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THE DESIGN OF AXIAL COMPRESSOR AIRFOILS USING ARBITRARY CHAMBER LINES

George R. Frost, et al

Aerospace Research Laboratories
Wright-Patterson Air Force Base, Ohio

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FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

PROJECT 7065

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This report describes a technique which has been developed for use in the design of axial compressor airfoils with camber lines of arbitrary shape. The slope of the camber line at several points on a streamsurface is determined from the air angles at these points as well as the incidence and deviation angle distributions for the blade. A camber line is produced by fitting a smooth curve segment through each pair of points from the leading to the trailing edge. A thickness distribution is applied to this camber line to produce the blade element. A computer program which uses this technique to produce blade elements, stack them, and then determine coordinates for plane surfaces through the resultant blade is also described.

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AEROSPACE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by Captain George P. Frost and Dr. Arthur J. Wennerstrom of the Fluid Dynamics Facilities Research Laboratory, Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio.

The report presents results from a portion of the effort of the Fluid Machinery Research Group supervised by Dr. Arthur J. Wennerstrom and was conducted under Work Unit 09 of Project 7065, "Aerospace Simulation Techniques Research" under the overall direction of Mr. Elmer G. Johnson.

ABSTRACT

This report describes a technique which has been developed for use in the design of axial compressor airfoils with camber lines of arbitrary shape. The slope of the camber line at several points on a streamsurface is determined from the air angles at these points as well as the incidence and deviation angle distributions for the blade. A camber line is produced by fitting a smooth curve segment through each pair of points from the leading to the trailing edge. A thickness distribution is applied to this camber line to produce the blade element. A computer program which uses this technique to produce blade elements, stack them, and then determine coordinates for plane surfaces through the resultant blade is also described.

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INTRODUCTION

The traditional approach to the selection of blades for axial-flow compressors has been to choose a specific type of airfoil, subsequently to adjust the parameters defining that airfoil to suit prevailing aerodynamic conditions. Many successful designs have been accomplished in this manner using such blades as NACA 65-series, double circular arc, multiple circular arc, etc. This approach has the virtue of employing airfoil sections about which something is usually known with respect to losses, deviation angle, and operating limits. Reference 1, an earlier publication of this laboratory, is representative of this approach.

A typical contemporary design will be accomplished using a streamline curvature or matrix through-flow analysis incorporating computing stations internal to blade rows as well as at blade edges and in free spaces. Some criterion for optimization of blade shape must be chosen. (The authors of this report choose to achieve a particular shape of static pressure distribution along streamlines.) The spanwise distributions of inlet and outlet relative flow angles, loss coefficients, etc. will have been determined through some preliminary design procedure. A rule for determining deviation angle and distributing it along streamlines will have been selected. Subsequently, the aerodynamic blade design procedure consists of assuming a blade geometry, performing an aerodynamic analysis using specified relative flow angles as input data, and then repeating this procedure as many times as necessary, varying the parameters describing the airfoil sections, until the result of the aerodynamic analysis adequately satisfies the chosen optimization criterion.

There are three principal disadvantages to employing this procedure for the design of transonic and supersonic blade rows. First, the iteration required is time consuming and, to some degree, laborious. Many adjustments to the geometry specified may be required before optimization objectives are met. Although the bulk of the calculations are performed by computer, the designer generally must still examine and evaluate the aerodynamic result and decide what to change, and how much, for the next attempt. Second, when airfoil shape is restricted to any particular class of airfoil, it will rarely be possible to achieve the optimization objectives as closely as might be desired, everywhere along the span. Some compromise will nearly always be necessary. Third, streamline curvature and matrix through-flow analyses sometimes experience difficulty in finding solutions for certain combinations of high relative Mach number and high absolute Mach number near choking when relative flow angle is specified as input data within blade rows. This is a numerical problem related to the construction of these computer programs and can vary considerably from one program to another.

A design method which eliminates or appreciably reduces these problems consists of specifying total temperature (in rotors) or the product of radius and whirl velocity (in stators) as input data to the aerodynamic analysis program and then fitting airfoils of arbitrary shape to the resulting relative flow angles. In so doing, one loses the data base which might be associated with a particular class of airfoil, but the value of such a geometrically-related data base is questionable for transonic and supersonic sections. Following this approach, the aerodynamic analysis can be optimized with considerably fewer iterations than are usually required with specified geometry. In most cases, optimization objectives can be achieved on nearly every streamsurface. Some interaction is required between the blade design program and the aerodynamic analysis to insure that the blade lean angles and blockages are kept up-to-date. However, the over-all effort required to achieve a satisfactory design using this method has been found to be substantially less.

The principal difficulty in developing a procedure to define arbitrary airfoils consists of arriving at a method which produces aerodynamically attractive shapes which are in addition practical from a structural and manufacturing viewpoint. This report describes one such method developed at the Aerospace Research Laboratories. The method has been incorporated into a computer program which is an extension of the work reported in Reference 1. In addition to determining the shape of the airfoils on aerodynamic surfaces, section properties are computed, the blade is stacked, and Cartesian coordinates are determined for manufacturing purposes.

The overall design technique is described in Section II. The mathematical details of implementing the technique in a calculation procedure are described in Sections III and IV. A method of producing the optimal camber line on a streamsurface is treated in Section III; the calculations related to other aspects of the blade design procedure are discussed briefly in Section IV. Sections V, VI, and VII present the details of and use of a computer program which incorporates this design technique, currently used at the Aerospace Research Laboratories in the design of axial compressor airfoils.

SECTION II

DESCRIPTION OF THE TECHNIQUE

1. TECHNIQUE OVERVIEW

The technique described in this report uses an iterative procedure to produce an "optimal" camber line on each streamsurface. A thickness destribution is applied to each camber line, and the resulting blade elements are stacked to produce the desired airfoil. The technique requires the designer to specify the incidence distribution radially at the blade leading edge, the location of the stack axis and the stacking offsets of each streamsurface section centroid therefrom, the parameters of the thickness distribution, and the chordwise distribution of deviation angle along the span.

The optimization criterion which has been selected for the section camber line is to maximize the absolute value of the minimum radius of curvature on the camber line. The "optimal" camber line is chosen from a set of camber lines containing the minimum number of inflection points. This original set of camber lines is generated by varying the second derivative at the leading edge.

The starting point of the design technique is output data from an aerodynamic analysis of a particular blade row which has been generated by specifying a parameter other than blade geometry, such as those suggested in the Introduction, across the blade row. This data is in the form of the meridional coordinates of the streamsurfaces and the chordwise distribution of the relative air angles on each streamsurface. The essential steps of the technique itself are described in a qualitative sense in the remainder of this section.

2. DETAILS OF THE TECHNIQUE

The first step of the overall procedure is to determine the optimal blade section on each streamsurface. This in itself is a multiple-step process which incorporates an iteration with solidity to establish a camber line for each of a range of values of the second derivative at the leading edge, a search procedure to choose the "optimal" camber line, and the application of a thickness distribution to this camber line.

The procedure begins with an initial estimate of solidity on the streamsurface. This estimate is made by applying the stagger angle, assumed equal to the average of the inlet and outlet relative air angles, to the meridional chord length, obtained by integrating along each streamline from the assumed leading to trailing edge, to get a first estimate of the true chord. The solidity is then computed from this estimate, the mean streamsurface radius, and the number of blades in the blade row.

The total deviation angle is computed from this estimate in some fashion, such as the modified Carter's Rule with appropriate constants. The deviation angle at each internal point is next determined as a designer-specified fraction of the total deviation. The required section angle at each internal point and at the trailing edge is then the difference between the relative air angle and the deviation angle, while the section angle at the leading edge is the difference between the relative air angle and the incidence angle.

Each section camber line is determined by fitting a segment of a smooth curve, such as a cubic, between each pair of points from the leading to the trailing edge of the section. The slope at the endpoint of each segment matches the specified section angle there. The true chord length and the associated value of solidity can then be determined. If the solidity differs by more than a prescribed tolerance from the previous estimate, the steps subsequent to and including the total deviation determination are repeated for the revised values of solidity until the desired tolerance is achieved.

The entire procedure described thus far is repeated for a range of values of the second derivative at the leading edge. The resultant set of camber lines are inspected first to focus only on those which contain the minimum number of inflection points, and from these to choose the camber line which is "optimal" in the sense previously described.

A thickness distribution is then applied to this camber line, and the procedure is repeated for each streamsurface. The blade sections are stacked, and the Cartesian coordinates of the resulting blade determined. In addition, the blade blockage and lean angle are computed at each appropriate streamsurface-computing station intersection point.

As a final step, the designer inspects the resulting blockages, Cartesian centroid offsets, blade lean angles, and coincidence of the blade edges with the designated computing stations. If necessary, appropriate changes are made in the inputs to the aerodynamic analysis, and the entire procedure recycled until adequate overall coincidence between the blade design and the aerodynamic analysis is achieved.

SECTION III

THE SECTION CAMBER LINE

The first item required in the application of the technique described in the preceding section is the meridional chord length of the blade element, obtained by integrating along the streamline between the assumed leading and trailing edges. This is accomplished by passing a spline curve through the meridional coordinates (x, r) of the streamsurface. The slope of the streamsurface is calculated (as the slope of the spline-curve) at 100 points distributed uniformly on the x-axis (axially) between the edges of the blade section. The chord length, C_m, is obtained from the equation

$$C_m = \sum_{n=2}^{100} (x_n - x_{n-1}) \sqrt{1 + \left[\left(\frac{dr}{dx_n} + \frac{dr}{dx_{n-1}} \right) \Big/ 2 \right]^2} \qquad (1)$$

An estimate of true chord is obtained by applying the stagger angle, assumed equal to the average of the inlet and outlet relative air angles, to the meridional chord so that the true chord estimate, C_e, is

$$C_e = \frac{C_m}{\cos\left(\frac{\beta_{\ell e} + \beta_{te}}{2} \right)} \qquad (2)$$

The first estimate of solidity may be computed from the equation

$$\sigma = \frac{NC_e}{2\pi \left(\frac{r_{\ell e} + r_{te}}{2} \right)} \qquad (3)$$

where N is the number of blades and $r_{\ell e}$, r_{te} are the radii of the streamsurface at the leading and trailing edges, respectively.

The calculation of the deviation angle, δ, follows the NASA method (Reference 2, Equations 269 and 271) with an additional term, γ.

$$\delta = \delta_{0_{10}} K_{\delta_s} K_{\delta_t} + \frac{m}{\sigma^b} (\beta_{\ell e} - i - \beta_{te} + \delta) + \gamma \qquad (4)$$

where

$\delta_{0_{10}}$	is the variation from the reference deviation for a 10 percent-thick NACA 65-series thickness distribution
K_{δ_s}	is a correction factor for a blade shape with a thickness distribution different from a 65-series blade
K_{δ_t}	is a correction factor for a maximum thickness other than 10 percent
m	is the slope of the deviation angle variation from reference deviation with camber
b	is the solidity exponent (variable with air inlet angle)
β_{xe}	is the relative air angle at the particular edge
i	is the incidence angle
γ	is the arbitrary extra deviation

Solving Eq (4) for δ yields

$$\delta = \frac{\delta_{0_{10}} K_{\delta_s} K_{\delta_t} + \frac{m}{\sigma^b} (\beta_{\ell e} - i - \beta_{te}) + \gamma}{\left(1 - \frac{m}{\sigma^b}\right)} \qquad (5)$$

For use in the calculation procedure, K_{δ_s}, i, and γ are specified by the designer. Several of the other quantities are obtained from known quantities and figures of Reference 2: $\delta_{0_{10}}$ from Figure 161; K_{δ_t}, Figure 172; m, Figure 166; and b, Figure 164.

The blade angle, α, is established at several points across the blade element from the relative air angle, β, modified by the proper consideration of incidence or deviation. At the leading edge,

$$\alpha_{\ell e} = \beta_{\ell e} - i \tag{6}$$

and at the trailing edge,

$$\alpha_{te} = \beta_{te} - \delta \tag{7}$$

At the other points, the blade angles are determined by subtracting a fraction f of the trailing-edge deviation from the relative air angle. At each internal point j,

$$\alpha_j = \beta_j - f_j\delta \tag{8}$$

The fraction f_j is determined by radial interpolation from the deviation distributions specified by the designer.

The camber line is constructed by fitting a third order polynomial (cubic) through each pair of points from the leading to the trailing edge of the section. Thus, each segment of the camber line is defined by equations of the form

$$y = ax^3 + bx^2 + cx + d \tag{9}$$

$$y' = 3ax^2 + 2bx + c \tag{10}$$

$$y'' = 6ax + 2b \tag{11}$$

As a result, each segment has at most one inflection point ($y'' = 0$) in its useful range, and in most instances has none.

The constants a, b, c, and d for any particular segment can be expressed in terms of the endpoints (denoted by subscripts 1 and 2) of that segment as

$$a = \frac{(y_2'-y_1') - y_1''(x_2-x_1)}{3\left[(x_2^2-x_1^2) - 2x_1(x_2-x_1)\right]} \tag{12}$$

$$b = \frac{y_1'' - 6ax_1}{2} \tag{13}$$

$$c = y_1' - 3ax_1^2 - 2bx_1 \tag{14}$$

$$d = y_1 - ax_1^3 - bx_1^2 - cx_1 \tag{15}$$

For simplicity, the leading edge of the camber line is placed at the origin of the coordinate system, resulting in the following boundary conditions for the first segment:

$$\begin{aligned} \text{At } x = 0,\ y &= 0 \\ y' &= \tan \alpha_{\ell e} \\ y'' &= y_o'' \end{aligned} \tag{16}$$

$$\text{At } x = x_1,\ y' = \tan \alpha_1 \tag{17}$$

With these boundary conditions, the appropriate values of a, b, c, and d for this segment are completely determined.

The boundary conditions for the second and subsequent segments are specified at one endpoint by equating the first and second derivatives to the values for the preceding segment at the point of juncture; for example, for the second segment,

$$\begin{aligned} \text{At } x = x_1,\ y &= y_{1\,(\text{first segment})} \\ y' &= \tan \alpha_1 \\ y'' &= y''_{1\,(\text{first segment})} \end{aligned} \tag{18}$$

and at the other endpoint,

$$\text{At } x = x_2,\ y' = \tan \alpha_2 \tag{19}$$

From these conditions, a distinct set of constants (a, b, c, d) are computed for the second segment. This same procedure is applied to each pair of points to produce a camber line with continuous first and second derivatives all along its length.

Note that the first segment of the camber line requires the specification of the second derivative y_o'' at the leading edge. This boundary condition affects the constants of the first segment and thus the nature of this entire segment, including the conditions (y_1, y_1'') at the other endpoint. Since the constants for the second segment are established from these conditions, and so on for the rest of the segments, the nature of the entire camber line depends on the value of y_o'' specified at the leading edge.

It has been found convenient to specify y_o'' in terms of a non-dimensional parameter S/R_o, the ratio of blade spacing, S, to the radius of curvature, R_o, at the leading edge. R_o is given by the equation

$$R_o = \frac{\left[1 + \tan^2 \alpha_{\ell e}\right]^{3/2}}{y_o''} \tag{20}$$

and S is obtained from

$$S = \frac{2\pi r_{\ell e}}{N} \tag{21}$$

From Equations (20) and (21),

$$\frac{S}{R_o} = \frac{2\pi r_{\ell e}\, y_o''}{N\left[1 + \tan^2 \alpha_{\ell e}\right]^{3/2}} \tag{22}$$

Solving for y_o'' gives

$$y_o'' = \frac{N\left[1 + \tan^2 \alpha_{\ell e}\right]^{3/2}}{2\pi r_{\ell e}} \cdot \frac{S}{R_o} \tag{23}$$

which indicates that y_o'' is the parameter S/R_o multiplied by a constant.

For a particular value of S/R_o, the true chord length of the resulting camber lines may be determined from the endpoint of the final segment as

$$C = \sqrt{(x_{te})^2 + (y_{te})^2} \tag{24}$$

This value is used to compute a revised value of solidity, which is compared to the original estimate. If satisfactory coincidence has not been achieved, a corrected deviation angle is computed from the revised solidity, and the camber line reconstructed. This iteration is repeated until adequate coincidence has been obtained.

It is difficult if not impossible to have an intuitive notion of a "good" value of y_o'' (hence, S/R_o). For some ranges of S/R_o, each camber line segment may contain an inflection point, while for other ranges, few if any segments may contain such a point. The authors of this report have assumed that, for aerodynamic as well as mechanical reasons, the most desirable airfoil among several matching the same flow angle at each computing station will be one having the minimum number of inflection points between leading and trailing edge. This is accomplished by calculating the camber line for a broad range of values of S/R_o and isolating the range in which the minimum total number of inflection points occurs. This range is examined with finer S/R_o increments to generate a new set of camber lines on which the minimum absolute radius of curvature is identified. The value of S/R_o which produces the largest such radius is then made the mid-value of S/R_o for the final search pass, using still finer S/R_o increments. The camber line which possesses the largest value of the minimum radius of curvature at the conclusion of this search procedure is chosen as opt

SECTION IV

OTHER ASPECTS OF THE CALCULATION PROCEDURE

Various other aspects of the calculation procedure are discussed briefly in this section. For greater detail on these topics, the reader's attention is directed to Reference 1, where these items are treated at some length as elements of the calculation procedure of which the subject procedure is a modification.

1. THE SECTION THICKNESS DISTRIBUTION

The thickness distribution which is applied to the camber line herein described is that referred to as the "Standard Thickness Distribution" in Reference 1. The distribution is defined by two third-order polynomials, one from the leading edge to the point of maximum thickness, and another from there to the trailing edge. At the point of juncture, the thickness and the first and second derivatives of thickness are equated. In order to prevent a reflex curvature from occurring in the thickness distribution near the leading edge, the second derivative of thickness is set equal to zero at the leading edge. The thickness of the leading and trailing edges is independently specified so that it need not be the same at both edges. At the leading edge, the blade surface is completed with a circular arc. At the trailing edge, the blade surface is truncated by connecting the two endpoints with a straight line.

2. CARTESIAN COORDINATES FOR THE BLADE

The preceding material has described the methods used to design individual blade sections. When located as desired relative to the blade stacking axis, the section coordinates are the coordinates of the streamsurface blade section. A series of sections on all streamsurfaces specifies the envelope of the blade, but the surface coordinates are not in a form convenient for manufacturing purposes. The calculation procedure uses a spline-curve to interpolate (or extrapolate) the coordinates of the blade surfaces for manufacturing purposes.

3. SECTION PROPERTIES

The stacking axis of the blade is passed through each streamsurface section either at one of the edges or at a point specified relative to the centroid of the section. Because the streamsurface sections are in general non-planar, the centroids of the manufacturing sections will not generally lie precisely on the stacking axis when the streamsurface sections are stacked on their centroids. By determining the locations of the centroids of the manufacturing sections so obtained, it is possible to estimate the offsets that must be applied when restacking the streamsurface sections to locate the manufacturing centroids as desired relative to the stacking axis.

To assist further in the mechanical analysis of the blade, the areas, second moments of area, principal axes, and principal second moments of area for both the streamsurface and manufacturing sections are also determined in the calculation procedure.

4. BLADE CHARACTERISTICS

A calculation of the volume enclosed by the blade between the innermost and outermost streamsurfaces is made. In addition, quantities which describe the blade on cylindrical surfaces and which may be required in an aerodynamic analysis of the blade are computed as an option. The calculations are presented here because a typographical error undetected during editing of Reference 1 has impaired their usefulness in that Reference.

First, the angular position of the camber line with respect to the stack axis at a streamsurface-computing station intersection is specified in terms of Φ, defined in Figure 1.

The physical passage blockage (B) due to the presence of the blades is determined as a percentage of the passage circumference in terms of the number of blades in the blade row and τ, the angle subtended on the cylindrical surface by each blade:

$$B = \frac{N\tau}{2\pi} \qquad (25)$$

The blade lean angle, ϵ , with respect to the radial direction at a given point is obtained from the slope of a spline-curve fit through the y-z Cartesian coordinates of the streamsurface section camber lines at the particular axial location.

Thus

$$\epsilon = \Phi - \operatorname{Arctan}\left(\frac{dy}{dz}\right) \qquad (26)$$

Two other quantities are needed to produce the proper mean-camber line angle on the cylindrical surface: The local computing station inclination, μ, obtained from the specified station description; and the local streamsurface inclination, γ, obtained from the specified x-r streamsurface description. Together with the camber line angle on the streamsurface, α_*, these quantities are employed in the following equation to calculate the proper cylindrical-surface section angle, α_*°:

$$\tan \alpha_*^\circ = \frac{\tan \gamma \tan \epsilon + \tan \alpha_*/\cos \gamma}{1 - \tan \mu \tan \gamma} \qquad (27)$$

SECTION V

USE OF THE PROGRAM

Basic information required by the user to run the ARL computer program which incorporates the calculation procedure described in this report is given in this section. The various input data items are defined first, and the input data format is then specified. A description of the output data that may be expected is given. (Implementation of the program on a computing system is not discussed here. but in the section entitled "Computer Program Details".)

1. DEFINITION OF INPUT DATA ITEMS

TITLE	An alphanumeric title of 72 characters that may be used to identify a run.
NLINES	The number of streamsurfaces which are defined and on which blade sections will be designed. Must satisfy $2 \le \text{NLINES} \le 15$.
NSTNS	The number of computing stations at which the streamsurface radii are specified. Must satisfy $3 \le \text{NSTNS} \le 10$.
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \le \text{NZ} \le 15$.
NSPEC	The number of radially-disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \le \text{NSPEC} \le 15$.
ISEGPT	The number of points to be used to define each segment of the camber line. $2 \le \text{ISEGPT} \le \text{Integer}\left(\frac{80}{\text{IRTE-IRLE}}\right)$
NBLADE	The number of blades in the blade row.
ISTAK	If ISTAK = 0, the blade will be stacked at the leading edge. If ISTAK = 1, the blade will be stacked at the trailing edge. If ISTAK = 2, the blade will be stacked at, or offset from, the section centroid.

IPUNCH	If IPUNCH = 0, the quantities necessary for aerodynamic analysis of the resulting blade are not produced on punched cards. If IPUNCH = 1, these quantities are produced on punched cards.
IFPLOT	Where CALCOMP software is incorporated into the computing system, IFPLOT specifies the creation of precision plots. (Further information regarding the requirements for this are given in the section entitled "Computer Program Details.") If IFPLOT = 0, no plots will be produced. If IFPLOT = 1, a plot of the streamsurface sections will be produced. All NLINES sections are shown superimposed. The origin for each section plot is offset from the centroid of the section by distances specified by DELX and DFLY. If IFPLOT = 2, a plot of the manufacturing sections will be produced. The origin is the blade stacking axis, and all NZ sections are shown superimposed. If IFPLOT = 3, both of the plots described for IFPLOT = 1 and 2 will be produced. If IFPLOT = 4, individual plots of each of the manufacturing sections will be produced. The axes are rotated clockwise by the section stagger angle for each plot.
IPRINT	The input data is always listed by the program. Details of the streamsurface and manufacturing sections are printed as prescribed by IPRINT. If IPRINT = 0, details of streamsurface and manufacturing sections are printed. If IPRINT = 1, details of streamsurface sections are printed. If IPRINT = 2, details of the manufacturing sections are printed.
ZINNER, ZOUTER	The NZ manufacturing sections are equispaced between z equals ZINNER and ZOUTER.
SCALE	When precision plots are produced, SCALE is the scale factor employed.

STACKX	The axial coordinate of the stacking axis for the blade, relative to the same origin as used for the station locations, XSTA.
PLTSZE	The size (inches) of the plotter to be used in the creation of precision plots.
IRLE	The number of the computing station designated as the blade leading edge.
IRTE	The number of the computing station designated as the blade trailing edge.
NRADEV	The number of radii at which the non-dimensional deviation distribution is specified. $1 \leq \text{NRADEV} \leq 5$.
NINC	The number of points which describe the incidence angle distribution. $1 \leq \text{NINC} \leq 15$.
NSIGN	An integer which specifies the sign convention of the particular blade. Conventionally positive rotors and stators have NSIGN values of -1 and +1, respectively.
IFCA	If IFCA = 1, the factor m in the deviation angle rule is that of the NACA-65-series mean line (Figure 195, Reference 2). If IFCA = 2, the factor m in the deviation angle rule is that of the circular-arc mean line.
IPASS	The number of initial values of S/R_o which are to be used in the procedure to find the optimal camber line. $20 \leq \text{IPASS} \leq 50$.
XKSHPE	The shape factor (K_{δ_s}) in the deviation equation.
SOLTOL	The solidity tolerance used in the iterative procedure to produce a consistent camber line.
NPTS	The number of points defining a particular chordwise deviation distribution. $1 \leq \text{NPTS} \leq 10$.
RADEV	Radius at which a particular deviation distribution applies.
SM	An array of NPTS meridional chord fractions which, together with DEVCRV, specify a particular deviation distribution.
DEVCRV	An array of NPTS normalized deviation fractions which, together with SM, specify a particular deviation distribution.

RINC	An array of NINC radii which, together with XINC, specify the incidence distribution at the leading edge.
XINC	An array of NINC incidence angles which, together with RINC, specify the incidence distribution. Input positive for conventionally positive rotors and stators (see NSIGN).
DELDEV	An array of NINC angles which, together with RINC, specify the distribution of the "arbitrary extra deviation" term in the deviation determination. Input positive for conventionally positive rotors and stators (see NSIGN).
KPTS	The number of points provided to specify the shape of a computing station. If KPTS = 1, the computing station is upright and linear. If KPTS = 2, the computing station is linear and either upright or inclined. If KPTS > 2, a spline curve is fitted through the points provided to specify the shape of the station.
IFANGS	If IFANGS = 0, the calculations of the quantities required for aerodynamic analysis will be omitted at a particular computing station. If IFANGS = 1, these calculations will be performed at that station.
XSTA	An array of KPTS axial coordinates (relative to an arbitrary origin) which, together with RSTA, specify the shape of a particular computing station.
RSTA	An array of KPTS radii which, together with XSTA, specify the shape of a particular computing station.
R	The streamsurface radii at NLINES locations at each of the NSTNS stations.
AIRANG	The relative air angles at NLINES locations at each of the NSTNS stations.

