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

by William D. McNally and James E. Crouse

Lewis Research Center
Cleveland, Ohio  44135

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# 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.

## Key Words (Suggested by Author(s))
- Turbomachinery blade sections
- Blade design
- Circular arc blades
- Single blade sections
- Tandem blade sections

## Distribution Statement

Unclassified - unlimited

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

by William D. McNally and James E. Crouse

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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 today's 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
R_l leading-edge radius of blade segment (fig. 3), ft; m
R_o 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)
Δκ 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.
Figure 1. - Computed blade sections.

(a) Single blade section.

(b) Tandem blade section.

Figure 2. - Cylindrical surface of blade section.
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 \( \sigma = \text{TC/}\text{S} \) (see fig. 1), inlet blade angle \( \kappa_{\text{in}} \), and radius from axis of rotation to cylindrical surface \( R_D \) (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 \( \text{TM/C, RI/C, and RO/C} \). Segments are related to each other by the gap between them (in the form of ratio to total chord, \( G/\text{TC} \)), their overlap (also a ratio, \( L/\text{TC} \)), 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 \( \varphi \) 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 $\Delta k$. 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 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 aligned 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, \( \sigma \)          | 1.235            |
| Overall camber, \( \Delta k \), deg | 72.24            |
| Inlet blade angle, \( \kappa_{in} \), 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.
Figure 4. - Input and generated plot of two-section tandem blade example.

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, \( \sigma \), 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, \( \kappa_{in} \), deg

**RADIUS**
radius from axis of rotation to cylindrical blade plane \( R_p \), 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.
DELK, the overall chamber, must be a positive number or zero. Values as high as the 180° will run, but the range from 5° to 120° is typical. If DELK has a small value (from 0° to 10°) 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° to 90° are allowable, but the range from -30° to 70° 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

<table>
<thead>
<tr>
<th>Blade Section</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total chord, TC, ft</td>
<td>0.192</td>
<td>Solidity, ( \sigma )</td>
<td>1.3</td>
<td>Overall camber, ( \Delta \alpha ), deg</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Run</th>
<th>Ratio of segment chord to chord of first blade segment, ( C/C(1) )</th>
<th>Ratio of segment chamber to first blade segment chamber, ( \varphi/\varphi(1) )</th>
<th>Ratio of gap to total chord, ( G/TC )</th>
<th>Ratio of overlap to total chord, ( L/TC )</th>
<th>Ratio of gap at channel inlet to gap at channel outlet, ( F )</th>
<th>Ratio of maximum thickness to local segment chord, ( TM/C )</th>
<th>Ratio of leading-edge radius to local segment chord, ( RI/C )</th>
<th>Ratio of trailing-edge radius to local segment chord, ( RO/C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>1.0</td>
<td>0.05</td>
<td>0.10</td>
<td>1.5</td>
<td>0.15</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>1.3</td>
<td>1.6</td>
<td>0.03</td>
<td>----</td>
<td>1.1</td>
<td>0.13</td>
<td>----</td>
<td>0.007</td>
</tr>
<tr>
<td>3</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>1.2</td>
<td>0.11</td>
<td>----</td>
<td>----</td>
</tr>
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</table>

Several 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 \( \varphi/\varphi(1) \) from 1.0 to 1.6. The channel gap was also decreased \((G/TC = 0.05 \text{ to } 0.03)\), as well as the channel convergence between blade segments \((F = 1.5 \text{ to } 1.1)\) 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).
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>
<thead>
<tr>
<th>EXAMPLE - TWO SECTION TANDEM BLADE</th>
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<tbody>
<tr>
<td>N</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>C(C1) ARRAY</td>
</tr>
<tr>
<td>PHI/PHI I ARRAY</td>
</tr>
<tr>
<td>G/C ARRAY</td>
</tr>
<tr>
<td>L/C ARRAY</td>
</tr>
<tr>
<td>F ARRAY</td>
</tr>
<tr>
<td>H/L ARRAY</td>
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<tr>
<td>H/L ARRAY</td>
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<tr>
<td>H/L ARRAY</td>
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<table>
<thead>
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<th>OVERALL BLADE PARAMETERS</th>
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<td>N</td>
</tr>
<tr>
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</tr>
<tr>
<td>C(C2)</td>
</tr>
<tr>
<td>XI</td>
</tr>
<tr>
<td>C(C2)</td>
</tr>
<tr>
<td>PHI</td>
</tr>
<tr>
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<td>C(C2)</td>
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<tr>
<td>C(C2)</td>
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| TABLE IV. - SAMPLE OUTPUT FOR TWO-SECTION TANDEM BLADE EXAMPLE |
TABLE IV. - Continued. SAMPLE OUTPUT FOR TWO-SECTION TANDEM BLADE EXAMPLE

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<th>RC</th>
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<tr>
<td>0.00223</td>
<td>C.CC233</td>
<td>0.11986</td>
<td>0.00082</td>
</tr>
<tr>
<td>0.00276</td>
<td>C.CC025</td>
<td>0.17488</td>
<td>0.06109</td>
</tr>
<tr>
<td>0.10049</td>
<td>C.CC265</td>
<td>0.07939</td>
<td>33.62912</td>
</tr>
<tr>
<td>0.12454</td>
<td>C.CC076</td>
<td>0.10927</td>
<td>20.35063</td>
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<th>BLADE SEGMENT NO. 2</th>
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<td>CHORD</td>
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<th>COMPILED INPUT FOR IDEAL FLOW PROGRAMS</th>
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<td>BLADE</td>
</tr>
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</tr>
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<th>RTHCL</th>
<th>MCT</th>
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<td>67.07086</td>
<td>10.55239</td>
<td>45.70413</td>
<td>33.46859</td>
<td>0.00140</td>
<td>0.00000</td>
<td>0.07209</td>
<td>0.07474</td>
<td>0.05761</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>45.84013</td>
<td>-24.19677</td>
<td>31.10818</td>
<td>-6.75690</td>
<td>0.06287</td>
<td>0.01357</td>
<td>0.03960</td>
<td>0.01746</td>
<td>0.08062</td>
<td>0.06214</td>
</tr>
</tbody>
</table>
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 $\theta$ direction or ratio of total chord to solidity $TC/\sigma$ (fig. 1), ft; m

**GAMB**  
age between chord line of first blade segment and chord line of overall blade section (fig. 9), deg
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
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 tan- 
    gents to the suction surface of the local blade segment and the pressure sur- 
    face of the previous blade segment where the line FA×GA meets these sur- 
    faces. The line containing FA×GA passes through the leading-edge circle 
    center of the local blade segment.)

\[ \text{Figure 12. - Input and output variables in overlap region.} \]
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.](image)

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, Rb, in fig. 2). This cylinder serves as the axisymmetric blade-to-blade surface required for the input of geometry to the ideal flow programs.
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 $\theta$ 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 $\theta$ 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 \( \theta \) 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 \( \theta \) 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 \( \times \) 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

\[ \text{TMOC} < 2.0 \times \text{RIOC} \]

\[ \text{TMOC} < 2.0 \times \text{ROOC} \]

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 PHOPHI 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.

\[ 1 \leq N \leq 5 \]

\[ \text{TCHORD} > 0. \]

\[ \text{SOLID} > 0. \]

\[ 0. \leq \text{DELK} \leq 180. \]

\[ -90. \leq \text{KAPIN} \leq 90. \]

\[ \text{RADIUS} > 0. \]

\[ \text{COCl} > 0. \]

\[ -1000. \leq \text{PHOPH1} \leq 1000. \]

\[ 0. \leq \text{GOTC} \leq 0.5 \]
-0.2 ≤ LOTC ≤ 0.4

0. ≤ F ≤ 10.

