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THE DESIGN OF AXIAL COMPRESSOR AIRF L3
USING ARBITRARY CHAMBER LINES

George R. Frost, et al

Aerospace Research Laboratories
Wright-Patterson Air Force Base, Ohio

July 1973

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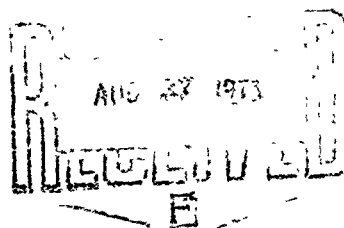
THE DESIGN OF AXIAL COMPRESSOR AIRFOILS USING ARBITRARY CAMBER LINES

GEORGE R. FROST, CAPTAIN, USAF

ARTHUR J. WENNERSTROM

FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

PROJECT 7065



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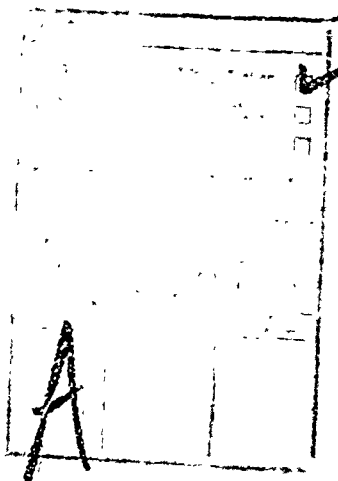
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THE DESIGN OF AXIAL COMPRESSOR AIRFOILS USING ARBITRARY CAMBER LINES

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FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

JULY 1973

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AEROSPACE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
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FOREWORD

This report was prepared by Captain George R. Frost and Dr. Arthur J. Wenneistrom 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. Wenneistrom 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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SECTION I

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 stream-surface. A thickness distribution 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 stream-surface-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

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

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

$$C_e = \frac{C_m}{\cos \left(\frac{\beta_{le} + \beta_{te}}{2} \right)} \quad (2)$$

The first estimate of solidity may be computed from the equation

$$\sigma = \frac{NC_e}{2\pi \left(\frac{r_{le} + r_{te}}{2} \right)} \quad (3)$$

where N is the number of blades and r_{le} , 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 .

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

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

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

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,

$$\alpha_{le} = \beta_{le} - i \quad (6)$$

and at the trailing edge,

$$\alpha_{te} = \beta_{te} - \delta \quad (7)$$

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 ,

$$\alpha_j = \beta_j - f_j \delta \quad (8)$$

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

$$y = ax^3 + bx^2 + cx + d \quad (9)$$

$$y' = 3ax^2 + 2bx + c \quad (10)$$

$$y'' = 6ax + 2b \quad (11)$$

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

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

$$b = \frac{y_1'' - 6ax_1}{2} \quad (13)$$

$$c = y_1' - 3ax_1^2 - 2bx_1 \quad (14)$$

$$d = y_1 - ax_1^3 - bx_1^2 - cx_1 \quad (15)$$

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:

$$\text{At } x = 0, y = 0$$

$$y' = \tan \alpha_{le} \quad (16)$$

$$y'' = y_0''$$

$$\text{At } x = x_1, y' = \tan \alpha_1 \quad (17)$$

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,

$$\text{At } x = x_1, y = y_{1(\text{first segment})}$$

$$y' = \tan \alpha_1 \quad (18)$$

$$y'' = y_{1(\text{first segment})}''$$

and at the other endpoint,

$$\text{At } x = x_2, y' = \tan \alpha_2 \quad (19)$$

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_0'' 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_0'' specified at the leading edge.

It has been found convenient to specify y_0'' in terms of a non-dimensional parameter S/R_0 , the ratio of blade spacing, S , to the radius of curvature, R_0 , at the leading edge. R_0 is given by the equation

$$R_0 = \frac{[1 + \tan^2 \alpha_{le}]^{3/2}}{y_0''} \quad (20)$$

and S is obtained from

$$S = \frac{2\pi r_{le}}{N} \quad (21)$$

From Equations (20) and (21),

$$\frac{S}{R_0} = \frac{2\pi r_{le} y_0''}{N [1 + \tan^2 \alpha_{le}]^{3/2}} \quad (22)$$

Solving for y_o'' gives

$$y_o'' = \frac{H \left[1 + \tan^2 \alpha_{le} \right]^{3/2}}{2\pi r_{le}} \cdot \frac{S}{R_o} \quad (23)$$

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

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

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 I'

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:

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

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

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

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_x^o :

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

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 $2 \leq \text{NLINES} \leq 15$.
NSTNS	The number of computing stations at which the streamsurface radii are specified. Must satisfy $3 \leq \text{NSTNS} \leq 10$.
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq \text{NZ} \leq 15$.
NSPEC	The number of radially-disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq \text{NSPEC} \leq 15$.
ISEGPT	The number of points to be used to define each segment of the camber line. $2 \leq \text{ISEGPT} \leq \text{Integer} \left(\frac{80}{\text{IRTE} - \text{IRLE}} \right)$
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_0 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 chord-wise 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_0 which, with SDIVR and IPASS, establishes the initial range of S/R_0 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_0 .