ZR	The variation of properties of the streamsurface blade sections is specified as a function of streamsurface number. The various quantities are then interpolated (or extrapolated) at each streamsurface. The streamsurfaces are numbered consecutively from the innermost outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.
YA	The fraction of meridional chord used as the leading edge in the calculation of the section chord for the solidity iteration on a particular streamsurface. If YA = 0., the true chord length is calculated. $0.0 \leq YA \leq 1.0$.
YB	The increment in S/R_o which, with SDIVR and IPASS, establishes the initial range of S/R_o which is inspected in the determination of the optimal camber line on a particular streamsurface. May be positive or negative.
YC	If YC = 0., the radius of curvature at the leading edge of each camber line will be considered in the procedure to identify the camber line which maximizes the minimum radius of curvature. If YC = 1.0, the radius of curvature at the leading edge will not be considered in this procedure.
YE	The maximum number of inflection points expected on a particular camber line. If the calculated minimum number is greater than YE, an informational diagnostic is printed.
RLE	The ratio of section leading edge radius to chord.
TC	The ratio of section maximum thickness to chord.
TE	The ratio of section trailing edge half-thickness to chord.
Z	The location of the section maximum thickness, as a fraction of camber line length.
SDIVR	The initial value of S/R_o.
DELX, DELY	The stacking axis passes through the streamsurface blade sections, offset from the centroid, leading, or trailing edge by DELX and DELY in the x and y directions, respectively.

2. INPUT DATA FORMAT

Data input is by punched card, and three formats are used. The first card only is alphanumeric, using the first 72 columns of the card. Integers are placed in three-column fields, which start with Column 1. No decimal points are used, and the integer should be right-justified. Real numbers are placed in 12-column fields, which also start with Column 1. Decimal points should be included, and the numbers may be placed anywhere in the field.

In the following chart, one line corresponds to one card.

```
TITLE

NLINES NSTNS NZ NSPEC ISEGPT NBLADE ISTAK IPUNCH IFPLOT IPRINT

ZINNER ZOUTER SCALE STACKX PLTSZE

IRLE IRTE NRADEV NINC NSIGN IFCA IPASS

XKSHPE SOLTOL

NPTS                                 }
                                     }
RADEV                                } repeated NRADEV times
                                     }
SM DEVCRV } repeated NPTS times      }

RINC XINC DELDEV } repeated NINC times

KPTS IFANGS                           }
                                      }
XSTA RSTA } repeated KPTS times       } repeated NSTNS times
                                      }
R AIRANG } repeated NLINES times      }

ZR YA YB YC YE RLE         }
                           } repeated NSPEC times
TC TE Z SDIVR DELX DELY    }
```

Listing of a sample input data deck is included under "Example of Use of the Program."

3. OUTPUT DATA

Printed output from the program may be considered to consist of four sections: a printout of the input data, details of the camber line and blade section on each streamsurface, a listing of quantities required for aerodynamic analysis, and details of the manufacturing sections determined on the constant-z planes. These are briefly described below.

The input data printout includes all quantities read in, and is self-explanatory.

Details of the streamsurface blade sections are printed if IPRINT = 0 or 1. Listed first are the results of the investigations of the S/R_o parameter. The initial table presents the results of the first iteration which is used to identify the range of S/R_o in which the minimum number of inflection points occur on the camber line. This range is in turn investigated with finer increments of S/R_o to determine the maximum value of the minimum radius of curvature. Then follow the details of the optimal camber line which has been identified by a third investigation of S/R_o with still finer parameter increments. These details include the deviation and solidity which have been calculated for this optimal S/R_o, and a description of the camber line in terms of coordinates, first and second derivatives, and the radii of curvature. Listed next are the parameters defining the blade section, some of which are computed and some of which are interpolated at the streamsurface from the tables read in. Then follow details of the blade section in "normalized" form. The blade section geometry is given for the particular section, except that the meridional projection of the chord is unity. For this section of the output, the coordinate origin is the blade leading edge. The following quantities are given: blade chord, stagger angle, camber angle, section area, location of centroid of the section, second moments of area of the section about the centroid, orientation of the principal axes, and the principal second moments of area of the section about the centroid. Then are listed the coordinates of the camber line, the camber line angle, the section thickness, and the coordinates of the blade surfaces. A line-printer plot of the normalized section follows. The scales for the plot are arranged so that the section just fills the page. Thus, the scales will generally differ from one plot to another. "Dimensional" details of the blade section are given next. The normalized data given previously is scaled to give the proper blade section. For this section of the output, the coordinates are with respect to the blade stacking axis. The following quantities are given: blade chord, radius and location of center of the leading edge, section area, the second moments of area of the section about the centroid, and the principal second moments of area of the section about the centroid. The coordinates of points on the blade surfaces are then listed, followed by the coordinates of 31 points distributed at six degree intervals around the leading edge. Finally, the coordinates of the blade surfaces and points around the leading edge are shown in Cartesian form.

The quantities required for aerodynamic analysis are printed at all computing stations specified by the IFANGS parameter. The radius, section angle, blade lean angle, blade blockage, and relative angular location of the camber line are printed at each streamsurface intersection with the particular computing station.

Details of the manufacturing sections are printed if IPRINT = 0 or 2. At each value of z specified by ZINNER, ZOUTER and NZ, section properties and coordinates are given. The origin for the coordinates is the blade stacking axis. The following quantities are given: section area, the location of the centroid of the section, the second moments of area of the section about the centroid, the principal second moments of area of the section about the centroid, the orientation of the principal axes, and the section torsional constant. Then the coordinates of points on the blade section surfaces are listed, followed by 31 points around the leading edge.

Precision plots are produced if IFPLOT = 1, 2, 3 or 4 as described under the definition of IFPLOT given previously.

If IPUNCH = 1, the program punches the quantities required for aerodynamic analysis, together with identifying indices denoting station number and streamsurface number, on cards in the following format: 5 fields each of 12 locations for the quantities themselves, followed by 2 fields each of 3 locations for the indices.

SECTION VI

EXAMPLE OF USE OF THE PROGRAM

This section shows the use of the program to generate a compressor rotor with an inlet hub-to-tip ratio of 0.31, a rather steep hub ramp angle (32.5°), and a constant outer radius. The blade is defined by six computing stations, one at either edge and four internal. This results in a camber line composed of five segments. Six streamlines have been used to define the flow and hence the blade by means of the streamsurface blade sections. The computing-stations and streamsurfaces which define the blade are depicted in a stack-axis projection in Figure 2.

1. INPUT DATA

The input data deck used for this example is listed below. Some points of interest are noted in the order in which they occur in the input.

As mentioned above, six streamsurface blade sections are used to define the blade. The streamsurface radii are specified at eight computing stations, the first and last of which are outside of the rotor. This ensures that the boundary conditions imposed on the spline-curve (zero curvature at the endpoints) have little influence on the shape of the curve representing the streamsurface within the blade. The useful relative air angles are specified at the six computing stations defining the blade. The computing stations within the blade are curved in an attempt to make the meridional projections of the camber line segments approximately equal. The parameters which define the streamsurface blade sections are given at six locations; that is, at every streamsurface. Twelve points are used to define each segment, which results in a camber line defined by a total of fifty-six points. (This number serves the purposes of this example well, but it would be advantageous to use more points if the precision-plot output is to be incorporated directly in the manufacturing procedure.) There are twenty blades in the particular blade row, stacked approximately on their streamsurface centroids. No punched output is requested. All optional sections of the printed output are to be printed, and superimposed section plots are to be produced on a plotter (with an 11-inch useful range) at two and one-half times full size.

Stations 2 and 7 are the leading and trailing edges of the blade, respectively. The deviation distribution is the same at all radii, since it is specified only at one radius. The incidence angles and the arbitrary extra deviation are specified at six points for this rotor blade. The factor m in the deviation calculation is to be that of a circular-arc camber line. Thirty camber lines will initially be investigated in the effort to identify the optimal camber line, representing a broad range of the S/R_o parameter. The shape factor in the deviation calculation is unity, and the tolerance on solidity in the iteration for each camber line is 0.005.

The streamsurface radii and relative air angles have been determined from an aerodynamic analysis of the flow through the blade row. The leading edge of the blade has been established as the point from which the chord length, and thus the solidity, will be computed.

The increment in the S/R_o parameter has been initially set equal to + 0.04 in the investigation to find the optimal camber line. This increment will automatically be reduced twice subsequently as the most favorable range of S/R_o is more closely scrutinized. It is anticipated that no inflection points will be required near the hub, while a single inflection point will probably be required in the mid and tip regions of the blade. The blade thickness distribution is determined by aerodynamic and mechanical factors. The leading edge radius and trailing edge half-thickness are set to approximately 0.005 inch, probably a practical minimum. Maximum thickness/chord ratios vary from 6 percent at the hub to 2.5 percent at the casing. The maximum thickness is placed in the rearward portion of the camber line, which helps to maintain a small leading edge wedge angle.

```
    EXAMPLE - LOW HUB/TIP RATIO COMPRESSOR ROTOR DESIGN
  6  8  7  6 12 20  2  0  3  0
2.5          8.50         2.5          -7.05        11.0
  2  7  1  6 -1  2 30
1.           .005
  6
3.3
0.           .1
0.2          .11
0.4          .15
.6           .22
.8           .38
1.           1.00
2.68         6.37         2.
3.84         5.57         2.
5.09         4.85         2.
6.42         4.2          2.
7.79         3.92         2.
8.5          3.69         2.
  1  0
-9.          2.35
2.35
3.6454
4.9893
6.3617
7.7723
8.5
  5  0
-8.51        2.6514
-8.5926      5.0663
-8.531       6.3989
-8.3115      7.7861
-8.161       8.5
      2.6514    -40.9695
      3.8041    -47.2370
      5.0786    -50.8039
      6.4109    -53.6378
      7.7902    -57.2964
      8.5000    -59.7859
  4  1
-7.905       3.0363
-8.000       5.07
-7.96        6.48
-7.725       8.5
      3.0363    -30.0198
      4.0696    -37.2906
      5.2456    -44.5116
      6.4975    -51.0404
      7.8091    -57.8178
      8.5000    -61.3719
```

```
  4  1
-7.35         3.3893
-7.395        5.385
-7.415        6.565
-7.311        8.5
      3.3893     -20.0393
      4.3344     -28.9282
      5.4154     -38.6681
      6.5824     -47.7054
      7.8307     -56.2706
      8.5000     -60.2293
  4  1
-6.801        3.7385
-6.801        5.49
-6.87         6.65
-6.94         8.5
      3.7385     -12.2698
      4.5798     -21.2618
      5.5662     -33.3334
      6.6591     -44.2126
      7.8459     -54.0832
      8.5000     -58.9884
  4  1
-6.251        4.0884
-6.18         5.7
-6.3          6.725
-6.56         8.5
      4.0884      -5.4451
      4.8259     -13.8107
      5.7147     -27.6798
      6.7242     -40.6966
      7.8575     -51.6465
      8.5000     -57.5196
  5  1
-5.665        4.4612
-5.5846       5.896
-5.7208       6.7945
-5.9516       7.8661
-6.134        8.5
      4.4612      11.5881
      5.0795      -7.0980
      5.8623     -25.6222
      6.7858     -40.0751
      7.8716     -51.3351
      8.5000     -56.5798
  4  0
-5.52         4.5534
-5.35         5.2
-5.3          5.80
-5.7          8.5
```

```
4.5534
5.1606
5.9412
6.8378
7.8677
8.5
1.0         0.          0.04        0.          0.          .00155
.06         .00155      .56         -0.2        .01
2.0         0.           .04        0.          0.          .00149
.0525       .00149      .59         -0.15       -.018
3.0         0.           .04        0.          1.          .00143
.0423       .00143      .62         -0.3        .035
4.          0.0         .04         0.0         1.0         .00137
.0325       .00137      .65         -1.3        .02
5.0         0.0          .04        0.          1.0         .00131
.0265       .00131      .68         -2.0        .01
6.          .0          0.04        0.          1.0         .00125
.025        .00125      .70         -2.3        -.001
```

2. OUTPUT DATA

The input data specified all optional output data, and a sample of each segment of the output is presented in this section. A brief description of some aspects of the output is presented below.

Shown first is the printout of the input data. This is followed by details of the first streamsurface blade section. The tables presenting the results of the S/R_Q investigations are followed by a description of the camber line which has been selected. Then appear the details of, and a line-printer plot of, the normalized blade section, followed by the specifications of the section scaled to the proper dimensions. Printed first are the 56 points specified for each blade surface. Next appear the 31 points describing the leading edge radius. The final data for the streamsurface section are the equivalent Cartesian coordinates for these same points.

The format is repeated for each of the remaining streamsurface blade sections, but these results are not reproduced here. Subsequent to the streamsurface data are printed the quantities required for aerodynamic analysis at those stations where requested by the IFANGS parameter.

Details for the seven manufacturing sections defining the blade follow. Reproduced below is the output relating to the first (innermost) section. Properties of the section are followed by coordinates of 56 points on each surface and 31 points around the leading edge. It will be noted that the section centroid is not calculated to be exactly on the stacking axis. If it were desired to have the centroids of the manufacturing sections lie more nearly precisely on the stacking axis, the program would be rerun with either DELX and DELY offsets specified so that they would counteract the mislocation of the centroids previously determined, or with a slightly shifted location of the stack axis. However, the user must bear in mind that the final step in the design procedure is to obtain satisfactory coincidence of the blade with the stations defining its leading and trailing edges in the meridional plane. It is possible that a blade which had all manufacturing sections stacked precisely on their centroids at a particular stacking-axis location would have quite an undesirable meridional profile. There are tradeoffs, then, between the stacking preciseness and the coincidence of the calculated blade's edges with its assumed profile on the one hand, and the number of iterations it would require to find the truly optimal stack location and centroid offsets, on the other.