0. ≤ TMOC ≤ 0.8

0. ≤ RIOC ≤ 0.4

0. ≤ ROOC ≤ 0.4

COMPLETE PROGRAM LISTING

$IEJCE
$IEFTC CATBP

COMMON /INPUT/N, TCHORD, SOLID, DELK, KAPIN, RADIUS, CCC1(5), PHOPH1(5),
IGOTC(5), LOTC(5), F(5), TMOC(5), RICC(5), ROCC(5), TITLE(12)
COMMON /OUTPUT/CHORD(5), GAMS(5), GAMR(5), FHIC(5), PITCH
COMMON /CLPLUT/XPEN, YPEN, NX, NY, IPEN, XLABEL(10), YLABEL(10)
1XG(5), YG(5), NDEL(5), XX(5,100), YY(5,100), YP(5,100)
COMMON /COM2/GAMS, MCHORD(5), RSTG(5), STGR(5), MLE(5), RTHLE(5),
1RTHCT(5), THCT(5), BETIS(5), BETCS(5), BETIP(5), BETCP(5), MSPS(5,100),
1RTHSPS(5,100), THSPS(5,100), MSFP(5,100), RTHSPP(5,100), THSPP(5,100)
REAL L, LOTC, NEWC, KIC, KOC, KIS, KCS, KIP, KOP, KCM,
1KGS1, KGS2, KGP1, KGP2, KGI, KAPIN
REAL MLE, MTE, MCL, MCT, MCHORD, MSPS, MSPP
1C CALL BLCRD
CALL IFNPT
CALL PLCTT
GO TO 10
END

$IEFTC BLCRD

SUBROUTINE BLCRD
COMMON /INPUT/N, TCHORD, SOLID, DELK, KAPIN, RADIUS, CCC1(5), PHOPH1(5),
IGOTC(5), LOTC(5), F(5), TMOC(5), RICC(5), ROCC(5), TITLE(12)
COMMON /OUTPUT/CHORD(5), GAMS(5), GAMR(5), FHIC(5), PITCH
1XG(5), YG(5), NDEL(5), XX(5,100), YS(5,100), YP(5,100)
REAL L, L0TG, NEWC, KIC, KGC, KIS, KCS, KIP, KCP, KCM, LC,
IKGS, KCS2, KGP1, KGP2, KGS1, KAPIA

C
C READ AND PRINT INPUT

1C WRITE(6,1000)
   REAC (5,125C) (TITLE(I),I=1,12)
   WRITE(6,1260) (TITLE(I),I=1,12)
   REAC (5,1020) N,TCHORD,SOLID,DELK,KAFIN,RADIUS
   WRITE(6,1030) N,TCHORD,SOLID,DELK,KAFIN,RADIUS
   REAC (5,1010) (COC1(J),J=2,N)
   WRITE(6,1040) (COC1(J),J=2,N)
   REAC (5,1010) (PHOPHI(J),J=2,N)
   WRITE(6,1050) (PHOPHI(J),J=2,N)
   REAC (5,1010) (GOTC(J),J=2,N)
   WRITE(6,1060) (GOTC(J),J=2,N)
   REAC (5,1010) (LUTC(J),J=2,N)
   WRITE(6,1070) (LUTC(J),J=2,N)
   REAC (5,1010) (F(J),J=2,N)
   WRITE(6,1080) (F(J),J=2,N)
   REAC (5,1010) (TIMC(J),J=1,N)
   WRITE(6,1090) (TIMC(J),J=1,N)
   REAC (5,1010) (RIMC(J),J=1,N)
   WRITE(6,1100) (RIMC(J),J=1,N)
   REAC (5,1010) (ROMC(J),J=1,N)
   WRITE(6,1110) (ROMC(J),J=1,N)

C
C INITIAL VALUES OF CAMBER AND CHORD

   DELK = DELK/57.255779
   PITCH= TCHORD/SOLID
   SUMC = 0.
   SUML = 0.
   SLMPHI = 0.
   PHOPHI(1) = 1.0
   IF (N.EQ.1) GO TO 30
   DO 20 J=2,N
   SUML = SUML + COC1(J)
   SUMC = SUMC + COC1(J)
   2C SUMPHI = SUMPHI + PHOPHI(J)
   3C FACTOR = 1.0/((1.0 - DELK**2/24.0)
   SUML = FACTOR * SUML
   SUMC = 1.0 * SUMC
   SUMPHI = 1.0 * SUMPHI
   IF (SUMPHI.GT..1) GO TO 4C
   WRITE(6,1270)
   GO TO 1C

4C CHORD(J) = TCHORD * SUML/SUMC
   PHIC(J) = DELK/SUMPHI
   IF (N.EQ.1) GC TO 60
   DO 50 J=2,N
   PHIC(J) = PHIC(J) + PHOPHI(J)
   5C CHORD(J) = CHORD(J) * COC1(J)

C
C SIZING OF OTHER BLADE SEGMENT DIMENSIONS

6C ITER = 1
   IF (N.EQ.1) GC TO 8C
   DO 70 J=2,N
   7C
L(J) = LTC(J)*ICHORD

7C  G(J) = GOTC(J)*ICHORD

8C  DO 50 J=1,N

7C  TM(J) = TMGC(J)*CHORD(J)

8C  R(J) = RIGC(J)*CHORD(J)

9C  RO(J) = ROOC(J)*CHORD(J)

10C  IF (2.*R(J) .LE. TM(J) .AND. 2.*RO(J) .LE. TM(J)) GC TO 90

11C  WRITE(6,J) 120

12C  GO TO 10

13C  CONTINUE

C

C SEGMENT CENTER LINE CALCULATIONS

C

DO 100 J=1,N

XI(J) = RI(J)

YI(J) = RI(J)

XU(J) = CHORD(J)-RC(J)

YO(J) = RO(J)

ARG=(YI(J)-YO(J))/XI(J)-XO(J)

1IC  THETA(J) = -ATAN(ARG)

11C  DO 130 J=1,N

KIC(J) = PHIC(J)/2.-THETA(J)

KDC(J) = -PHIC(J)/2.-THETA(J)

10C  IF (ABS(PHIC(J)) .LT. 0.001) GC TO 120

BC(J) = (XI(J)**2+YI(J)**2-VO(J)**2-VO(J)**2-2.*XI(J)-XO(J))*XI(J)

11C  I(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 120

12C  BC(J) = 999.99999

11C  IF (PHIC(J) .LT. 0.001) GC TO 100

HC(J) = -CHORD(J)/2.