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

SM DEVC RV } repeated NPTS times

} repeated NRADEV 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

TC TE Z SDIVR DELX DELY

} repeated NSPEC times

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_0 parameter. The initial table presents the results of the first iteration which is used to identify the range of S/R_0 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_0 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_0 with still finer parameter increments. These details include the deviation and solidity which have been calculated for this optimal S/R_0 , 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 stream-surface 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 stream-surface 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 n 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_0 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_0 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_0 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.

6	8	7	6	12	20	2	0	3	0
2.5				8.50			2.5		-7.05
2	7	1	6	-1	2	30			11.0
1.				.005					
6									
3.3									
0.				.1					
0.2				.11					
0.4				.15					
.6				.22					
.8				.36					
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	
-7.511		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		-40.6566
	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
 5.1806
 5.9412
 6.8278
 7.8877
 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_0 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(LE) ARBITRARY CAMBER LINE PROGRAM

EXAMPLE ~ LOW HUB/TIP RATIO COMPRESSOR ROTOR DESIGN

TITLE =
NUMBER OF STREAMSURFACES = 6
NUMBER OF STATIONS = 8
NUMBER OF CONSTANT-Z PLANES = 7
NUMBER OF BLADE DATA POINTS = 6
NUMBER OF PCINTS 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
PLTSE = 11.0000

LEADING EDGE STATION NUMBER = 2
TRAILING EDGE STATION NUMBER = 7
RADI1 SPECIFYING DEVIATION = 1
RADI2 SPECIFYING INCIDENCE = 6
SENSE OF ROTATION INDICATOR = -1
DEVIATION CALCULATION INDEX = 2
NUMBER OF INITIAL S/R TRIALS = 30

SHAPE FACTOR = 1.0000
SOLICITY TOLERANCE = .0050

DEVIATION CURVE 1 NUMBER OF POINTS = 6 RADIUS = 3.3000

POINT	NORMALIZED MERIODIONAL CHCRC	NORMALIZED DEVIATION DISTRIBUTION
1	0.0000	.1000
2	.2000	.1100
3	.4000	.1500
4	.6000	.2200
5	.8000	.3000
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

IFANGS(1)= 0

NUMBER OF DESCRIBING POINTS= 2

COMPUTING STATION 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADIUS	AIR ANGLE
------------------	---	----------------------	--------	-----------

-9.0900	2.3500	1	2.3500	-0.0000
-9.0900	3.3500	2	3.6454	-0.0000
		3	4.9893	-0.0000
		4	6.3617	-0.0000
		5	7.7723	-0.0000
		6	8.5100	-0.0000

IFANGS(2)= 0

NUMBER OF DESCRIBING POINTS= 5

COMPUTING STATION 2

DESCRIPTION X	R	STREAMLINE NUMBER	RADIUS	AIR ANGLE
------------------	---	----------------------	--------	-----------

-8.5100	2.6514	1	2.6514	-40.9855
-0.5926	5.0663	2	3.8041	-47.2370
-8.5310	6.3989	3	5.0706	-50.8039
-8.3115	7.7861	4	6.4109	-53.6378
-8.1610	8.5000	5	7.7502	-57.2964
		6	8.5000	-59.7859

IFANGS(3)= 1

NUMBER OF DESCRIBING POINTS= 4

COMPUTING STATION 3

DESCRIPTION X	R	STREAMLINE NUMBER	RADIUS	AIR ANGLE
------------------	---	----------------------	--------	-----------

-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	6.4475	-51.0404
		5	7.8091	-57.8178
		6	8.5000	-61.3719

IFANGS(4)= 1

NUMBER OF DESCRIBING POINTS= 4

COMPUTING STATION 4

DESCRIPTION X	R	STREAMLINE NUMBER	RADIUS	AIR ANGLE
------------------	---	----------------------	--------	-----------

-7.3500	3.3893	1	3.3893	-20.0393
-7.3950	5.3850	2	4.3244	-28.9282
-7.4150	6.5650	3	5.4154	-38.6681
-7.3110	8.5000	4	6.5624	-47.7054
		5	7.6207	-56.2706
		6	8.5100	-60.2253

COMPUTING STATION 5

NUMBER OF DESCRIBING POINTS= 4

IFANGS (5) = 1

DESCRIPTION X STREAMLINE NUMBER RADIUS AIR ANGLE

-6.0010	3.3385	1	3.7285	-12.2650
-6.0010	5.4900	2	4.5798	-21.2618
-6.0700	6.6500	3	5.5662	-33.3334
-6.0900	8.5000	4	6.6591	-44.2126
		5	7.8459	-54.0832
		6	8.5100	-56.5864