The input data specified superimposed precision plots of both the streamsurface sections and the manufacturing sections. These plots are reproduced (at reduced size) as Figures 3 and 4, respectively. It is of interest to refer also to Figure 2. The innermost manufacturing plane is well below the lowest point on the hub streamsurface section in the plane of the stacking axis. The Cartesian coordinates of this streamsurface section show that the lowest point on the section (the 14th point on the leading edge) is at Z = 2.57224. The streamsurface radius at this point is 2.6514, and the innermost manufacturing plane is at Z = 2.5. Thus, at the leading edge, the extrapolation required to define the manufacturing section is somewhat smaller than might first appear. At the trailing edge, extrapolation is required for the first three manufacturing sections. The streamsurface radius at the casing and the Z-coordinate for the outermost manufacturing plane both equal 8.5; however, the Z-coordinates of the blade section are all actually below 8.5. Thus, the outermost section too is defined completely by extrapolation. Of course, portions of the blade that are defined by extrapolation do not appear on the final blade, but facilitate manufacture.

```
                                         USAF - ARL(LF) ARBITRARY CAMBER LINE PROGRAM
                                         ********************************************

     TITLE                             =     EXAMPLE - LOW HUB/TIP RATIO COMPRESSOR ROTOR DESIGN
     NUMBER OF STREAMSURFACES          =  6
     NUMBER OF STATIONS                =  8
     NUMBER OF CONSTANT-Z PLANES       =  7
     NUMBER OF BLADE DATA POINTS       =  6
     NUMBER OF POINTS PER SEGMENT      = 12
     NUMBER OF BLADES IN BLADE ROW     = 20
     ISTAK                             =  2
     IPUNCH                            =  0
     IFPLOT                            =  3
     IPRINT                            =  0

     ZINNER                            =  2.5000
     ZOUTER                            =  8.5000
     SCALE                             =  2.5000
     STACKX                            = -7.0500
     PLTSZE                            = 11.0000


     LEADING EDGE STATION NUMBER       =  2
     TRAILING EDGE STATION NUMBER      =  7
     RADII SPECIFYING DEVIATION        =  1
     RADII SPECIFYING INCIDENCE        =  6
     SENSE OF ROTATION INDICATOR       = -1
     DEVIATION CALCULATION INDEX       =  2
     NUMBER OF INITIAL S/R TRIALS      = 30

     SHAPE FACTOR                      =  1.0000
     SOLIDITY TOLERANCE                =   .0050

DEVIATION CURVE  1     NUMBER OF POINTS = 6     RADIUS =  3.3000

     POINT     NORMALIZED MERIDIONAL     NORMALIZED DEVIATION
                       CHORD                  DISTRIBUTION

       1               0.0000                     .1000
       2                .2000                     .1100
       3                .4000                     .1500
       4                .6000                     .2200
       5                .8000                     .3800
       6               1.0000                    1.0000

INCIDENCE AND EXTRA DEVIATION DISTRIBUTION

     INLET RADIUS     INCIDENCE     EXTRA DEVIATION

        2.6800          6.370           2.000
        3.8400          5.570           2.000
        5.0900          4.850           2.000
        6.4200          4.200           2.000
        7.7900          3.920           2.000
        8.5000          3.690           2.000
```

```
                  STREAMSURFACE GEOMETRY SPECIFICATION

          COMPUTING STATION  1     NUMBER OF DESCRIBING POINTS=  2      IFANGS( 1)=  0

     DESCRIPTION            STREAMLINE     RADII           AIR ANGLE
       X          R           NUMBER


   -9.0000     2.3500          1           2.3500          -0.0000
   -9.0000     3.3500          2           3.6454          -0.0000
                               3           4.9893          -0.0000
                               4           6.3617          -0.0000
                               5           7.7723          -0.0000
                               6           8.5000          -0.0000
          COMPUTING STATION  2     NUMBER OF DESCRIBING POINTS=  5      IFANGS( 2)=  0

     DESCRIPTION            STREAMLINE     RADII           AIR ANGLE
       X          R           NUMBER


   -8.5100     2.6514          1           2.6514         -40.9695
   -8.5926     5.0663          2           3.8041         -47.2370
   -8.5310     6.3989          3           5.0786         -50.8039
   -8.3115     7.7861          4           6.4109         -53.6378
   -8.1610     8.5000          5           7.7902         -57.2964
                               6           8.5000         -59.7859
          COMPUTING STATION  3     NUMBER OF DESCRIBING POINTS=  4      IFANGS( 3)=  1

     DESCRIPTION            STREAMLINE     RADII           AIR ANGLE
       X          R           NUMBER


   -7.9050     3.0363          1           3.0363         -30.0198
   -8.0000     5.0700          2           4.0696         -37.2906
   -7.9600     6.4800          3           5.2456         -44.5116
   -7.7250     8.5000          4           6.4975         -51.0404
                               5           7.8091         -57.8178
                               6           8.5000         -61.3719
          COMPUTING STATION  4     NUMBER OF DESCRIBING POINTS=  4      IFANGS( 4)=  1

     DESCRIPTION            STREAMLINE     RADII           AIR ANGLE
       X          R           NUMBER


   -7.3500     3.3893          1           3.3893         -20.0393
   -7.3950     5.3850          2           4.3344         -28.9282
   -7.4150     6.5650          3           5.4154         -38.6681
   -7.3110     8.5000          4           6.5624         -47.7054
                               5           7.8307         -56.2706
                               6           8.5000         -60.2293
```

```
      COMPUTING STATION  5      NUMBER OF DESCRIBING POINTS=  4       IFANGS( 5)=  1

   DESCRIPTION             STREAMLINE      RADII             AIR ANGLE
   X           R             NUMBER


 -6.8010     3.7385             1            3.7385          -12.2698
 -6.8010     5.4900             2            4.5798          -21.2618
 -6.8700     6.6500             3            5.5662          -33.3334
 -6.9400     8.5000             4            6.6591          -44.2126
                                5            7.8459          -54.0832
                                6            8.5000          -56.9884

      COMPUTING STATION  6      NUMBER OF DESCRIBING POINTS=  4       IFANGS( 6)=  1

   DESCRIPTION             STREAMLINE      RADII             AIR ANGLE
   X           R             NUMBER


 -6.2510     4.0884             1            4.0884           -5.4451
 -6.1800     5.7000             2            4.8259          -13.8107
 -6.3000     6.7250             3            5.7147          -27.6798
 -6.5600     8.5000             4            6.7242          -40.6966
                                5            7.8575          -51.6465
                                6            8.5000          -57.5196

      COMPUTING STATION  7      NUMBER OF DESCRIBING POINTS=  5       IFANGS( 7)=  1

   DESCRIPTION             STREAMLINE      RADII             AIR ANGLE
   X           R             NUMBER


 -5.6650     4.4612             1            4.4612           11.5881
 -5.5846     5.8960             2            5.0795           -7.0980
 -5.7208     6.7945             3            5.8623          -25.6222
 -5.9516     7.8661             4            6.7258          -40.0751
 -6.1340     8.5000             5            7.8716          -51.3351
                                6            8.5000          -56.5798

      COMPUTING STATION  8      NUMBER OF DESCRIBING POINTS=  4       IFANGS( 8)=  0

   DESCRIPTION             STREAMLINE      RADII             AIR ANGLE
   X           R             NUMBER


 -5.5200     4.5534             1            4.5534           -0.0000
 -5.3500     5.2000             2            5.1806           -0.0000
 -5.3000     5.8000             3            5.9412           -0.0000
 -5.7000     8.5000             4            6.8378           -0.0000
                                5            7.8877           -0.0000
                                6            8.5000           -0.0000
```

```
                SECTION GEOMETRY SPECIFICATION

STREAMLINE   SLD         IN.DEL      CONSID     NO.ALC    LE RADIUS MAX THICK TE THICK  POINT OF START VAL    X STACK    Y STACK
 NUMBER      CL FT        S/RC    LE RC CRV INFL. PTS   /CHORD     /CHORD   /2*CHORD  MAX THICK  OF S/F      OFFSET     OFFSET

  1.00       0.000        .040     0.0000     0.0000    .00155     .06000    .00155     .5600     -.2000     .010000 -0.000000
  2.00       0.000        .040     0.0000     0.0000    .00149     .05250    .00149     .5900     -.1500    -.018000 -0.000000
  3.00       0.000        .040     0.0000     1.0000    .00143     .04230    .00143     .6200     -.3000     .035000 -0.000000
  4.00       0.000        .040     0.0000     1.0000    .00137     .03250    .00137     .6900    -1.3000     .020000 -0.000000
  5.00       0.000        .040     0.0000     1.0000    .00131     .02650    .00131     .6800    -2.0000     .010000 -0.000000
  6.00       0.000        .040     0.0000     1.0000    .00125     .02500    .00125     .7000    -2.3000    -.001000 -0.000000
```

```
STREAMSURFACE  1
     ITERATION  1
     ************

     INITIAL S/R =    -.2000          INCREMENTAL S/R =    .0400

          PASS NO.     NO. OF INFLECTION PTS     MIN. RADIUS OF CURVATURE

              1                    1                        .340
              2                    1                        .348
              3                    1                        .357
              4                    1                        .367
              5                    1                        .376
              6                    1                        .387
              7                    0                        .398
              8                    0                        .409
              9                    0                        .421
             10                    0                        .434
             11                    0                        .448
             12                    0                        .463
             13                    0                        .477
             14                    2                        .492
             15                    2                        .505
             16                    2                        .517
             17                    2                        .522
             18                    2                        .521
             19                    2                        .511
             20                    2                        .492
             21                    4                        .472
             22                    4                        .454
             23                    4                        .437
             24                    4                        .421
             25                    4                        .406
             26                    4                        .393
             27                    4                        .380
             28                    4                        .368
             29                    4                        .357
             30                    4                        .346
```

```
STREAMSURFACE  1
    ITERATION  2
    ************

    INITIAL S/R =    0.0000          INCREMENTAL S/R =   .0110

         PASS NO.     NO. OF INFLECTION PTS     MIN. RADIUS OF CURVATURE

             1                 1                         .387
             2                 0                         .390
             3                 0                         .393
             4                 0                         .396
             5                 0                         .399
             6                 0                         .402
             7                 0                         .405
             8                 0                         .408
             9                 0                         .412
            10                 0                         .415
            11                 0                         .418
            12                 0                         .422
            13                 0                         .425
            14                 0                         .429
            15                 0                         .433
            16                 0                         .436
            17                 0                         .440
            18                 0                         .444
            19                 0                         .448
            20                 0                         .452
            21                 0                         .456
            22                 0                         .460
            23                 0                         .464
            24                 0                         .468
            25                 0                         .472
            26                 0                         .476
            27                 0                         .480
            28                 0                         .484
            29                 2                         .488
            30                 2                         .492

THE MAXIMUM VALUE OF THE MINIMUM RADIUS OF CURVATURE OCCURS AT AN END POINT OF THE PRESENT S/R RANGE
```

```
OPTIMAL SECTION
***************

FINAL S/R =    .3025

ITERATIONS ON SOLIDITY
                      ITERATION  1   DEVIATION =  8.666   SOLIDITY = 3.1200
                      ITERATION  2   DEVIATION =  8.666   SOLIDITY = 3.1211

POINT     NORMALIZED MERIDIONAL     TANGENTIAL     CAMBER LINE      SECOND        RADIUS OF
               COORDINATE           COORDINATE        SLOPE       DERIVATIVE      CURVATURE

  1             0.0000                0.0000          -.6893         .6506          2.754
  2              .0193               -.0132           -.6768         .6466          2.723
  3              .0387               -.0262           -.6643         .6427          2.692
  4              .0580               -.0389           -.6519         .6388          2.663
  5              .0773               -.0514           -.6396         .6349          2.635
  6              .0967               -.0636           -.6274         .6309          2.607
  7              .1160               -.0756           -.6152         .6270          2.581
  8              .1353               -.0874           -.6031         .6231          2.556
  9              .1547               -.0990           -.5911         .6192          2.532
 10              .1740               -.1103           -.5792         .6152          2.508
 11              .1933               -.1213           -.5673         .6113          2.486
 12              .2127               -.1322           -.5556         .6074          2.465
 13              .2304               -.1420           -.5440         .6989          2.111
 14              .2481               -.1515           -.5308         .7905          1.836
 15              .2659               -.1608           -.5159         .8821          1.615
 16              .2836               -.1698           -.4995         .9736          1.435
 17              .3013               -.1785           -.4814        1.0652          1.283
 18              .3191               -.1868           -.4617        1.1568          1.155
 19              .3368               -.1948           -.4404        1.2483          1.045
 20              .3545               -.2025           -.4174        1.3399           .950
 21              .3723               -.2096           -.3929        1.4314           .866
 22              .3900               -.2164           -.3667        1.5230           .793
 23              .4077               -.2226           -.3388        1.6146           .729
 24              .4253               -.2283           -.3118        1.4680           .783
 25              .4428               -.2336           -.2873        1.3214           .852
 26              .4604               -.2384           -.2654        1.1749           .943
 27              .4779               -.2429           -.2461        1.0283          1.062
 28              .4954               -.2471           -.2294         .8817          1.225
 29              .5130               -.2510           -.2152         .7351          1.456
 30              .5305               -.2546           -.2036         .5886          1.806
 31              .5481               -.2581           -.1945         .4420          2.392
 32              .5656               -.2615           -.1881         .2954          3.566
 33              .5832               -.2647           -.1842         .1489          7.063
 34              .6007               -.2680           -.1828         .0023        459.928
 35              .6183               -.2712           -.1816         .1369          7.670
 36              .6358               -.2743           -.1780         .2715          3.860
 37              .6534               -.2774           -.1721         .4061          2.573
 38              .6710               -.2804           -.1638         .5407          1.924
 39              .6886               -.2832           -.1531         .6753          1.533
 40              .7061               -.2857           -.1400         .8099          1.271
 41              .7237               -.2881           -.1246         .9445          1.084
 42              .7413               -.2901           -.1068        1.0791           .943
 43              .7589               -.2918           -.0867        1.2137           .833
 44              .7764               -.2931           -.0642        1.3483           .746
 45              .7940               -.2940           -.0393        1.4829           .676
 46              .8127               -.2945           -.0107        1.5737           .636
 47              .8315               -.2944            .0197        1.6644           .601
 48              .8502               -.2938            .0517        1.7552           .572
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 49          .8689        -.2925    .0854    1.8460    .548
 50          .8876        -.2906    .1208    1.9368    .528
 51          .9064        -.2880    .1579    2.0275    .512
 52          .9251        -.2846    .1967    2.1183    .500
 53          .9438        -.2806    .2373    2.2091    .491
 54          .9625        -.2757    .2795    2.2998    .487
 55          .9813        -.2701    .3234    2.3906    .486
 56         1.0000        -.2636    .3690    2.4814    .488
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                      STREAMSURFACE GEOMETRY ON STREAMLINE NUMBER  1
                      **********************************************

    BETA1            =-34.579      (BLADE INLET ANGLE.)
    BETA2            = 20.254      (BLADE OUTLET ANGLE.)
    YZERO            =  .00155     (BLADE LEADING EDGE RADIUS AS A FRACTION OF CHORD.)
    T                =  .06000     (BLADE MAXIMUM THICKNESS AS A FRACTION OF CHORD.)
    YCNE             =  .00155     (BLADE TRAILING EDGE HALF-THICKNESS AS A FRACTION OF CHORD.)
    Z                =  .5600      (LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN LINE.)
    CCRC             = 3.3719      (MERIDIONAL CHORD OF SECTION.)

 NORMALISED RESULTS - ALL THE FOLLOWING REFER TO ABLADE HAVING A MERIDIONAL CHORD PROJECTION OF UNITY
 ****************************************************************************************************

    BLADE CHORD     = 1.0325

    STAGGER ANGLE   =-14.745

    CAMBER ANGLE    =-54.833

    SECTION AREA    = .04394

    LOCATION OF CENTROID RELATIVE TO LEADING EDGE

              XBAR =  .50573
              YBAR = -.22597

    SECOND MOMENTS OF AREA ABOUT CENTROID

              IX    =  .00021
              IY    =  .00233
              IXY   = -.00063

    ANGLE OF INCLINATION OF (ONE) PRINCIPAL AXIS TO 'X' AXIS =-15.355

    PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

              IPX   = .00004        (AT-15.355 WITH 'X' AXIS)
              IPY   = .00250        (AT-15.355 WITH 'Y' AXIS)

         POINT        M E A N L I N E  D A T A             SURFACE COORDINATE DATA
         NUMBER      X        Y      ANGLE THICKNESS      XS        YS        XP       YP

           1       .00160 0.00000-34.579  .00320        .00251   .00132   .00069 -.00132
           2       .02069 -.01318-34.069  .00665        .02276 -.01042   .01903 -.01593
           3       .04018 -.02611-33.596  .01007        .04297 -.02192   .03740 -.03038
           4       .05948 -.03881-33.101  .01345        .06315 -.03318   .05580 -.04444
           5       .07877 -.05126-32.603  .01677        .08328 -.04420   .07425 -.05833
           6       .09806 -.06349-32.103  .02004        .10330 -.05500   .09273 -.07197
           7       .11735 -.07547-31.600  .02324        .12344 -.06557   .11126 -.08537
           8       .13664 -.08722-31.095  .02637        .14345 -.07593   .12963 -.09851
           9       .15593 -.09874-30.588  .02941        .16341 -.08608   .14845 -.11140
          10       .17522 -.11003-30.079  .03236        .18333 -.09603   .16711 -.12403
          11       .19451 -.12109-29.568  .03522        .20320 -.10577   .18582 -.13640
          12       .21360 -.13192-29.055  .03796        .22302 -.11533   .20459 -.14851
          13       .23150 -.14165-28.545  .04038        .24115 -.12391   .22185 -.15938
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POINT        M E A N L I N E  D A T A                 SURFACE COORDINATE DATA
NUMEER      X        Y     ANGLE THICKNESS          XS       YS       XP       YF


 14       .24919 -.15116-27.958  .04265           .25920 -.13231  .23919 -.17001
 15       .26689 -.16042-27.291  .04489           .27718 -.14048  .25660 -.10037
 16       .28459 -.16941-26.541  .04698           .29508 -.14839  .27409 -.19043
 17       .30228 -.17809-25.706  .04695           .31290 -.15604  .29166 -.20014
 18       .31998 -.18644-24.783  .05079           .33062 -.16338  .30933 -.20950
 19       .33767 -.19442-23.768  .05250           .34825 -.17040  .32709 -.21845
 20       .35537 -.20201-22.657  .05408           .36573 -.17706  .34495 -.22697
 21       .37306 -.20919-21.448  .05553           .38321 -.18334  .36291 -.23503
 22       .39076 -.21591-20.136  .05683           .40054 -.18923  .38098 -.24258
 23       .40845 -.22215-18.718  .05799           .41776 -.19469  .39915 -.24961
 24       .42596 -.22784-17.317  .05900           .43474 -.19968  .41718 -.25600
 25       .44346 -.23308-16.031  .05986           .45173 -.20432  .43520 -.26185
 26       .46097 -.23792-14.866  .06058           .46874 -.20864  .45319 -.26719
 27       .47847 -.24239-13.826  .06116           .48578 -.21270  .47116 -.27208
 28       .49598 -.24655-12.918  .06159           .50286 -.21653  .48909 -.27656
 29       .51348 -.25043-12.144  .06187           .51999 -.22019  .50697 -.28068
 30       .53098 -.25410-11.506  .06200           .53717 -.22372  .52480 -.28447
 31       .54849 -.25758-11.000  .06198           .55441 -.22716  .54257 -.28799
 32       .56599 -.26092-10.651  .06179           .57170 -.23056  .56026 -.29128
 33       .58350 -.26418-10.435  .06145           .58906 -.23396  .57793 -.29439
 34       .60100 -.26738-10.361  .06094           .60648 -.23741  .59552 -.29736
 35       .61854 -.27058-10.294  .06028           .62392 -.24093  .61315 -.30024
 36       .63608 -.27374-10.094  .05944           .64128 -.24448  .63087 -.30300
 37       .65361 -.27681 -9.763  .05845           .65857 -.24801  .64866 -.30561
 38       .67115 -.27976 -9.300  .05729           .67578 -.25149  .66652 -.30803
 39       .68869 -.28254 -8.703  .05596           .69292 -.254[illegible]8  .68445 -.31020
 40       .70622 -.28512 -7.970  .05447           .71000 -.25814  .70245 -.31209
 41       .72376 -.28744 -7.102  .05282           .72703 -.26123  .72050 -.31365
 42       .74130 -.28947 -6.097  .05100           .74401 -.26412  .73859 -.31483
 43       .75884 -.29117 -4.953  .04901           .76095 -.26676  .75672 -.31559
 44       .77637 -.29250 -3.671  .04685           .77787 -.26912  .77487 -.31588
 45       .79391 -.29341 -2.249  .04453           .79478 -.27116  .79304 -.31566
 46       .81260 -.29388   -.611  .04187           .81282 -.27295  .81237 -.31481
 47       .83128 -.29380  1.126  .03901           .83090 -.27430  .83166 -.31330
 48       .84997 -.29313  2.958  .03595           .84904 -.27518  .85089 -.31108
 49       .86865 -.29185  4.881  .03268           .86726 -.27557  .87004 -.30814
 50       .88734 -.28993  6.889  .02920           .88558 -.27544  .88909 -.30443
 51       .90602 -.28733  8.974  .02550           .90403 -.27474  .90801 -.29992
 52       .92471 -.28402 11.130  .02156           .92262 -.27344  .92679 -.29460
 53       .94339 -.27997 13.347  .01738           .94138 -.27151  .94540 -.28842
 54       .96208 -.27514 15.614  .01294           .96033 -.26891  .96382 -.28137
 55       .98076 -.26951 17.921  .00822           .97950 -.26560  .98202 -.27342
 56       .99945 -.26305 20.254  .00320           .99889 -.26154 1.00000 -.26455
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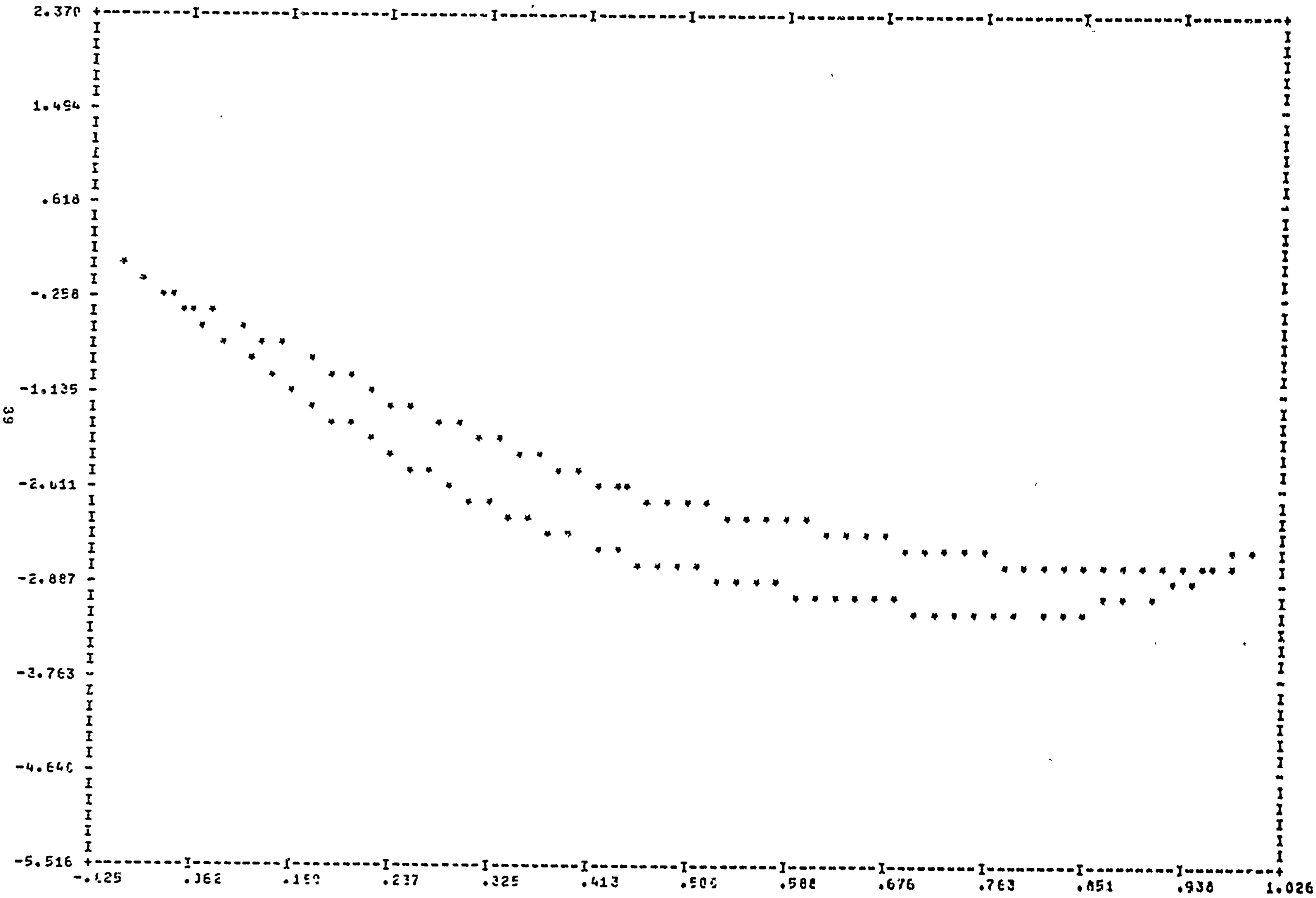
NORMALISED PLOT OF SECTION NUMBER 1

SCALES - 'X' IS SHOWN TIMES 10 TO THE POWER OF -0   'Y' IS SHOWN TIMES 10 TO THE POWER OF 1



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                DIMENSIONAL RESULTS - ALL RESULTS REFER TO A BLADE OF SPECIFIED CHORD
                *********************************************************************

        BLADE CHORD     = 3.48493E+00

        L.E.RADIUS      = 5.40164E-03         CENTERED AT X= -1.70986E+00 Y=  7.61934E-01

        SECTION AREA    = 4.99538E-01

        SECOND MOMENTS OF AREA ABOUT CENTROID

                IX      = 2.68937E-02
                IY      = 3.00714E-01
                IXY     =-8.13213E-02

        PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

                IPX     = 4.56332E-03  (AT-15.355 WITH 'X' AXIS)
                IPY     = 3.23044E-01  (AT-15.355 WITH 'Y' AXIS)

PT     SUCTION------SURFACE          PRESSURE-----SURFACE             PT     SUCTION------SURFACE          PRESSURE-----SURFACE
NO        X              Y              X              Y              NO        X              Y              X              Y


 1  -1.70620E+00   7.66381E-01  -1.71293E+00   7.57486E-01            2  -1.63653E+00   7.26791E-01  -1.65110E+00   7.08218E-01
 3  -1.57038E+00   6.88326E-01  -1.58916E+00   6.59750E-01            4  -1.50234E+00   6.50070E-01  -1.52710E+00   6.12092E-01
 5  -1.43444E+00   6.12899E-01  -1.46491E+00   5.65255E-01            6  -1.36667E+00   5.76494E-01  -1.40259E+00   5.19247E-01
 7  -1.29905E+00   5.40836E-01  -1.34012E+00   4.74080E-01            8  -1.23157E+00   5.05905E-01  -1.27750E+00   4.29763E-01
 9  -1.16425E+00   4.71682E-01  -1.21472E+00   3.86304E-01           10  -1.09710E+00   4.38148E-01  -1.15179E+00   3.43715E-01
11  -1.03010E+00   4.05283E-01  -1.08869E+00   3.02003E-01           12  -9.63269E-01   3.73069E-01  -1.02543E+00   2.61178E-01
13  -9.02155E-01   3.44111E-01  -9.67211E-01   2.24516E-01           14  -8.41275E-01   3.15814E-01  -9.08758E-01   1.88670E-01
15  -7.80647E-01   2.88271E-01  -8.50053E-01   1.53745E-01           16  -7.20289E-01   2.61570E-01  -7.91079E-01   1.19843E-01
17  -6.60220E-01   2.35796E-01  -7.31814E-01   8.70756E-02           18  -6.00455E-01   2.11038E-01  -6.72246E-01   5.55459E-02
19  -5.41009E-01   1.87384E-01  -6.12360E-01   2.53600E-02           20  -4.81893E-01   1.64919E-01  -5.52143E-01  -3.37286E-03
21  -4.23122E-01   1.43722E-01  -4.91581E-01  -3.05387E-02           22  -3.64704E-01   1.23076E-01  -4.30666E-01  -5.60261E-02
23  -3.06645E-01   1.05462E-01  -3.69392E-01  -7.97227E-02           24  -2.49390E-01   8.86345E-02  -3.08603E-01  -1.01272E-01
25  -1.92104E-01   7.30086E-02  -2.47844E-01  -1.20982E-01           26  -1.34748E-01   5.84325E-02  -1.87156E-01  -1.39007E-01
27  -7.72876E-02   4.47546E-02  -1.26572E-01  -1.55496E-01           28  -1.96936E-02   3.18229E-02  -6.61219E-02  -1.70603E-01
29   3.80587E-02   1.94856E-02  -5.82985E-03  -1.84478E-01           30   9.59806E-02   7.59163E-03   5.42846E-02  -1.97274E-01
31   1.54111E-01  -4.01143E-03   1.14207E-01  -2.09142E-01           32   2.12435E-01  -1.54738E-02   1.73927E-01  -2.20236E-01
33   2.70966E-01  -2.69447E-02   2.33440E-01  -2.30709E-01           34   3.29705E-01  -3.85753E-02   2.92746E-01  -2.40714E-01
35   3.88517E-01  -5.04460E-02   3.52199E-01  -2.50416E-01           36   4.47056E-01  -6.24097E-02   4.11925E-01  -2.59744E-01
37   5.05324E-01  -7.43260E-02   4.71913E-01  -2.68554E-01           38   5.63365E-01  -8.60644E-02   5.32140E-01  -2.76697E-01
39   6.21165E-01  -9.74940E-02   5.92613E-01  -2.84025E-01           40   6.78757E-01  -1.08485E-01   6.53287E-01  -2.90380E-01
41   7.36165E-01  -1.16908E-01   7.14145E-01  -2.95636E-01           42   7.93419E-01  -1.28636E-01   7.75196E-01  -2.99615E-01
43   8.50555E-01  -1.37543E-01   8.36286E-01  -3.02173E-01           44   9.07610E-01  -1.45500E-01   8.97496E-01  -3.03157E-01
45   9.64632E-01  -1.52383E-01   9.58740E-01  -3.02414E-01           46   1.02544E+00  -1.50400E-01   1.02394E+00  -2.99561E-01
47   1.08640E+00  -1.62955E-01   1.08899E+00  -2.94457E-01           48   1.14757E+00  -1.65943E-01   1.15362E+00  -2.86991E-01
49   1.20901E+00  -1.67259E-01   1.21839E+00  -2.77057E-01           50   1.27080E+00  -1.66796E-01   1.20261E+00  -2.64547E-01
51   1.33300E+00  -1.64439E-01   1.34641E+00  -2.49360E-01           52   1.39569E+00  -1.60070E-01   1.40973E+00  -2.31401E-01
53   1.45895E+00  -1.53966E-01   1.47248E+00  -2.10580E-01           54   1.52284E+00  -1.44799E-01   1.53459E+00  -1.86809E-01
55   1.58745E+00  -1.23639E-01   1.59598E+00  -1.60004E-01           56   1.65285E+00  -1.19951E-01   1.65659E+00  -1.30086E-01
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POINTS DESCRIBING LEADING EDGE RADIUS

POINT NO.        X              Y

  1      -1.71293E+00   7.57486E-01
  2      -1.71336E+00   7.57831E-01
  3      -1.71378E+00   7.58221E-01
  4      -1.71415E+00   7.58651E-01
  5      -1.71447E+00   7.59110E-01
  6      -1.71474E+00   7.59615E-01
  7      -1.71496E+00   7.60138E-01
  8      -1.71512E+00   7.60680E-01
  9      -1.71522E+00   7.61236E-01
 10      -1.71526E+00   7.61800E-01
 11      -1.71525E+00   7.62365E-01
 12      -1.71517E+00   7.62926E-01
 13      -1.71504E+00   7.63475E-01
 14      -1.71485E+00   7.64008E-01
 15      -1.71461E+00   7.64518E-01
 16      -1.71431E+00   7.64999E-01
 17      -1.71396E+00   7.65448E-01
 18      -1.71357E+00   7.65857E-01
 19      -1.71314E+00   7.66224E-01
 20      -1.71268E+00   7.66543E-01
 21      -1.71218E+00   7.66812E-01
 22      -1.71166E+00   7.67028E-01
 23      -1.71112E+00   7.67188E-01
 24      -1.71056E+00   7.67290E-01
 25      -1.71000E+00   7.67334E-01
 26      -1.70943E+00   7.67318E-01
 27      -1.70887E+00   7.67244E-01
 28      -1.70832E+00   7.67111E-01
 29      -1.70779E+00   7.66921E-01
 30      -1.70728E+00   7.66677E-01
 31      -1.70680E+00   7.66381E-01
CARTESIAN COORDINATES ON STREAMSURFACE  1

POINT NO      ZS            XS             YS                ZP            XP            YP

   1      2.57578E+00  -1.44008E+00   6.79391E-01       2.57488E+00  -1.44527E+00   6.69983E-01
   2      2.62081E+00  -1.38231E+00   6.49769E-01       2.61872E+00  -1.39294E+00   6.30152E-01
   3      2.66530E+00  -1.32471E+00   6.20279E-01       2.66178E+00  -1.34058E+00   5.90498E-01
   4      2.70925E+00  -1.26726E+00   5.90880E-01       2.70411E+00  -1.28816E+00   5.51002E-01
   5      2.75268E+00  -1.20996E+00   5.61579E-01       2.74574E+00  -1.23567E+00   5.11703E-01
   6      2.79558E+00  -1.15281E+00   5.32384E-01       2.78670E+00  -1.18309E+00   4.72643E-01
   7      2.83795E+00  -1.09581E+00   5.03302E-01       2.82702E+00  -1.13042E+00   4.33856E-01
   8      2.87980E+00  -1.03895E+00   4.74340E-01       2.86671E+00  -1.07765E+00   3.95394E-01
   9      2.92113E+00  -9.82233E-01   4.45503E-01       2.90581E+00  -1.02475E+00   3.57260E-01
  10      2.96194E+00  -9.25647E-01   4.16797E-01       2.94435E+00  -9.71731E-01   3.19507E-01
  11      3.00224E+00  -8.69188E-01   3.88229E-01       2.98234E+00  -9.18567E-01   2.82142E-01
  12      3.04201E+00  -8.12852E-01   3.59810E-01       3.01981E+00  -8.65253E-01   2.45204E-01
  13      3.07802E+00  -7.61318E-01   3.33904E-01       3.05376E+00  -8.16176E-01   2.11720E-01
  14      3.11357E+00  -7.09968E-01   3.08275E-01       3.08736E+00  -7.66887E-01   1.78735E-01
  15      3.14865E+00  -6.58818E-01   2.83013E-01       3.12065E+00  -7.17373E-01   1.46309E-01
  16      3.18328E+00  -6.07888E-01   2.58203E-01       3.15367E+00  -6.67620E-01   1.14560E-01
  17      3.21746E+00  -5.57193E-01   2.34006E-01       3.18646E+00  -6.17614E-01   8.36502E-02
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POINT NO       ZS            XS            YS                    ZP            XF            YF

   18      3.25119E+00  -5.06751E-01   2.10564E-01          3.21906E+00  -5.67343E-01   5.37112E-02
   19      3.28450E+00  -4.56573E-01   1.87920E-01          3.25152E+00  -5.16799E-01   2.48061E-02
   20      3.31739E+00  -4.06673E-01   1.66147E-01          3.28390E+00  -4.65971E-01  -2.93534E-03
   21      3.34990E+00  -3.57064E-01   1.45434E-01          3.31623E+00  -4.14851E-01  -2.93572E-02
   22      3.38203E+00  -3.07756E-01   1.25900E-01          3.34857E+00  -3.63432E-01  -5.42882E-02
   23      3.41381E+00  -2.58754E-01   1.07566E-01          3.38097E+00  -3.11713E-01  -7.76772E-02
   24      3.44503E+00  -2.10439E-01   9.05985E-02          3.41302E+00  -2.60406E-01  -9.91429E-02
   25      3.47615E+00  -1.62093E-01   7.47768E-02          3.44499E+00  -2.09131E-01  -1.18983E-01
   26      3.50722E+00  -1.13695E-01   5.98300E-02          3.47690E+00  -1.57917E-01  -1.37239E-01
   27      3.53827E+00  -6.52108E-02   4.56249E-02          3.50873E+00  -1.06796E-01  -1.54107E-01
   28      3.56934E+00  -1.66159E-02   3.20936E-02          3.54049E+00  -5.57894E-02  -1.69744E-01
   29      3.60043E+00   3.21106E-02   1.90469E-02          3.57217E+00  -4.91876E-03  -1.84299E-01
   30      3.63158E+00   8.09859E-02   6.31238E-03          3.60377E+00   4.58005E-02  -1.97856E-01
   31      3.66278E+00   1.30023E-01  -6.22530E-03          3.63527E+00   9.63565E-02  -2.10575E-01
   32      3.69405E+00   1.79230E-01  -1.86887E-02          3.66667E+00   1.46741E-01  -2.22632E-01
   33      3.72539E+00   2.28612E-01  -3.12768E-02          3.69797E+00   1.96951E-01  -2.34168E-01
   34      3.75680E+00   2.78169E-01  -4.41188E-02          3.72916E+00   2.46987E-01  -2.45314E-01
   35      3.78820E+00   3.27789E-01  -5.72821E-02          3.76042E+00   2.97148E-01  -2.56238E-01
   36      3.81940E+00   3.77180E-01  -7.06083E-02          3.79182E+00   3.47540E-01  -2.66890E-01
   37      3.85042E+00   4.26351E-01  -8.39795E-02          3.82337E+00   3.98153E-01  -2.77138E-01
   38      3.88127E+00   4.75313E-01  -9.72590E-02          3.85508E+00   4.48975E-01  -2.86795E-01
   39      3.91196E+00   5.24082E-01  -1.10269E-01          3.88695E+00   4.99992E-01  -2.95709E-01
   40      3.94251E+00   5.72679E-01  -1.22881E-01          3.91900E+00   5.51185E-01  -3.03773E-01
   41      3.97294E+00   6.21112E-01  -1.35037E-01          3.95121E+00   6.02533E-01  -3.10827E-01
   42      4.00328E+00   6.69420E-01  -1.46540E-01          3.98360E+00   6.54011E-01  -3.16636E-01
   43      4.03357E+00   7.17627E-01  -1.57192E-01          4.01616E+00   7.05589E-01  -3.21038E-01
   44      4.06383E+00   7.65767E-01  -1.66934E-01          4.04889E+00   7.57233E-01  -3.23994E-01
   45      4.09409E+00   8.13878E-01  -1.75753E-01          4.08176E+00   8.08906E-01  -3.25300E-01
   46      4.12642E+00   8.65183E-01  -1.83771E-01          4.11692E+00   8.63914E-01  -3.24608E-01
   47      4.15888E+00   9.16614E-01  -1.90288E-01          4.15218E+00   9.18796E-01  -3.21628E-01
   48      4.19152E+00   9.68223E-01  -1.95189E-01          4.18750E+00   9.73500E-01  -3.16241E-01
   49      4.22439E+00   1.02006E+00  -1.98421E-01          4.22284E+00   1.02797E+00  -3.08315E-01
   50      4.25752E+00   1.07219E+00  -1.99973E-01          4.25815E+00   1.08216E+00  -2.97855E-01
   51      4.29097E+00   1.12467E+00  -1.99567E-01          4.29338E+00   1.13599E+00  -2.84696E-01
   52      4.32477E+00   1.17797E+00  -1.97042E-01          4.32846E+00   1.18941E+00  -2.68643E-01
   53      4.35897E+00   1.23094E+00  -1.92257E-01          4.36334E+00   1.24235E+00  -2.49569E-01
   54      4.39361E+00   1.28485E+00  -1.85063E-01          4.39793E+00   1.29476E+00  -2.27356E-01
   55      4.42871E+00   1.33937E+00  -1.75321E-01          4.43216E+00   1.34656E+00  -2.01093E-01
   56      4.46431E+00   1.39455E+00  -1.62832E-01          4.46593E+00   1.39771E+00  -1.72984E-01

POINT NO     ZSEMI         XSEMI         YSEMI

    1      2.57488E+00  -1.44527E+00   6.69983E-01
    2      2.57456E+00  -1.44569E+00   6.70258E-01
    3      2.57425E+00  -1.44600E+00   6.70581E-01
    4      2.57396E+00  -1.44631E+00   6.70949E-01
    5      2.57368E+00  -1.44658E+00   6.71358E-01
    6      2.57341E+00  -1.44681E+00   6.71804E-01
    7      2.57317E+00  -1.44699E+00   6.72281E-01
    8      2.57295E+00  -1.44712E+00   6.72784E-01
    9      2.57276E+00  -1.44721E+00   6.73309E-01
   10      2.57259E+00  -1.44725E+00   6.73848E-01
   11      2.57246E+00  -1.44723E+00   6.74397E-01
   12      2.57235E+00  -1.44717E+00   6.74949E-01
   13      2.57228E+00  -1.44706E+00   6.75498E-01
   14      2.57224E+00  -1.44690E+00   6.76039E-01
   15      2.57224E+00  -1.44669E+00   6.76564E-01
   16      2.57227E+00  -1.44644E+00   6.77069E-01
```

```
POINT NO      ZSEMI          XSEMI           YSEMI

   17       2.57233E+00   -1.44615E+00    6.77548E-01
   18       2.57243E+00   -1.44582E+00    6.77996E-01
   19       2.57255E+00   -1.44545E+00    6.78407E-01
   20       2.57271E+00   -1.44506E+00    6.78777E-01
   21       2.57290E+00   -1.44464E+00    6.79103E-01
   22       2.57311E+00   -1.44420E+00    6.79380E-01
   23       2.57335E+00   -1.44374E+00    6.79606E-01
   24       2.57361E+00   -1.44327E+00    6.79778E-01
   25       2.57389E+00   -1.44279E+00    6.79894E-01
   26       2.57418E+00   -1.44231E+00    6.79953E-01
   27       2.57449E+00   -1.44184E+00    6.79954E-01
   28       2.57481E+00   -1.44137E+00    6.79898E-01
   29       2.57513E+00   -1.44092E+00    6.79784E-01
   30       2.57545E+00   -1.44049E+00    6.79615E-01
   31       2.57578E+00   -1.44008E+00    6.79391E-01
```

```
                   BLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS
                   *******************************************

                  STATION  3     NUMBER OF RADII=  6

   RADIUS      SECTION      LEAN          BLADE         THETA
                ANGLE       ANGLE       BLOCKAGE

   3.0363     -34.5568     -5.7373
   4.0696     -39.5746     -2.4342       .1506         .1030
   5.2456     -45.2380     -2.5753       .1002         .1238
   6.4975     -51.2117     -1.0540       .0763         .1326
   7.8091     -57.5491      2.4170       .0541         .1424
   8.5000     -60.9948      2.7736       .0419         .1388
                                          .0373         .1350


                  STATION  4     NUMBER OF RADII=  6

   RADIUS      SECTION      LEAN          BLADE         THETA
                ANGLE       ANGLE       BLOCKAGE

   3.3893     -25.0291     -5.4105
   4.3344     -31.0055     -2.1185       .1931         .0062
   5.4154     -38.8175     -3.6777       .1407         .0223
   6.5824     -47.5182     -3.3044       .1073         .0305
   7.8307     -55.7777       .4414       .0795         .0462
   8.5000     -59.8318       .6624       .0341         .0490
                                          .0595         .0482


                  STATION  5     NUMBER OF RADII=  6

   RADIUS      SECTION      LEAN          BLADE         THETA
                ANGLE       ANGLE       BLOCKAGE

   3.7385     -12.8974      -.4802
   4.5798     -20.6393      1.8574       .1783        -.0379
   5.5662     -32.2241      -.5642       .1366         .0403
   6.6591     -43.3122     -3.2075       .1076        -.0453
   7.8499     -53.2632     -3.0393       .0847        -.0369
   8.5000     -58.3039     -4.1039       .0707        -.0290
                                          .0674        -.0240


                  STATION  6     NUMBER OF RADII=  6

   RADIUS      SECTION      LEAN          BLADE         THETA
                ANGLE       ANGLE       BLOCKAGE

   4.0884       -.6910      3.8433
   4.8259      -8.6767      9.3017       .1186        -.0610
   5.7147     -23.7341      6.1020       .0958        -.0832
   6.7242     -38.5832     -1.9136       .0751        -.1076
   7.8575     -50.1964     -4.9335       .0668        -.1115
   8.5000     -56.4561     -7.4341       .0608        -.1033
                                          .0613        -.0948
```

```
                 STATION  7      NUMBER OF RADII=  6

RADIUS       SECTION      LEAN          BLADE         THETA
              ANGLE       ANGLE        BLOCKAGE

4.4612      38.0404      21.8805        .0108        -.0386
5.0795      11.3631      23.1255        .0143        -.0924
5.8623     -14.4548      17.0305        .0034        -.1486
6.7858     -33.9363       5.1628        .0059        -.1758
7.8716     -47.4131      -5.0787        .0046        -.1770
8.5000     -53.4651     -11.9278        .0076        -.1656
```

```
BLADE SURFACE GEOMETRY IN CARTESIAN COORDINATES AT SPECIFIED VALUES OF 'Z'
***************************************************************************

                    SECTION NUMBER  1    'Z' =    2.5000
                    **********************************

SECTION PROPERTIES       SECTION AREA                              =  4.3539E-01

                         LOCATION OF CENTROID          XBAR        = -8.1846E-02
                         RELATIVE TO STACK AXIS        YBAR        =  8.9764E-02

                         SECOND MOMENTS OF AREA        IX          =  1.3782E-02
                         ABOUT CENTROID                IY          =  1.5176E-01
                                                       IXY         = -6.9456E-03

                         PRINCIPAL SECOND MOMENTS      IPX         =  1.3204E-02 (AT  -3.69 DEGREES TO 'X' AXIS)
                         OF AREA ABOUT CENTROID        IPY         =  1.5234E-01 (AT  -3.69 DEGREES TO 'Y' AXIS)

                         TORSIONAL CONSTANT                        =  5.2463E-03

SECTION COORDINATES

          POINT NO      XS              YS                  XP              YP

             1      -1.44001E+00    6.62066E-01        -1.44511E+00     6.52778E-01
             2      -1.38221E+00    6.23323E-01        -1.39263E+00     6.03771E-01
             3      -1.32456E+00    5.85687E-01        -1.34005E+00     5.55753E-01
             4      -1.26704E+00    5.49081E-01        -1.28734E+00     5.08661E-01
             5      -1.20964E+00    5.13470E-01        -1.23447E+00     4.62494E-01
             6      -1.15234E+00    4.78814E-01        -1.18142E+00     4.17246E-01
             7      -1.09513E+00    4.45071E-01        -1.12818E+00     3.72926E-01
             8      -1.03801E+00    4.12206E-01        -1.07475E+00     3.29548E-01
             9      -9.80971E-01    3.80153E-01        -1.02110E+00     2.87040E-01
            10      -9.24008E-01    3.48853E-01        -9.67243E-01     2.45386E-01
            11      -8.67123E-01    3.18240E-01        -9.13172E-01     2.04565E-01
            12      -8.10307E-01    2.88257E-01        -8.58896E-01     1.64563E-01
            13      -7.61139E-01    2.63141E-01        -8.11443E-01     1.30679E-01
            14      -7.12531E-01    2.38813E-01        -7.64062E-01     9.76913E-02
            15      -6.64526E-01    2.15356E-01        -7.16732E-01     6.56798E-02
            16      -6.17158E-01    1.92875E-01        -6.69433E-01     3.47820E-02
            17      -5.70473E-01    1.71620E-01        -6.22150E-01     5.21168E-03
            18      -5.24507E-01    1.51894E-01        -5.74863E-01    -2.28647E-02
            19      -4.79303E-01    1.33574E-01        -5.27566E-01    -4.94102E-02
            20      -4.34902E-01    1.16868E-01        -4.80238E-01    -7.41219E-02
            21      -3.91358E-01    1.02111E-01        -4.32870E-01    -9.67267E-02
            22      -3.48707E-01    8.96025E-02        -3.85448E-01    -1.16884E-01
            23      -3.08999E-01    7.94374E-02        -3.37976E-01    -1.34486E-01
            24      -2.64881E-01    7.09582E-02        -2.89695E-01    -1.49950E-01
            25      -2.23028E-01    6.47642E-02        -2.41839E-01    -1.62525E-01
            26      -1.81382E-01    6.04421E-02        -1.94489E-01    -1.72093E-01
            27      -1.39893E-01    5.78008E-02        -1.47741E-01    -1.79023E-01
            28      -9.85226E-02    5.69800E-02        -1.01673E-01    -1.83634E-01
            29      -5.72268E-02    5.72920E-02        -5.63686E-02    -1.86170E-01
            30      -1.59913E-02    5.85703E-02        -1.18989E-02    -1.86619E-01
            31       2.52156E-02    6.06622E-02         3.16699E-02    -1.85335E-01
            32       6.64000E-02    6.32903E-02         7.42715E-02    -1.82722E-01
            33       1.07567E-01    6.59070E-02         1.15659E-01    -1.79194E-01
            34       1.48727E-01    6.83091E-02         1.56375E-01    -1.74940E-01
```

```
POINT NO      XS            YS                    XP            YP

   35       1.87827E-01   7.07226E-02          1.94538E-01  -1.69955E-01
   36       2.25936E-01   7.29277E-02          2.32328E-01  -1.64692E-01
   37       2.63043E-01   7.50131E-02          2.69747E-01  -1.58903E-01
   38       2.99151E-01   7.73488E-02          3.06779E-01  -1.52265E-01
   39       3.34271E-01   8.03610E-02          3.43413E-01  -1.44451E-01
   40       3.66422E-01   8.43596E-02          3.79642E-01  -1.35235E-01
   41       4.01630E-01   8.92567E-02          4.15442E-01  -1.24240E-01
   42       4.33945E-01   9.57912E-02          4.50806E-01  -1.10735E-01
   43       4.65402E-01   1.04638E-01          4.85701E-01  -9.43730E-02
   44       4.96101E-01   1.15936E-01          5.20122E-01  -7.52074E-02
   45       5.26081E-01   1.29543E-01          5.54018E-01  -5.25993E-02
   46       5.65661E-01   1.47128E-01          5.98442E-01  -2.30496E-02
   47       6.05137E-01   1.69887E-01          6.42467E-01   1.30288E-02
   48       6.45567E-01   1.98633E-01          6.85914E-01   5.62132E-02
   49       6.84044E-01   2.33723E-01          7.28558E-01   1.07248E-01
   50       7.23652E-01   2.75563E-01          7.70158E-01   1.66419E-01
   51       7.63492E-01   3.29882E-01          8.10429E-01   2.34813E-01
   52       8.03664E-01   3.86627E-01          8.49057E-01   3.14310E-01
   53       8.44294E-01   4.58989E-01          8.85717E-01   4.05505E-01
   54       8.85492E-01   5.44508E-01          9.20050E-01   5.09385E-01
   55       9.27413E-01   6.45143E-01          9.51715E-01   6.27039E-01
   56       9.70160E-01   7.63431E-01          9.80319E-01   7.59971E-01

POINT NO      XSEMI         YSEMI

    1      -1.44511E+00   6.52778E-01
    2      -1.44549E+00   6.53122E-01
    3      -1.44584E+00   6.53514E-01
    4      -1.44616E+00   6.53948E-01
    5      -1.44643E+00   6.54420E-01
    6      -1.44666E+00   6.54925E-01
    7      -1.44685E+00   6.55458E-01
    8      -1.44699E+00   6.56012E-01
    9      -1.44708E+00   6.56581E-01
   10      -1.44712E+00   6.57160E-01
   11      -1.44711E+00   6.57742E-01
   12      -1.44705E+00   6.58320E-01
   13      -1.44695E+00   6.58888E-01
   14      -1.44679E+00   6.59440E-01
   15      -1.44659E+00   6.59971E-01
   16      -1.44634E+00   6.60473E-01
   17      -1.44606E+00   6.60942E-01
   18      -1.44573E+00   6.61372E-01
   19      -1.44537E+00   6.61759E-01
   20      -1.44498E+00   6.62099E-01
   21      -1.44456E+00   6.62387E-01
   22      -1.44412E+00   6.62621E-01
   23      -1.44366E+00   6.62798E-01
   24      -1.44319E+00   6.62916E-01
   25      -1.44272E+00   6.62973E-01
   26      -1.44224E+00   6.62970E-01
   27      -1.44177E+00   6.62906E-01
   28      -1.44130E+00   6.62782E-01
   29      -1.44085E+00   6.62599E-01
   30      -1.44042E+00   6.62360E-01
   31      -1.44031E+00   6.62066E-01
```