RC(J) = 999.99999

13C  CONTINUE

C

C SEGMENT SURFACE CALCULATIONS

C

DO 27C J=1,N

K1 = 0

ITIR = 0

CEL = 0.1*CHORD(J)

10C  IF (K1(J) .EQ. 0.) GC TO 140

RUK1 = RO(J)/RI(J)-1.

GO TO 150

14C  RORI = 0.

15C  ROMRI = R0(J)-RI(J)

CRO = CHORD(J)-2.*RO(J)

CV = (TM(J)-2.*RI(J))/CHORD(J)

XCM(J) = CHORD(J)/2.

XCMI = XCM(J)

LC = SQRT((CHORD(J)-RI(J)-RC(J))**2+(RI(J)-RC(J))**2)/2.0

PC = PHIC(J)/2.0

HCM = LC*TAN(PC/2.0)

XCM(RI(J)+LC*COS(THETA(J))+HCM*SIN(THETA(J))

16C  YCM(J) = RO(J)+(RI(J)-RO(J))*(CHORD(J)-XCM(J)-RO(J))/(CHORD(J)

1-R1(RJ)-RO(J))

IF (ABS(PHIC(J)) .LT. 0.0001) GC TO 170

ALPHA = THETA(J)+ASIN((XCM(J)/LC*COS(PC)-SIN(THETA(J))

17C  YCM(J) = YCM(J)+LC*COS(THETA(J))*SIN(PC)/(1.+COS(PC)))-SIN(ALPHA)**2

1/1.0+COS(ALPHA)**2

SIN(PC)

13C  ARG = -(XCM(J)-RI(J))*SIN(PC) / LC*SIN(KIC(J)) / ((YCM(J)-RI(J))

131
KCM(J) = ATAN(ARG)

**C SUCTION SURFACE**

\[
XSM(J) = XCM(J) - TM(J) / 2 \cdot \sin(KCM(J))
\]
\[
YSM(J) = YCM(J) + TM(J) / 2 \cdot \cos(KCM(J))
\]
\[
DS = XSM(J) \cdot RORI + CRO
\]
\[
XMRI = XSM(J) - RI(J)
\]
\[
XMRI2 = XSM(J) - 2 \cdot RI(J)
\]
\[
YMRI = YSM(J) - RI(J)
\]
\[
YMRI2 = YSM(J) - 2 \cdot RI(J)
\]
\[
XMV = XSM(J) \cdot 2 \cdot YSM(J) \cdot 2
\]
\[
AAS = XSM(J) \cdot XMRI2 \cdot YSM(J) \cdot 2 \cdot RORI \cdot 2 \cdot XSM(J) \cdot XMRI \cdot YSM(J) \cdot RORI \cdot DS
\]
\[
1 \cdot YSM(J) \cdot XMRI2 \cdot DS \cdot 2
\]
\[
BBS = (XMY \cdot YMRI + RI(J) \cdot 3 - 3 \cdot RI(J) \cdot 2 \cdot YSM(J) \cdot DS \cdot 2 - (XMY \cdot YMRI)
\]
\[
1 \cdot RI(J) \cdot 3 - 3 \cdot RI(J) \cdot 2 \cdot XSM(J) \cdot YSM(J) \cdot RORI \cdot DS + (XSM(J) \cdot XMRI2 \cdot YSM(J)
\]
\[
2 \cdot RORI \cdot XMRI \cdot YMRRI \cdot OS = (XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RC(J) \cdot RCMRI)
\]
\[
CCS = (XMY \cdot 2 \cdot RI(J) \cdot 4 - 6 \cdot RI(J) \cdot 2 \cdot XMY) \cdot DS \cdot 2 \cdot XSM(J) \cdot XMRI2
\]
\[
1 \cdot (XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RCMRI) \cdot DS \cdot 2 \cdot 2 \cdot (XMY \cdot XMRI2 \cdot RI(J) \cdot 3)
\]
\[
2 - 3 \cdot RI(J) \cdot 2 \cdot XSM(J) \cdot (XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RC(J) \cdot RCMRI)
\]
\[
IF (RI(J) \cdot EQ.C) \text{ GO TO 180}
\]
\[
BSJ(J) = (-BBS + SQRT(BBS \cdot 2 - AAS \cdot CCS)) / (2 \cdot AAS)
\]
\[
GO TO 190
\]

**18C BSJ(J) = -BBS / (2 \cdot AAS)

19C HSJ(J) = (-XMY \cdot RORI1 + CHORD(J) \cdot CRO \cdot RO(J) \cdot RCMRI \cdot 2 \cdot YSM(J) \cdot RORI \cdot BSJ(J)) / (2 \cdot (XSM(J) \cdot RORI + CRO))

SLJ(J) = -(XSM(J) \cdot HSJ(J)) / (YSM(J) \cdot BSJ(J))

**C PRESSURE SURFACE**

\[
XPM(J) = XCM(J) \cdot YP(J) / 2 \cdot \sin(KCM(J))
\]
\[
YP(J) = YCM(J) + TM(J) / 2 \cdot \cos(KCM(J))
\]
\[
DP = XPM(J) \cdot RORI + CRO
\]
\[
XMRI = XPM(J) - RI(J)
\]
\[
XMRI2 = XPM(J) - 2 \cdot RI(J)
\]
\[
YMRI = YPM(J) - RI(J)
\]
\[
YMRI2 = YPM(J) - 2 \cdot RI(J)
\]
\[
XMV = XPM(J) \cdot 2 \cdot YPM(J) \cdot 2
\]
\[
AAP = XPM(J) \cdot XMRI2 \cdot YPM(J) \cdot 2 \cdot RORI \cdot 2 \cdot XSM(J) \cdot XMRI \cdot YPM(J) \cdot RORI \cdot DP
\]
\[
1 \cdot YPM(J) \cdot YMRI \cdot DP \cdot 2
\]
\[
BBP = (XMY \cdot YMRI + RI(J) \cdot 3 - 3 \cdot RI(J) \cdot 2 \cdot YPM(J) \cdot DP \cdot 2 - (XMY \cdot YMRI)
\]
\[
1 \cdot RI(J) \cdot 3 - 3 \cdot RI(J) \cdot 2 \cdot XPM(J) \cdot YPM(J) \cdot RORI \cdot DP + (XPM(J) \cdot XMRI2 \cdot YPM(J)
\]
\[
2 \cdot RORI - XMRI \cdot YMRI \cdot DP \cdot (XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RC(J) \cdot RCMRI)
\]
\[
CCP = (XMY \cdot 2 \cdot RI(J) \cdot 4 - 6 \cdot RI(J) \cdot 2 \cdot XMY) \cdot DP \cdot 2 \cdot XPM(J) \cdot XMRI2
\]
\[
1 \cdot (XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RO(J) \cdot RCMRI) \cdot 2 \cdot 2 \cdot (XMY \cdot XMRI2 \cdot RI(J) \cdot 3)
\]
\[
2 - 3 \cdot RI(J) \cdot 2 \cdot XPM(J) \cdot (XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RC(J) \cdot RCMRI \cdot 2 \cdot C)
\]
\[
IF (RI(J) \cdot EQ.C) \text{ GO TO 200}
\]
\[
BP(J) = (-BBP - SQRT(BBP \cdot 2 + AAP \cdot CCP)) / (2 \cdot AAP)
\]
\[
GO TO 210
\]