COMPUTING STATION 6

NUMBER OF DESCRIBING POINTS= 4

IFANGS (6) = 1

DESCRIPTION X STREAMLINE NUMBER RADIUS AIR ANGLE

-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	-27.6750
-6.5600	8.5000	4	6.7242	-40.6966
		5	7.8575	-51.6465
		6	8.5100	-57.5156

COMPUTING STATION 7

NUMBER OF DESCRIBING POINTS= 5

IFANGS (7) = 1

DESCRIPTION X STREAMLINE NUMBER RADIUS AIR ANGLE

-5.6650	4.4612	1	4.4612	11.5881
-5.5846	5.8960	2	5.0795	-7.0960
-5.7208	6.7945	3	5.8623	-25.6222
-5.9516	7.8661	4	6.7350	-40.0751
-6.1340	8.5000	5	7.8716	-51.3351
		6	8.5100	-56.5750

COMPUTING STATION 8

NUMBER OF DESCRIBING POINTS= 4

IFANGS (8) = 0

DESCRIPTION X STREAMLINE NUMBER RADIUS AIR ANGLE

-5.5200	4.5534	1	4.5534	-0.0000
-5.3500	5.2000	2	5.1406	-0.0000
-5.3000	5.8000	3	5.9412	-0.0000
-5.7000	8.5000	4	6.8378	-0.0000
		5	7.8677	-0.0000
		6	8.5000	-0.0000

SECTION GEOMETRY SPECIFICATION

STREAMLINE NUMBER	SLO CL FT	INCEL S/R	CONSID LL MC CRV INFL. FTS	NC.ALC	LE RADIUS /CHCRC	MAX THICK /CHCRC	IE THICK /2*CHCRC	POINT OF START VAL MAX THICK OF S/R	X STACK CFFSET	Y STACK CFFSET
1.00	0.000	0.40	0.000	0.000	0.0151	0.6000	0.0155	-0.2000	0.01000	-0.000000
2.00	0.000	0.40	0.000	0.000	0.0149	0.5250	0.0149	-0.1500	-0.01000	-0.000000
3.00	0.000	0.40	0.000	1.000	0.0142	0.4230	0.0143	-0.3000	0.035000	-0.000000
4.00	0.000	0.40	0.000	1.000	0.0137	0.3250	0.0137	-1.3000	0.020000	-0.000000
5.00	0.000	0.40	0.000	1.000	0.0131	0.2650	0.0131	-2.0000	0.010000	-0.000000
6.00	0.000	0.40	0.000	1.000	0.0125	0.2500	0.0125	-2.3000	-0.001000	-0.000000

STREAMSURFACE 1
 ITERATION 1

INITIAL S/R = -.2000 INCREMENTAL S/R = .0400
 PASS NC. NC. OF INFLECTION PTS MIN. RADII OF CURVATURE

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

STREAMSURFACE 1
 ITERATION 2

INITIAL S/R = 0.0000 INCREMENTAL S/R = .0110
 PASS NC. NO. OF INFLECTION PTS MIN. RADIUS OF CURVATURE

1	1	.387
2	0	.350
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

OPTICAL SECTION

FINAL S/R = .3025

ITERATIONS CH SOLICITY

ITERATION 1 DEVIATION = 8.666 SOLICITY = 3.1200
ITERATION 2 DEVIATION = 8.666 SOLICITY = 3.1211

PCINT	NORMALIZED MERIDIONAL COORDINATE	TANGENTIAL COORDINATE	CAMBER LINE SLOPE	SECOND DERIVATIVE	RADIALS OF CURVATURE
1	0.0000	0.0000	-.6093	.6506	2.754
2	.0193	-.0132	-.6768	.6466	2.721
3	.0387	-.0262	-.6643	.6427	2.692
4	.0580	-.0389	-.6519	.6380	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	.6039	2.445
14	.2481	-.1515	-.5308	.7905	1.836
15	.2659	-.1608	-.5159	.8821	1.615
16	.2836	-.1698	-.4995	.9736	1.435
17	.3013	-.1765	-.4814	1.0652	1.283
18	.3191	-.1868	-.4617	1.1568	1.155
19	.3368	-.1948	-.4414	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	-.3386	1.6146	.729
24	.4253	-.2283	-.3118	1.6880	.681
25	.4428	-.2336	-.2873	1.7214	.652
26	.4604	-.2384	-.2654	1.779	.632
27	.4779	-.2429	-.2461	1.8283	1.062
28	.4954	-.2471	-.2294	.8817	1.235
29	.5130	-.2510	-.2152	.7311	1.466
30	.5305	-.2546	-.2036	.5886	1.806
31	.5481	-.2581	-.1945	.4430	2.392
32	.5656	-.2615	-.1881	.2954	3.566
33	.5832	-.2647	-.1842	.1483	7.063
34	.6007	-.2680	-.1828	.3033	459.326
35	.6183	-.2712	-.1816	.1369	7.670
36	.6358	-.2743	-.1760	.2715	3.660
37	.6534	-.2774	-.1721	.4061	2.573
38	.6710	-.2804	-.1638	.5407	1.524
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	1.0781	.943
43	.7589	-.2918	-.0857	1.2127	.833
44	.7764	-.2931	-.0642	1.3483	.746
45	.7940	-.2940	-.0393	1.4839	.676
46	.8127	-.2945	-.0107	1.5727	.626
47	.8315	-.2944	.0197	1.6644	.601
48	.8502	-.2938	.0517	1.7552	.572