SECTION VII

COMPUTER PROGRAM DETAILS

1. IMPLEMENTATION OF THE COMPUTER PROGRAM

The program is written in FORTRAN IV and was developed on a CDC 6000 Series System, incorporating the version 3.3 SCOPE Operating System. When loaded into core, the program (and resident system) occupies about 32K of storage, so that the program will probably not be usable without modification on a relatively small computer. Apart from this limitation, the program should be compatible with the majority of modern computing systems. The program consists of a main program, and Subroutines BQ, CQ, D1, EQ, and FQ. The six decks have been given the identifiers A, B, C, D, E, and F, respectively. Listings of the decks are shown below, and the deck set-up required for the CDC 6000 Series System is also presented.

The program uses three numerical system units for its input and output routines. Input is drawn from the card unit via READ statements referring to Unit LOG 1; output is sent to the line printer by WRITE statements referring to Unit LOG 2; and punched output is produced via WRITE statements referenced to Unit LOG 3. Units LOG 1, LOG 2, and LOG 3 are set equal to 5, 6, and 7, respectively, on cards A130-140 in the FORTRAN programming. On the CDC 6000 Series System, the "PROGRAM" card must also establish the input and output linkages. On other computing systems, the "PROGRAM" card may not be required, and the input-output files may be established via control cards.

The program as presented herein utilizes an on-line precision plotting capability available at the program development site. Calls to four subroutines not included in the deck are included in the program. These calls are executed only if precision plots are specified in the input data, and the entry points expressed are part of standard CALCOMP software normally supplied to users of CALCOMP precision plotting equipment. The various call statements used in the program are explained below, to facilitate modification should the need arise.

CALL PLOT (XPLOT, YPLOT, N)

The majority of plotting is done using this form of call. The parameters XPLOT and YPLOT are the "x" and "y" coordinates (in inches) on the paper to which the pen is being directed. The parameter N indicates pen up or down, $|N| = 3$ or $|N| = 2$, respectively, and will cause XPLOT or YPLOT to be assigned as the origin for further coordinates if N is negative.

CALL SYMBOL (X, Y, H, TEXT, THETA, N)

This call is used to title the plots. The parameters X and Y are the coordinates (in inches) of the lower left hand corner of the first character, H is the character height (in inches), TEXT is the character to be printed, THETA is the angle of the lettering with respect to the "x" axis and N is the total number of characters to be printed.

CALL NUMBER (X, Y, H, F, THETA, N)

This call causes the printing of the number F. The parameters X, Y, H, and THETA are used as for CALL SYMBOL. The parameter N indicates the number of digits following the decimal point if positive, or truncation to an integer if equal to -1.

CALL PLOTE

This call terminates the tape.

In the event the program is used on a computing system which does not include CALCOMP software, and the operating system will not execute a program with unsatisfied external references, dummy entry points may be supplied by adding to the deck a subroutine such as the following:

```
SUBROUTINE PLOT

A = A

ENTRY SYMBOL

ENTRY NUMBER

ENTRY PLOTE

RETURN

END
```

2. DECK SETUP FOR CDC 6000 SERIES SYSTEM

The deck setup required to run the program on a CDC 6000 Series System incorporating the SCOPE 3.3 Operating System is shown below. Production runs of the program would usually employ relocatable binary forms of the routines produced from the source decks to avoid having to compile the FORTRAN for each run and the waste of associated computer resources.

```
JOB                         Identification, etc.

FTN.

LGO.

7/8/9  End of Record

  SOURCE DECK A

  SOURCE DECK B

  SOURCE DECK C

  SOURCE DECK D

  SOURCE DECK E

  SOURCE DECK F

7/8/9  End of Record

  DATA DECK

6/7/8/9  End of Job
```