**2CC BP(J) = -BBP / (2 \cdot AAP)

210 IP(J) = -(XMY \cdot RORI + CHORD(J) \cdot CRO \cdot RO(J) \cdot RCMRI \cdot 2 \cdot YPM(J) \cdot RORI \cdot BP(J)) / (2 \cdot (XPM(J) \cdot RORI + CRO))

SLP(J) = -(XPM(J) + HP(J)) / (YPM(J) + BP(J))

**C CHECK FOR MAX THICKNESS POINT CONVERGENCE**

\[
DSL = SLS(J) - SLP(J)
\]
\[
IF (CV \cdot EQ.C) \text{ GO TO 260}
\]
\[
IF (APS(DSL) \cdot LE \cdot C001 \cdot CV) \text{ GC TC 260}
\]
\[
IF (ITIR \cdot EQ.0) \text{ GO TO 22C}
\]
\[
IF (DSL / DSLM1 \cdot 1 \cdot 0) \kappa \text{ 1}
\]
\[
22C ITIR = ITIR + 1
\]
\[
IF (K1 \cdot EQ.0) \text{ GC TO 23C}
\]
\[
GO TO 240
\]

**23C XCM(J) = XCM(J) + DSL / ABS(DSL) \cdot DEL

GO TO 250

24C XCM(J) = XCM1 + (XCM2 - XCM1) / (1 - CSLM1 / DSL)