49
50
51
52
53
54
55
56

• 8689
• 8876
• 9064
• 9251
• 9438
• 9625
• 9813
1.0000

--.2925
--.2906
--.2880
--.2846
--.2806
--.2757
--.2701
--.2636

• 0854
• 1208
• 1579
• 1967
• 2373
• 2795
• 3234
• 3690

1.8460
1.9368
2.0275
2.1183
2.2091
2.2998
2.3906
2.4814

• 548
• 528
• 512
• 500
• 491
• 487
• 486
• 480

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.)
 GCRC = 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 = -54.633
 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 (CNE) PRINCIPAL AXIS TO 'X' AXIS = -15.355

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

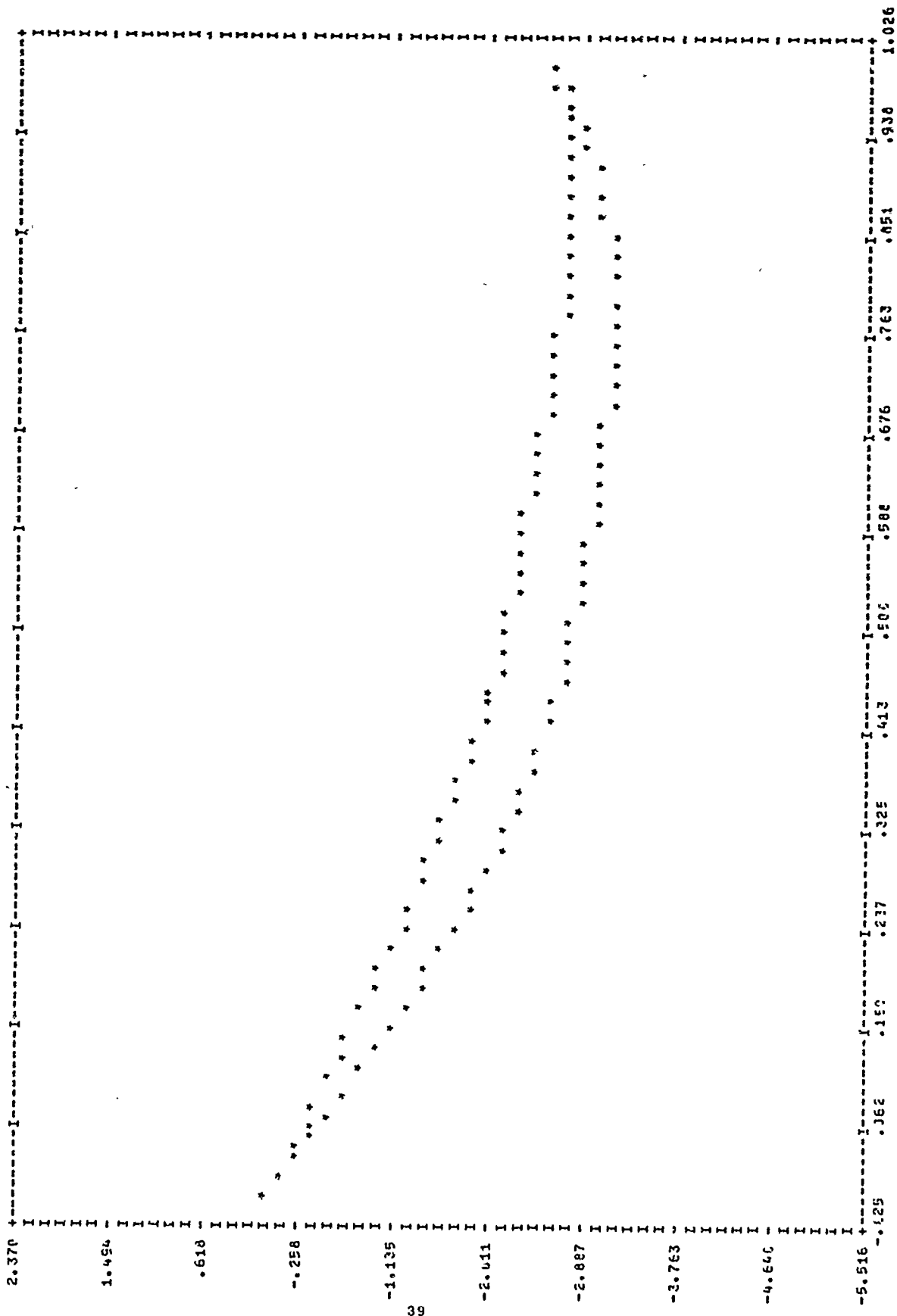
IPX = .00004 (AT -15.355 WITH 'X' AXIS)
 IPY = .00250 (AT -15.355 WITH 'Y' AXIS)