3. FORTRAN PROGRAM LISTING

A listing of the FORTRAN program appears on the following pages with each subroutine started on a new page.

```
      PROGRAM ARBITR(INPUT,OUTPUT,PUNCH,PLOT,TAPE5=INPUT,TAPE6=OUTPUT,
     1TAPE7=PUNCH)
      DIMENSION AIRANG(10,15), YPRME(81), SL(82), YU(81), BETMET(10), SH
     1(10,5), DEVCRV(10,5), RADEV(5), RINC(15), XINC(15), EXB(15), S1(10
     2), DEVRAD(10), LL(10), CELDEV(15), F137B(8), F137S(5), F161D(8,5),
     3 F195M(8,2), F164XB(8), F172K(7), F142TC(7), NPTS(15), YMPRME(81),
     4 YA(15), YB(15), YC(15), YE(15), NOINF(51), SDRARR(51), RDMIN(51)
      COMMON EPZ(100,3),R(10,15),ZOUT(15),SS(100),X(100),YPRIME(100),YS(
     115,81),YP(15,81),XP(15,81),XS(15,81),YSEMI(15,31),XSEMI(15,31),ZS(
     215,81),ZP(15,81),ZSEMI(15,31),TITLE(8),XHERE(10),XTEMP(100),RAD(10
     30),TEMP1(15),TEMP2(15),TEMP3(15),TEMP4(15),ZR(15),ZZ(15),RLE(15),T
     4C(15),TE(15),SDIVR(15),DELX(15),DELY(15),XSTA(15,10),RSTA(15,10),K
     5PTS(15),SIGMA(100),TANPHI(10,15),ZCAMB(15,10),YCAMB(15,10),IFANGS(
     610),THETA(15,10),ALPHA(15,10)
      REAL IX,IY,IXY,IPX,IPY,IXN,IYN,IXYN,IXO,IYO
      DATA F137B/0.0,10.0,20.0,30.0,40.0,50.0,60.0,70.0/
      DATA F137S/0.4,0.8,1.2,1.6,2.0/
      DATA F142TC/0.0,0.02,0.04,0.06,0.08,0.10,0.12/
      DATA F161D/0.0,0.009,0.17,0.29,0.42,0.59,0.79,1.05,0.0,0.12,0.30,0
     1.51,0.75,1.05,1.47,2.07,0.0,0.16,0.33,0.61,0.95,1.42,2.12,3.07,0.0
     2,0.17,0.40,0.72,1.11,1.71,2.62,3.95,0.0,0.2,0.44,0.78,1.21,1.90,3.
     301,4.75/
      DATA F195M/0.17,0.173,0.179,0.189,0.206,0.232,0.269,0.310,0.25,0.2
     155,0.261,0.268,0.278,0.292,0.312,0.342/
      DATA F164XB/0.965,0.945,0.921,0.890,0.850,0.782,0.679,0.550/
      DATA F172K/0.0,0.160,0.331,0.521,0.74,1.0,1.300/
      LOG1=5
      LOG2=6
      LOG3=7
      PI=3.1415926536
      C1=180.0/PI
      READ (LOG1,5) TITLE
    5 FORMAT (7A10,A2)
      WRITE (LOG2,10) TITLE
   10 FORMAT (1H1,38X,44HUSAF - ARL(LF) ARBITRARY CAMBER LINE PROGRAM,/,
     139X,44(1H*),//,10X,5HTITLE,25X,1H=,7A10,A2)
      READ (LOG1,15) NLINES,NSTNS,NZ,NSPEC,ISEGPT,NBLADE,ISTAK,IPUNCH,IF
     1PLOT,IPRINT
   15 FORMAT (12I3)
      WRITE (LOG2,20) NLINES,NSTNS,NZ,NSPEC,ISEGPT,NBLADE,ISTAK,IPUNCH,I
     1FPLOT,IPRINT
```

```
20    FORMAT (10X,24HNUMBER OF STREAMSURFACES,6X,1H=,I3,/,10X,18HNUMBER
     1OF STATIONS,12X,1H=,I3,/,10X,27HNUMBER OF CONSTANT-Z PLANES,3X,1H=
     2,I3,/,10X,27HNUMBER OF BLADE DATA POINTS,3X,1H=,I3,/,10X,31HNUMBER
     3 OF POINTS PER SEGMENT  =,I3,/,10X,29HNUMBER OF BLADES IN BLADE RO
     4W,1X,1H=,I3,/,10X,5HISTAK,25X,1H=,I3,/,10X,6HIPUNCH,24X,1H=,I3,/,1
     50X,6HIFPLOT,24X,1H=,I3,/,10X,6HIPRINT,24X,1H=,I3)
      READ (LOG1,25) ZINNER,ZOUTER,SCALE,STACKX,PLTSZE
      WRITE (LOG2,30) ZINNER,ZOUTER,SCALE,STACKX,PLTSZE
25    FORMAT (5F12.0)
30    FORMAT (/,10X,6HZINNER,24X,1H=,F8.4,/,10X,6HZOUTER,24X,1H=,F8.4,/,
     110X,5HSCALE,25X,1H=,F8.4,/,10X,6HSTACKX,24X,1H=,F8.4,/,10X,6HPLTSZ
     2E,24X,1H=,F8.4,//,2X)
      READ (LOG1,15) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
      WRITE (LOG2,35) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
35    FORMAT (10X,27HLEADING EDGE STATION NUMBER,3X,1H=,I3,/,10X,28HTRAI
     1LING EDGE STATION NUMBER,2X,1H=,I3,/,10X,26HRADII SPECIFYING DEVIA
     2TION,4X,1H=,I3,/,10X,26HRADII SPECIFYING INCIDENCE,4X,1H=,I3/10X,2
     37HSENSE OF ROTATION INDICATOR,3X,1H=,I3,/,10X,27HDEVIATION CALCULA
     4TION INDEX,3X,1H=,I3,/,10X,28HNUMBER OF INITIAL S/R TRIALS,2X,1H=,
     5I3,/,2X)
      READ (LOG1,25) XKSHPE,SOLTOL
      WRITE (LOG2,40) XKSHPE,SOLTOL
40    FORMAT (10X,12HSHAPE FACTOR,18X,1H=,F8.4,/,10X,18HSOLIDITY TOLERAN
     1CE,12X,1H=,F8.4,//,2X)
      DO 55 K=1,NRADEV
      READ (LOG1,15) NPTS(K)
      READ (LOG1,25) RADEV(K)
      WRITE (LOG2,45) K,NPTS(K),RADEV(K)
45    FORMAT (5X,16HDEVIATION CURVE ,I2,5X,18HNUMBER OF POINTS =,I2,5X,8
     1HRADIUS =,F8.4,/,2X)
      NPT=NPTS(K)
      READ (LOG1,50) (SM(J,K),DEVCRV(J,K),J=1,NPT)
50    FORMAT (2F12.0)
55    WRITE (LOG2,60) (J,SM(J,K),DEVCRV(J,K),J=1,NPT)
60    FORMAT (10X,5HPOINT,5X,22HNORMALIZED MERIDIONAL,5X,20HNORMALIZED
     1DEVIATION,/,28X,5HCHORD,18X,12HDISTRIBUTION,//(11X,I2,14X,F6.4,20X
     2,F6.4))
      READ (LOG1,65) (RINC(J),XINC(J),DELDEV(J),J=1,NINC)
65    FORMAT (3F12.0)
      WRITE (LOG2,70) (RINC(J),XINC(J),DELDEV(J),J=1,NINC)
```

```
   70 FORMAT (2X,//,5X,42HINCIDENCE AND EXTRA DEVIATION DISTRIBUTION,//,
     110X,12HINLET RADIUS,4X,9HINCIDENCE,4X,15HEXTRA DEVIATION,//(F19.4,
     22F14.3,F15.3))
      LNCT=3
      WRITE (LOG2,75)
   75 FORMAT (1H1,//,20X,36HSTREAMSURFACE GEOMETRY SPECIFICATION)
      DO 120 I=1,NSTNS
      READ (LOG1,15) KPTS(I),IFANGS(I),LOG8
      IF (LOG8.EQ.0) LOG8=5
      KPT=KPTS(I)
      READ (LOG1,50) (XSTA(K,I),RSTA(K,I),K=1,KPT)
      IF (KPTS(I).GE.2) GO TO 80
      KPTS(I)=2
      XSTA(2,I)=XSTA(1,I)
      RSTA(2,I)=RSTA(1,I)+1.0
   80 READ (LOG8,50) (R(I,J),AIRANG(I,J),J=1,NLINES)
      IDUM=KPTS(I)
      IF (NLINES.GT.IDUM) IDUM=NLINES
      IF (LNCT.LE.54-NLINES) GO TO 90
      WRITE (LOG2,85)
   85 FORMAT (1H1)
      LNCT=1
   90 LNCT=LNCT+IDUM+6
      WRITE (LOG2,95) I,KPTS(I),I,IFANGS(I)
   95 FORMAT (2X,/,10X,17HCOMPUTING STATION,I3,5X,28HNUMBER OF DESCRIBIN
     1G POINTS=,I3,6X,7HIFANGS(,I2,2H)=,I3,//6X,11HDESCRIPTION,9X,10HSTR
     2EAMLINE,5X,5HRADII,11X,9HAIR ANGLE,/,6X,1HX,9X,1HR,11X,6HNUMBER,//
     3,2X)
      DO 100 K=1,IDUM
      IF (K.LE.KPTS(I).AND.K.LE.NLINES) WRITE (LOG2,105) XSTA(K,I),RSTA(
     1K,I),K,R(I,K),AIRANG(I,K)
      IF (K.LE.KPTS(I).AND.K.GT.NLINES) WRITE (LOG2,110) XSTA(K,I),RSTA(
     1K,I)
      IF (K.GT.KPTS(I).AND.K.LE.NLINES) WRITE (LOG2,115) K,R(I,K),AIRANG
     1(I,K)
  100 CONTINUE
  105 FORMAT (3X,F8.4,2X,F8.4,8X,I2,9X,F8.4,9X,F8.4)
  110 FORMAT (3X,F8.4,2X,F8.4)
  115 FORMAT (29X,I2,9X,F8.4,9X,F8.4)
  120 CONTINUE
```

```
      IF (LNCT.LE.54-NSPEC) GO TO 125
      WRITE (LOG2,85)
      LNCT=1
125   LNCT=LNCT+NSPEC+6
      READ (LOG1,130) (ZR(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J),
     1ZZ(J),SDIVR(J),DELX(J),DELY(J),J=1,NSPEC)
130   FORMAT (6F12.0)
      WRITE (LOG2,135) (ZR(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J)
     1,ZZ(J),SDIVR(J),DELX(J),DELY(J),J=1,NSPEC)
135   FORMAT (2X,/,20X,30HSECTION GEOMETRY SPECIFICATION,//,10X,10HSTREA
     1MLINE,2X,5HSLD  ,5X,6HIN.DEL,4X,6HCONSID,4X,6HNO.ALD,3X,48HLE RADI
     2US MAX THICK TE THICK  POINT OF START VAL,3X,7HX STACK,3X,7HY STAC
     3K,/,11X,6HNUMBER,5X,5HCL FT,5X,5H S/R0,3X,19HLE RD CRV INFL. PTS,3
     4X,6H/CHORD,4X,6H/CHORD,3X,8H/2*CHORD,2X,18HMAX THICK  OF S/R ,4X,6
     5HOFFSET,4X,6HOFFSET,//,(10X,F7.2,3X,F8.3,F10.3,2F10.4,3F10.5,2F10.
     64,F11.6,F10.6))
      IF (IFPLOT.EQ.4) CALL PLOT (0.0,-PLTSZE,-3)
      IF (IFPLOT.EQ.0.OR.IFPLOT.EQ.4) GO TO 140
      IKDUM=0
      IF ((AIRANG(IRLE,1)-AIRANG(IRTE,1)).LT.0.) IKDUM=1
      IF (IFPLOT.EQ.1.OR.IFPLOT.EQ.3) CALL FQ (ISTAK,PLTSZE,1,TITLE,IKDU
     1M,IFPLOT)
140   DO 465 J=1,NLINES
      DO 145 I=IRLE,IRTE
      KPT=KPTS(I)
145   CALL D1 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
      X(1)=XHERE(IRLE)
      X(100)=XHERE(IRTE)
      AX=(X(100)-X(1))/99.0
      DO 150 I=2,99
150   X(I)=X(I-1)+AX
      ICORIT=IRTE-IRLE+1
      CALL CQ (XHERE(IRLE),R(IRLE,J),ICORIT,X,XDUM,YPRIME,100,1)
      SS(1)=0.0
      DO 155 I=2,100
155   SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)+YPRIME(I-1))/2.0)**2)
      XJ=J
      CALL D1 (ZR,RLE,NSPEC,XJ,YZERO,1,0)
      CALL D1 (ZR,TC,NSPEC,XJ,T,1,0)
      CALL D1 (ZR,TE,NSPEC,XJ,YONE,1,0)
```

```
      CALL D1 (ZR,DELX,NSPEC,XJ,XDEL,1,0)                                A 805
      CALL D1 (ZR,DELY,NSPEC,XJ,YDEL,1,0)                                A 810
      CALL D1 (ZR,ZZ,NSPEC,XJ,Z,1,0)                                     A 815
      CALL D1 (ZR,YA,NSPEC,XJ,SSOLID,1,0)                                A 820
      CALL D1 (ZR,SDIVR,NSPEC,XJ,SDR,1,0)                                A 825
      CALL D1 (ZR,YB,NSPEC,XJ,DELSDR,1,0)                                A 830
      CALL D1 (ZR,YC,NSPEC,XJ,RDLEMN,1,0)                                A 835
      CALL D1 (ZR,YE,NSPEC,XJ,ACCIFP,1,0)                                A 840
      IJ=IPASS-1                                                         A 845
      LMN=0                                                              A 850
      IJK=-1                                                             A 855
      PRNT=0.                                                            A 860
      XSIGN=NSIGN                                                        A 865
      STAGER=(AIRANG(IRLE,J)+AIRANG(IRTE,J))/2.                          A 870
      RINSCL=(R(IRLE,J)+R(IRTE,J))/2.                                    A 875
      SDR1=SDR                                                           A 880
  160 CHORC=SS(100)/COS(STAGER/C1)                                       A 885
      IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TC 170                         A 890
      IF (IJK.EQ.3) WRITE (LOG2,165) SDR                                 A 895
  165 FORMAT (1H1,9X,15HOPTIMAL SECTICN,/,10X,15(1H*),//,10X,11HFINAL S/ A 900
     1R =,F8.4,//,10X,23HITERATIONS ON SOLIDITY )                        A 905
  170 SOLID=CHORD/RINSOL/2./PI*FLOAT(NBLADE)                             A 910
      CALL D1 (RINC,XINC,NINC,R(IRLE,J),TEMP2,1,0)                       A 915
      CALL D1 (RINC,DELDEV,NINC,R(IRLE,J),TEMP3,1,0)                     A 920
      BETMET(1)=AIRANG(IRLE,J)-XSIGN*TEMP2(1)                            A 925
      BETS=AIRANG(IRLE,J)*XSIGN                                          A 930
      DO 175 K=1,5                                                       A 935
  175 CALL D1 (F137B,F161D(1,K),8,BETS,EXB(K),1,0)                       A 940
      CALL D1 (F137B,F195M(1,IFCA),8,BETS,XMS,1,0)                       A 945
      CALL D1 (F137B,F164YB,8,BETS,XTEMP,1,0)                            A 950
      CALL D1 (ZR,TC,NSPEC,XJ,X1,1,0)                                    A 955
      CALL D1 (F142TC,F172K,7,X1,XKDT,1,0)                               A 960
      BETS=BETMET(1)*XSIGN                                               A 965
      NN=0                                                               A 970
  180 NN=NN+1                                                            A 975
      IF (NN.GT.20) GC TO 700                                            A 980
      CALL C1 (F137S,EXB,5,SOLID,DO,1,1)                                 A 985
      XMM=XMS/SOLID**XTEMP(1)                                            A 990
      DEV=(DO*XKDT*XKSHPE+XMM*(BETS-XSIGN*AIRANG(IRTE,J))+TEMP3(1))*1.0/ A 995
     1(1.-XMM)                                                           A1000
```

```
      IF (IJK.EQ.3.AND.IPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SCLIC        A1005
185   FORMAT (33X,10HITERATION ,I2,3X,11HDEVIATION =,F7.3,3X,10HSOLIDITY A1010
     1 =,F7.4)                                                           A1015
      MN=IRTE-IRLE+1                                                     A1020
      BETMET(MN)=AIRANG(IRTE,J)-DEV*XSIGN                                A1025
      S1(1)=0.                                                           A1030
      DO 205 I=1,NSTNS                                                   A1035
      IF (I-IRLE) 205,205,190                                            A1040
190   IF (IRTE-I) 205,205,195                                            A1045
195   L=I-IRLE+1                                                         A1050
      CALL D1 (X,SS,100,XHERE(I),S1(L),1,1)                              A1055
      S1(L)=S1(L)/SS(100)                                                A1060
      DO 200 K=1,NRADEV                                                  A1065
200   CALL D1 (SM(1,K),DEVCRV(1,K),NPTS(K),S1(L),DEVRAD(K),1,0)          A1070
      CALL D1 (RADEV,DEVRAD,NRADEV,R(IRTE,J),DEVPCT,1,0)                 A1075
      BETMET(L)=AIRANG(I,J)-DEV*DEVPCT*XSIGN                             A1080
205   CONTINUE                                                           A1085
      S1(MN)=1.                                                          A1090
      YP1=TAN(BETMET(1)/C1)                                              A1095
      YMPRME(1)=YP1                                                      A1100
      YU(1)=0.                                                           A1105
      IPOINT=1                                                           A1110
      SU(1)=0.                                                           A1115
      Y1=0.                                                              A1120
      YPP1=SDR/2./PI/R(IRLE,J)*FLOAT(NBLADE)*(1.+YP1*YP1)**(1.5)         A1125
      YPPME(1)=YPP1                                                      A1130
      IF (YPP1.NE.0.) GO TO 210                                          A1135
      YPRIME(1)=1000.                                                    A1140
      GO TO 215                                                          A1145
210   CONTINUE                                                           A1150
      YPRIME(1)=(1.+YMPRME(1)*YMPRME(1))**(1.5)/YPPME(1)                 A1155
215   CONTINUE                                                           A1160
      S11=0.                                                             A1165
      S12=0.                                                             A1170
      LL(1)=0                                                            A1175
      DO 230 K=2,MN                                                      A1180
      YP2=TAN(BETMET(K)/C1)                                              A1185
      LL(K)=0                                                            A1190
      S2=S1(K)                                                           A1195
      S22=S2*S2                                                          A1200
```

```
      A=(YP2-YP1-YPP1*(S2-S11))/3./(S22-S12-2.*S11*(S2-S11))            A1205
      B=(YPP1-6.*A*S11)/2.                                              A1210
      C=YP1-3.*A*S12-2.*B*S11                                           A1215
      D=Y1-A*S12*S11-B*S12-C*S11                                        A1220
      SDIFF=(S2-S11)/FLOAT(ISEGPT-1)                                    A1225
      KL=IPOINT+1                                                       A1230
      KJ=IPOINT+ISEGPT-1                                                A1235
      DO 225 L=KL,KJ                                                    A1240
      SU(L)=SU(L-1)+SDIFF                                               A1245
      YU(L)=D+SU(L)*(C+SU(L)*(B+A*SU(L)))                               A1250
      YMPRME(L)=C+SU(L)*(B*2.+A*3.*SU(L))                               A1255
      YPPME(L)=6.*A*SU(L)+2.*B                                          A1260
      IF (YPPME(L).EQ.0.) YPRIME(L)=1000.                               A1265
      IF (YPPME(L).EQ.0.) GO TO 225                                     A1270
      YPRIME(L)=(1.+YMPRME(L)*YMPRME(L))**(1.5)/YPPME(L)                A1275
      SLPE=ABS(YPPME(L)-YPPME(L-1))                                     A1280
      IF (SLPE.GE.ABS(YPPME(L)).AND.SLPE.GE.ABS(YPPME(L-1))) GO TO 220  A1285
      GO TO 225                                                         A1290
  220 LL(K)=L                                                           A1295
  225 CONTINUE                                                          A1300
      IPOINT=KJ                                                         A1305
      Y1=YU(IPOINT)                                                     A1310
      YPP1=YPPME(KJ)                                                    A1315
      S11=S2                                                            A1320
      S12=S22                                                           A1325
  230 YP1=YP2                                                           A1330
      IS=0                                                              A1335
      DO 235 K=1,NN                                                     A1340
      IF (LL(K).NE.0) IS=IS+1                                           A1345
  235 CONTINUE                                                          A1350
      CHORD1=SQRT(YU(IPOINT)**2+1.)*SS(100)                             A1355
      CALL D1 (SU,YU,IPOINT,SSOLID,YSOLID,1,1)                          A1360
      CHORD=SQRT((SU(IPOINT)-SSOLID)**2+(YU(IPOINT)-YSOLID)**2)*SS(100) A1365
      SOLID1=CHORD/RINSOL/2./PI*FLOAT(NBLADE)                           A1370
      DIFF=SOLID-SOLID1                                                 A1375
      IF (ABS(DIFF).LT.SOLTOL*SOLID) GO TO 240                          A1380
      SOLID=SOLID1                                                      A1385
      GO TO 180                                                         A1390
  240 IF (IJK.EQ.3.AND.IPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SOLID1      A1395
      IF (IJK.EQ.3) GO TO 305                                           A1400
```

```
      LMN=LMN+1                                                         A1405
      NOINF(LMN)=IS                                                     A1410
      SDRARR(LMN)=SDR                                                   A1415
      SDR=SDR+DELSDR                                                    A1420
      RDMIN(LMN)=1000.                                                  A1425
      DO 245 L=1,IPOINT                                                 A1430
      IF (L.EQ.1.AND.ROLEMN.EQ.1.0) GO TO 245                           A1435
      IF (ABS(YPRIME(L)).LT.RDMIN(LMN)) RDMIN(LMN)=ABS(YPRIME(L))       A1440
  245 CONTINUE                                                          A1445
      IF (LMN.LE.IJ.AND.IJK.LE.0) GO TO 160                             A1450
      IF (LMN.GT.IJ.AND.IJK.LE.0) GO TO 250                             A1455
      IF (LMN.GT.19) GO TO 250                                          A1460
      GO TO 160                                                         A1465
  250 IF (LMN.EQ.20.OR.LMN.EQ.IPASS) IJK=IJK+1                          A1470
      IF (IJK.EQ.2.OR.IJK.EQ.3) GO TO 290                               A1475
      NMNINF=20                                                         A1480
      DO 255 LMN=1,IPASS                                                A1485
      IF (NOINF(LMN).LT.NMNINF) IFIRST=LMN                              A1490
      IF (NOINF(LMN).LT.NMNINF) NMNINF=NOINF(LMN)                       A1495
  255 CONTINUE                                                          A1500
      IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TO 275                        A1505
      WRITE (LOG2,85)                                                   A1510
      IF (FLOAT(NMNINF).GE.(ACCIFF+1.).AND.IPRINT.NE.2) WRITE (LOG2,260)A1515
     1                                                                  A1520
  260 FORMAT (74H NOTE THAT THE MINIMUM NUMBER OF INFLECTION POINTS IS G A1525
     1REATER THAN DESIRED,/2X)                                          A1530
      INDEX=IJK+1                                                       A1535
      WRITE (LOG2,265) J,INDEX,SDR1,DELSDR                              A1540
  265 FORMAT (5X,14HSTREAMSURFACE ,I2,/10X,10HITERATION ,I2,/,10X,12(1H* A1545
     1),//,10X,14HINITIAL S/R = ,F8.4,10X,17HINCREMENTAL S/R =,F8.4,//,1 A1550
     25X,8HPASS NO.,5X,21HNO. OF INFLECTION PTS,5X,24HMIN. RADIUS OF CUR A1555
     3VATURE,/,2X)                                                      A1560
      WRITE (LOG2,270) (LMN,NOINF(LMN),RDMIN(LMN),LMN=1,IPASS)          A1565
  270 FORMAT (18X,I2,18X,I2,22X,F8.3)                                   A1570
  275 ILAST=0                                                           A1575
      DO 280 LMN=IFIRST,IPASS                                           A1580
      IF (NOINF(LMN).GT.NMNINF) ILAST=LMN                               A1585
      IF (NOINF(LMN).GT.NMNINF) GO TO 285                               A1590
  280 CONTINUE                                                          A1595
      ILAST=IPASS                                                       A1600
```

```
  285   IF (IJK.EQ.0) IFIRST=IFIRST-1                                      A1605
        IF (IFIRST.EQ.0) IFIRST=1                                          A1610
        IF (IFIRST.EQ.IPASS) IFIRST=IJ                                     A1615
        IF (IJK.EQ.1.AND.NOINF(IPASS).GT.NMNINF) ILAST=ILAST-1             A1620
        IF (ILAST.EQ.IFIRST) ILAST=ILAST+1                                 A1625
        IF (ILAST.EQ.(IPASS+1).OR.ILAST.EQ.0) ILAST=IPASS                  A1630
        IF (IJK.EQ.0) LJ=IPASS-1                                           A1635
        IF (IJK.EQ.1) LJ=19                                                A1640
        DELSDR=(SDRARR(ILAST)-SDRARR(IFIRST))/FLOAT(LJ)                    A1645
        SDR=SDRARR(IFIRST)                                                 A1650
        SDR1=SDR                                                           A1655
        LMN=0                                                              A1660
        GO TO 160                                                          A1665
  290   RADMX=0.                                                           A1670
        DO 295 L=1,20                                                      A1675
        IF (RDMIN(L).GT.RADMX.AND.NOINF(L).EQ.NMNINF) LMN=L                A1680
        IF (RDMIN(L).GT.RADMX.AND.NOINF(L).EQ.NMNINF) RADMX=RDMIN(L)       A1685
  295   CONTINUE                                                           A1690
        IF (LMN.EQ.1.AND.IPRINT.NE.2) WRITE (LOG2,300)                     A1695
        IF (LMN.EQ.20.AND.IPRINT.NE.2) WRITE (LOG2,300)                    A1700
  300   FORMAT (//101H THE MAXIMUM VALUE OF THE MINIMUM RADIUS OF CURVATUR A1705
       1E OCCURS AT AN END POINT OF THE PRESENT S/R RANGE)                 A1710
        IF (IJK.EQ.3) SDR=SDRARR(LMN)                                      A1715
        IF (IJK.EQ.3) PRNT=1.                                              A1720
        IF (IJK.EQ.3) GO TO 160                                            A1725
        SDR=SDRARR(LMN)-3.0*DELSDR                                         A1730
        DELSDR=6.*DELSDR/20.                                               A1735
        LMN=0                                                              A1740
        GO TO 160                                                          A1745
  305   IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TO 320                         A1750
        WRITE (LOG2,310)                                                   A1755
  310   FORMAT (/10X,5HPOINT,5X,22HNORMALIZED MERIODIONAL,5X,10HTANGENTIAL A1760
       1,5X,11HCAMBER LINE,7X,6HSECOND,7X,9HRADIUS OF,/,26X,10HCOORDINATE, A1765
       211X,10HCOORDINATE,8X,5HSLOPE,8X,10HDERIVATIVE,5X,9HCURVATURE,/2X)  A1770
        IP=IPOINT                                                          A1775
        IF (IPOINT.GE.49) IP=48                                            A1780
        WRITE (LOG2,315) (L,SU(L),YU(L),YMPRME(L),YPPME(L),YPRIME(L),L=1,I A1785
       1P)                                                                 A1790
        IF (IPOINT.GE.49) WRITE (LOG2,85)                                  A1795
        IF (IPOINT.GE.49) WRITE (LOG2,315) (L,SU(L),YU(L),YMPRME(L),YPPME( A1800
```