25C CSLM1 = DSL

32
XCMM2 = XCMM1
XCMM1 = XCMM(J)
GO TO 160
C FINAL CALCULATIONS AFTER CONVERGENCE
26C 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)+FP(J))/(RI(J)+BF(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)
PHIP(J) = KIP(J)-KOP(J)
C LOCATION OF BLADE SEGMENTS WITH RESPECT TO ONE ANOTHER
C
GAM(1) = 0.
GAMR(1) = 0.
IF (N.EQ.1) GO TO 33C
DO 210 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(KP(J-1)**2-(XR(J)+HP(J-1))**2)-BP(J-1)-F(J)*G(J)-RI(J)
GO TO 290
28C YR(J) = -SQRT(RP(J-1)**2-(XR(J)+HP(J-1))**2)-BP(J-1)-F(J)*G(J)-RI(J)
290 XR(J) = CHORD(J-1)-RO(J-1)
YR(J) = -G(J)
AA = 2.*((XG(J)-XR(J))+(YG(J)-YR(J))+(RI(J)+HS(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
30C SINGAM = (BB*CC-AA*SQRT(AA**2+BB**2-CC**2))/(AA**2+BB**2)
31C GAM(J) = ARSIN(SINGAM)
C CHECK ON OVERALL BLADE TURNING AND FIESIZING CAMBERS OF BLADE SEGMENTS
C
DO 320 J=2,N
22C GAMR(J) = GAMR(J-1)+GAM(J)
23C DELKT = KIC(1)+GAMR(N)-KCC(N)
DIFF = DELK-DELKT
IF (ABS(DIFF).LT.0.001) GO TO 360
ITER = ITER+1
IENC = C
IF (ITER.GT.25) GO TO 350
DO 340 J=1,N
34C PHIC(J) = PHIC(J)+DIFF*PHOPH(J)/SLMPHI
GO TO 370
35C WRITE (6,1130)
GO TO 10
C RESIZING CHORDS OF BLADE SEGMENTS
C
36C IEND = 1
37C XOB = X0(N)
YOB = Y0(N)
IF (N.EQ.1) GO TO 39C
DO 380 K=2,N
38C
36 J = N-K+2
SING = SIN(GAM(J))
COSG = COS(GAM(J))
XOB3 = X(RJ)*XCB*COSG+YOB*SING-RI(J)*(SING+COSG)
YOB3 = Y(RJ)*YCB*COSG-XCB*SING+RI(J)*(SING-COSG)
XOB = XOB3
38 YOB = YOB3
39 IF (IENC.EQ.1) GO TO 41C
NEWG = SQRT((XOB-XI(1))**2+(YOB-YI(1))**2)+RI(1)+RC(N)
CRATIO = TCHORD/NEWG
DO 44C J=1,N
4CC CHORD(J) = CHORD(J)*CRATIO
GO TO 60
C
C OVERALL BLADE THETA AND GAMMA
C
41C ARG = (RI(1)-RC(N))/(TCHORD-RI(1)-RO(N))
THETB = ATAN(ARG)
ARG = (YI(1)-YOB)/(XCB-XI(1))
GAMTB = ATAN(ARG)
GAME = (AMB-THETB)
IF (N.EQ.1) GO TO 430
C
C PSEUDO-INCIENCE ANGLES ON AFT BLADES
C
DO 42C J=2,N
ARC = (CHORD(J-1)+HC(J-1)-RC(J-1))/RC(J-1)
RHD1 = ARSIN(ARG)
ARC = (HC(J-1)+HC(J-1)-RC(J-1)-L(J))/RC(J-1)
RHD2 = ARSIN(ARG)
RHO = RHD1-RHD2
42C SIN(J) = -(KIC(J)-GAM(J)-KCC(J-1)-RHC)
C
C ELACE SECTION COORDINATES AT DELX INCREMENTS
C
43C DO 49C J=1,N
TEM = CHORD(J)**2/10000.
NEXP = 0
44C NEXP = NEXP+1
TEM = 10.*TEM
IF (TEM-1.**LT.C.) GO TO 44C
M = 1
IF (M.GE.2) GO TO 45C
M = 2
GO TO 470
45C IF (M.GE.5) GO TO 46C
M = 5
GO TO 470
46C DELX = FLGAT(M)**1C.*(4-NEXP)
NDEL(J) = CHORD(J)/DELX+1.
XX(J,1) = 0.
NDELIJ = NDEL(J)
DO 45C K=1,NDELIJ
YS(J,K) = SQRT(RS(J)**2-(XX(J,K)+HS(J))**2)-8S(J)
IF (R(P(J),LT,0)) GO TO 48C
YP(J,K) = SQRT(RP(J)**2-(XX(J,K)+HF(J))**2)-8P(J)
GO TO 490
48C YP(J,K) = -SQRT(RP(J)**2-(XX(J,K)+HP(J))**2)-8P(J)
49C XX(J,K+1) = XX(J,K)+DELX
C
C RELATION OF SEGMENT ORIGINS TO PRINCIPAL ORIGIN
C
34
C
X1(I) = 0.
Y1(I) = 0.
XZ(I) = C
Y2(I) = C
IF (N.E.C.) GO TO 5EC
DO 5CC J = 2, N
TEM = XR(J) - RI(J) * COS(GAP(J)) + SIN(GAM(J))
TEMB = YR(J) * RI(J) * COS(GAM(J)) - CPS(GAM(J))
TEMN = TEMB/COS(GAMR(J-1))
TEM = TEMN * SIN(GAMR(J-1))
TEM = TEM + TEM
TEMF = TEM * SIN(GAM(J-1))
DX = TEMF * COS(GAMR(J-1))
CY = TEMF * TEMN
X1(J) = X1(J-1) + DX
Y1(J) = Y1(J-1) - DY
X2(J) = X1(J) + CHORD(J) * COS(GAMR(J))
5CC Y2(J) = Y1(J)-CHORD(J) * SIN(GAM(R(J)))
C
DO 57C J = 2, N
C REAR PCTIION OF GAP
KGS1 = 100.
1C ARG = -(XG(J) - XR(J)) * CPS(GAM(J)) - (YG(J) - YR(J)) * SIN(GAM(J))
1R(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) GC TC 520
BETA = KGS2 - GAM(J)
CA = (XG(J-1) + YC(J-1)) * TAN(BETA) - XR(J) * CPS(GAM(J) +
1YR(J) = SIN(GAM(J)) + RI(J) * HS(J)
CB = -TAN(BETA) * COS(GAM(J)) + SIN(GAM(J))
CC = (XG(J-1) + YO(J-1)) * TAN(BETA) - XR(J) * SIN(GAM(J))
1YR(J) = CCS(GAM(J)) + RI(J) * BS(J)
CD = COS(GAM(J)) - TAN(BETA) * SIN(GAM(J))
CE = CB**2 + CD**2
CF = CA * CB + CC * CD
CG = C**2 + CC**2 - RS(J)**2
YG(J) = (CF + SQRT((CF**2 + CE*CG) / (2*CE))) / (2*CE)
XG(J) = XG(J-1) - (YG(J) - YO(J-1)) * TAN(BETA)
5CC KGS1 = KGS2
GO TO 510
52C GAI(J) = SQRT((XG(J) - XO(J-1))**2 + (YG(J) - YC(J-1))**2) - RC(J-1)
GAO(J) = GAI(J) / CHORD(J-1)
C FCRWARC PCTIION OF GAP
KGP1 = 100.
XP = XR(J)
YGP = SQR(T(RP(J-1))**2 - (XG+HP(J-1))**2) - BP(J-1)
3C ARG = -(XG+HP(J-1)) / (YGP + BP(J-1))
KGP2 = ATAN(ARG)
IF (ABS(KGP2-KGP1).LE.01) GC TC 560
ARG = (-HS(J) - RI(J)) / (BS(J) + RI(J))
KGS1 = ATAN(ARG) - GAM(J)
BETA = (KGP2*KGS1) / 2.
CL = 1.0 * TAN(BETA)**2
CM = 2.0 * (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 + CL*CN)) / (2*CL)
GO TO 550
54C YGP = -(CM - SQRT(CM**2 + CL*CN)) / (2*CL)
<table>
<thead>
<tr>
<th>Line Number</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>550</td>
<td>XGP = XR(J) - (YGP - YR(J)) * TAN(BETA)</td>
</tr>
<tr>
<td>551</td>
<td>KGP = KGP2</td>
</tr>
<tr>
<td>552</td>
<td>GO TO 530</td>
</tr>
<tr>
<td>560</td>
<td>FG = SQRT(((XR(J) - XGP)^2 + (YR(J) - YGP)^2)2)</td>
</tr>
<tr>
<td>561</td>
<td>BETA = BETA + GAM(J)</td>
</tr>
<tr>
<td>562</td>
<td>CL = J * (TAN(BETA))^2</td>
</tr>
<tr>
<td>563</td>
<td>CM = 2 * (BS(J) - (XI(J) + YI(J) * TAN(BETA) + HS(J)) * TAN(BETA))</td>
</tr>
<tr>
<td>564</td>
<td>CN = (XI(J) + YI(J) * TAN(BETA) + HS(J))^2 + BS(J)^2 - RS(J)^2</td>
</tr>
<tr>
<td>565</td>
<td>YGS = (-CM + SQRT(CM^2 - 4 * CL * CN) / (2 * CL))</td>
</tr>
<tr>
<td>566</td>
<td>XGS = XI(J) - (YGS - YI(J)) * TAN(BETA)</td>
</tr>
<tr>
<td>567</td>
<td>FG2 = SQRT((XGS - XI(J))^2 + (YGS - YI(J))^2)</td>
</tr>
<tr>
<td>568</td>
<td>FG = FG2</td>
</tr>
<tr>
<td>570</td>
<td>FA(J) = FG / GA(J)</td>
</tr>
</tbody>
</table>

C PLT OLTPU1 ANGLES IN DEGREES

C

C 580 DELK = DELK * 57.25779
C 581 GAMB = GAMB * 57.295779
C 582 THEB = THEB * 57.25779
C 583 DO 550 J = 1, N
C 584 GAM(J) = GAM(J) * 57.255779
C 585 GAMR(J) = GAMR(J) * 57.25779
C 586 THE(J) = THE(J) * 57.29779
C 587 SINC(J) = SINC(J) * 57.25779
C 588 PHIC(J) = PHIC(J) * 57.25779
C 589 PHIS(J) = PHIS(J) * 57.25779
C 590 PHI(J) = PHI(J) * 57.25779
C 591 KIC(J) = KIC(J) * 57.25779
C 592 KIS(J) = KIS(J) * 57.25779
C 593 KIP(J) = KIP(J) * 57.25779
C 594 KOC(J) = KOC(J) * 57.29779
C 595 KGS(J) = KGS(J) * 57.29779
C 596 KOP(J) = KOP(J) * 57.25779
C 597 C CHANGE SINC CF SELECTED OLTPUS
C 598 DO 600 J = 1, N
C 599 HS(J) = -HS(J)
C 600 HP(J) = -HP(J)
C 601 KOS(J) = -KOS(J)
C 602 KOC(J) = -KOC(J)
C 603 YI(J) = -YI(J)
C 604 YOB = -YOB
C 605 C PRINT OUTPLT
C 606 WRITE(6, 1140) N, TCHORD, PITCH, SCLID, DELK, KAFIN, GAMB, THEB, XCB, YOB
C 607 DO 620 J = 1, N
C 608 WRITE(6, 1150) J
C 609 WRITE(6, 1160) CHORD(J), R1(J), R2(J), THE(J)
C 610 WRITE(6, 1170) XI(J), YI(J), XC(J), YC(J), XM(J), YM(J)
C 611 WRITE(6, 1180) XI(J), YI(J), X2(J), Y2(J), GAM(J), GAMR(J)
C 612 WRITE(6, 1190) PHIS(J), KS(J), HS(J), BS(J), KS(J), KCS(J)
C 613 WRITE(6, 1200) PHIC(J), KC(J), HC(J), BC(J), KC(J), KCC(J)
C 614 WRITE(6, 1210) PHI(J), P(J), HP(J), BF(J), KIP(J), KCP(J)
C 615 IF (J.EQ.1) GO TO 61C
C 616 WRITE(6, 1220) G(J), GA(J), GAO(J), L(J), F(J), FA(J), SINC(J)