POINT NUMBER	X	Y	ANGLE	THICKNESS	XS	YS	XP	YP
1	.00160	0.00000	-34.579	.00320	.00251	.00132	.00069	-.00132
2	.02069	-.01318	-34.089	.00665	.02276	-.01042	.01903	-.01593
3	.04018	-.02611	-33.596	.01007	.04297	-.02192	.03740	-.03030
4	.05948	-.03881	-33.101	.01345	.06315	-.03310	.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	-.08527
8	.13664	-.08722	-31.095	.02637	.14345	-.07593	.12983	-.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	.22105	-.15938

POINT NUMBER	H E A N L I N E D A T A		SURFACE COORDINATE DATA		
	X	Y	XS	YS	VF
14	.24919	-.15116-27.950	.04265	.04489	.23919
15	.26689	-.16042-27.291	.04489	.04698	.25660
16	.28459	-.16941-26.541	.04698	.04895	.27409
17	.30228	-.17809-25.706	.04895	.05079	.29166
18	.31958	-.18644-24.783	.05079	.05250	.30933
19	.33767	-.19442-23.768	.05250	.05408	.32705
20	.35537	-.20201-22.657	.05408	.05553	.34495
21	.37306	-.20919-21.448	.05553	.05683	.36291
22	.39076	-.21551-20.136	.05683	.05795	.38098
23	.40845	-.22215-18.718	.05795	.05900	.39915
24	.42595	-.22784-17.317	.05900	.06058	.41718
25	.44346	-.23308-16.031	.06058	.06116	.43520
26	.46097	-.23792-14.866	.06116	.06159	.45319
27	.47847	-.24239-13.826	.06159	.06187	.47116
28	.49598	-.24655-12.918	.06187	.06200	.48909
29	.51348	-.25043-12.144	.06200	.06179	.50697
30	.53098	-.25410-11.506	.06179	.06028	.52480
31	.54849	-.25758-11.000	.06028	.05544	.54257
32	.56599	-.26092-10.651	.05544	.05729	.56028
33	.58350	-.26418-10.435	.05729	.05596	.57793
34	.60100	-.26738-10.361	.05596	.05447	.59552
35	.61854	-.27058-10.294	.05447	.05282	.61315
36	.63608	-.27374-10.094	.05282	.05100	.63087
37	.65361	-.27681-9.763	.05100	.04901	.64866
38	.67115	-.27976-9.300	.04901	.04685	.66652
39	.68869	-.28254-8.703	.04685	.04453	.68445
40	.70622	-.28512-7.970	.04453	.04167	.70245
41	.72376	-.28744-7.102	.04167	.03901	.72050
42	.74130	-.28947-6.097	.03901	.03595	.73859
43	.75884	-.29117-4.953	.03595	.03268	.75672
44	.77637	-.29250-3.671	.03268	.02920	.77487
45	.79391	-.29341-2.249	.02920	.02550	.79304
46	.81260	-.29388-1.611	.02550	.02156	.81237
47	.83128	-.29380 1.126	.02156	.01738	.83166
48	.84997	-.29313 2.958	.01738	.01294	.85069
49	.86865	-.29185 4.881	.01294	.00822	.86909
50	.88734	-.28993 6.889	.00822	.00320	.88704
51	.90602	-.28733 8.974	.00320	.00000	.90501
52	.92471	-.28402 11.130	.00000		.92279
53	.94339	-.27997 13.347			.94130
54	.96200	-.27514 15.614			.96033
55	.98076	-.26951 17.921			.97950
56	.99945	-.26305 20.254			.99889

NORMALISED PLOT OF SECTION NUMBER 1

SCALES - 'X' IS SPCNN TIMES 10 TO THE POWER OF -C 'Y' IS SPCNN TIMES 10 TO THE POWER OF 1



THE UNIVERSITY OF CHICAGO

BLACE CHCR = 3.48493E+03

L.E.RADIUS = 5.40164E-03
 CENTEREC AT X= -1.70988E+00 Y= 7.61934E-01

SECTION AREA = 4.59E38E-01

SECOND MOMENTS OF AREA ABOUT CENTROID

IX = 2.68937E-02

IIY = 3.00714E-01

IXY = -8.13213E-02

PRINCIPAL SECCNC MOMENTS CF AREA ABOUT CENTROID

IFX = 4.56332E-03 (AT-15.355 WITH 'Y' AXIS)