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     1L),YPRIME(L),L=49,IPOINT)                                             A1805
315   FORMAT (12X,I2,14X,F6.4,14X,F7.4,6X,F8.4,9X,F8.4,7X,F8.3)             A1810
320   NPOINT=IPOINT                                                         A1815
      XNORMC=CHORD1/SS(100)                                                 A1820
      AXIALC=SS(100)                                                        A1825
      DO 325 I=1,NSTNS                                                      A1830
      KPT=KPTS(I)                                                           A1835
325   CALL D1 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)                 A1840
      X(1)=XHERE(1)                                                         A1845
      X(100)=XHERE(NSTNS)                                                   A1850
      AX=(X(100)-X(1))/99.0                                                 A1855
      DO 330 I=2,99                                                         A1860
330   X(I)=X(I-1)+AX                                                        A1865
      CALL CQ (XHERE,R(1,J),NSTNS,X,XDUM,YPRIME,100,1)                      A1870
      CALL CQ (XHERE,R(1,J),NSTNS,XHERE,XDUM,TANPHI(1,J),NSTNS,1)           A1875
      SS(1)=0.0                                                             A1880
      DO 335 I=2,100                                                        A1885
335   SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)+YPRIME(I-1))/2.0)**2)           A1890
      CALL D1 (X,SS,100,STACKX,EX,1,1)                                      A1895
      CALL BQ (J,YS,YP,XS,XP,YSEMI,XSEMI,LOG2,IPOINT,IPRINT,BETMET(1),BE    A1900
     1TMET(MN),YZERO,T,YONE,XCEL,YDEL,Z,XNORMC,LNCT,XTEMP,YPRIME,RAD,SIG    A1905
     2MA,EPZ,XHERE,X,SS,NSTNS,R,BX,SU,YU,YMPRME,AXIALC,ISTAK)               A1910
      CALL D1 (X,SS,100,STACKX,EX,1,1)                                      A1915
      DO 340 I=1,100                                                        A1920
      X(I)=X(I)-STACKX                                                      A1925
340   SS(I)=SS(I)-BX                                                        A1930
      DO 345 I=1,NSTNS                                                      A1935
345   XHERE(I)=XHERE(I)-STACKX                                              A1940
      IF (IFPLOT.EQ.0.OR.IFPLOT.EQ.2.OR.IFPLOT.EQ.4) GO TO 365              A1945
      XPLOT=XS(J,1)*SCALE                                                   A1950
      YPLOT=YS(J,1)*SCALE                                                   A1955
      CALL PLOT (XPLOT,YPLOT,3)                                             A1960
      DO 350 I=2,NPOINT                                                     A1965
      XPLOT=XS(J,I)*SCALE                                                   A1970
      YPLOT=YS(J,I)*SCALE                                                   A1975
350   CALL PLOT (XPLOT,YPLOT,2)                                             A1980
      DO 355 II=1,NPOINT                                                    A1985
      I=NPOINT-II+1                                                         A1990
      XPLOT=XP(J,I)*SCALE                                                   A1995
      YPLOT=YP(J,I)*SCALE                                                   A2000
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355   CALL PLOT (XPLOT,YPLOT,2)                                          A2005
      DO 360 I=2,30                                                      A2010
      XPLOT=XSEMI(J,I)*SCALE                                             A2015
      YPLOT=YSEMI(J,I)*SCALE                                             A2020
360   CALL PLOT (XPLOT,YPLOT,2)                                          A2025
      XPLOT=XS(J,1)*SCALE                                                A2030
      YPLOT=YS(J,1)*SCALE                                                A2035
      CALL PLOT (XPLOT,YPLOT,2)                                          A2040
365   IJDUM=0                                                            A2045
      DO 370 I=1,NSTNS                                                   A2050
      IF (IFANGS(I).EQ.1) IJDUM=1                                        A2055
370   CONTINUE                                                           A2060
      IF (IJDUM.EQ.0) GO TO 380                                          A2065
      CALL D1 (SS,X,100,XTEMP,XTEMP,100,1)                               A2070
      DO 375 I=1,NSTNS                                                   A2075
      CALL D1 (XTEMP,SIGMA,100,XHERE(I),THETA(J,I),1,1)                  A2080
      CALL D1 (XTEMP,YPRIME,100,XHERE(I),ALPHA(J,I),1,1)                 A2085
      ZCAME(J,I)=R(I,J)*COS(THETA(J,I))                                  A2090
375   YCAME(J,I)=R(I,J)*SIN(THETA(J,I))                                  A2095
380   DO 385 I=1,NPOINT                                                  A2100
385   XTEMP(I)=XS(J,I)                                                   A2105
      CALL D1 (SS,X,100,XTEMP,XTEMP,NPOINT,1)                            A2110
      CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)                    A2115
      K=1                                                                A2120
      DO 390 I=1,NPOINT                                                  A2125
      EPS=EPZ(I,K)                                                       A2130
      ZS(J,I)=RAD(I)*COS(EPS)                                            A2135
      YS(J,I)=RAD(I)*SIN(EPS)                                            A2140
390   XS(J,I)=XTEMP(I)                                                   A2145
      DO 395 I=1,NPOINT                                                  A2150
395   XTEMP(I)=XP(J,I)                                                   A2155
      CALL D1 (SS,X,100,XTEMP,XTEMP,NPOINT,1)                            A2160
      CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)                    A2165
      K=2                                                                A2170
      DO 400 I=1,NPOINT                                                  A2175
      EPS=EPZ(I,K)                                                       A2180
      ZP(J,I)=RAD(I)*COS(EPS)                                            A2185
      YP(J,I)=RAD(I)*SIN(EPS)                                            A2190
400   XP(J,I)=XTEMP(I)                                                   A2195
      DO 405 I=1,31                                                      A2200
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 405  XTEMP(I)=XSEMI(J,I)                                                 A2205
      CALL D1 (SS,X,100,XTEMP,XTEMP,31,1)                                 A2210
      CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,31,0)                         A2215
      K=3                                                                 A2220
      DO 410 I=1,31                                                       A2225
      EPS=EPZ(I,K)                                                        A2230
      ZSEMI(J,I)=RAD(I)*COS(EPS)                                          A2235
      YSEMI(J,I)=RAD(I)*SIN(EPS)                                          A2240
 410  XSEMI(J,I)=XTEMP(I)                                                 A2245
      IF (IPRINT.EQ.2) GO TO 465                                          A2250
      IF (LNCT.LE.50) GO TO 415                                           A2255
      WRITE (LOG2,85)                                                     A2260
      LNCT=1                                                              A2265
 415  LNCT=LNCT+5                                                         A2270
      WRITE (LOG2,420) J                                                  A2275
 420  FORMAT (2X,/,10X,38HCARTESIAN COORDINATES ON STREAMSURFACE,I3,//,1  A2280
     110X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2HXP,12X,2HYP A2285
     2,/,2X)                                                              A2290
      I=1                                                                 A2295
 425  WRITE (LOG2,430) I,ZS(J,I),XS(J,I),YS(J,I),ZP(J,I),XP(J,I),YP(J,I)  A2300
 430  FORMAT (10X,I5,3X,1P3E14.5,4X,1P3E14.5)                             A2305
      I=I+1                                                               A2310
      LNCT=LNCT+1                                                         A2315
      IF (I.GT.NPOINT) GO TO 440                                          A2320
      IF (LNCT.LE.59) GO TO 425                                           A2325
      WRITE (LOG2,435)                                                    A2330
 435  FORMAT (1H1,9X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2  A2335
     1HXP,12X,2HYP,/,2X)                                                  A2340
      LNCT=2                                                              A2345
      GO TO 425                                                           A2350
 440  IF (LNCT.LE.50) GO TO 445                                           A2355
      WRITE (LOG2,85)                                                     A2360
      LNCT=1                                                              A2365
 445  LNCT=LNCT+3                                                         A2370
      WRITE (LOG2,450)                                                    A2375
 450  FORMAT (2X,/,10X,8HPOINT NO,4X,5HZSEMI,9X,5HXSEMI,9X,5HYSEMI,/,2X)  A2380
      I=1                                                                 A2385
 455  WRITE (LOG2,460) I,ZSEMI(J,I),XSEMI(J,I),YSEMI(J,I)                 A2390
 460  FORMAT (10X,I5,3X,1P3E14.5)                                         A2395
      I=I+1                                                               A2400
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      LNCT=LNCT+1
      IF (I.GT.31) GO TO 465
      IF (LNCT.LE.59) GO TO 455
      WRITE (LOG2,85)
      WRITE (LOG2,450)
      LNCT=4
      GO TO 455
465   CONTINUE
      IF (IPRINT.EQ.1) GO TO 530
      VOL=0.0
      DO 470 J=2,NLINES
      VOL=VOL+(((XS(J,1)-XP(J,1))**2+(YS(J,1)-YF(J,1))**2)+((XS(J-1,1)-X
     1P(J-1,1))**2+(YS(J-1,1)-YF(J-1,1))**2))*(ZS(J,1)+ZP(J,1)-ZS(J-1,1)
     2-ZP(J-1,1))*PI/32.0
      DO 470 I=2,NPOINT
470   VOL=VOL+((SQRT((XS(J,I)-XF(J,I))**2+(YS(J,I)-YF(J,I))**2)+SQRT((XS
     1(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2))*(SQRT((XS(J,I-1)-
     2XS(J,I))**2+(YS(J,I-1)-YS(J,I))**2)+SQRT((XP(J,I-1)-XP(J,I))**2+(Y
     3P(J,I-1)-YF(J,I))**2))+(SQRT((XS(J-1,I)-XF(J-1,I))**2+(YS(J-1,I)-Y
     4P(J-1,I))**2)+SQRT((XS(J-1,I-1)-XF(J-1,I-1))**2+(YS(J-1,I-1)-YP(J-
     51,I-1))**2))*(SQRT((XS(J-1,I-1)-XS(J-1,I))**2+(YS(J-1,I-1)-YS(J-1,
     6I))**2)+SQRT((XP(J-1,I-1)-XF(J-1,I))**2+(YP(J-1,I-1)-YF(J-1,I))**2
     7)))*(ZS(J,I)+ZS(J,I-1)+ZP(J,I)+ZP(J,I-1)-ZS(J-1,I)-ZS(J-1,I-1)-ZP(
     8J-1,I)-ZP(J-1,I-1))/32.0
      IF (LNCT.LE.56) GO TO 475
      LNCT=1
      WRITE (LOG2,85)
475   LNCT=LNCT+4
      WRITE (LOG2,480) VOL
480   FORMAT (2X,/,2X,/,40X,25HVOLUME OF BLADE SECTION =,1PE11.4,/,40X,3
     15(1H*))
      IF (IJDUM.EQ.0) GO TO 530
      WRITE (LOG2,85)
      WRITE (LOG2,485)
485   FORMAT (43X,43HBLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS,/,43X,4
     13(1H*))
      IDUM=7
      LNCT=3
      DO 525 I=1,NSTNS
      IF (IFANGS(I).EQ.0) GO TO 525
```

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      DO 495 J=1,NLINES
      CALL D1 (RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,1,0)
      CALL CQ (RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,ZR(J),1,1)
      DO 490 K=1,NPOINT
      SS(K)=XS(J,K)
      RAD(K)=YS(J,K)
      XTEMP(K)=XP(J,K)
  490 X(K)=YP(J,K)
      XDUM=XDUM-STACKX
      CALL D1 (SS,RAD,NPOINT,XDUM,YY1,1,1)
      CALL D1 (XTEMP,X,NPOINT,XDUM,YY2,1,1)
      W1=YY1/R(I,J)
      W2=YY2/R(I,J)
      TC(J)=ABS(ATAN(W1/SQRT(1.-W1**2))-ATAN(W2/SQRT(1.-W2**2)))/(2.*PI)
     1*FLOAT(NBLADE)
  495 CONTINUE
      CALL CQ (ZCAMB(1,I),YCAMB(1,I),NLINES,ZCAMB(1,I),XDUM,RLE,NLINES,1
     1)
      IF (LNCT+IDUM+NLINES.LE.59) GO TO 500
      WRITE (LOG2,85)
      LNCT=2
  500 LNCT=LNCT+IDUM+NLINES
      WRITE (LOG2,505) I,NLINES
  505 FORMAT (///,48X,8HSTATION ,I2,5X,17HNUMBER OF RADII= ,I2,//,36X,6H
     1RADIUS,5X,7HSECTION,6X,4HLEAN,9X,5HBLADE,7X,5HTHETA,/,48X,5HANGLE,
     26X,5HANGLE,7X,8HBLOCKAGE,/,2X)
      DO 510 J=1,NLINES
      EPS=(THETA(J,I)-ATAN(RLE(J)))*C1
      ALPHB=ALPHA(J,I)
      ALP=(ATAN((TANPHI(I,J)*TAN(EPS/C1)+ALPHB*SQRT(1.+TANPHI(I,J)**2))/
     1(1.-TANPHI(I,J)*ZR(J))))*C1
      WRITE (LOG2,515) R(I,J),ALP,EPS,TC(J),THETA(J,I)
      IF (IPUNCH.EQ.0) GO TO 510
      WRITE (LOG3,520) R(I,J),ALP,EPS,TC(J),THETA(J,I),I,J
  510 CONTINUE
  515 FORMAT (30X,5F12.4)
  520 FORMAT (5F12.7,2I3)
  525 CONTINUE
  530 IF (IFPLOT.LT.2.OR.IFPLOT.EQ.4) GO TO 535
      CALL FQ (ISTAK,PLTSZE,2,TITLE,IKDUM,IFPLOT)
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535   IF (IPRINT.EQ.1) GO TO 545                                        A2805
      LNCT=2                                                            A2810
      WRITE (LOG2,540)                                                  A2815
540   FORMAT (1H1,27X,74HBLADE SURFACE GEOMETRY IN CARTESIAN COORDINATES A2820
     1 AT SPECIFIED VALUES OF 'Z',/,28X,74H*****************************A2825
     2*********************************************)                    A2830
545   IF (IPRINT.EQ.1.AND.IFPLOT.LE.1) GO TO 695                        A2835
      XZ=NZ-1                                                           A2840
      DZ=(ZOUTER-ZINNER)/XZ                                             A2845
      ZOUT(1)=ZINNER                                                    A2850
      DO 550 J=3,NZ                                                     A2855
550   ZOUT(J-1)=ZOUT(J-2)+DZ                                            A2860
      ZOUT(NZ)=ZOUTER                                                   A2865
      DO 555 I=1,NPOINT                                                 A2870
      CALL D1 (ZS(1,I),XS(1,I),NLINES,ZOUT,TEMP1,NZ,0)                  A2875
      CALL D1 (ZS(1,I),YS(1,I),NLINES,ZOUT,TEMP2,NZ,0)                  A2880
      CALL D1 (ZP(1,I),XP(1,I),NLINES,ZOUT,TEMP3,NZ,0)                  A2885
      CALL D1 (ZP(1,I),YP(1,I),NLINES,ZOUT,TEMP4,NZ,0)                  A2890
      DO 555 J=1,NZ                                                     A2895
      XS(J,I)=TEMP1(J)                                                  A2900
      YS(J,I)=TEMP2(J)                                                  A2905
      XP(J,I)=TEMP3(J)                                                  A2910
555   YP(J,I)=TEMP4(J)                                                  A2915
      DO 560 I=1,31                                                     A2920
      CALL D1 (ZSEMI(1,I),XSEMI(1,I),NLINES,ZOUT,TEMP1,NZ,0)            A2925
      CALL D1 (ZSEMI(1,I),YSEMI(1,I),NLINES,ZOUT,TEMP2,NZ,0)            A2930
      DO 560 J=1,NZ                                                     A2935
      XSEMI(J,I)=TEMP1(J)                                               A2940
560   YSEMI(J,I)=TEMP2(J)                                               A2945
      DO 690 J=1,NZ                                                     A2950
      RD=SQRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)/2.0            A2955
      AREA=PI*RD**2/2.0                                                 A2960
      BETA1=ATAN((YS(J,2)+YP(J,2)-YS(J,1)-YP(J,1))/(XS(J,2)+XP(J,2)-XS(J A2965
     1,1)-XP(J,1)))                                                     A2970
      XINT=AREA*((XP(J,1)+XS(J,1))/2.0-COS(BETA1)*4.0/(3.0*PI)*RD)      A2975
      YINT=AREA*((YP(J,1)+YS(J,1))/2.0-SIN(BETA1)*4.0/(3.0*PI)*RD)      A2980
      DO 565 I=2,NPOINT                                                 A2985
      DELA=(SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)+SQRT((XS(J,I A2990
     1-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2))*(SQRT((XS(J,I-1)-XS(J A2995
     2,I))**2+(YS(J,I-1)-YS(J,I))**2)+SQRT((XP(J,I-1)-XP(J,I))**2+(YP(J, A3000
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     3I-1)-YP(J,I))**2))/4.0                                            A3005
      AREA=AREA+DELA                                                    A3010
      XINT=XINT+DELA*(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0          A3015
  565 YINT=YINT+DELA*(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0          A3020
      YINT=YINT/AREA                                                    A3025
      XINT=XINT/AREA                                                    A3030
      X1=(XS(J,1)+XP(J,1))/2.                                           A3035
      Y1=(YS(J,1)+YP(J,1))/2.                                           A3040
      T1=SQRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)                A3045
      F=0.                                                              A3050
      U=0.                                                              A3055
      DO 570 I=2,NPCINT                                                 A3060
      T2=SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)                A3065
      X2=(XS(J,I)+XP(J,I))/2.                                           A3070
      Y2=(YS(J,I)+YP(J,I))/2.                                           A3075
      DELU=SQRT((X2-X1)**2+(Y2-Y1)**2)                                  A3080
      U=U+DELU                                                          A3085
      TAV3=(T1**3+T2**3)/2.                                             A3090
      F=F+TAV3*DELU                                                     A3095
      X1=X2                                                             A3100
      Y1=Y2                                                             A3105
  570 T1=T2                                                             A3110
      TORCCN=((1./3.)*F)/(1.+(4./3.)*F/AREA/U**2)                       A3115
      IX=0.0                                                            A3120
      IY=0.0                                                            A3125
      IXY=0.0                                                           A3130
      DO 575 I=2,NPCINT                                                 A3135
      XD=(SQRT((XS(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2)+SQRT((A3140
     1XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2))/2.0                    A3145
      YD=(SQRT((XS(J,I)-XS(J,I-1))**2+(YS(J,I)-YS(J,I-1))**2)+SQRT((XP(JA3150
     1,I)-XP(J,I-1))**2+(YP(J,I)-YP(J,I-1))**2))/2.0                    A3155
      IXD=YD*YD*YD*XD/12.0                                              A3160
      IYD=XD*XD*XD*YD/12.0                                              A3165
      ANG=ATAN((YS(J,I)+YP(J,I)-YS(J,I-1)-YP(J,I-1))/(XP(J,I)+XS(J,I)-XPA3170
     1(J,I-1)-XS(J,I-1)))                                               A3175
      COSANG=COS(2.0*ANG)                                               A3180
      IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0                                A3185
      IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0                                A3190
      IXYN=0.0                                                          A3195
      IF (ANG.NE.0.0) IXYN=((IXN-IYN)*COSANG-IXD+IYD)/(2.0*SIN(2.0*ANG))A3200
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```
      DELA=XC*YD                                                        A3205
      YMN=(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0-YINT                A3210
      XMN=(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0-XINT                A3215
      IX=IX+IXN+DELA*YMN*YMN                                            A3220
      IY=IY+IYN+DELA*XMN*XMN                                            A3225
  575 IXY=IXY+IXYN+DELA*YMN*XMN                                         A3230
      ANG=ATAN(2.0*IXY/(IY-IX))                                         A3235
      IPX=(IX+IY)/2.0+(IX-IY)/2.0*COS(ANG)-IXY*SIN(ANG)                 A3240
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*COS(ANG)+IXY*SIN(ANG)                 A3245
      ANG=ANG/2.0*C1                                                    A3250
      IF (IPRINT.EQ.1) GO TO 640                                        A3255
      IF (LNCT.LE.45) GO TO 580                                         A3260
      WRITE (LOG2,85)                                                   A3265
      LNCT=1                                                            A3270
  580 LNCT=LNCT+16                                                      A3275
      WRITE (LOG2,585) J,ZOUT(J),AREA,XINT,YINT,IX,IY,IXY,IPX,ANG,IPY,AN A3280
     1G                                                                 A3285
  585 FORMAT (2X,/,50X,14HSECTION NUMBER,I3,3X,5H'Z' =,F9.4,/,50X,34H*** A3290
     1*******************************,///,20X,18HSECTION PROPERTIES,7X,1 A3295
     22HSECTION AREA,26X,1H=,1PE12.4,//,45X,20HLOCATION OF CENTROID,11X, A3300
     34HXBAR,3X,1H=,E12.4,/,45X,22HRELATIVE TO STACK AXIS,9X,4HYBAR,3X,1 A3305
     4H=,E12.4,//,45X,22HSECOND MOMENTS OF AREA,9X,2HIX,5X,1H=,E12.4,/,4 A3310
     55X,14HABOUT CENTROID,17X,2HIY,5X,1H=,E12.4,/,76X,3HIXY,4X,1H=,E12. A3315
     64,//,45X,24HPRINCIPAL SECOND MOMENTS,7X,3HIPX,4X,1H=,E12.4,4H (AT, A3320
     70PF7.2,21H DEGREES TO 'X' AXIS),/,45X,22HOF AREA ABOUT CENTROID,9X A3325
     8,3HIPY,4X,1H=,1PE12.4,4H (AT,0PF7.2,21H DEGREES TO 'Y' AXIS))     A3330
      WRITE (LOG2,590) TORCON                                           A3335
  590 FORMAT (/,45X,18HTORSIONAL CONSTANT,20X,1H=,1PE12.4,/,2X)          A3340
      LNCT=LNCT+3                                                       A3345
      IF (LNCT.LE.50) GO TO 595                                         A3350
      WRITE (LOG2,85)                                                   A3355
      LNCT=1                                                            A3360
  595 LNCT=LNCT+5                                                       A3365
      WRITE (LOG2,600)                                                  A3370
  600 FORMAT (2X,/,20X,19HSECTION COORDINATES,/,2X)                     A3375
      WRITE (LOG2,605)                                                  A3380
  605 FORMAT (31X,8HPOINT NO,5X,2HXS,12X,2HYS,16X,2HXP,12X,2HYP,/,2X)   A3385
      DO 610 I=1,NPOINT                                                 A3390
      LNCT=LNCT+1                                                       A3395
      IF (LNCT.LE.60) GO TO 610                                         A3400
```

```
        LNCT=4                                                          A3405
        WRITE (LOG2,85)                                                 A3410
        WRITE (LOG2,605)                                                A3415
  610   WRITE (LOG2,615) I,XS(J,I),YS(J,I),XP(J,I),YP(J,I)              A3420
  615   FORMAT (31X,I5,3X,1F2E14.5,4X,2E14.5)                           A3425
        IF (LNCT.LE.55) GO TO 620                                       A3430
        LNCT=1                                                          A3435
        WRITE (LOG3,85)                                                 A3440
  620   LNCT=LNCT+3                                                     A3445
        WRITE (LCG2,625)                                                A3450
  625   FORMAT (2X,/,31X,8HFOINT NO,5X,5HXSEMI,9X,5HYSEMI,/,2X)         A3455
        CO 630 I=1,31                                                   A3460
        LNCT=LNCT+1                                                     A3465
        IF (LNCT.LE.60) GO TO 630                                       A3470
        WRITE (LOG2,85)                                                 A3475
        WRITE (LCG2,625)                                                A3480
        LNCT=4                                                          A3485
  630   WRITE (LOG2,635) I,XSEMI(J,I),YSEMI(J,I)                        A3490
  635   FORMAT (31X,I5,3X,1P2E14.5)                                     A3495
  640   IF (IFPLCT.LT.2) GO TO 690                                      A3500
        IF (IFPLCT.EQ.4) GO TO 660                                      A3505
        XPLOT=XS(J,1)*SCALE                                             A3510
        YPLCT=YS(J,1)*SCALE                                             A3515
        CALL PLOT (XPLOT,YPLOT,3)                                       A3520
        DO 645 I=2,NPCINT                                               A3525
        XPLOT=XS(J,I)*SCALE                                             A3530
        YPLOT=YS(J,I)*SCALE                                             A3535
  645   CALL PLCT (XPLOT,YPLOT,2)                                       A3540
        DO 650 II=1,NPOINT                                              A3545
        I=NPCINT+1-II                                                   A3550
        XPLOT=XP(J,I)*SCALE                                             A3555
        YPLOT=YP(J,I)*SCALE                                             A3560
  650   CALL PLOT (XPLOT,YPLOT,2)                                       A3565
        DO 655 I=2,30                                                   A3570
        XPLCT=XSEMI(J,I)*SCALE                                          A3575
        YPLOT=YSEMI(J,I)*SCALE                                          A3580
  655   CALL FLCT (XPLOT,YPLOT,2)                                       A3585
        XPLOT=XS(J,1)*SCALE                                             A3590
        YPLOT=YS(J,1)*SCALE                                             A3595
        CALL FLCT (XPLOT,YPLOT,2)                                       A3600
```

```
      GO TC 690                                                         A3605
  660 CALL SYMBOL (19.9,2.0,.175,22HCARTESIAN SECTICN NO. ,0.0,22)      A3610
      XJ=J                                                              A3615
      CALL NUMBER (23.75,2.,.175,XJ,0.0,-1)                             A3620
      CALL SYMBOL (20.6,1.0,.175,10HSTAGGER = ,0.0,10)                  A3625
      STAGER=ATAN((YS(J,NFOINT)+YF(J,NPOINT)-YS(J,1)-YP(J,1))/(XS(J,NPOI A3630
     1NT)+XP(J,NFCINT)-XS(J,1)-XP(J,1)))*C1                             A3635
      CALL NUMBER (22.35,1.,.175,STAGER,0.0,3)                          A3640
      CALL FLCT (22.0,5.25,-3)                                          A3645
      SINSTG=SIN(STAGER/C1)                                             A3650
      COSSTG=COS(STAGER/C1)                                             A3655
      YPLOT=4.75                                                        A3660
      XPLOT=4.75*SINSTG/CCSSTG                                          A3665
      IF (ABS(XPLOT).LE.22.0) GC TO 665                                 A3670
      XPLOT=22.0                                                        A3675
      YPLOT=-22.0/SINSTG*COSSTG                                         A3680
  665 CALL FLCT (XPLOT,YPLOT,3)                                         A3685
      XPLOT=-XPLCT                                                      A3690
      YFLOT=-YPLCT                                                      A3695
      CALL FLCT (XPLOT,YPLOT,2)                                         A3700
      XPLOT=22.0                                                        A3705
      YPLOT=-22.0*SINSTG/COSSTG                                         A3710
      IF (ABS(YPLOT).LE.4.75) GC TO 670                                 A3715
      YPLOT=-4.75                                                       A3720
      XPLOT=4.75/SINSTG*CCSSTG                                          A3725
  670 CALL PLCT (XPLOT,YPLOT,3)                                         A3730
      XPLOT=-XFLCT                                                      A3735
      YPLOT=-YPLOT                                                      A3740
      CALL FLCT (XPLOT,YPLOT,2)                                         A3745
      XPLOT=SCALE*(XS(J,1)*CCSSTG+YS(J,1)*SINSTG)                       A3750
      YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)                       A3755
      CALL FLCT (XPLOT,YPLOT,3)                                         A3760
      DO 675 I=2,NPOINT                                                 A3765
      XPLOT=SCALE*(XS(J,I)*COSSTG+YS(J,I)*SINSTG)                       A3770
      YPLOT=SCALE*(YS(J,I)*COSSTG-XS(J,I)*SINSTG)                       A3775
  675 CALL PLCT (XPLOT,YPLOT,2)                                         A3780
      DO 680 II=1,NFOINT                                                A3785
      I=NPCINT+1-II                                                     A3790
      XPLOT=SCALE*(XP(J,I)*CCSSTG+YP(J,I)*SINSTG)                       A3795
      YPLOT=SCALE*(YP(J,I)*COSSTG-XP(J,I)*SINSTG)                       A3800
```

```
680   CALL PLCT (XPLOT,YPLOT,2)                                       A3805
      DO 685 I=2,30                                                   A3810
      XPLOT=SCALE*(XSEMI(J,I)*CCSSTG+YSEMI(J,I)*SINSTG)               A3815
      YPLOT=SCALE*(YSEMI(J,I)*CCSSTG-XSEMI(J,I)*SINSTG)               A3820
685   CALL PLOT (XPLOT,YPLOT,2)                                       A3825
      XPLOT=SCALE*(XS(J,1)*COSSTG+YS(J,1)*SINSTG)                     A3830
      YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)                     A3835
      CALL FLCT (XPLOT,YPLOT,2)                                       A3840
      CALL PLOT (23.0,-5.25,-3)                                       A3845
690   CONTINUE                                                        A3850
695   IF (IFPLOT.NE.0) CALL PLOTE                                     A3855
      GO TO 710                                                       A3860
700   WRITE (LOG2,705) J                                              A3865
705   FORMAT (10X,8HFAILED   ,I2)                                     A3870
710   CONTINUE                                                        A3875
      STOP                                                            A3880
      END                                                             A3885-
```

```
      SUBRCUTINE BQ (IBL,YS,YF,XS,XP,YSEMI,XSEMI,LOG2,N,IPRINT,BETA1,BET
     1A2,YZERO,T,YONE,XDEL,YDEL,Z,XNORMC,LNCT,DX,Y,CY,SIGMA,SS1,XHERE,X,
     2SS,NSTNS,R,BX,XM,YM,AM,AXIALC,ISTAK)
      REAL IX,IY,IXY,IPX,IPY,IXC,IYD,IXN,IYN,IXYN
      DIMENSICN YS(15,81), YF(15,81), XS(15,81), XP(15,81), YSEMI(15,31)
     1, XSEMI(15,31), S(81), Y(100), THICK2(81), XM(82), YM(81), AM(81),
     2 XHERE(100), X(100), SS(100), R(10,15), DX(100), CY(100), SS1(100,
     333), SIGMA(100)
    5 FORMAT (1H1)
      PI=3.1415926535
      C1=180.0/PI
      IF (IPRINT.EQ.2) GO TO 15
      WRITE (LOG2,10) IBL,BETA1,BETA2,YZERO,T,YONE,Z,AXIALC
   10 FORMAT (1H1,44X,43HSTREAMSURFACE GEOMETRY ON STREAMLINE NUMBER,I3,
     1/45X,46(1H*),//,20X,5HBETA1,11X,1H=,F7.3,6X,20H(BLADE INLET ANGLE.
     2),/,20X,5HBETA2,11X,1H=,F7.3,6X,21H(BLADE OUTLET ANGLE.),/,20X,5HY
     3ZERO,11X,1H=,F8.5,5X,51H(BLADE LEADING EDGE RADIUS AS A FRACTION O
     4F CHORD.),/,20X,1HT,15X,1H=,F8.5,5X,49H(BLADE MAXIMUM THICKNESS AS
     5 A FRACTION OF CHORD.),/,20X,4HYONE,12X,1H=,F8.5,5X,60H(BLADE TRAI
     6LING EDGE HALF-THICKNESS AS A FRACTION CF CHORD.),/,20X,1HZ,15X,1H
     7=,F7.4,6X,59H(LOCATION CF MAXIMUM THICKNESS AS A FRACTICN CF MEAN
     8LINE.),/,20X,4HCORD,12X,1H=,F7.4,6X,30H(MERIDICNAL CHORD OF SECTIO
     9N.))
   15 CHORD=XNORMC/(1.0-YZERO+XNORMC*(YZERO+ABS(YONE*SIN(BETA2/C1))))
      FCSLMN=1.0-CHORD*(YZERO+ABS(YONE*SIN(BETA2/C1)))
      AX=1./99.
      DX(1)=0.
      DO 20 IK=2,100
   20 DX(IK)=DX(IK-1)+AX
      CALL D1 (XM,YM,N,DX,DY,100,1)
      SIGMA(1)=0.
      DO 25 K=2,100
   25 SIGMA(K)=SIGMA(K-1)+SQRT((DX(K)-DX(K-1))**2+(DY(K)-DY(K-1))**2)
      CALL D1 (DX,SIGMA,100,XM,S,N,1)
      YZERO=YZERO*CHORD/FCSLMN
      YONE=YONE*CHORD/FCSLMN
      T=T*CHORD/FCSLMN
      S(1)=0.0
      AT=(YZERO-T/2.0)/(2.0*Z**2)
      CT=(T/2.0-YZERO)*3.0/(2.0*Z)
```

```
      DT=YZERO                                                          B 205
      ET=(YONE-T/2.0)/(1.0-Z)**3-1.5*(YZERO-T/2.0)/(Z**2*(1.0-Z))       B 210
      FT=1.5*(YZERO-T/2.0)/Z**2                                         B 215