36
$\text{ifa} \text{ FMTN} \text{ then return }$
IK(5), YG(5), DEL(5), XX(5), YS(5), YP(5), 10
COMMUN/COX, GAP, ECHORD(5), RSTGR(5), STGR(5), MLE(5), RTHLE(5), 11
REAL L, D, IC, NEP, KIC, KCC, KIS, KCS, KIP, KPC, KCM, 15
KG(1), KC(1), KG(1), KOP(1), KOP(1), KG(1), KAP(1) 16
REAL MLE, MIE, MCL, MCT, ECHORD, MSHP, MSHP 17
18
C
C COMPUTATION OF GEOMETRICAL INPUT FOR TANDEM BLADE, IDEAL FLOW PROGRAM 20
C CHANGE SIGN OF SELECTED PARAMETERS 21
C
CD IC = 1, N 22
KOS(J) = -KOS(J) 23
KOC(J) = -KOC(J) 24
KOP(J) = -KOP(J) 25
Y1(J) = -Y1(J) 26
IC Y2(J) = -Y2(J) 27
Y2B = -Y2B 28

C LOCATION OF CENTERS OF LEADING EDGE CIRCLES 29
C
GAMS = (KAPIN-KIC(1))/57.29775 30
CD J = 1, N 31
GAMR(J) = GAMM(J)/57.29775 32
GAMJ = GAMS-GAMR(J) 33
TEM1 = (X1(J)-RI(1))#COS(GAMS)-(Y1(J)-RI(1))#SIN(GAMS)+RI(1) 34
TEM2 = (X1(J)-RI(1))#SIN(GAMS)+(Y1(J)-RI(1))#CCS(GAMS) 35
MCL(J) = TEM1-RI(J)#SIN(GAMS)+RI(J)#CCS(GAMS) 36
RTHCL(J) = TEM2#RI(J)#CCS(GAMS)+RI(J)#SIN(GAMS) 37

C LOCATION OF CENTERS OF TRAILING EDGE CIRCLES 38
C
DCC J = 1, N 39
GAMS = GAMM(J) 40
TEM1 = (X2(J)-RI(1))#COS(GAMS)-(Y2(J)-RI(1))#SIN(GAMS)+RI(1) 41
TEM2 = (X2(J)-RI(1))#SIN(GAMS)+(Y2(J)-RI(1))#CCS(GAMS) 42
MCT(J) = TEM1-RC(J)#SIN(GAMS)-RC(J)#CCS(GAMS) 43
RTHCT(J) = TEM2#KO(J)#CCS(GAMS)-RC(J)#SIN(GAMS) 44

C LOCATION OF LEADING EDGES 45
C
CD J = 1, N 46
MLE(J) = MCL(J)-RI(J) 47
RTHLE(J) = RTHCL(J) 48

C LOCATION OF TRAILING EDGES 49
C
CD J = 1, N 50
MLE(J) = MCT(J)+RC(J) 51
RTHLE(J) = RTHCT(J) 52

C LOCATION OF LOCAL BLADE CHORDS AND STAGGERS 53
C
38
CO  EC  J=1,N
MCHORD(J) = MTE(J)-MLE(J)
RSTGR(J) = RTHTE(J)-RTHLE(J)
6C STGR(J) = THTe(J)-THLE(J)
C
C LOCATION CF SPLINE CURVE ANGLES
C
DO  EC  J=1,N
GAMJ = GAMS-GAMR(J)
BETA(S) = KIS(J)+GAMJ*57.255779
BETOS(J) = KOS(J)+GAMJ*57.295779
BETIPS(J) = KIPS(J)+GAMJ*57.255779
7C BETOT(J) = KUP(J)+GAMJ*57.255779
C
C LOCATION CF SPLINE POINTS CN BLADES
C
DO  EC  J=1,N
GAMJ = GAMS-GAMR(J)
TEMP1 = (X1(J)-RI(1)) * COS(GAMS)- (Y1(J)-RI(1)) * SIN(GAMS) + FI(1)
TEMP2 = (X1(J)-RI(1)) * SIN(GAMS)+ (Y1(J)-RI(1)) * COS(GAMS)
NDELJ = NDEL(J)
DO  80  K=1,NDELJ
MSPS(J,K) = TEMP1*XX(J,K)+GAMJ*YS(J,K)*SIN(GAMJ)-MLE(J)
MSPP(J,K) = TEMP1*XX(J,K)+GAMJ*YS(J,K)*SIN(GAMJ)-MLE(J)
RTHSPS(J,K) = TEMP2*XX(J,K)*SIN(GAMJ)+YS(J,K)*COS(GAMJ)-RTHLE(J)
RTHSPP(J,K) = TEM2*XX(J,K)*SIN(GAPJ)+YP(J,K)*COS(GAPJ)-RTHLE(J)
C
C PRINT CLFILT
C
WRITE(6,13CC)
WRITE(6,12C)
WRITE(6,12C2) (J,MCHORD(J),STGR(J),RSTGR(J),RI(J),RC(J),
MTE(J),THLE(J),RTHLE(J),MTE(J),THTE(J),RTHTE(J),J=1,N)
WRITE(6,12C2)
WRITE(6,12C4) (J,BETA(S),BETCS(J),BETIP(J),BETCF(J),
MCL(J),THCL(J),RTHCL(J),MCT(J),THCT(J),RTHCT(J),J=1,N)
DO  SC  J=1,N
WRITE(6,105C) J
WRITE(6,105C2)
NDELJ = NDEL(J)
C
WRITE(6,11C5) (MSPS(J,K),RTHSPS(J,K),THSPS(J,K),RTHSPP(J,K),J=1,NDELJ)
RETURN
C
C FCMAT STATEMENTS
C
1000 FORMAT(1I1,///10X,38HCCOMPLETED INPUT FOR IDEAL FLOW PROGRAMS///)
1010 FORMAT(14X,5HBLADE,5X,6HMCHCRO,4X,4HSTGR,6X,5HRSTGR,6X,2HR1,8X,
12HR0,E7,3HMTE,6X,4HTMLE,6X,5HRTHE,6X,3HPTE,6X,4HTTHE,6X,5FRTHTE)
1020 FORMAT(15X,k12,3X,11F10.5)
1030 FORMAT(///14X,5HBLADE,5X,5HBETCS,5X,5HETCS,5X,5HETIP,5X,5HBETOP,
1.1O6X,3MCL,6X,4HTCL,6X,5HRHCL,6X,3MCJ,6X,4HTCT,6X,5FRHTCT)
1040 FORMAT(15X,k12,3X,4F10.5,10X,6F10.5)
1050 FORMAT(///10X,1HBLADE SEGMENT NO.,12)
1060 FORMAT(///14X,6HMSPP,6X,6HRTHSPS,6X,6HRTHSPS,15X,4HMSPP,6X,
15F10.5,6F10.5)
1070 FORMAT(11X,3F10.5,11X,3F10.5)
END
SIEFIC PLT