IFY = 5.2304E-01 (AT-15.255 WITH 'Y' AXIS)

FT NC	SUCTION-----SURFACE X Y	PRESSURE-----SURFACE X Y	SUCTION-----SURFACE X Y	PRESSURE-----SURFACE X Y
1	-1.70620E+00	7.66301E-01	-1.71293E+00	7.57485E-01
2	-1.57028E+00	6.88026E-01	-1.58916E+00	6.59750E-01
3	-1.43444E+00	6.12899E-01	-1.46491E+00	5.65255E-01
4	-1.29909E+00	5.40836E-01	-1.34012E+00	4.74080E-01
5	-1.16425E+00	4.71682E-01	-1.22412E+00	3.86308E-01
6	-1.03010E+00	4.05203E-01	-1.08669E+00	3.02003E-01
7	-9.02155E-01	3.44111E-01	-9.67211E-01	2.24516E-01
8	-7.86047E-01	2.88271E-01	-8.50093E-01	1.53749E-01
9	-6.68242E-01	2.35736E-01	-7.31814E-01	6.70755E-02
10	-5.41009E-01	1.87384E-01	-6.12360E-01	2.53600E-02
11	-4.23122E-01	1.43722E-01	-4.95181E-01	-3.05387E-02
12	-3.06045E-01	1.05542E-01	-3.69392E-01	-7.97227E-02
13	-1.92304E-01	7.30086E-02	-2.47844E-01	-1.20988E-01
14	-7.28766E-02	4.47546E-02	-1.26572E-01	-1.55496E-01
15	3.80587E-02	4.75456E-02	-5.82585E-03	-1.64474E-01
16	1.54111E-01	-4.01114E-03	1.14207E-01	-2.09142E-01
17	3.88917E-01	-2.69440E-02	7.79963E-01	-3.34400E-01
18	3.88917E-01	-5.94460E-02	3.52199E-01	-2.50415E-01
19	5.93244E-01	-7.43260E-02	4.71513E-01	-2.68558E-01
20	6.21155E-01	-5.74540E-02	5.92613E-01	-2.84025E-01
21	7.36165E-01	-1.19508E-01	7.14145E-01	-2.95635E-01
22	8.05555E-01	-1.37543E-01	7.36286E-01	-3.02173E-01
23	9.06466E-01	-1.52385E-01	8.58740E-01	-3.02414E-01
24	1.08646E+00	-1.62955E-01	1.08699E+00	-2.94457E-01
25	1.20901E+00	-1.67259E-01	1.21239E+00	-2.77057E-01
26	1.33662E+00	-1.64439E-01	1.34641E+00	-2.49360E-01
27	1.45895E+00	-1.53666E-01	1.47248E+00	-2.10580E-01
28	1.58745E+00	-1.32363E-01	1.55598E+00	-1.60000E-01
29	1.71541E-01	-4.01114E-03	1.14207E-01	-2.09142E-01
30	3.88917E-01	-2.69440E-02	7.79963E-01	-3.34400E-01
31	3.88917E-01	-5.94460E-02	3.52199E-01	-2.50415E-01
32	5.93244E-01	-7.43260E-02	4.71513E-01	-2.68558E-01
33	6.21155E-01	-5.74540E-02	5.92613E-01	-2.84025E-01
34	7.36165E-01	-1.19508E-01	7.14145E-01	-2.95635E-01
35	8.05555E-01	-1.37543E-01	7.36286E-01	-3.02173E-01
36	9.06466E-01	-1.52385E-01	8.58740E-01	-3.02414E-01
37	1.08646E+00	-1.62955E-01	1.08699E+00	-2.94457E-01
38	1.20901E+00	-1.67259E-01	1.21239E+00	-2.77057E-01
39	1.33662E+00	-1.64439E-01	1.34641E+00	-2.49360E-01
40	1.45895E+00	-1.53666E-01	1.47248E+00	-2.10580E-01
41	1.58745E+00	-1.32363E-01	1.55598E+00	-1.60000E-01
42	1.71541E-01	-4.01114E-03	1.14207E-01	-2.09142E-01
43	3.88917E-01	-2.69440E-02	7.79963E-01	-3.34400E-01
44	3.88917E-01	-5.94460E-02	3.52199E-01	-2.50415E-01
45	5.93244E-01	-7.43260E-02	4.71513E-01	-2.68558E-01
46	6.21155E-01	-5.74540E-02	5.92613E-01	-2.84025E-01
47	7.36165E-01	-1.19508E-01	7.14145E-01	-2.95635E-01
48	8.05555E-01	-1.37543E-01	7.36286E-01	-3.02173E-01
49	9.06466E-01	-1.52385E-01	8.58740E-01	-3.02414E-01
50	1.08646E+00	-1.62955E-01	1.08699E+00	-2.94457E-01
51	1.20901E+00	-1.67259E-01	1.21239E+00	-2.77057E-01
52	1.33662E+00	-1.64439E-01	1.34641E+00	-2.49360E-01
53	1.45895E+00	-1.53666E-01	1.47248E+00	-2

