTINUE
C
C  SEGMENT SURFACE CALCULATIONS
C
      DO 270 J=1,N
      K1 = 0
      ITIR= 0
      DEL = 0.1*CHORD(J)
      IF (RI(J).EQ.0.) GO TO 140
      RORI = RO(J)/RI(J)-1.
      GO TO 150
  140 RORI= 0.
  150 ROMRI= RO(J)-RI(J)
      CRO = CHORD(J)-2.*RO(J)
      CV = (TM(J)-2.*RI(J))/CHORD(J)
      XCM(J) = CHORD(J)/2.
      XCMM1 = XCM(J)
      LC= SQRT((CHORD(J)-RI(J)-RO(J))**2+(RI(J)-RO(J))**2)/2.0
      PC= PHIC(J)/2.0
      HCM= LC*TAN(PC/2.0)
      XC= RI(J)+LC*COS(THETA(J))+HCM*SIN(THETA(J))
  160 YCM(J)= RO(J)+(RI(J)-RO(J))*(CHORD(J)-XCM(J)-RO(J))/(CHORD(J)
     1-RI(J)-RO(J))
      IF (ABS(PHIC(J)).LT..0001) GO TO 170
      ALPH= THETA(J)+ASIN((XC-XCM(J))/LC*SIN(PC)-SIN(THETA(J)))
      YCM(J)= YCM(J)+LC/COS(THETA(J))*(SIN(PC)/(1.+COS(PC))-SIN(ALPH)**2
     1/((1.+COS(ALPH))*SIN(PC)))
  170 ARG= -((XCM(J)-RI(J))*SIN(PC)-LC*SIN(KIC(J)))/((YCM(J)-RI(J))*
     1SIN(PC)+LC*COS(KIC(J)))
```

```
      KCM(J)= ATAN(ARG)
C   SUCTION SURFACE
      XSM(J) = XCM(J)-TM(J)/2.*SIN(KCM(J))
      YSM(J) = YCM(J)+TM(J)/2.*COS(KCM(J))
      DS = XSM(J)*RORI+CRO
      XMRI = XSM(J)-RI(J)
      XMRI2 = XSM(J)-2.*RI(J)
      YMRI = YSM(J)-RI(J)
      YMRI2 = YSM(J)-2.*RI(J)
      XMYM = XSM(J)**2+YSM(J)**2
      AAS = XSM(J)*XMRI2*YSM(J)**2*RORI**2-2.*XMRI*YMRI*YSM(J)*RORI*DS
     1+YSM(J)*YMRI2*DS**2
      BBS = (XMYM*YMRI+RI(J)**3-3.*RI(J)**2*YSM(J))*DS**2-(XMYM*XMRI
     1+RI(J)**3-3.*RI(J)**2*XSM(J))*YSM(J)*RORI*DS+(XSM(J)*XMRI2*YSM(J)
     2*RORI-XMRI*YMRI*DS)*(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI)
      CCS = (XMYM**2+RI(J)**4-6.*RI(J)**2*XMYM)*DS**2+XSM(J)*XMRI2
     1*(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI)**2-2.*(XMYM*XMRI+RI(J)**3
     2-3.*RI(J)**2*XSM(J))*(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI)*DS
      IF (RI(J).EQ.0.) GO TO 180
      BS(J) = (-BBS+SQRT(BBS**2-AAS*CCS))/(2.*AAS)
      GO TO 190
  180 BS(J)= -BBS/(2.*AAS)
  190 HS(J) = -(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI+2.*YSM(J)*RORI*BS(J))
     1/(2.*(XSM(J)*RORI+CRO))
      SLS(J) = -(XSM(J)+HS(J))/(YSM(J)+BS(J))
C   PRESSURE SURFACE
      XPM(J) = XCM(J)+TM(J)/2.*SIN(KCM(J))
      YPM(J) = YCM(J)-TM(J)/2.*COS(KCM(J))
      DP = XPM(J)*RORI+CRO
      XMRI = XPM(J)-RI(J)
      XMRI2 = XPM(J)-2.*RI(J)
      YMRI = YPM(J)-RI(J)
      YMRI2 = YPM(J)-2.*RI(J)
      XMYM = XPM(J)**2+YPM(J)**2
      AAP = XPM(J)*XMRI2*YPM(J)**2*RORI**2-2.*XMRI*YMRI*YPM(J)*RORI*DP
     1+YPM(J)*YMRI2*DP**2
      BBP = (XMYM*YMRI+RI(J)**3-3.*RI(J)**2*YPM(J))*DP**2-(XMYM*XMRI
     1+RI(J)**3-3.*RI(J)**2*XPM(J))*YPM(J)*RORI*DP+(XPM(J)*XMRI2*YPM(J)
     2*RORI-XMRI*YMRI*DP)*(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI)
      CCP = (XMYM**2+RI(J)**4-6.*RI(J)**2*XMYM)*DP**2+XPM(J)*XMRI2
     1*(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI)**2-2.*(XMYM*XMRI+RI(J)**3
     2-3.*RI(J)**2*XPM(J))*(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI)*DP
      IF (RI(J).EQ.0.) GO TO 200
      BP(J) = (-BBP-SQRT(BBP**2-AAP*CCP))/(2.*AAP)
      GO TO 210
  200 BP(J)= -BBP/(2.*AAP)
  210 HP(J) = -(XMYM*RORI+CHORD(J)*CRO+RO(J)*ROMRI+2.*YPM(J)*RORI*BP(J))
     1/(2.*(XPM(J)*RORI+CRO))
      SLP(J) = -(XPM(J)+HP(J))/(YPM(J)+BP(J))
C   CHECK FOR MAX THICKNESS POINT CONVERGENCE
      DSL = SLS(J)-SLP(J)
      IF (CV.EQ.0.) GO TO 260
      IF (ABS(DSL).LE..0001*CV) GO TO 260
      IF (ITIR.EQ.0) GO TO 220
      IF (DSL/DSLM1.LT..0) K1=1
  220 ITIR= ITIR+1
      IF (K1.EQ.0) GO TO 230
      GO TO 240
  230 XCM(J) = XCM(J)+DSL/ABS(DSL)*DEL
      GO TO 250
  240 XCM(J) = XCMM1+(XCMM2-XCMM1)/(1.-DSLM1/DSL)
  250 DSLM1 = DSL
```

```
      XCMM2 = XCMM1
      XCMM1 = XCM(J)
      GO TO 160
C  FINAL CALCULATIONS AFTER CONVERGENCE
  260 RS(J) = SQRT((XSM(J)+HS(J))**2+(YSM(J)+BS(J))**2)
      RP(J) = SQRT((XPM(J)+HP(J))**2+(YPM(J)+BP(J))**2)
      ARG = -(RI(J)+HS(J))/(RI(J)+BS(J))
      KIS(J) = ATAN(ARG)
      ARG = -(RI(J)+HP(J))/(RI(J)+BP(J))
      KIP(J) = ATAN(ARG)
      ARG = -(CHORD(J)+HS(J)-RO(J))/(RO(J)+BS(J))
      KOS(J) = ATAN(ARG)
      ARG = -(CHORD(J)+HP(J)-RO(J))/(RO(J)+BP(J))
      KOP(J) = ATAN(ARG)
      PHIS(J) = KIS(J)-KOS(J)
  270 PHIP(J) = KIP(J)-KOP(J)
C
C  LOCATION OF BLADE SEGMENTS WITH RESPECT TO ONE ANOTHER
C
      GAM(1) = 0.