SUBROUTINE PLCTT
COMMON /INP1TN,TCHORD,SOLID,DELK,KAPIN,RADIUS,CCL(5),P0PHI(5),
COMMON /OUTPLT/CHORD(5),GAM(5),GAMR(5),PHIC(5),PITCH
COMMON /CLPLOT/XPEN,YPEN,NX,NY,IPEN,TLABEL(10),YLABEL(10)
1XG(5),YG(5),NDEL(5),XX(5),ICC(5),YS(5),100,YP(5),100)
COMMON /COM2/GAMPS,MCHORD(5),RSTGR(5),STCR(5),MLE(5),RTHLE(5),
1RTHCL(5),RHTC(5),BETIS(5),BETCS(5),BETIP(5),BETCP(5),MSPS(5),100,1
1RTHCL(5),ICT(5),THSPS(5),100,MSFP(5),100,1RTHSP(5),100,THSPP(5),100,
1INDL(5),ADELP(5),N1(5),N2(5),NPAIS(5),XCRX(5),YCRY(5),XI(5),
1Y(5),X(5),Y(5),X(5),C(5),X(5),C(5),Y(5),100,1XC5,100,1Y(5),XC5,100,1
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
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1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
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1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
1Y(5),X(5),100,1XC5,100,1Y(5),XC5,100,
Y1S(J) = YI(J)*RI(J)*CCS(K1S(J))
X1P(J) = XI(J)*RI(J)*SIN(K1P(J))
Y1P(J) = YI(J)-RI(J)*CCS(K1P(J))
X2S(J) = CHORD(J)-RC(J)*(1.0+SIN(KCS(J)))
Y2S(J) = YO(J)+RC(J)*CCS(KGS(J))
X2P(J) = CHORD(J)-RC(J)*(1.0-SIN(KCP(J)))
2C Y2P(J) = YO(J)-RC(J)*COS(KGP(J))

C ELIMINATION OF XX, YS, AND YP POINTS NOT ON THE BLADE SURFACES
C
DO 11C J=1,N
NDELJ = NDEL(J)
C SELECTION SURFACE
M = 1
DO 20 K=1,NDELJ
IF (XX(J,K)*GT.X1S(JJ) GO TO 40
3C CONTINUE
4C XSI(J,J) = X1S(JJ
YSI(J,J) = Y1S(JJ
KK = K
DO 50 K=KK,NDELJ
IF (XX(J,K)*GT.X2S(JJ) GO TO 60
M = M+1
XSI(J,M,J) = XX(J,KJ
YSI(J,M,J) = Y2S(JJ
NDELS(J) = M
C PRESSURE SURFACE
M = 1
DO 7C K=1,NDELJ
IF (XX(J,K)*GT.X1P(JJ) GO TO 80
7C CONTINUE
8C XP(J,J) = X1P(JJ
YP(J,J) = Y1P(JJ
KK = K
DO 50 K=KK,NDELJ
IF (XX(J,K)*GT.X2P(JJ) GO TO 100
M = M+1
XP(J,M,J) = XX(J,KJ
YP(J,M,J) = Y2P(JJ
10C M = M+1
XP(J,M,J) = X2P(JJ
YP(J,M,J) = Y2P(JJ
11C NDELP(J) = M
C LOCAL ATION OF LOCAL BLADE ORIGINS WITH RESPECT TO FLCT ORIGIN
C
DO 12C J=1,N
XORX(J,J) = XI(JJ+XT
12C YORY(J,J) = YI-J1Y(JJ
C LOCALATION OF BLADE SURFACE COORDINATES WITH RESPECT TO FLCT ORIGIN
C
DO 15C J=1,N
SING = SIN(GAMR(JJ
COSG = COS(GAMR(JJ
NDELSJ = NDELS(JJ
DO 13C K=1,NDELJ
XSX(J,J) = XORX(JJ+XS(J,J)*CCSG+YS(JJ,SING

C
13C \( Y_{SY}(J,K) = Y_{ORY}(J) + X_S(J,K) \times \text{SING} - Y_S(J,K) \times \text{COSG} \)

NDELJ = NDELP(J)

DO 14C K=1,NDELJ

\( XP(X,J,K) = X_{ORX}(J) + X_P(J,K) \times \text{CCSG} + Y_P(J,K) \times \text{SING} \)

14C \( Y_{PY}(J,K) = Y_{ORY}(J) + X_P(J,K) \times \text{SING} - Y_P(J,K) \times \text{COSG} \)

15C CONTINUE

DO 16C J=1,N

\( \text{SING} = \sin(GAMR(J)) \)

\( \text{COSG} = \cos(GAMR(J)) \)

\( XIX(J) = X_{ORX}(J) + R_I(J) \times (\text{SING} + \text{CCSG}) \)

\( Y_{IV}(J) = Y_{ORY}(J) + R_I(J) \times (\text{SING} - \text{CCSG}) \)

\( XOX(J) = X_{ORX}(J) + \text{CHORD}(J) \times \text{CCSG} + RC(J) \times (\text{SING} - \text{COSG}) \)

16C \( Y_{YI}(J) = Y_{ORY}(J) + \text{CHORD}(J) \times \text{SING} - RC(J) \times \text{COSG} \)

DO 17C J=1,N

\( \text{ANG1} = PI - KIS(J) + KIP(J) \)

\( N(J) = ANG1 / 2 \)

\( ANG1 = PI / 2 - GAMM(J) + KIS(J) \)

\( N(J) = ANG(J) \)

DO 18C K=1,N1J

\( XIXC(J,J,K) = XIX(J) + R_I(J) \times \text{CCS}(ANG1) \)

17C \( Y_{YI}(J,K) = Y_{YI}(J) - R_I(J) \times \sin(ANG1) \)

DO 17C J=1,N

\( \text{ANG2} = PI + KODS(J) - KUP(J) \)

\( N2(J) = ANG2 / 2 \)

\( ANG2 = PI / 2 - GAMM(J) + KCP(J) \)

\( N2(J) = N2(J) \)

DO 18C K=1,N2J

\( ANG2 = ANG2 / 2 \)

\( XOXC(J,J,K) = XOXC(J) - RC(J) \times \text{CCS}(ANG2) \)

18C \( Y_{YO}(J,K) = Y_{YO}(J) - \text{RC}(J) \times \sin(ANG2) \)

DO 20C J=1,N

\( \text{M} = C \)

\( \text{DC} = 23G J=1,N \)

NPTS(J+) = NDELS(J) + NDELP(J) + N(J) + N2(J)