      HT=T/2.0                                                          B 220
      DO 40 J=1,N                                                       B 225
      SN=S(J)/S(N)                                                      B 230
      IF (SN.GT.Z) GO TO 30                                             B 235
      THICK2(J)=(AT*SN**2+CT)*SN+DT                                     B 240
      GO TO 35                                                          B 245
   30 SN=SN-Z                                                           B 250
      THICK2(J)=(ET*SN+FT)*SN**2+HT                                     B 255
   35 FYPR=1./SQRT(1.+AM(J)**2)                                         B 260
      YPRIME=AM(J)                                                      B 265
      XS(IBL,J)=(XM(J)-THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN              B 270
      YS(IBL,J)=(YM(J)+THICK2(J)*FYPR)*FCSLMN                           B 275
      XP(IBL,J)=(XM(J)+THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN              B 280
      YP(IBL,J)=(YM(J)-THICK2(J)*FYPR)*FCSLMN                           B 285
      AM(J)=ATAN(AM(J))*C1                                              B 290
      XM(J)=(XM(J)+YZERO)*FCSLMN                                        B 295
      YM(J)=YM(J)*FCSLMN                                                B 300
      THICK2(J)=THICK2(J)*FCSLMN                                        B 305
   40 S(J)=S(J)*FCSLMN                                                  B 310
      YZERO=YZERO*FCSLMN                                                B 315
      AREA=PI/2.0*YZERO**2                                              B 320
      XINT=YZERO*(1.0-COS(BETA1/C1)*4.0/(3.0*PI))*AREA                  B 325
      YINT=-4.0/(3.0*PI)*YZERO*AREA*SIN(BETA1/C1)                       B 330
      DO 45 J=2,N                                                       B 335
      DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))                        B 340
      AREA=AREA+DELA                                                    B 345
      XINT=XINT+DELA*(XM(J)+XM(J-1))/2.0                                B 350
   45 YINT=YINT+DELA*(YM(J)+YM(J-1))/2.0                                B 355
      XBAR=XINT/AREA                                                    B 360
      YBAR=YINT/AREA                                                    B 365
      XBARB=XBAR                                                        B 370
      YBARB=YBAR                                                        B 375
      YBAR=YBAR+YDEL/AXIALC                                             B 380
      XBAR=XBAR+XDEL/AXIALC                                             B 385
      CALL D1 (XM,AM,N,DX,SS1(1,1),100,1)                               B 390
      DO 50 IK=1,100                                                    B 395
      SS1(IK,1)=TAN(SS1(IK,1)/C1)                                       B 400
```

```
      Y(IK)=DY(IK)*FCSLMN
   50 SIGMA(IK)=DX(IK)*FCSLMN+YZERO
      CALL D1 (SIGMA,Y,100,DX,DY,100,1)
      CALL D1 (SIGMA,SS1(1,1),100,DX,Y,100,1)
      CALL D1 (DX,DY,100,XBAR,XAB,1,1)
      CALL C1 (DX,Y,100,XBAR,XBC,1,1)
      XBAR=XBARB
      YBAR=YBARB
      IX=0.0
      IY=0.0
      IXY=0.0
      DO 55 J=2,N
      DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
      IXD=(THICK2(J)+THICK2(J-1))**3*(S(J)-S(J-1))/12.0
      IYD=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))**3/12.0
      COSANG=COS((AM(J)+AM(J-1))/C1)
      IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
      IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
      IXYN=0.0
      IF ((AM(J)+AM(J-1)).NE.0.0) IXYN=((IXN-IYN)*COSANG-IXD+IYD)/(2.0*S
     1IN((AM(J)+AM(J-1))/C1))
      IX=IX+IXN+DELA*((YM(J)+YM(J-1))/2.0-YBAR)**2
      IY=IY+IYN+DELA*((XM(J)+XM(J-1))/2.0-XBAR)**2
   55 IXY=IXY+IXYN+DELA*(YBAR-(YM(J)+YM(J-1))/2.0)*(XBAR-(XM(J)+XM(J-1))
     1/2.0)
      ANG=ATAN(2.0*IXY/(IY-IX))
      IPX=(IX+IY)/2.0+(IX-IY)/2.0*COS(ANG)-IXY*SIN(ANG)
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*COS(ANG)+IXY*SIN(ANG)
      ANG=ANG/2.0*C1
      STAGER=ATAN(YM(N)/XM(N))*C1
      XML=XM(N)
      YML=YM(N)
      CAMBER=BETA1-BETA2
      IF (IPRINT.EQ.2) GO TO 95
      LNCT=47
      WRITE (LCG2,60) CHORD,STAGER,CAMBER,AREA,XBAR,YBAR,IX,IY,IXY,ANG,I
     1PX,ANG,IPY,ANG
   60 FORMAT (/,16X,100HNORMALISED RESULTS - ALL THE FOLLOWING REFER TO
     1ABLADE HAVING A MERIDIONAL CHORD PROJECTION OF UNITY,/,16X,100(1H*
     2),//20X,11HBLADE CHORD,4X,1H=,F7.4,//,20X,16HSTAGGER ANGLE  =,F7.3
```

```
     3,//,20X,16HCAMBER ANGLE   =,F7.3,//,20X,16HSECTION AREA   =,F7.5,/
     4/,20X,45HLOCATION OF CENTROID RELATIVE TO LEADING EDGE,//,30X,6HXB
     5AR =,F8.5,/,30X,6HYBAR =,F8.5,//,20X,37HSECOND MOMENTS OF AREA ABO
     6UT CENTROID,//,30X,6HIX   =,F8.5,/,30X,6HIY   =,F8.5,/,30X,6HIXY
     7=,F8.5,//,20X,58HANGLE OF INCLINATION OF (ONE) PRINCIPAL AXIS TO '
     8X' AXIS =,F7.3,//,20X,47HPRINCIPAL SECOND MOMENTS OF AREA ABOUT CE
     9NTROID,//,30X,6HIPX  =,F7.5,6X,3H(AT,F7.3,15H WITH 'X' AXIS),/,30X
     $,6HIPY  =,F7.5,6X,3H(AT,F7.3,15H WITH 'Y' AXIS),//)
65    FORMAT (27X,5HPOINT,8X,24HM E A N L I N E  D A T A,13X,23HSURFACE
     1COORDINATE DATA,/,27X,6HNUMBER,5X,1HX,7X,1HY,5X,15HANGLE THICKNESS
     2,9X,2HXS,6X,2HYS,6X,2HXP,6X,2HYP,//)
      WRITE (LOG2,65)
      DO 75 J=1,N
      IF (LNCT.NE.60) GO TO 70
      WRITE (LOG2,5)
      WRITE (LOG2,65)
      LNCT=4
70    LNCT=LNCT+1
      TM=THICK2(J)*2.0
75    WRITE (LOG2,80) J,XM(J),YM(J),AM(J),TM,XS(IBL,J),YS(IBL,J),XP(IBL,
     1J),YP(IBL,J)
80    FORMAT (27X,I3,F13.5,F8.5,F7.3,F8.5,F16.5,3F8.5)
      DO 85 J=1,N
      XM(J)=XS(IBL,J)
      YM(J)=YS(IBL,J)
      AM(J)=XP(IBL,J)
85    THICK2(J)=YP(IBL,J)
      WRITE (LOG2,90) IBL
90    FORMAT (1H1,45X,33HNORMALISED PLOT OF SECTION NUMBER,I3,/,2X)
      CALL EQ (N,LOG2,XM,YM,AM,THICK2)
95    A2=AXIALC**2
      A4=A2**2
      IX=IX*A4
      IY=IY*A4
      IXY=IXY*A4
      IPX=IPX*A4
      IPY=IPY*A4
      IF (ISTAK.GT.1) GO TO 100
      XBAR=ISTAK
      IF (ISTAK.EQ.0) YBAR=0.
```

```
      IF (ISTAK.EQ.1) YBAR=YML
  100 RLE=YZERO*AXIALC
      CHORD=CHORD*AXIALC
      AREA=AREA*A2
      XC=RLE-XBAR*AXIALC-XDEL
      YC=-YBAR*AXIALC-YDEL
      IF (IPRINT.EQ.2) GO TO 120
      WRITE (LCG2,105) CHCRD,RLE,XC,YC,AREA,IX,IY,IXY,IPX,ANG,IPY,ANG
  105 FCRMAT (1H1,31X,69HCIMENSIONAL RESULTS - ALL RESULTS REFER TC A BL
     1ADE CF SPECIFIED CHCRD,/,32X,69H*********************************
     2********************************,//,20X,11HBLADE CHORD,4X,1H=,1
     3PE12.5,//,20X,10HL.E.RADIUS,5X,1H=,1PE12.5,8X,14HCENTERED AT X=,1P
     4E13.5,3H Y=,1PE13.5,//,20X,16HSECTION AREA    =,1PE12.5,//,20X,37HS
     5ECONC MCMENTS OF AREA ABOUT CENTROID,//,30X,6HIX    =,1PE12.5,/,30X
     6,6HIY    =,1PE12.5,/,30X,6HIXY   =,1PE12.5,//,20X,47HPRINCIPAL SECON
     7D MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIPX   =,1PE12.5,5H  (AT,0
     8PF7.3,15H WITH 'X' AXIS),/,30X,6HIPY   =-1PE12.5,5H  (AT,0PF7.3,15H
     9 WITH 'Y' AXIS),//)
      WRITE (LOG2,110)
      WRITE (LOG2,115)
  110 FORMAT (124H    PT      SUCTION------SURFACE         PRESSURE-----SU
     1RFACE          PT     SUCTICN------SURFACE         PRESSURE-----SUR
     2FACE)
  115 FORMAT (4X,2HNO,8X,1HX,13X,1HY,13X,1HX,13X,1HY,12X,2HNO,8X,1HX13X,
     11HY,13X,1HX,13X,1HY,//)
      LNCT=24
  120 DO 135 J=1,N
      XS(IBL,J)=(XS(IBL,J)-XBAR)*AXIALC-XDEL
      YS(IBL,J)=(YS(IBL,J)-YBAR)*AXIALC-YDEL
      XP(IBL,J)=(XP(IBL,J)-XBAR)*AXIALC-XDEL
      YP(IBL,J)=(YP(IBL,J)-YBAR)*AXIALC-YDEL
      IF (IPRINT.EQ.2) GO TO 135
      IF ((J/2)*2.NE.J) GC TO 135
      IF (LNCT.NE.60) GO TO 125
      LNCT=4
      WRITE (LCG2,5)
      WRITE (LCG2,110)
      WRITE (LCG2,115)
  125 LNCT=LNCT+1
      JM1=J-1
```

```
      WRITE (LOG2,130) JM1,XS(IBL,JM1),YS(IBL,JM1),XP(IBL,JM1),YP(IBL,JM  B1005
     11),J,XS(IBL,J),YS(IBL,J),XP(IBL,J),YP(IBL,J)                       B1010
  130 FORMAT (3X,I3,4(2X,1PE12.5),6X,I3,4(2X,1PE12.5))                   B1015
  135 CONTINUE                                                           B1020
      IF (IPRINT.EQ.2) GO TO 150                                         B1025
      IF (LNCT.GT.24) WRITE (LOG2,140)                                   B1030
  140 FORMAT (1H1)                                                       B1035
      IF (LNCT.GT.24) LNCT=2                                             B1040
      LNCT=LNCT+5                                                        B1045
      WRITE (LOG2,145)                                                   B1050
  145 FORMAT (2X,/,48X,37HPOINTS DESCRIBING LEADING EDGE RADIUS,//,48X,9 B1055
     1HPOINT NO.,6X,1HX,13X,1HY,/,2X)                                    B1060
  150 EPS=BETA1+180.0                                                    B1065
      DO 160 J=1,31                                                      B1070
      XSEMI(IBL,J)=XC-RLE*SIN(EPS/C1)                                    B1075
      YSEMI(IBL,J)=YC+RLE*COS(EPS/C1)                                    B1080
      EPS=EPS-6.0                                                        B1085
      IF (IPRINT.EQ.2) GO TO 160                                         B1090
      WRITE (LOG2,155) J,XSEMI(IBL,J),YSEMI(IBL,J)                       B1095
      LNCT=LNCT+1                                                        B1100
  155 FORMAT (48X,I5,1PE17.5,1PE14.5)                                    B1105
  160 CONTINUE                                                           B1110
      SSURF=AXIALC                                                       B1115
      SS2=BX-AXIALC*XBAR-XDEL                                            B1120
      SBAR=SS2+AXIALC*XBARB+XDEL                                         B1125
      DO 165 IK=1,100                                                    B1130
  165 SS(IK)=SS(IK)-SBAR                                                 B1135
      CALL D1 (SS,X,100,0.,SBAR,1,1)                                     B1140
      CALL D1 (XHERE,R(1,IBL),NSTNS,SBAR,RXBAR,1,0)                      B1145
      XBARC=XBAR                                                         B1150
      YBARC=YBAR                                                         B1155
      XBAR=XBARB+XDEL/AXIALC                                             B1160
      YBAR=YBARB+YDEL/AXIALC                                             B1165
      SS1(1,1)=SS(1)                                                     B1170
      S23=AXIALC/99.                                                     B1175
      SS(1)=SS(1)+SS2                                                    B1180
      DO 170 IK=2,100                                                    B1185
      SS1(IK,1)=SS(IK)                                                   B1190
  170 SS(IK)=SS(IK-1)+S23                                                B1195
      SIGMAC=(XAB-YBAR)/RXBAR*AXIALC                                     B1200
```

```
      DO 175 IK=2,100                                                   B1205
      IF (XBAR.EQ.DX(IK)) GO TO 185                                     B1210
      IF (XBAR.GT.DX(IK-1).AND.XBAR.LT.DX(IK)) GO TO 190                B1215
175   CONTINUE                                                          B1220
      WRITE (LOG2,180)                                                  B1225
180   FORMAT (1H1,23H XBAR CANNOT BE LOCATED)                           B1230
185   SIGMA(IK)=SIGMAC                                                  B1235
      KL=IK+1                                                           B1240
      GO TO 195                                                         B1245
190   KL=IK                                                             B1250
      SIGMA(IK-1)=SIGMAO                                                B1255
195   SSDUM=SS(KL-1)                                                    B1260
      SS(KL-1)=0.                                                       B1265
      YP1=XBC                                                           B1270
      RX1=RXBAR                                                         B1275
      DO 200 IK=KL,100                                                  B1280
      XSURF=SS2+DX(IK)*SSURF+SS1(1,1)                                   B1285
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)                           B1290
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)                           B1295
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)                           B1300
      CALL D1 (XHERE,R(1,IBL),NSTNS,XDUM,RX2,1,0)                       B1305
      SIGMA(IK)=SIGMA(IK-1)+(Y(IK)/RX2+YP1/RX1)/2.*(SS(IK)-SS(IK-1))    B1310
      YP1=Y(IK)                                                         B1315
200   RX1=RX2                                                           B1320
      SS(KL-1)=SSDUM                                                    B1325
      SSDUM=SS(KL)                                                      B1330
      SIGDUM=SIGMA(KL)                                                  B1335
      SIGMA(KL)=SIGMAC                                                  B1340
      SS(KL)=0.                                                         B1345
      RX1=RXBAR                                                         B1350
      YP1=XBC                                                           B1355
      KM=KL-1                                                           B1360
      DO 205 IK=1,KM                                                    B1365
      KJ=KL-IK                                                          B1370
      XSURF=SS2+DX(KJ)*SSURF+SS1(1,1)                                   B1375
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)                           B1380
      CALL D1 (XHERE,R(1,IBL),NSTNS,XDUM,RX2,1,0)                       B1385
      SIGMA(KJ)=SIGMA(KJ+1)-(Y(KJ)/RX2+YP1/RX1)/2.*(SS(KJ+1)-SS(KJ))    B1390
      YP1=Y(KJ)                                                         B1395
205   RX1=RX2                                                           B1400
```

```
      SIGMA(KL)=SIGDUM                                                  B1405
      SS(KL)=SSDUM                                                      B1410
      DO 210 IK=1,100                                                   B1415
  210 SS(IK)=SS1(IK,1)                                                  B1420
      XBAR=XBARC                                                        B1425
      YBAR=YBARC                                                        B1430
      DO 215 IK=1,N                                                     B1435
      SS1(IK,1)=SS2+((XS(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)         B1440
  215 SS1(IK,2)=SS2+((XP(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)         B1445
      DO 220 IK=1,31                                                    B1450
  220 SS1(IK,3)=SS2+((XSEMI(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)      B1455
      CALL D1 (SS,X,100,SS1(1,1),SS1(1,1),N,1)                          B1460
      CALL D1 (SS,X,100,SS1(1,2),SS1(1,2),N,1)                          B1465
      CALL D1 (SS,X,100,SS1(1,3),SS1(1,3),31,1)                         B1470
      IF (ISTAK.GT.1) GO TO 230                                         B1475
      IF (ISTAK.EQ.1) SIGMAO=SIGMA(100)                                 B1480
      IF (ISTAK.EQ.0) SIGMAO=SIGMA(1)                                   B1485
      DO 225 IK=1,100                                                   B1490
  225 SIGMA(IK)=SIGMA(IK)-SIGMAO                                        B1495
  230 DO 235 IK=1,100                                                   B1500
      DX(IK)=(DX(IK)-XBAR)*AXIALC-XDEL                                  B1505
  235 DY(IK)=(DY(IK)-YBAR)*AXIALC-YDEL                                  B1510
      DO 245 MK=1,3                                                     B1515
      IF (MK.EQ.3) NNN=31                                               B1520
      IF (MK.EQ.1.OR.MK.EQ.2) NNN=N                                     B1525
      DO 240 IK=1,NNN                                                   B1530
      IF (MK.EQ.1) YP1=YS(IBL,IK)                                       B1535
      IF (MK.EQ.2) YP1=YP(IBL,IK)                                       B1540
      IF (MK.EQ.3) YP1=YSEMI(IBL,IK)                                    B1545
      IF (MK.EQ.1) RX1=XS(IBL,IK)                                       B1550
      IF (MK.EQ.2) RX1=XP(IBL,IK)                                       B1555
      IF (MK.EQ.3) RX1=XSEMI(IBL,IK)                                    B1560
      CALL D1 (DX,DY,100,RX1,RXBAR,1,1)                                 B1565
      DELLY=YP1-RXBAR                                                   B1570
      CALL D1 (XHERE,R(1,IBL),NSTNS,SS1(IK,MK),RAB,1,0)                 B1575
      DELSIG=DELLY/RAB                                                  B1580
      CALL D1 (DX,SIGMA,100,RX1,XAB,1,1)                                B1585
  240 SS1(IK,MK)=XAB+DELSIG                                             B1590
  245 CONTINUE                                                          B1595
      RETURN                                                            B1600
      END                                                               B1605-
```

```
      SUBROUTINE CQ (XDATA,YDATA,NDATA,XIN,YOUT,YPRIME,NXY,NNOT)
      REAL M
      DIMENSION A(65), B(65), D(65), M(65), XDATA(1), YDATA(1), XIN(1),
     1YOUT(1), YPRIME(1)
      IF (NDATA-2) 120,5,35
5     IF (NNOT-1) 10,20,10
10    DO 15 I=1,NXY
15    YOUT(I)=((YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1)))*(XIN(I)-XDATA(1)
     1)+YDATA(1)
20    IF (NNOT) 120,120,25
25    DO 30 I=1,NXY
30    YPRIME(I)=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))
      GO TO 120
35    CONTINUE
      E1=1.0
      E2=1.0
      A(1)=1.0
      B(1)=-E1
      D(1)=0.0
      N=NDATA-1
      DO 40 I=2,N
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*B(I-1)/(6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0
40    D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-(YDATA(I)-YDATA(I
     1-1))/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*D(I-1)/6.0/A(I-1)
      A(NDATA)=-E2
      B(NDATA)=1.0
      D(NDATA)=0.0
      M(NDATA)=A(NDATA)*D(N)/(A(NDATA)*B(N)-A(N)*B(NDATA))
      DO 45 II=2,NDATA
      I=NDATA+1-II
45    M(I)=(D(I)-B(I)*M(I+1))/A(I)
      J=1
      I=1
50    IF (XIN(I)-XDATA(1)) 95,95,55
55    IF (XIN(I)-XDATA(J+1)) 70,70,60
60    IF (J+1-NDATA) 65,70,70
65    J=J+1
      GO TO 55
```

```
70     IF (XIN(I)-XDATA(NDATA)) 75,110,110                                C 205
75     DX=XDATA(J+1)-XDATA(J)                                             C 210
       IF (NWCT-1) 80,85,80                                               C 215
80     YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))**3+M(J+1)/(6.0*DX)*(XIN( C 220
      1I)-XDATA(J))**3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN C 225
      2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)                        C 230
       IF (NWOT) 85,90,85                                                 C 235
85     YPRIME(I)=(-M(J)*(XDATA(J+1)-XIN(I))**2/2.0+M(J+1)*(XIN(I)-XDATA(J C 240
      1))**2/2.0+YDATA(J+1)-YDATA(J))/DX-(M(J+1)-M(J))/6.0*DX             C 245
90     I=I+1                                                              C 250
       IF (I-NXY) 50,50,120                                               C 255
95     YDASH=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))-(M(1)/3.0+M(2)/6.0)* C 260
      1(XDATA(2)-XDATA(1))                                                C 265
       IF (NWCT-1) 100,105,100                                            C 270
100    YOUT(I)=YDATA(1)-YDASH*(XDATA(1)-XIN(I))                           C 275
       IF (NWOT) 105,90,105                                               C 280
105    YPRIME(I)=YDASH                                                    C 285
       GO TO 90                                                           C 290
110    YDASH=(YDATA(NDATA)-YDATA(N))/(XDATA(NDATA)-XDATA(N))+(M(NDATA)/3. C 295
      10+M(N)/6.0)*(XDATA(NDATA)-XDATA(N))                                C 300
       IF (NWCT-1) 115,105,115                                            C 305
115    YOUT(I)=YDATA(NDATA)+YDASH*(XIN(I)-XDATA(NDATA))                   C 310
       IF (NWOT) 105,90,105                                               C 315
120    RETURN                                                             C 320
       END                                                                C 325-
```

```
      SUBROUTINE D1 (XDATA,YDATA,NDATA,XIN,YOUT,NXY,NTYPE)
      REAL M
      DIMENSION M(15), A(15), B(15), D(15), XDATA(1), YDATA(1), XIN(1),
     1YOUT(1)
      IF (NDATA-1) 5,5,15
5     DO 10 I=1,NXY
10    YOUT(I)=YDATA(1)
      RETURN
15    IF (NDATA-2) 25,25,20
20    IF (NTYPE) 90,90,25
25    J=1
      I=1
30    IF (XIN(I)-XDATA(2)) 65,65,35
35    IF (XIN(I)-XDATA(NDATA-1)) 40,70,70
40    IF (XIN(I)-XDATA(J)) 50,60,45
45    IF (XIN(I)-XDATA(J+1)) 60,60,50
50    J=J+1
      IF (J-NDATA) 40,55,55
55    J=1
      GO TO 40
60    YOUT(I)=YDATA(J)+(YDATA(J+1)-YDATA(J))/(XDATA(J+1)-XDATA(J))*(XIN(
     1I)-XDATA(J))
      GO TO 75
65    YOUT(I)=YDATA(1)+(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))*(XIN(I)-X
     1DATA(1))
      GO TO 75
70    YOUT(I)=YDATA(NDATA-1)+(YDATA(NDATA)-YDATA(NDATA-1))/(XDATA(NDATA)
     1-XDATA(NDATA-1))*(XIN(I)-XDATA(NDATA-1))
75    IF (I-NXY) 80,85,85
80    I=I+1
      GO TO 30
85    RETURN
90    A(1)=1.0
      B(1)=0.0
      D(1)=0.0
      N=NDATA-1
      DO 95 I=2,N
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*B(I-1)/(6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0
```

```
   95 D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-(YDATA(I)-YDATA(I  D 205
     1-1))/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*D(I-1)/6.0/A(I-1)  D 210
      M(NDATA)=0.0                                                         D 215
      DO 100 II=2,N                                                        D 220
      I=NDATA+1-II                                                         D 225
  100 M(I)=(D(I)-B(I)*M(I+1))/A(I)                                         D 230
      M(1)=0.0                                                             D 235
      J=1                                                                  D 240
      I=1                                                                  D 245
  105 IF (XIN(I)-XDATA(1)) 115,130,110                                     D 250
  110 IF (XIN(I)-XDATA(NDATA)) 140,135,120                                 D 255
  115 JP=1                                                                 D 260
      KP=2                                                                 D 265
      GC TC 125                                                            D 270
  120 JP=NCATA                                                             D 275
      KP=NCATA-1                                                           D 280
  125 YPRIME=(YDATA(KP)-YCATA(JP))/(XDATA(KP)-XCATA(JP))-M(KP)/6.0*(XDAT  D 285
     1A(KP)-XDATA(JP))                                                     D 290
      YOUT(I)=YDATA(JP)+(XIN(I)-XDATA(JP))*YPRIME                          D 295
      GO TO 175                                                            D 300
  130 YOUT(I)=YCATA(1)                                                     D 305
      GO TC 175                                                            D 310
  135 YCUT(I)=YDATA(NCATA)                                                 D 315
      GO TC 175                                                            D 320
  140 IF (XIN(I)-XDATA(J)) 150,160,145                                     D 325
  145 IF (XIN(I)-XDATA(J+1)) 170,165,150                                   D 330
  150 J=J+1                                                                D 335
      IF (J-NDATA) 140,155,155                                             D 340
  155 J=1                                                                  D 345
      GC TO 140                                                            D 350
  160 YOUT(I)=YDATA(J)                                                     D 355
      GO TC 175                                                            D 360
  165 YOUT(I)=YDATA(J+1)                                                   D 365
      GO TC 175                                                            D 370
  170 DX=XDATA(J+1)-XDATA(J)                                               D 375
      YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))**3+M(J+1)/(6.0*DX)*(XIN(  D 380
     1I)-XCATA(J))**3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN  D 385
     2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)                          D 390
  175 IF (I-NXY) 180,185,185                                               D 395
  180 I=I+1                                                                D 400
      GO TC 105                                                            D 405
  185 RETURN                                                               C 410
      END                                                                  D 415-
```

```
      SUBROUTINE EQ (IX,LOG1,X1,Y1,X2,Y2)                             E   5
      REAL LINE                                                       E  10
      DIMENSION X1(1), Y1(1), X2(1), Y2(1), LINE(121), XNUM(13)       E  15
      DATA SYMBOL/1H*/,DASH/1H-/,CROSS/1H+/,BLANK/1H /,XI/1HI/        E  20
      YMIN=Y1(1)                                                      E  25
      XMIN=X1(1)                                                      E  30
      YMAX=YMIN                                                       E  35
      XMAX=XMIN                                                       E  40
      DO 5 I=1,IX                                                     E  45
      IF (Y2(I).LT.YMIN)  YMIN=Y2(I)                                  E  50
      IF (Y2(I).GT.YMAX)  YMAX=Y2(I)                                  E  55
      IF (X2(I).LT.XMIN)  XMIN=X2(I)                                  E  60
      IF (X2(I).GT.XMAX)  XMAX=X2(I)                                  E  65
      IF (Y1(I).GT.YMAX)  YMAX=Y1(I)                                  E  70
      IF (X1(I).GT.XMAX)  XMAX=X1(I)                                  E  75
    5 CONTINUE                                                        E  80
      IF (XMAX.EQ.XMIN.OR.YMIN.EQ.YMAX) GO TO 85                      E  85
      YH=YMAX+(YMAX-YMIN)/25.0                                        E  90
      YL=YMIN-(YMAX-YMIN)/25.0                                        E  95
      XH=XMAX+(XMAX-XMIN)/38.3333                                     E 100
      XL=XMIN-(XMAX-XMIN)/38.3333                                     E 105
      IF ((YH-YL)/(XH-XL).GT.0.75) XH=1.3333*(YH-YL)+XL               E 110
      IF ((YH-YL)/(XH-XL).LT.0.75) YH=0.75*(XH-XL)+YL                 E 115
      XMAX=(XMIN+XMAX-XH+XL)/2.0                                      E 120
      XH=XH-XL+XMAX                                                   E 125
      XL=XMAX                                                         E 130
      XMAX=(YMIN+YMAX-YH+YL)/2.0                                      E 135
      YH=YH-YL+XMAX                                                   E 140
      YL=XMAX                                                         E 145
      XMAX=ABS(XH)                                                    E 150
      XMIN=ABS(XL)                                                    E 155
      YMIN=ABS(YL)                                                    E 160
      YMAX=ABS(YH)                                                    E 165
      IF (XMIN.GT.XMAX) XMAX=XMIN                                     E 170
      IF (YMIN.GT.YMAX) YMAX=YMIN                                     E 175
      XMAX=ALOG10(XMAX)                                               E 180
      YMAX=ALOG10(YMAX)                                               E 185
      IF (XMAX.LT.0.0) XMAX=XMAX-1.0                                  E 190
      IF (YMAX.LT.0.0) YMAX=YMAX-1.0                                  E 195
      MX=-XMAX                                                        E 200
```

```
      MY=-YMAX
      WRITE (LOG1,10) MX,MY
   10 FORMAT (20X,46HSCALES - 'X' IS SHOWN TIMES 10 TC THE POWER OF,I3,4
     10H   'Y' IS SHOWN TIMES 10 TO THE POWER OF,I3,/)
      YINC=(YH-YL)/54.0
      YINC2=YINC/2.0
      XRANGE=XH-XL
      DO 70 KLINE=1,55
      IF (KLINE.EQ.1.OR.KLINE.EC.55) GO TC 25
      DO 15 L=2,120
   15 LINE(L)=BLANK
      IF (KLINE.EQ.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.CR.KLINE.EQ.25.CR.KLI
     1NE.EC.31.OR.KLINE.EC.37.OR.KLINE.EQ.43.CR.KLINE.EQ.49) GC TO 20
      LINE(1)=XI
      LINE(121)=XI
      GO TC 40
   20 LINE(1)=DASH
      LINE(121)=DASH
      GO TC 40
   25 DO 30 L=2,120
   30 LINE(L)=DASH
      LINE(1)=CRCSS
      LINE(121)=CROSS
      DO 35 L=11,111,10
   35 LINE(L)=XI
      GC TC 60
   40 DO 50 I=1,IX
      IF (Y2(I).GT.YH+YINC2.OR.Y2(I).LE.YH-YINC2) GC TO 45
      L=(X2(I)-XL)/XRANGE*120.0+1.5
      LINE(L)=SYMBOL
   45 IF (Y1(I).GT.YH+YINC2.OR.Y1(I).LE.YH-YINC2) GO TO 50
      L=(X1(I)-XL)/XRANGE*120.0+1.5
      LINE(L)=SYMBOL
   50 CONTINUE
      TF (KLINE.EQ.1.CR.KLINE.EG.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLIN
     1E.EQ.25.OR.KLINE.EQ.31.CR.KLINE.EQ.37.OR.KLINE.EQ.43.OR.KLINE.EQ.4
     29.OR.KLINE.EQ.55) GC TC 60
      WRITE (LOG1,55) LINE
   55 FCRMAT (8X,121A1)
      GO TC 70
```

```
60      YNUM=YH*10.0**MY                                                    E 405
        WRITE (LOG1,65) YNUM,LINE                                           E 410
65      FORMAT (1X,F6.3,1X,121A1)                                           E 415
70      YH=YH-YINC                                                          E 420
        XNUM(1)=XL*10.0**MX                                                 E 425
        XINC=((XH-XL)/12.0)*10.0**MX                                        E 430
        DO 75 I=2,13                                                        E 435
75      XNUM(I)=XNUM(I-1)+XINC                                              E 440
        WRITE (LCG1,80) XNUM                                                E 445
80      FORMAT (6X,12(F6.3,4X),F6.3)                                        E 450
        RETURN                                                              E 455
85      WRITE (LCG1,90)                                                     E 460
90      FORMAT (//,35X,54HNC PLCT HAS BEEN MACE BECAUSE 'X' CR 'Y' RANGE I  E 465
       1S ZERO)                                                             E 470
        RETURN                                                              E 475
        END                                                                 E 480-
```

```
      SUBROUTINE FQ (ISTAK,PLTSZE,ITRIG,TITLE,IKDUM,IFPLOT)
      DIMENSION TITLE(8)
      IF (ITRIG.EQ.2.AND.IFPLOT.NE.2) CALL PLOT (PLTSZE,0.,-3)
      PLTTIT=PLTSZE*.1
      IF (ISTAK.LT.2) GO TO 5
      BAL=.35*PLTSZE
      XLEN1=.3*PLTSZE
      XLEN2=XLEN1
      YLEN1=.25*PLTSZE
      YLEN2=-1.*YLEN1
      XBACK1=-1.9
      XBACK2=-6.2
      GO TO 25
    5 IF (ISTAK.EQ.0) GO TO 10
      XLEN1=.70*PLTSZE
      XLEN2=.15*PLTSZE
      XBACK1=-1.9-.20*PLTSZE
      XBACK2=-6.2-.20*PLTSZE
      IF (IKDUM.EQ.1) GO TO 15
      GO TO 20
   10 CONTINUE
      XLEN1=.15*PLTSZE
      XLEN2=.70*PLTSZE
      XBACK1=-1.9+.20*PLTSZE
      XBACK2=-6.2+.20*PLTSZE
      IF (IKDUM.EQ.1) GO TO 20
   15 BAL=.25*PLTSZE
      YLEN1=.50*PLTSZE
      YLEN2=-.15*PLTSZE
      GO TO 25
   20 BAL=.50*PLTSZE
      YLEN1=.15*PLTSZE
      YLEN2=-.50*PLTSZE
   25 CONTINUE
      YBACK1=-(.35+BAL)
      YBACK2=YBACK1-.01*PLTSZE-.175
      CALL PLOT (0.0,-PLTSZE,-3)
      CALL PLOT (7.0,PLTTIT,-3)
      CALL PLOT (0.0,BAL,3)
      CALL PLOT (XLEN1,BAL,-2)
```

```
      CALL PLOT (XLEN2,0.0,2)
      CALL PLOT (0.0,YLEN1,3)
      CALL PLOT (0.0,YLEN2,2)
      GO TO (30,35), ITRIG
30    CALL SYMBOL (XBACK1,YBACK1,.175,22HSTREAMSURFACE SECTIONS,0.0,22)
      GO TO 40
35    XBACK1=XBACK1+0.35
      CALL SYMBOL (XBACK1,YBACK1,.175,18HCARTESIAN SECTIONS,0.0,18)
40    CALL SYMBOL (XBACK2,YBACK2,.175,TITLE,0.0,72)
      RETURN
      END
```