      GAMR(1)= 0.
      IF (N.EQ.1) GO TO 330
      DO 310 J=2,N
      XR(J)= CHORD(J-1)-RO(J-1)-L(J)
      IF (BP(J-1).LT..0) GO TO 280
      YR(J)= SQRT(RP(J-1)**2-(XR(J)+HP(J-1))**2)-BP(J-1)-F(J)*G(J)-RI(J)
      GO TO 290
  280 YR(J)=-SQRT(RP(J-1)**2-(XR(J)+HP(J-1))**2)-BP(J-1)-F(J)*G(J)-RI(J)
  290 XG(J)= CHORD(J-1)-RO(J-1)
      YG(J)= -G(J)
      AA= 2.*((XG(J)-XR(J))*(RI(J)+HS(J))+(YG(J)-YR(J))*(RI(J)+BS(J)))
      BB= 2.*((XG(J)-XR(J))*(RI(J)+BS(J))-(YG(J)-YR(J))*(RI(J)+HS(J)))
      CC= RI(J)*(2.0*RS(J)-RI(J))-(XG(J)-XR(J))**2-(YG(J)-YR(J))**2
      IF (L(J).LT.0.) GO TO 300
      SINGAM = (BB*CC-AA*SQRT(AA**2+BB**2-CC**2))/(AA**2+BB**2)
      GO TO 310
  300 SINGAM = (BB*CC+AA*SQRT(AA**2+BB**2-CC**2))/(AA**2+BB**2)
  310 GAM(J)= ARSIN(SINGAM)
C
C  CHECK ON OVERALL BLADE TURNING AND RESIZING CAMBERS OF BLADE SEGMENTS
C
      DO 320 J=2,N
  320 GAMR(J)= GAMR(J-1)+GAM(J)
  330 DELKT= KIC(1)+GAMR(N)-KOC(N)
      DIFF= DELK-DELKT
      IF (ABS(DIFF).LT..001) GO TO 360
      ITER=ITER+1
      IEND= 0
      IF (ITER.GT.25) GO TO 350
      DO 340 J=1,N
  340 PHIC(J)= PHIC(J)+DIFF*PHOPH1(J)/SUMPHI
      GO TO 370
  350 WRITE(6,1130)
      GO TO 10
C
C  RESIZING CHORDS OF BLADE SEGMENTS
C
  360 IEND= 1
  370 XOB = XO(N)
      YOB = YO(N)
      IF (N.EQ.1) GO TO 390
      DO 380 K=2,N
```

```
      J= N-K+2
      SING= SIN(GAM(J))
      COSG= COS(GAM(J))
      XOBB= XR(J)+XCB*COSG+YOB*SING-RI(J)*(SING+COSG)
      YOBB= YR(J)+YCB*COSG-XCB*SING+RI(J)*(SING-COSG)
      XOB = XOBB
  380 YOB = YOBB
  390 IF (IEND.EQ.1) GO TO 410
      NEWC = SQRT((XOB-XI(1))**2+(YOB-YI(1))**2)+RI(1)+RO(N)
      CRATIO= TCHORD/NEWC
      DO 400 J=1,N
  400 CHORD(J)= CHORD(J)*CRATIO
      GO TO 60
C
C  OVERALL BLADE THETA AND GAMMA
C
  410 ARG= (RI(1)-RO(N))/(TCHORD-RI(1)-RO(N))
      THETB = ATAN(ARG)
      ARG= (YI(1)-YOB)/(XOB-XI(1))
      GAMBTB= ATAN(ARG)
      GAMB= GAMBTB-THETB
      IF (N.EQ.1) GO TO 430
C
C  PSEUDO-INCIDENCE ANGLES ON AFT BLADES
C
      DO 420 J=2,N
      ARG= (CHORD(J-1)+HO(J-1)-RO(J-1))/RO(J-1)
      RHO1= ARSIN(ARG)
      ARG= (CHORD(J-1)+HO(J-1)-RO(J-1)-L(J))/RO(J-1)
      RHO2= ARSIN(ARG)
      RHO= RHO1-RHO2
  420 SINC(J)= -(KIC(J)-GAM(J)-KOC(J-1)-RHO)
C
C  BLADE SECTION COORDINATES AT DELX INCREMENTS
C
  430 DO 490 J=1,N
      TEM = CHORD(J)/20./10000.
      NEXP = 0
  440 NEXP = NEXP+1
      TEM = 10.*TEM
      IF (TEM-1..LT.0.) GO TO 440
      M = TEM
      IF (M.GE.2) GO TO 450
      M = 1
      GO TO 470
  450 IF (M.GE.5) GO TO 460
      M = 2
      GO TO 470
  460 M = 5
  470 DELX = FLOAT(M)*10.**(4-NEXP)
      NDEL(J)= CHORD(J)/DELX+1.
      XX(J,1)=0.
      NDELJ = NDEL(J)
      DO 490 K=1,NDELJ
      YS(J,K)= SQRT(RS(J)**2-(XX(J,K)+HS(J))**2)-BS(J)
      IF (BP(J).LT..0) GO TO 480
      YP(J,K)= SQRT(RP(J)**2-(XX(J,K)+HP(J))**2)-BP(J)
      GO TO 490
  480 YP(J,K)=-SQRT(RP(J)**2-(XX(J,K)+HP(J))**2)-BP(J)
  490 XX(J,K+1)= XX(J,K)+DELX
C
C  RELATION OF SEGMENT ORIGINS TO PRINCIPAL ORIGIN
```

```
C
      X1(1) = 0.