C PRESSURE : SURFACE

NDELJ = NDELP(J)

DO 19C K=1,NDELJ

\( M = M + 1 \)

\( \text{XDOWN}(M) = Y_{PY}(J,K) \)

15C \( Y_{ACR}(M) = XPX(J,K) \)

C TRAILING EDGE

\( N2(J) = N2(J) \)

DO 20C K=1,N2J

\( M = M + 1 \)

\( \text{XDOWN}(M) = Y_{YO}(J,K) \)

20C \( Y_{ACR}(M) = XOXC(J,K) \)

C SECTION SURFACE

NDELJ = NDELS(J)

DO 21C K=1,NDELJ

42
MM = NCELJ-K+1
M = M+1
XDCW(I) = YSY(J,MM)
21C YACROS(M) = XSY(J,MM)
C LEADING EDGE
11J = NI(J)
GO 22C K=1,N1J
M = M+1
XDCW(N) = YICY(J,K)
22C YACROS(M) = XIXC(J,K)
22C CONTINUE
C
C ROTATE BLADES TO NORMAL CASCADE SETTING
C
24C I=1,M
XTEMP(I) = (YACROS(I)-XIX(I))*COS(GAMS)+(XDCW(I)-YIY(I))
1*SIN(GAMS)
24C YTEMP(I) = -(YACROS(I)-XIX(I))*SIN(GAMS)+(XDCW(I)-YIY(I))
1*COS(GAMS)
C
C FIND MAXIMUM AND MINIMUM LIMITS OF FLCT, AND SHIFT BLADES
C
XMIN= C.
GO 25C I=1,M
25C XMIN = XMIN(XMIN,XTEMP(I))
XMAX= C.
CC 26C I=1,M
26C XMAX = XMAX(XMAX,XTEMP(I))
YMIN = C.
GO 27C I=1,M
27C YMIN = YMIN(YMIN,YTEMP(I))
YMAX = C.
GO 28C I=1,M
28C YMAX = YMAX(YMAX,YTEMP(I))
DX = XMAX-XMIN
DY = YMAX-YMIN
XT = -XMIN+CX/1E.
YT = -YMIN+CY/5.
GO 29C I=1,M
XDCW(I) = YTEMP(I)+YT
29C YACROS(I) = XTEMP(I)+XT
C
C CLIPlicate BLADES FOR CASCADE EFFECT
C
MM = 5
GO 31C K=1,MM
M = MM+K
XDCW(N) = XDCW(N)+PITCH
3CC YACROS(M) = YACROS(K)
DO 31C J=1,N
31C GAMR(J) = GAMR(J)*57.29577S
C
C PREPARE KKK AND P AND CALL CALPLT
C
KKK(1) = 4
KKK(2) = C
KKK(3) = 2*N
KKK(4) = 1
GO 32C J=1,N
32C KKK(J+5) = NPNTS(J)
DO 33C J=1,N
K = J+5*N
$SIEFTC
title$

SLRCLINE Caltit
COMMON/INFL/N, TCHORD, SCL10, DELK, KAPIN, RADIUS, CCCC1(5), PFOFPH1(5),
COMMON/GLPIXT/CHORD(5), GAM(5), GAMR(5), FHIC(5), PITCH
COMMON/CGLPIXT/YPEN, XYPEN, NX, NY, IPEN, XLABEL(10), YLABEL(10)
DIMENSION TITL1(3), TITL2(5), TITL3(5), TITL4(7), TITL5(5), TITL6(7)
DATA (TITL1(1), TITL2(5), TITL3(5), TITL4(7), TITL5(5), TITL6(7))
= '1, 3, ' / HTOTAL, 6H / 1C, ' 3HTAL/
DATA (TITL2(1), TITL3(5), TITL4(7), TITL5(5), TITL6(7))
= 'C6H, MBER, 6H / SCL, 5HICITY/
DATA (TITL3(1), TITL4(7), TITL5(5), TITL6(7))
= '77/C1 / PH1, 6H / PH1(1, 6H) / 1C.
16HTC L, 6H / TC, 2H F/
DATA (TITL5(1), TITL6(1), TITL7(1))
= '77/C1 / R, 6H / R, 2F/C/
16H M, 6H / GAMR/
CALL SYMBOL(-6, C7, 5, C8, TITLE, C0, 72)
CALL SYMBOL(-6, C8, 75, 0.15, TITLE, C0, 15)
CALL SYMBOL(-6, C8, 5, C15, TITLE2, C0, 29)
CALL SYMBOL(-6, C7, 4.9, C15, TITLE3, C0, 27)
CALL SYMBOL(-6, C8, 3, C15, TITLE4, C0, 38)
CALL SYMBOL(-6, C4, 6, C15, TITLE5, C0, 26)
CALL SYMBOL(-6, C2, 7, C15, TITLE6, C0, 36)
CALL NUMBER(-6, C8, 3, C12, TCHORD, C0, 0.5)
CALL NUMBER(-6, C8, 3, C12, DELK, C0, 4)
CALL NUMBER(-6, C8, 3, C12, SCL10, C0, 4)
CALL NUMBER(-6, C7, 2, C12, PITCH, C0, 5)
CALL NUMBER(-4, 7.2, C12, KAPIN, C0, 4)
CALL NUMBER(-4, 3, 7.2, C12, RADIUS, C0, 5)
IF (N.EQ.1) GO TO 20
YX = 6.2
DO 10 C = 2, N
CALL NUMBER(-6, C, YYY, C12, CCCC1(J), 0, 0, 4)
CALL NUMBER(-4.0, YYYY, C.12, PHC PH1(J), 0.0, 4)
CALL NUMBER(-2.2, YYYY, C.12, GCTC(J), 0.0, 4)
CALL NUMBER(-2.2, YYYY, C.12, LCTC(J), 0.0, 4)
1C CALL NUMBER(-1.5, YYYY, C.12, F(J), 0.0, 4)
2C YYYY = 4.6
   DO 3C J=1,N
      YYYY = YYYY + 2.
   CALL NUMBER(-6.6, YYYY, 0.12, IMCC(J), 0.0, 4)
   CALL NUMBER(-4.6, YYYY, C.12, RICC(J), 0.0, 4)
3C CALL NUMBER(-3.2, YYYY, C.12, RCCC(J), 0.0, 4)
   YYYY = 2.7
   DO 4C J=1,N
      YYYY = YYYY + 2.
   CALL NUMBER(-6.6, YYYY, C.12, CHCRD(J), 0.0, 5)
   CALL NUMBER(-4.7, YYYY, C.12, PHIC(J), 0.0, 4)
   CALL NUMBER(-3.3, YYYY, C.12, GAM(J), 0.0, 4)
4C CALL NUMBER(-1.5, YYYY, C.12, GAMR(J), 0.0, 4)
RETURN
END

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 22, 1970
126-15.
REFERENCES


'The aeronautical and space activities of the United States shall be conducted so as to contribute ... to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof.'

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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