PCINTS DESCRIBING LEADING EGGE RADIUS

PCINT NC.	X	Y
1	-1.71293E+00	7.57486E-01
2	-1.71336E+00	7.57431E-01
3	-1.71378E+00	7.58221E-01
4	-1.71415E+00	7.58651E-01
5	-1.71447E+00	7.59118E-01
6	-1.71474E+00	7.59615E-01
7	-1.71496E+00	7.60138E-01
8	-1.71512E+00	7.60650E-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	7.66361E-01

CARTESIAN COORDINATES ON STREAMSURFACE 1

PCINT NC	ZS	XS	YS	ZP	XP	YP
1	2.57578E+00	-1.44008E+00	6.793391E-01	2.57486E+00	-1.44527E+00	6.65503E-01
2	2.62081E+00	-1.38231E+00	6.49769E-01	2.57431E+00	-1.39254E+00	6.30152E-01
3	2.66533E+00	-1.32471E+00	6.20275E-01	2.56178E+00	-1.34058E+00	5.90458E-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	5.03202E-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	3.95254E-01
9	2.92113E+00	-9.82233E-01	4.45030E-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	2.98198E+00	-9.18567E-01	2.82142E-01
12	3.04201E+00	-8.12852E-01	3.59610E-01	3.01981E+00	-8.65253E-01	2.45204E-01
13	3.07802E+00	-7.56131E-01	3.30504E-01	3.05376E+00	-8.11617E-01	2.11720E-01
14	3.11357E+00	-7.09568E-01	3.08275E-01	3.08736E+00	-7.58087E-01	1.78735E-01
15	3.14865E+00	-6.58812E-01	2.83013E-01	3.12065E+00	-7.01737E-01	1.46309E-01
16	3.18328E+00	-6.07888E-01	2.58203E-01	3.15367E+00	-6.46762E-01	1.14560E-01
17	3.21746E+00	-5.57193E-01	2.34005E-01	3.18646E+00	-5.91761E-01	8.36502E-02

PCINT	NC	ZS	XS	YS	ZP	XF	YF
12	2	2.55119E+00	-5.06751E-01	2.10564E-01	3.21908E+00	-5.67343E-01	5.37112E-02
13	3	3.28455E+00	-4.56573E-01	1.67220E-01	3.25152E+00	-5.16799E-01	2.40061E-02
14	4	3.21173E+00	-4.06673E-01	1.66147E-01	3.28350E+00	-4.65971E-01	-2.93533E-03
15	5	3.24960E+00	-3.7064E-01	1.5434E-01	3.21623E+00	-4.14051E-01	-2.53578E-02
16	6	3.28263E+00	-3.27756E-01	1.5500E-01	3.34855E+00	-3.63432E-01	-5.42682E-02
17	7	3.21381E+00	-2.56754E-01	1.7566E-01	3.38095E+00	-3.11713E-01	-7.76772E-02
18	8	3.24503E+00	-2.10435E-01	1.5595E-02	3.41303E+00	-2.60406E-01	-5.51429E-02
19	9	3.27615E+00	-1.62093E-01	7.47768E-02	3.44495E+00	-2.05131E-01	-1.18943E-01
20	10	3.25072E+00	-1.13655E-01	5.63700E-02	3.47695E+00	-1.57917E-01	-1.37233E-01
21	11	3.25392E+00	-6.95210E-02	4.56249E-02	3.50873E+00	-1.06795E-01	-1.54107E-01
22	12	3.26934E+00	-1.66155E-02	3.20536E-02	3.54045E+00	-5.57894E-02	-1.69744E-01
23	13	3.26004E+00	3.2110E-02	1.50465E-02	3.57217E+00	-4.91876E-03	-1.84259E-01
24	14	3.26315E+00	8.05855E-02	6.3123E-03	3.60377E+00	4.58055E-02	-1.5750E-01
25	15	3.26627E+00	1.30023E-01	-6.22831E-01	3.63565E-02	5.63565E-02	-2.10575E-01
26	16	3.26940E+00	1.79230E-01	-1.16887E-02	3.6666E+00	1.46741E-01	-2.22633E-01
27	17	3.27253E+00	2.28612E-01	-3.12768E-02	3.69797E+00	1.96951E-01	-2.34168E-01
28	18	3.27566E+00	2.78165E-01	-4.41188E-02	3.72951E+00	2.46987E-01	-2.45214E-01
29	19	3.27882E+00	3.27785E-01	-5.72821E-02	3.76042E+00	2.97142E-01	-2.56238E-01
30	20	3.28194E+00	3.7718E-01	-7.16083E-02	3.79182E+00	3.47540E-01	-2.66650E-01
31	21	3.28507E+00	4.26351E-01	-8.59795E-02	3.82337E+00	3.98153E-01	-2.77138E-01
32	22	3.28812E+00	4.75313E-01	-9.72590E-02	3.85508E+00	4.48979E-01	-2.86755E-01
33	23	3.29125E+00	5.24082E-01	-1.10265E-01	3.88655E+00	4.95992E-01	-2.95705E-01
34	24	3.29438E+00	5.72675E-01	-1.22881E-01	3.91908E+00	5.41183E-01	-3.03773E-01
35	25	3.29751E+00	6.21112E-01	-1.35137E-01	3.95121E+00	5.82533E-01	-3.10827E-01
36	26	3.30064E+00	6.69420E-01	-1.46546E-01	3.98366E+00	6.24011E-01	-3.16625E-01
37	27	3.30377E+00	7.17627E-01	-1.57192E-01	4.01616E+00	6.65565E-01	-3.21038E-01
38	28	3.30690E+00	7.65767E-01	-1.68334E-01	4.04898E+00	7.05233E-01	-3.23599E-01
39	29	3.31003E+00	8.13878E-01	-1.75753E-01	4.08176E+00	7.45291E-01	-3.25300E-01
40	30	3.31316E+00	8.61483E-01	-1.83771E-01	4.11522E+00	7.82914E-01	-3.24608E-01
41	31	3.31629E+00	9.0914E-01	-1.90288E-01	4.15219E+00	8.16785E-01	-3.21628E-01
42	32	3.31942E+00	9.56822E-01	-1.95189E-01	4.18750E+00	8.47350E-01	-3.16241E-01
43	33	3.32255E+00	1.02066E+00	-1.99421E-01	4.22284E+00	8.72500E-01	-3.02315E-01
44	34	3.32568E+00	1.07215E+00	-1.9973E-01	4.25815E+00	8.98291E-01	-2.87855E-01
45	35	3.32881E+00	1.12467E+00	-1.99567E-01	4.29338E+00	9.24695E-01	-2.64695E-01
46	36	3.33194E+00	1.17757E+00	-1.97642E-01	4.32844E+00	9.49417E+00	-2.36643E-01
47	37	3.33507E+00	1.23094E+00	-1.92257E-01	4.36335E+00	9.62335E+00	-2.04556E-01
48	38	3.33820E+00	1.28485E+00	-1.85063E-01	4.39795E+00	9.72500E+00	-2.27355E-01
49	39	3.34133E+00	1.33937E+00	-1.75321E-01	4.43216E+00	9.84655E+00	-2.01053E-01
50	40	3.34446E+00	1.39455E+00	-1.62632E-01	4.46555E+00	9.97771E+00	-1.72984E-01