      Y1(1) = 0.
      X2(1) = CHORD(1)
      Y2(1) = 0.
      IF (N.EQ.1) GO TO 580
      DO 500 J=2,N
      TEMA = XR(J)-RI(J)*(COS(GAM(J))+SIN(GAM(J)))
      TEMB = YR(J)+RI(J)*(SIN(GAM(J))-COS(GAM(J)))
      TEMC = TEMB/COS(GAMR(J-1))
      TEMD = TEMC*SIN(GAMR(J-1))
      TEME= TEMA+TEMD
      TEMF = TEME*SIN(GAMR(J-1))
      DX = TEME*COS(GAMR(J-1))
      DY = TEMF-TEMC
      X1(J) = X1(J-1)+DX
      Y1(J) = Y1(J-1)-DY
      X2(J) = X1(J)+CHORD(J)*COS(GAMR(J))
  500 Y2(J) = Y1(J)-CHORD(J)*SIN(GAMR(J))
C
C  COMPUTATION OF ACTUAL GAPS
C
      DO 570 J=2,N
C  REAR PORTION OF GAP
      KGS1 = 100.
  510 ARG = -((XG(J)-XR(J))*COS(GAM(J))-(YG(J)-YR(J))*SIN(GAM(J))
     1+RI(J)+HS(J))/((XG(J)-XR(J))*SIN(GAM(J))+(YG(J)-YR(J))*COS(GAM(J))
     2+RI(J)+BS(J))
      KGS2 = ATAN(ARG)
      IF (ABS(KGS2-KGS1).LE..01) GO TO 520
      BETA = KGS2-GAM(J)
      CA = (XO(J-1)+YO(J-1)*TAN(BETA)-XR(J))*COS(GAM(J))+
     1YR(J)*SIN(GAM(J))+RI(J)+HS(J)
      CB = -(TAN(BETA)*COS(GAM(J))+SIN(GAM(J)))
      CC = (XO(J-1)+YO(J-1)*TAN(BETA)-XR(J))*SIN(GAM(J))-
     1YR(J)*COS(GAM(J))+RI(J)+BS(J)
      CD = COS(GAM(J))-TAN(BETA)*SIN(GAM(J))
      CE = CB**2+CD**2
      CF = 2.*(CA*CB+CC*CD)
      CG = CA**2+CC**2-RS(J)**2
      YG(J) = (-CF+SQRT(CF**2-4.*CE*CG))/(2.*CE)
      XG(J) = XO(J-1)-(YG(J)-YO(J-1))*TAN(BETA)
      KGS1 = KGS2
      GO TO 510
  520 GA(J) = SQRT((XG(J)-XO(J-1))**2+(YG(J)-YO(J-1))**2)-RO(J-1)
      GAOC(J)= GA(J)/CHORD(J-1)
C  FORWARD PORTION OF GAP
      KGP1 = 100.
      XGP = XR(J)
      YGP = SQRT(RP(J-1)**2-(XGP+HP(J-1))**2)-BP(J-1)
  530 ARG = -(XGP+HP(J-1))/(YGP+BP(J-1))
      KGP2 = ATAN(ARG)
      IF (ABS(KGP2-KGP1).LE..01) GO TO 560
      ARG = (-HS(J)-RI(J))/(BS(J)+RI(J))
      KGSI = ATAN(ARG)-GAM(J)
      BETA = (KGP2+KGSI)/2.
      CL = 1.+(TAN(BETA))**2
      CM = 2.*(BP(J-1)-(XR(J)+YR(J)*TAN(BETA)+HP(J-1))*TAN(BETA))
      CN = (XR(J)+YR(J)*TAN(BETA)+HP(J-1))**2+BP(J-1)**2-RP(J-1)**2
      IF (BP(J-1).LT..0) GO TO 540
      YGP = (-CM+SQRT(CM**2-4.*CL*CN))/(2.*CL)
      GO TO 550
  540 YGP = (-CM-SQRT(CM**2-4.*CL*CN))/(2.*CL)
```

```
  550 XGP = XR(J)-(YGP-YR(J))*TAN(BETA)
      KGP1 = KGP2
      GO TO 530
  560 FG = SQRT((XR(J)-XGP)**2+(YR(J)-YGP)**2)
      BETA = BETA+GAM(J)
      CL = 1.+(TAN(BETA))**2
      CM = 2.*(BS(J)-(XI(J)+YI(J)*TAN(BETA)+HS(J))*TAN(BETA))
      CN = (XI(J)+YI(J)*TAN(BETA)+HS(J))**2+BS(J)**2-RS(J)**2
      YGS = (-CM+SQRT(CM**2-4.*CL*CN))/(2.*CL)
      XGS = XI(J)-(YGS-YI(J))*TAN(BETA)
      FG2 = SQRT((XGS-XI(J))**2+(YGS-YI(J))**2)
      FG = FG-FG2
  570 FA(J) = FG/GA(J)
C
C  PUT OUTPUT ANGLES IN DEGREES
C
  580 DELK = DELK*57.295779
      GAMB = GAMB*57.295779
      THETB = THETB*57.295779
      DO 590 J=1,N
      GAM(J) = GAM(J)*57.295779
      GAMR(J) = GAMR(J)*57.295779
      THETA(J) = THETA(J)*57.295779
      SINC(J)= SINC(J)*57.295779
      PHIC(J) = PHIC(J)*57.295779
      PHIS(J) = PHIS(J)*57.295779
      PHIP(J) = PHIP(J)*57.295779
      KIC(J) = KIC(J)*57.295779
      KIS(J) = KIS(J)*57.295779
      KIP(J) = KIP(J)*57.295779
      KOC(J) = KOC(J)*57.295779
      KOS(J) = KOS(J)*57.295779
  590 KOP(J) = KOP(J)*57.295779
C
C  CHANGE SIGN OF SELECTED OUTPUTS
C
      DO 600 J=1,N
      HS(J)= -HS(J)
      HC(J)= -HC(J)
      HP(J)= -HP(J)
      KOS(J)= -KOS(J)