4. PROGRAM LOGIC

The calculation procedure which has been described in this report is performed primarily in the main program and Subroutine BQ. The calculations regarding the construction of the camber line, the stacking of the streamsurface blade sections, and the determination of manufacturing sections are performed in the main program. Subroutine BQ applies the thickness distribution to the camber line and determines quantities necessary to obtain the Cartesian coordinates of the section from the streamsurface coordinates. Subroutine D1 is the curve-fitting routine, and CQ is used to determine slopes of various spline curves at particular points. EQ produces the line-printer section plot in the printed portion of the output, and FQ produces axes on the section plots for IFPLOT = 1, 2, or 3.

A description of the calculation procedure employed in the main program and in Subroutine BQ is described below. Each step is keyed to its location in the program by the parenthetical deck serialization.

1. The input data is read and printed. (A155-A680)

2. If precision plotting is specified, the plot is initialized, and axes produced if IFPLOT = 1 or 3. (A695-A710)

3. A loop which creates a section on each streamsurface is commenced. (A715)

4. The axial locations of the intersections of a particular streamsurface with the computing stations describing the blade are determined. The meridional streamsurface length is obtained as described in Equation (1). (A720-A780)

5. The parameters relating to the streamsurface blade section are interpolated (or extrapolated) from the input tables. If NSPEC = 1, they are taken to be radially uniform. If NSPEC = 2, linear interpolation is used; if NSPEC = 3, spline-curve interpolation is employed. (A785-A840)

6. The loop to determine the optimal camber line is initiated. (A855)

7. The first estimate of true chord is calculated per Equation (2), and the solidity as in Equation (3). (A870-A910)

8. The incidence angle and extra deviation applicable to the particular section are obtained by interpolation of the radius at the leading edge of the streamsurface in the input tables. (A915-A920)

9. The section angle at the leading edge is determined as in Equation (6). (A925)

10. The quantities required for the deviation angle calculation are obtained by interpolation from various figures of Reference 2. (A935-A960)

11. The deviation angle is calculated using Equation (5). (A995-A1000)

12. The section angle at the trailing edge is calculated using Equation (7), and at internal points using Equation (8), with fractions of deviation obtained by radial interpolation from the input distributions based on the streamsurface radius at the trailing edge of the blade. (A1020-A1085)

13. A camber line is constructed of cubic segments following the analysis of Equations (9) - (15) for the initial value of S/R_o. The number of inflection points is determined. (A1090-A1350)

14. The iteration on solidity is performed until the tolerance is within the prescribed limit. (A1355-A1395)

15. Steps 13 and 14 are repeated for IPASS-1 values of the S/R_o parameter. (A1400-A1450)

16. The range of S/R_o with the minimum number of inflection points is established. (A1480-A1600)

17. Steps 13, 14 and 15 are repeated for finer increments of the S/R_o parameter in the range determined in 16. The maximum value of the minimum radius of curvature in this range is determined. (A1645-A1690)

18. Still finer increments of S/R_o on either side of the S/R_o value which produced the maximum value of the minimum radius of curvature in 17 are examined to find the optimal S/R_o value. (A1730-A1745)

19. The details of the optimal camber line are printed if IPRINT = 0 or 1. (A1755-A1810)

20. The normalized chord length of the optimal camber line is computed. (A1820)

21. The total streamsurface length is calculated. (A1830-A1890)

22. If IPRINT = 0 or 1, the parameters defining the section are printed. (B65-B115)

23. The coefficients of the two thickness equations are computed. (B175-B220)

24. At each point of the camber line, the corresponding coordinates on each blade surface are obtained from the coordinates and slope of the camber line, and the appropriate thickness, scaled for an overall section meridional chord of unity. (B225-B310)

25. The section area and centroid location are determined. (B315-B365)

26. The camber line is redefined in terms of 100 points to assure sufficient points for accurate linear interpolation in the determination of Φ (Figure 1), needed for the eventual Cartesian coordinate determination. (B380-B440)

27. The various streamsurface section properties are determined. (B445-B560)

28. If IPRINT = 0 or 1, details of the normalized blade section and a line-printer plot are produced. (B575-B750)

29. Sectional properties are scaled to produce the "dimensional" results. (B755-B830)

30. If IPRINT = 0 or 1, the section information is printed. (B840-B1095)

31. The coordinates of 31 points describing the leading edge are determined. (B1070-B1080)

32. The origin of the coordinate system is shifted to the stack axis, and the relative Φ values for the blade surfaces are determined. (B1120-B1595)

33. If IFPLOT = 1 or 3, the streamsurface section plot is produced. (A1950-A2040)

34. If the calculations for aerodynamic analysis are required, various items related to the camber line are stored. (A2045-A2095)

35. The Cartesian coordinates for each point on the section surface are computed, and printed if IPRINT = 0 or 1. (A2100-A2435)

36. The loop initiated in 3 is repeated for each streamsurface. (A2440)

37. Unless IPRINT = 1, the volume of the blade is computed and printed. (A2445-A2555)

38. If specified, the calculations for aerodynamic analysis are performed and printed, and punched if IPUNCH = 1. (A2560-A2790)

39. If IFPLOT = 2 or 3, the axes are drawn and titled for the superimposed plot of the manufacturing sections. (A2800)

40. If no output relating to manufacturing sections is specified by either IFPLOT or IPRINT, the remainder of the program is bypassed. Alternatively, if printed details of the manufacturing sections are specified, a heading is printed. (A2805-A2835)

41. The location of each of the manufacturing planes is determined. (A2840-A2865)

42. The (Cartesian) coordinates of each point on the blade surface are obtained by spline-curve interpolation at each of the manufacturing sections. (A2870-A2945)

43. A loop that is performed for each manufacturing section is initiated. This loop contains the determination of section properties and the output of results for the section. If IPRINT = 0 or 2, section properties and coordinates are printed. (A2950-A3495)

44. If IFPLOT = 2 or 3, a plot of the manufacturing sections is produced. (A3510-A3605)

45. If IFPLOT = 4, an individual plot of the manufacturing sections is made. The axes are rotated clockwise until the chord line is horizontal. The angle of rotation is indicated as the stagger angle. (A3610-A3845)

46. The loop initiated in Step 43 for each manufacturing section is terminated. (A3850)

47. If precision plots have been made, the plotting is terminated. (A3855)

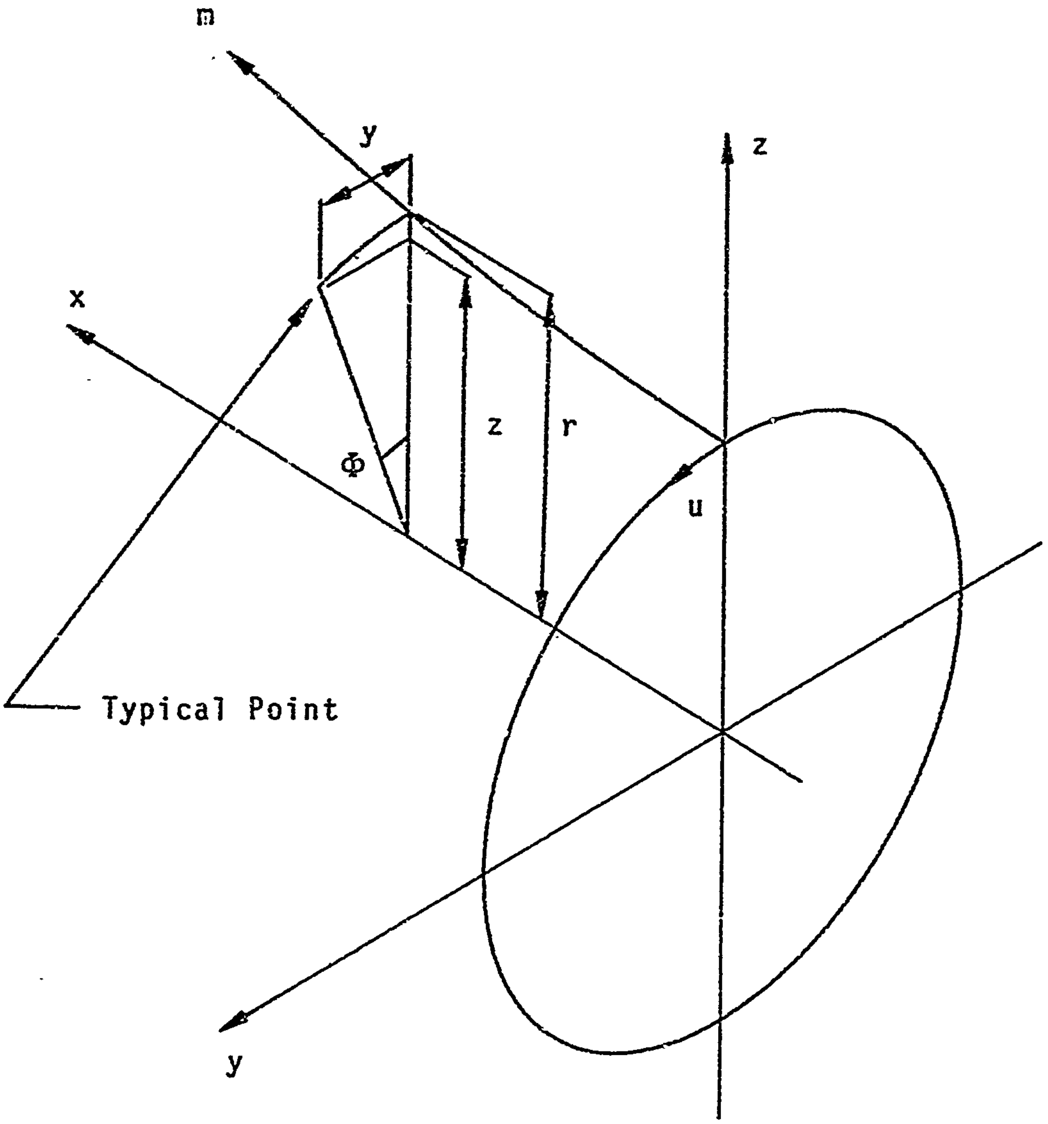

Figure 1. Cartesian and Streamsurface Coordinates of a Point

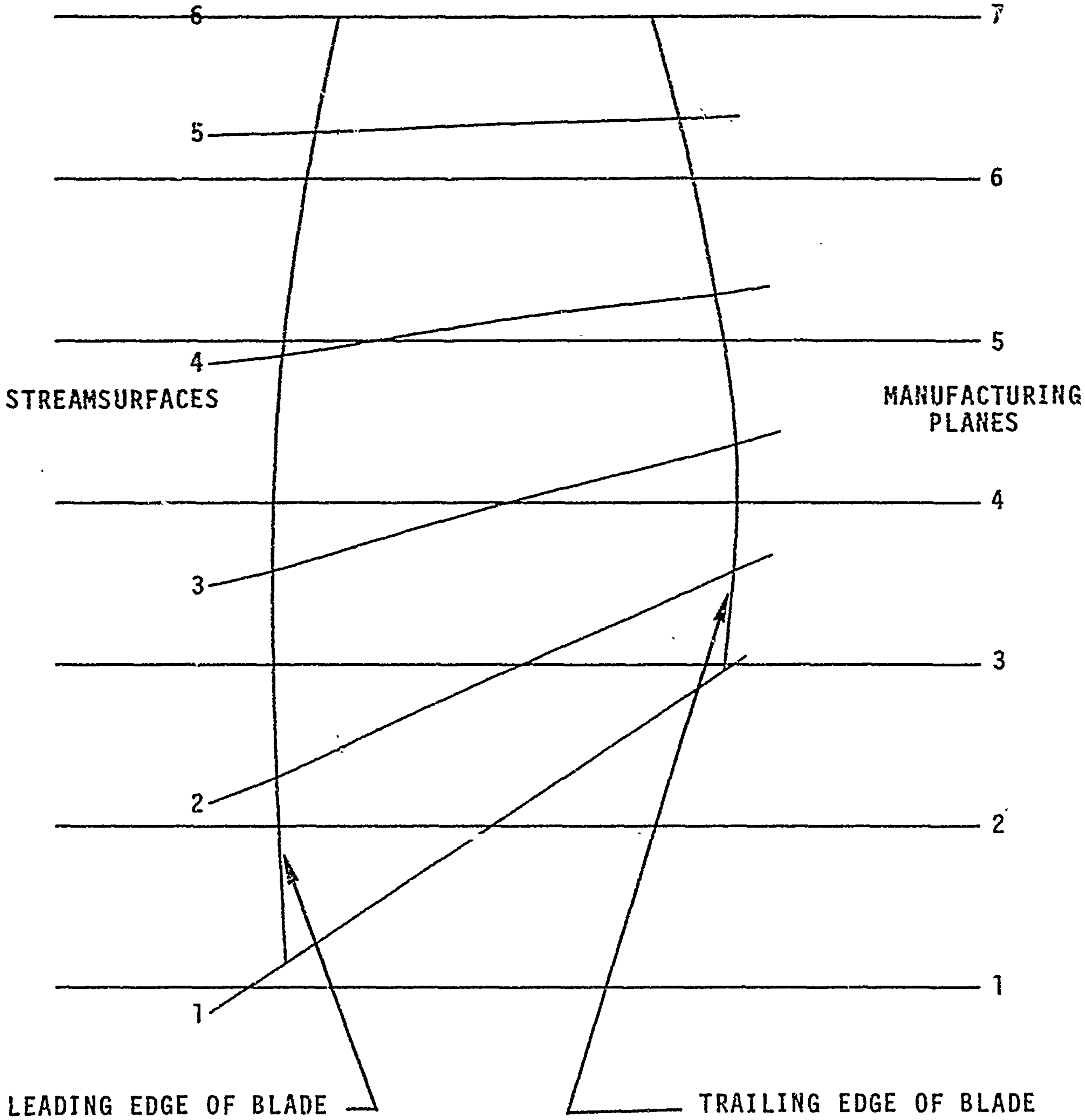

Figure 2. Locations of Streamsurfaces and Manufacturing Planes for Example Blade Design

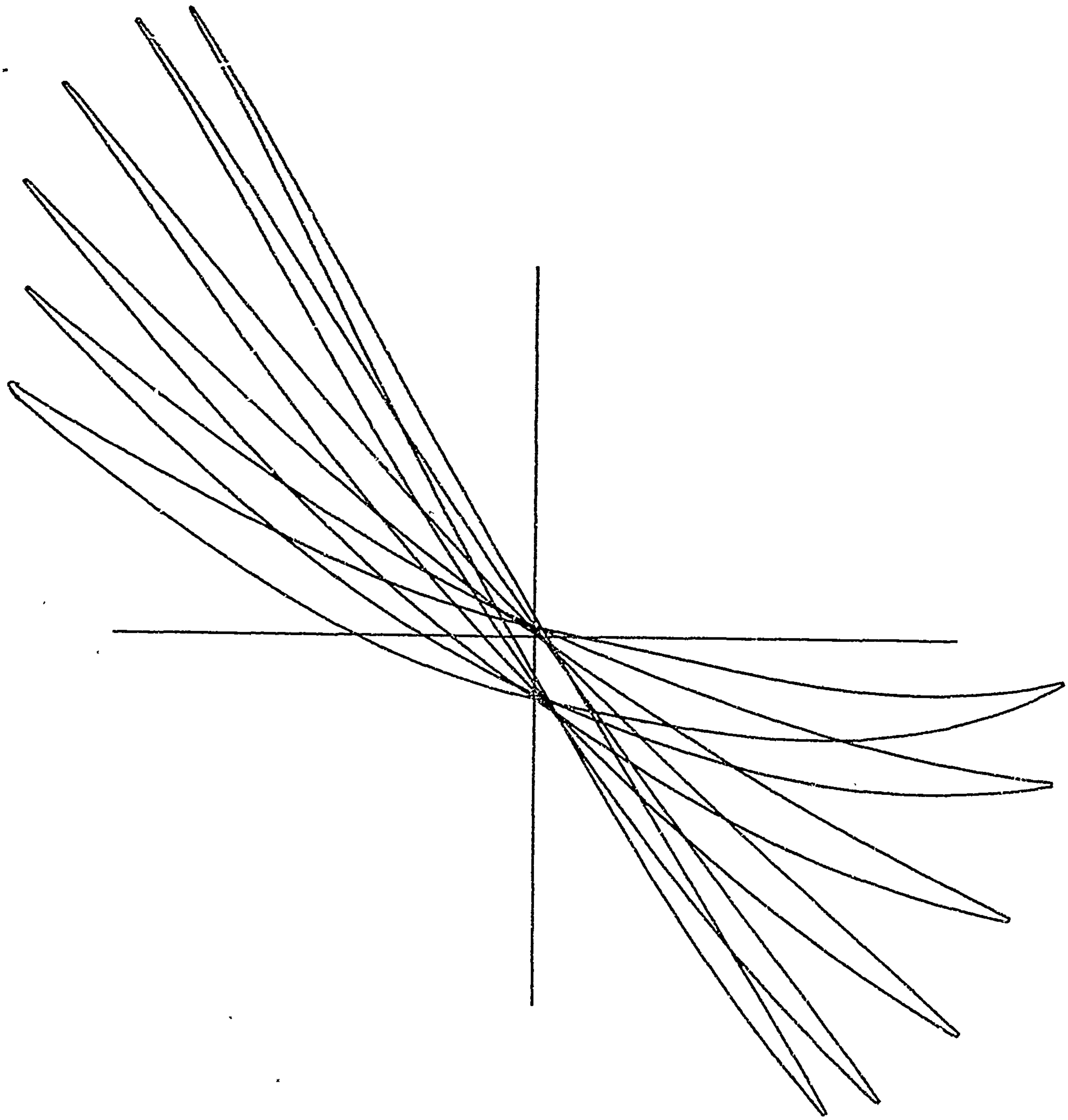

Figure 3, Example Blade Design:
Streamsurface Sections

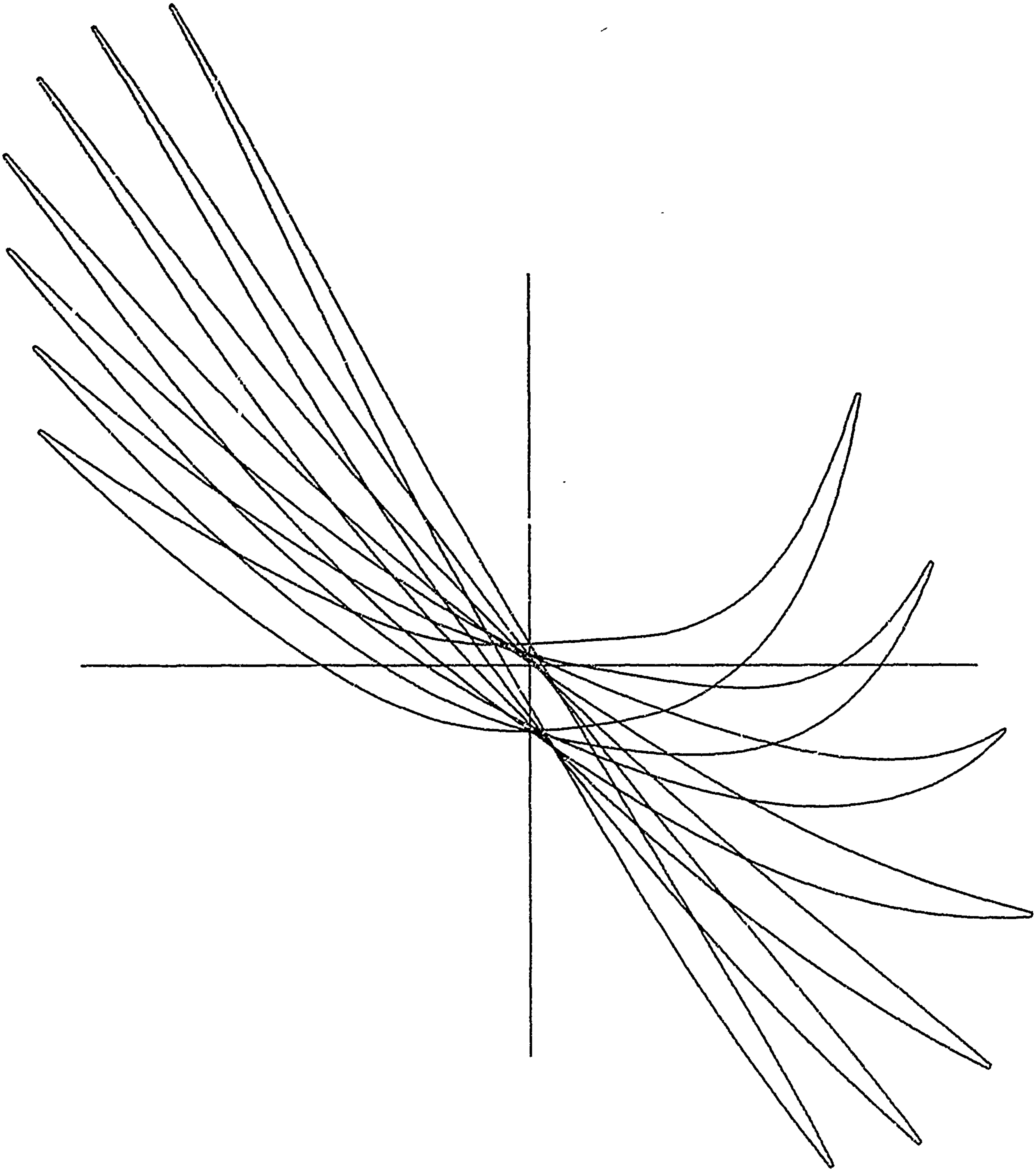

Figure 4. Example Blade Design: Cartesian Sections

REFERENCES

1. Frost, G.R., Hearsey, R.M., and Wennerstrom, A.J., "A Computer Program for the Specification of Axial Compressor Airfoils," Aerospace Research Laboratories, Wright-Patterson AFB, Ohio, ARL 72-0171, AD 756879, December 1972.

2. Johnsen, I.A., Bullock, R.O., et al, "Aerodynamic Design of Axial Flow Compressors," Lewis Research Center, Cleveland, Ohio, NASA SP-36, 1965.