      KOC(J)= -KOC(J)
      KOP(J)= -KOP(J)
      Y1(J)= -Y1(J)
  600 Y2(J)= -Y2(J)
      YOB= -YOB
C
C  PRINT OUTPUT
C
      WRITE(6,1000)
      WRITE(6,1140) N,TCHORD,PITCH,SOLID,DELK,KAFIN,GAMB,THETB,XCB,YOB
      DO 620 J=1,N
      WRITE(6,1150) J
      WRITE(6,1160) CHORD(J),RI(J),RO(J),THETA(J)
      WRITE(6,1170) XI(J),YI(J),XC(J),YC(J),XCM(J),YCM(J)
      WRITE(6,1180) X1(J),Y1(J),X2(J),Y2(J),GAM(J),GAMR(J)
      WRITE(6,1190) PHIS(J),RS(J),HS(J),BS(J),KIS(J),KOS(J)
      WRITE(6,1200) PHIC(J),RC(J),HC(J),BC(J),KIC(J),KOC(J)
      WRITE(6,1210) PHIP(J),RP(J),HP(J),BP(J),KIP(J),KOP(J)
      IF (J.EQ.1) GO TO 610
      WRITE(6,1220) G(J),GA(J),GAOC(J),L(J),F(J),FA(J),SINC(J)
```

```
  610 WRITE(6,1230) NDEL(J)
      NDELJ = NDEL(J)
  620 WRITE(6,1240) (XX(J,K),YS(J,K),YP(J,K), K=1,NDELJ)
      RETURN
C
C   FORMAT STATEMENTS
C
 1000 FORMAT(1H1///)
 1010 FORMAT(8F10.5)
 1020 FORMAT(I10,5F10.5)
 1030 FORMAT(//6X,1HN,6X,6HTCHORD,6X,5HSOLID,6X,4HDELK,6X,5HKAPIN,5X,
     16HRADIUS/5X,I2,5X,F8.5,3X,F8.4,3X,F7.3,4X,F7.3,3X,F8.5)
 1040 FORMAT(/6X,12HC/C(1) ARRAY/(19X,5(F9.5,1X)))
 1050 FORMAT(/6X,16HPHI/PHI(1) ARRAY/(19X,5(F9.5,1X)))
 1060 FORMAT(/6X,10HG/TC ARRAY/(19X,5(F9.5,1X)))
 1070 FORMAT(/6X,10HL/TC ARRAY/(19X,5(F9.5,1X)))
 1080 FORMAT(/6X,7HF ARRAY/(19X,5(F9.5,1X)))
 1090 FORMAT(/6X,10HTM/C ARRAY/(9X,5(F9.5,1X)))
 1100 FORMAT(/6X,10HRI/C ARRAY/(9X,5(F9.5,1X)))
 1110 FORMAT(/6X,10HRO/C ARRAY/(9X,5(F9.5,1X)))
 1120 FORMAT(///////10X,93HMAX THICKNESS OF SOME SEGMENT IS LESS THAN LE
     1ADING OR TRAILING EDGE THICKNESS OF THAT SEGMENT)
 1130 FORMAT(///////10X,72HPROCEDURE FOR SIZING OF BLADE CAMBERS HAS NOT
     1 CONVERGED IN 25 ITERATIONS)
 1140 FORMAT(10X,24HOVERALL BLADE PARAMETERS/14X,1HN,6X,6HTCHORD,7X,
     15HPITCH,6X,5HSOLID,7X,4HDELK,7X,5HKAPIN,7X,4HGAMB,6X,5HTHETB,7X,
     23HXOB,8X,3HYOB/13X,I2,5X,F8.5,4X,F8.5,4X,F7.4,3X,F8.3,3X,F9.4,
     33X,F9.4,3X,F7.4,2X,F9.5,2X,F9.5)
 1150 FORMAT(///10X,18HBLADE SEGMENT NO. ,I2)
 1160 FORMAT(/13X,5HCHORD,6X,2HRI,8X,2HRO,7X,5HTHETA/10X,4(F9.5,1X))
 1170 FORMAT(/14X,2HXI,8X,2HYI,8X,2HXO,8X,2HYO,8X,3HXCM,7X,3HYCM/
     110X,6(F9.5,1X))
 1180 FORMAT(/14X,2HX1,8X,2HY1,8X,2HX2,8X,2HY2,7X,3HGAM,7X,4HGAMR/
     110X,6(F9.5,1X))
 1190 FORMAT(/13X,4HPHIS,7X,2HRS,8X,2HHS,8X,2HBS,7X,3HKIS,7X,3HKOS/
     110X,6(F9.5,1X))
 1200 FORMAT(/13X,4HPHIC,7X,2HRC,8X,2HHC,8X,2HBC,7X,3HKIC,7X,3HKOC/
     110X,6(F9.5,1X))
 1210 FORMAT(/13X,4HPHIP,7X,2HRP,8X,2HHP,8X,2HBP,7X,3HKIP,7X,3HKOP/
     110X,6(F9.5,1X))
 1220 FORMAT(/14X,1HG,9X,2HGA,7X,4HGACC,7X,1HL,9X,1HF,9X,2HFA,7X,4HSINC/
     110X,7(F9.5,1X))
 1230 FORMAT(/14X,2HXX,8X,2HYS,8X,2HYP,5X,7HNDEL = ,I2)
 1240 FORMAT((10X,3(F9.5,1X)))
 1250 FORMAT(12A6)
 1260 FORMAT(1X,12A6)
 1270 FORMAT(///////10X,75HTHE SUM OF ONE PLUS THE VALUES IN THE PHOPHI
     1ARRAY MUST BE GREATER THAN 0.1)
      END
```

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$IBFTC IFINP

      SUBROUTINE IFINPT
      COMMON/INPUT/N,TCHORD,SOLID,DELK,KAPIN,RADIUS,COC1(5),PHOPHI(5),
     1GOTC(5),LOTC(5),F(5),TMOC(5),RIOC(5),ROOC(5),TITLE(12)
      COMMON/OUTPUT/CHORD(5),GAM(5),GAMR(5),PHIC(5),PITCH
      COMMON/COM1/RI(5),RO(5),THETA(5),XI(5),YI(5),XO(5),YO(5),
     1XCM(5),YCM(5),X1(5),Y1(5),X2(5),Y2(5),SLS(5),SLP(5),XSM(5),YSM(5),
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     1XPM(5),YPM(5),KCM(5),G(5),GA(5),GACC(5),L(5),FA(5),SINC(5),
     1RC(5),HC(5),BC(5),KIC(5),KOC(5),RS(5),HS(5),BS(5),KIS(5),KOS(5),
     1PHIS(5),RP(5),HP(5),BP(5),KIP(5),KOP(5),PHIP(5),TM(5),XR(5),YR(5),
     1XG(5),YG(5),NDEL(5),XX(5,100),YS(5,100),YP(5,100)
      COMMON/COM2/GAMS,MCHORD(5),RSTGR(5),STGR(5),MLE(5),RTHLE(5),
     1THLE(5),MTE(5),RTHTE(5),THTE(5),MCL(5),RTHCL(5),THCL(5),MCT(5),
     1RTHCT(5),THCT(5),BETIS(5),BETCS(5),BETIP(5),BETCP(5),MSPS(5,100),
     1RTHSPS(5,100),THSPS(5,100),MSPP(5,100),RTHSPP(5,100),THSPP(5,100)
      REAL L,LOTC,NEWC,KIC,KOC,KIS,KOS,KIP,KOP,KCM,
     1KGS1,KGS2,KGP1,KGP2,KGSI,KAPIN
      REAL MLE,MTE,MCL,MCT,MCHORD,MSPS,MSPP
C
C
C  COMPUTATION OF GEOMETRICAL INPUT FOR TANDEM BLADE, IDEAL FLOW PROGRAM
C
C  CHANGE SIGN OF SELECTED PARAMETERS
C
      DO 10 J=1,N
      KOS(J)= -KOS(J)
      KOC(J)= -KOC(J)
      KOP(J)= -KOP(J)
      Y1(J)= -Y1(J)
   10 Y2(J)= -Y2(J)
      YOB= -YOB
C  LOCATION OF CENTERS OF LEADING EDGE CIRCLES
C
      GAMS = (KAPIN-KIC(1))/57.295779
      DO 20 J=1,N
      GAMR(J) = GAMR(J)/57.295779
      GAMJ = GAMS-GAMR(J)
      TEM1 = (X1(J)-RI(1))*COS(GAMS)-(Y1(J)-RI(1))*SIN(GAMS)+RI(1)
      TEM2 = (X1(J)-RI(1))*SIN(GAMS)+(Y1(J)-RI(1))*COS(GAMS)
      MCL(J) = TEM1-RI(J)*SIN(GAMJ)+RI(J)*COS(GAMJ)
      RTHCL(J) = TEM2+RI(J)*COS(GAMJ)+RI(J)*SIN(GAMJ)
   20 THCL(J) = RTHCL(J)/RADIUS
C
C  LOCATION OF CENTERS OF TRAILING EDGE CIRCLES
C
      DO 30 J=1,N
      GAMJ = GAMS-GAMR(J)
      TEM1 = (X2(J)-RI(1))*COS(GAMS)-(Y2(J)-RI(1))*SIN(GAMS)+RI(1)
      TEM2 = (X2(J)-RI(1))*SIN(GAMS)+(Y2(J)-RI(1))*COS(GAMS)
      MCT(J) = TEM1-RO(J)*SIN(GAMJ)-RO(J)*COS(GAMJ)
      RTHCT(J) = TEM2+RO(J)*COS(GAMJ)-RO(J)*SIN(GAMJ)
   30 THCT(J) = RTHCT(J)/RADIUS
C
C  LOCATION OF LEADING EDGES
C
      DO 40 J=1,N
      MLE(J) = MCL(J)-RI(J)
      RTHLE(J) = RTHCL(J)
   40 THLE(J) = THCL(J)
C
C  LOCATION OF TRAILING EDGES
C
      DO 50 J=1,N
      MTE(J) = MCT(J)+RO(J)
      RTHTE(J) = RTHCT(J)
   50 THTE(J) = THCT(J)
C
C  LOCATION OF LOCAL BLADE CHORDS AND STAGGERS
C
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```
      DO 60 J=1,N
      MCHORD(J) = MTE(J)-MLE(J)
      RSTGR(J) = RTHTE(J)-RTHLE(J)
   60 STGR(J) = THTE(J)-THLE(J)
C
C  LOCATION OF SPLINE CURVE ANGLES
C
      DO 70 J=1,N
      GAMJ = GAMS-GAMR(J)
      BETIS(J) = KIS(J)+GAMJ*57.295779
      BETOS(J) = KOS(J)+GAMJ*57.295779
      BETIP(J) = KIP(J)+GAMJ*57.295779
   70 BETOP(J) = KOP(J)+GAMJ*57.295779
C
C  LOCATION OF SPLINE POINTS ON BLADES
C
      DO 80 J=1,N
      GAMJ = GAMS-GAMR(J)
      TEM1 = (X1(J)-RI(1))*COS(GAMS)-(Y1(J)-RI(1))*SIN(GAMS)+RI(1)
      TEM2 = (X1(J)-RI(1))*SIN(GAMS)+(Y1(J)-RI(1))*COS(GAMS)
      NDELJ = NDEL(J)
      DO 80 K=1,NDELJ
      MSPS(J,K) = TEM1+XX(J,K)*COS(GAMJ)-YS(J,K)*SIN(GAMJ)-MLE(J)
      MSPP(J,K) = TEM1+XX(J,K)*COS(GAMJ)-YP(J,K)*SIN(GAMJ)-MLE(J)
      RTHSPS(J,K) = TEM2+XX(J,K)*SIN(GAMJ)+YS(J,K)*COS(GAMJ)-RTHLE(J)
      RTHSPP(J,K) = TEM2+XX(J,K)*SIN(GAMJ)+YP(J,K)*COS(GAMJ)-RTHLE(J)
      THSPS(J,K) = RTHSPS(J,K)/RADIUS
   80 THSPP(J,K) = RTHSPP(J,K)/RADIUS
C
C  PRINT OUTPUT
C
      WRITE(6,1000)
      WRITE(6,1010)
      WRITE(6,1020) (J,MCHORD(J),STGR(J),RSTGR(J),RI(J),RO(J),
     1MLE(J),THLE(J),RTHLE(J),MTE(J),THTE(J),RTHTE(J),J=1,N)
      WRITE(6,1030)
      WRITE(6,1040) (J,BETIS(J),BETOS(J),BETIP(J),BETOP(J),
     1MCL(J),THCL(J),RTHCL(J),MCT(J),THCT(J),RTHCT(J),J=1,N)
      DO 90 J=1,N
      WRITE(6,1050) J
      WRITE(6,1060)
      NDELJ = NDEL(J)
   90 WRITE(6,1070) (MSPS(J,K),THSPS(J,K),RTHSPS(J,K),
     1MSPP(J,K),THSPP(J,K),RTHSPP(J,K),K=1,NDELJ)
      RETURN
C
C  FORMAT STATEMENTS
C
 1000 FORMAT(1H1/////10X,38HCOMPUTED INPUT FOR IDEAL FLOW PROGRAMS////)
 1010 FORMAT(14X,5HBLADE,5X,6HMCHORD,4X,4HSTGR,6X,5HRSTGR,6X,2HRI,8X,
     12HRO,8X,3HMLE,6X,4HTHLE,6X,5HRTHLE,6X,3HMTE,6X,4HTHTE,6X,5HRTHTE)
 1020 FORMAT(15X,I2,3X,11F10.5)
 1030 FORMAT(////14X,5HBLADE,5X,5HBETIS,5X,5HBETOS,5X,5HBETIP,5X,5HBETOP
     1,16X,3HMCL,6X,4HTHCL,6X,5HRTHCL,6X,3HMCT,6X,4HTHCT,6X,5HRTHCT)
 1040 FORMAT(15X,I2,3X,4F10.5,10X,6F10.5)
 1050 FORMAT(///10X,18HBLADE SEGMENT NO. ,I2)
 1060 FORMAT(/14X,4HMSPS,6X,5HTHSPS,4X,6HRTHSPS,15X,4HMSPP,6X,
     15HTHSPP,4X,6HRTHSPP)
 1070 FORMAT((10X,3F10.5,10X,3F10.5))
      END
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$IBFTC PLT

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      SUBROUTINE PLOTT
      COMMON/INPUT/N,TCHORD,SOLID,DELK,KAPIN,RADIUS,CCCI(5),PHOPHI(5),
     1GOTC(5),LOTC(5),F(5),TMOC(5),RICC(5),ROCC(5),TITLE(12)
      COMMON/OUTPUT/CHORD(5),GAM(5),GAMR(5),PHIC(5),PITCH
      COMMON/CLPLOT/XPEN,YPEN,NX,NY,IPEN,XLABEL(10),YLABEL(10)
      COMMON/COM1/RI(5),RO(5),THETA(5),XI(5),YI(5),XC(5),YC(5),
     1XCM(5),YCM(5),X1(5),Y1(5),X2(5),Y2(5),SLS(5),SLP(5),XSM(5),YSM(5),
     1XPM(5),YPM(5),KCM(5),G(5),GA(5),GAOC(5),L(5),FA(5),SINC(5),
     1RC(5),FC(5),BC(5),KIC(5),KCC(5),FS(5),HS(5),BS(5),KIS(5),KCS(5),
     1PHIS(5),RP(5),HP(5),BP(5),KIP(5),KOP(5),PHIP(5),TM(5),XR(5),YR(5),
     1XG(5),YG(5),NDEL(5),XX(5,100),YS(5,100),YP(5,100)
      COMMON/COM2/GAMS,MCHORD(5),RSTGR(5),STGR(5),MLE(5),RTHLE(5),
     1THLE(5),MTE(5),RTHTE(5),THTE(5),MCL(5),RTHCL(5),THCL(5),MCT(5),
     1RTHCT(5),THCT(5),BETIS(5),BETCS(5),BETIP(5),BETCP(5),MSPS(5,100),
     1RTHSPS(5,100),THSPS(5,100),MSPP(5,100),RTHSPP(5,100),THSPP(5,100)
      DIMENSION X1S(5),Y1S(5),X1P(5),Y1P(5),X2S(5),Y2S(5),X2P(5),Y2P(5),
     1NDELS(5),NDELP(5),N1(5),N2(5),NPNTS(5),XCRX(5),YCRY(5),XIX(5),
     1YIY(5),XOX(5),YOY(5),XS(5,100),XP(5,100),XSX(5,100),YSY(5,100),
     1XPX(5,100),YPY(5,100),XIXC(5,100),YIYC(5,100),XOXC(5,100),
     1YOYC(5,100),XDOWN(2000),YACROS(2000),XTEMP(1000),YTEMP(1000),
     1KKK(25),P(25)
      EQUIVALENCE (XS(1,1),MSPS(1,1)),(XP(1,1),RTHSPS(1,1)),
     1(XSX(1,1),THSPS(1,1)),(YSY(1,1),MSPP(1,1)),
     1(XPX(1,1),RTHSPP(1,1)),(YPY(1,1),THSPP(1,1))
      REAL L,LOTC,NEWC,KIC,KCC,KIS,KCS,KIP,KCP,KCM,
     1KGS1,KGS2,KGP1,KGP2,KGSI,KAPIN
      REAL MLE,MTE,MCL,MCT,MCHORD,MSPS,MSPP
C
C
C   CALCULATION OF INPUT FOR CALCOMP PLOTTER
C
C
C   PUT ANGLES IN RADIANS
C
      PI = 3.14159265
      DO 10 J=1,N
      KIS(J) = KIS(J)/57.295779
      KIP(J) = KIP(J)/57.295779
      KOS(J) = KOS(J)/57.295779
   10 KOP(J) = KOP(J)/57.295779
C
C   OVERALL BLADE SIZE
C
      YMAX = RS(1)-BS(1)
      YMIN = YOB-RO(N)
      XMAX = XOB+RO(N)
      XMIN = 0.
      DX = XMAX-XMIN
      DY = YMAX-YMIN
C
C   LOCATION OF OVERALL BLADE ORIGIN WITH RESPECT TO PLOT ORIGIN
C
      XT = DX/18.
      YT = YMAX+DX/9.
C
C   LOCATION OF POINTS WHERE LEADING AND TRAILING EDGE RADII MEET
C   BLADE SURFACES
C
      DO 20 J=1,N
      X1S(J) = XI(J)-RI(J)*SIN(KIS(J))
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```
      Y1S(J) = YI(J)+RI(J)*COS(KIS(J))
      X1P(J) = XI(J)+RI(J)*SIN(KIP(J))
      Y1P(J) = YI(J)-RI(J)*COS(KIP(J))
      X2S(J) = CHORD(J)-RO(J)*(1.+SIN(KOS(J)))
      Y2S(J) = YO(J)+RO(J)*COS(KOS(J))
      X2P(J) = CHORD(J)-RO(J)*(1.-SIN(KOP(J)))
   20 Y2P(J) = YO(J)-RO(J)*COS(KOP(J))
C
C   ELIMINATION OF XX,YS, AND YP POINTS NOT ON THE BLADE SURFACES
C
      DO 110 J=1,N
      NDELJ = NDEL(J)
C   SUCTION SURFACE
      M = 1
      DO 30 K=1,NDELJ
      IF (XX(J,K).GT.X1S(J)) GO TO 40
   30 CONTINUE
   40 XS(J,1) = X1S(J)
      YS(J,1) = Y1S(J)
      KK = K
      DO 50 K=KK,NDELJ
      IF (XX(J,K).GT.X2S(J)) GO TO 60
      M = M+1
      XS(J,M) = XX(J,K)
   50 YS(J,M) = YS(J,K)
   60 M = M+1
      XS(J,M) = X2S(J)
      YS(J,M) = Y2S(J)
      NDELS(J) = M
C   PRESSURE SURFACE
      M = 1
      DO 70 K=1,NDELJ
      IF (XX(J,K).GT.X1P(J)) GO TO 80
   70 CONTINUE
   80 XP(J,1) = X1P(J)
      YP(J,1) = Y1P(J)
      KK = K
      DO 90 K=KK,NDELJ
      IF (XX(J,K).GT.X2P(J)) GO TO 100
      M = M+1
      XP(J,M) = XX(J,K)
   90 YP(J,M) = YP(J,K)
  100 M = M+1
      XP(J,M) = X2P(J)
      YP(J,M) = Y2P(J)
  110 NDELP(J) = M
C
C   LOCATION OF LOCAL BLADE ORIGINS WITH RESPECT TO PLOT ORIGIN
C
      DO 120 J=1,N
      XORX(J) = X1(J)+XT
  120 YORY(J) = YT-Y1(J)
C
C   LOCATION OF BLADE SURFACE COORDINATES WITH RESPECT TO PLOT ORIGIN
C
      DO 150 J=1,N
      SING = SIN(GAMR(J))
      COSG = COS(GAMR(J))
      NDELJ = NDELS(J)
      DO 130 K=1,NDELJ
      XSX(J,K) = XORX(J)+XS(J,K)*COSG+YS(J,K)*SING
```

```
  130 YSY(J,K) = YORY(J)+XS(J,K)*SING-YS(J,K)*COSG
      NDELJ = NDELP(J)
      DO 140 K=1,NDELJ
      XPX(J,K) = XORX(J)+XP(J,K)*COSG+YP(J,K)*SING
  140 YPY(J,K) = YORY(J)+XP(J,K)*SING-YP(J,K)*COSG
  150 CONTINUE
C
C  LOCATION OF LEADING AND TRAILING EDGE CIRCLE CENTERS WITH RESPECT TO
C  PLOT ORIGIN
C
      DO 160 J=1,N
      SING = SIN(GAMR(J))
      COSG = COS(GAMR(J))
      XIX(J) = XORX(J)+RI(J)*(SING+COSG)
      YIY(J) = YORY(J)+RI(J)*(SING-COSG)
      XOX(J) = XORX(J)+CHORD(J)*COSG+RO(J)*(SING-COSG)
  160 YOY(J) = YORY(J)+CHORD(J)*SING-RO(J)*(SING+COSG)
C
C  LOCATION OF BLADE SURFACE POINTS AROUND LEADING EDGE
C
      DO 170 J=1,N
      ANG1 = PI-KIS(J)+KIP(J)
      N1(J) = ANG1/.1
      ANG1 = PI/2.-GAMR(J)+KIS(J)
      N1J = N1(J)
      DO 170 K=1,N1J
      ANG1 = ANG1+.1
      XIXC(J,K) = XIX(J)+RI(J)*COS(ANG1)
  170 YIYC(J,K) = YIY(J)-RI(J)*SIN(ANG1)
C
C  LOCATION OF BLADE SURFACE POINTS AROUND TRAILING EDGE
C
      DO 180 J=1,N
      ANG2 = PI+KOS(J)-KOP(J)
      N2(J) = ANG2/.2
      ANG2 = PI/2.-GAMR(J)+KOP(J)
      N2J = N2(J)
      DO 180 K=1,N2J
      ANG2 = ANG2+.2
      XOXC(J,K) = XOX(J)-RO(J)*COS(ANG2)
  180 YOYC(J,K) = YOY(J)+RO(J)*SIN(ANG2)
C
C  STORE BLADE SURFACE POINTS INTO XDOWN AND YACROS
C
      M = 0
      DO 230 J=1,N
      NPNTS(J) = NDELS(J)+NDELP(J)+N1(J)+N2(J)
C  PRESSURE SURFACE
      NDELJ = NDELP(J)
      DO 190 K=1,NDELJ
      M = M+1
      XDOWN(M) = YPY(J,K)
  190 YACROS(M) = XPX(J,K)
C  TRAILING EDGE
      N2J = N2(J)
      DO 200 K=1,N2J
      M = M+1
      XDOWN(M) = YOYC(J,K)
  200 YACROS(M) = XOXC(J,K)
C  SUCTION SURFACE
      NDELJ = NDELS(J)
      DO 210 K=1,NDELJ
```

```
      MM = NCELJ-K+1
      M = M+1
      XDOWN(M) =  YSY(J,MM)
  210 YACROS(M) = XSX(J,MM)
C  LEADING EDGE
      N1J = N1(J)
      DO 220 K=1,N1J
      M = M+1
      XDOWN(M) =  YIYC(J,K)
  220 YACROS(M) = XIXC(J,K)
  230 CONTINUE
C
C  ROTATE BLADES TO NORMAL CASCADE SETTING
C
      DO 240 I=1,M
      XTEMP(I) = (YACROS(I)-XIX(1))*COS(GAMS)+(XDOWN(I)-YIY(1))
     1*SIN(GAMS)
  240 YTEMP(I) = -(YACROS(I)-XIX(1))*SIN(GAMS)+(XDOWN(I)-YIY(1))
     1*COS(GAMS)
C
C   FIND MAXIMUM AND MINIMUM LIMITS OF PLOT, AND SHIFT BLADES
C
      XMIN= 0.
      DO 250 I=1,M
  250 XMIN= AMIN1(XMIN,XTEMP(I))
      XMAX= 0.
      DO 260 I=1,M
  260 XMAX= AMAX1(XMAX,XTEMP(I))
      YMIN = 0.
      DO 270 I=1,M
  270 YMIN = AMIN1(YMIN,YTEMP(I))
      YMAX = 0.
      DO 280 I=1,M
  280 YMAX = AMAX1(YMAX,YTEMP(I))
      DX= XMAX-XMIN
      DY= YMAX-YMIN
      XT= -XMIN+DX/18.
      YT= -YMIN+DX/9.
      DO 290 I=1,M
      XDOWN(I) = YTEMP(I)+YT
  290 YACROS(I) = XTEMP(I)+XT
C
C  DUPLICATE BLADES FOR CASCADE EFFECT
C
      MM = M
      DO 300 K=1,MM
      M = MM+K
      XDOWN(M) = XDOWN(K)+PITCH
  300 YACROS(M) = YACROS(K)
      DO 310 J=1,N
  310 GAMR(J) = GAMR(J)*57.295779
C
C  PREPARE KKK AND P      AND CALL CALPLT
C
      KKK(1) = 4
      KKK(2) = 0
      KKK(3) = 2*N
      KKK(4) = 1
      DO 320 J=1,N
  320 KKK(J+5) = NPNTS(J)
      DO 330 J=1,N
      K = J+5+N
```

```
 330 KKK(K) = NPNTS(J)
     P(1) = 3.0
     P(2) = 9./DX*(DY+PITCH)+2.
     P(3) = 0.0
     P(4) = DY+PITCH+2./9.*DX
     P(5) = 10.0
     P(6) = 0.0
     P(7) = 10./9.*DX
     P(8) = 10.0
     P(9) = 0.
     P(10) = 0.
     P(11) = 0.
     P(12) = 0.
     P(13) = 0.
     P(14) = 90.
     NX = -1
     NY = +1
     DATA XLABEL(1)/1H /
     DATA YLABEL(1)/1H /
     CALL CALPLT(XDOWN,YACROS,KKK,P)
     RETURN
     END
```

```
$IBFTC CTITLE
      SUBROUTINE CALTIT
      COMMON/INPUT/N,TCHORD,SOLID,DELK,KAPIN,RADIUS,CCC1(5),PHOPHI(5),
     1GOTC(5),LOTC(5),F(5),TMCC(5),RICC(5),ROOC(5),TITLE(12)
      COMMON/OUTPUT/CHORD(5),GAM(5),GAMR(5),PHIC(5),PITCH
      COMMON/CLPLOT/XPEN,YPEN,NX,NY,IPEN,XLABEL(10),YLABEL(10)
      DIMENSION TITL1(3),TITL2(5),TITL3(5),TITL4(7),TITL5(5),TITL6(7)
      DATA(TITL1(I),I=1,3)/6HTOTAL ,6H    TO,3HTAL/
      DATA(TITL2(I),I=1,5)/6HCHORD ,6H    CA,6HMBER  ,6H   SOL,5HIDITY/
      DATA(TITL3(I),I=1,5)/6HPITCH ,6H    KA,6HPIN   ,6H   RAD,3HIUS/
      DATA(TITL4(I),I=1,7)/6HC/C(1),6H   PHI,6H/PHI(1,6H)    G/,
     16HTC   L,6H/TC   ,2H F/
      DATA(TITL5(I),I=1,5)/6HTM/C  ,6H     R,6HI/C   ,6H    RO,2H/C/
      DATA(TITL6(I),I=1,7)/6H  C   ,6H     P,6HHI    ,6H    GA,
     16HM     ,6H  GAMR/
      CALL SYMBOL(-6.0,9.5,0.08,TITLE,0.0,72)
      CALL SYMBOL(-6.0,8.75,0.15,TITL1,0.0,15)
      CALL SYMBOL(-6.0,8.5,0.15,TITL2,0.0,29)
      CALL SYMBOL(-6.0,7.4,0.15,TITL3,0.0,27)
      CALL SYMBOL(-6.0,6.3,0.15,TITL4,0.0,38)
      CALL SYMBOL(-6.0,4.6,0.15,TITL5,0.0,26)
      CALL SYMBOL(-6.0,2.7,0.15,TITL6,0.0,36)
      CALL NUMBER(-6.0,8.3,0.12,TCHORD,0.0,5)
      CALL NUMBER(-4.7,8.3,0.12,DELK,0.0,4)
      CALL NUMBER(-3.1,8.3,0.12,SOLID,0.0,4)
      CALL NUMBER(-6.0,7.2,0.12,PITCH,0.0,5)
      CALL NUMBER(-4.7,7.2,0.12,KAPIN,0.0,4)
      CALL NUMBER(-3.1,7.2,0.12,RADIUS,0.0,5)
      IF (N.EQ.1) GO TO 20
      YYY= 6.3
      DO 10 J=2,N
      YYY = YYY-0.2
      CALL NUMBER(-6.0,YYY,0.12,CCC1(J),0.0,4)
```

```
      CALL NUMBER(-4.6,YYY,C.12,PHCPH1(J),0.0,4)
      CALL NUMBER(-3.2,YYY,C.12,GCTC(J),0.0,4)
      CALL NUMBER(-2.3,YYY,C.12,LCTC(J),0.0,4)
   1C CALL NUMBER(-1.5,YYY,C.12,F(J),0.C,4)
   2C YYY= 4.6
      CO 3C J=1,N
      YYY = YYY-C.2
      CALL NUMBER(-6.C,YYY,0.12,TMCC(J),0.0,4)
      CALL NUMBER(-4.6,YYY,C.12,RICC(J),C.0,4)
   3C CALL NUMBER(-3.2,YYY,C.12,RCCC(J),C.0,4)
      YYY= 2.7
      CO 4C J=1,N
      YYY = YYY-C.2
      CALL NUMBER(-6.C,YYY,C.12,CHCRD(J),0.0,5)
      CALL NUMBER(-4.7,YYY,C.12,PHIC(J),0.0,4)
      CALL NUMBER(-3.3,YYY,C.12,GAM(J),0.0,4)
   4C CALL NUMBER(-1.9,YYY,0.12,GAMR(J),0.0,4)
      RETURN
      END
```

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, June 22, 1970

126-15.

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