PCINT	NC	ZSEMI	XSEMI	YSEMI
1	2	2.57488E+00	-1.44527E+00	6.69583E-01
2	3	2.57456E+00	-1.44565E+00	6.70258E-01
3	4	2.57425E+00	-1.44603E+00	6.70581E-01
4	5	2.57396E+00	-1.44631E+00	6.70945E-01
5	6	2.57368E+00	-1.44658E+00	6.71358E-01
6	7	2.57341E+00	-1.44681E+00	6.71804E-01
7	8	2.57317E+00	-1.44699E+00	6.72281E-01
8	9	2.57295E+00	-1.44712E+00	6.72784E-01
9	10	2.57276E+00	-1.44721E+00	6.73309E-01
10	11	2.57259E+00	-1.44725E+00	6.73848E-01
11	12	2.57246E+00	-1.44723E+00	6.74397E-01
12	13	2.57235E+00	-1.44717E+00	6.74945E-01
13	14	2.57228E+00	-1.44706E+00	6.75498E-01
14	15	2.57224E+00	-1.44691E+00	6.76139E-01
15	16	2.57224E+00	-1.44669E+00	6.76564E-01
16	17	2.57227E+00	-1.44644E+00	6.77069E-01

POINT NC	ZSEMI	XSEMI	YSEMI
17	2.57233E+00	-1.44615E+00	6.77548E-01
18	2.57243E+00	-1.44582E+00	6.77596E-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	-1.44275E+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	-1.44045E+00	6.79615E-01
31	2.57578E+00	-1.44008E+00	6.79391E-01

BLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS *****

RADIUS	STATION 3				NUMBER OF RACII= 6				THETA
	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE						
2.9363	-34.5568	-5.7373	.1506						.1030
4.0696	-35.5746	-2.4342	.1002						.1238
5.2456	-45.2380	-2.5753	.0763						.1326
6.4575	-51.2117	-1.0540	.0541						.1424
7.8091	-57.5491	2.4170	.0415						.1388
8.5100	-60.9548	2.7736	.0373						.1350

RADIUS	STATION 4				NUMBER OF RACII= 6				THETA
	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE						
3.3897	-25.0291	-5.4105	.1531						.0062
4.3344	-31.0055	-2.1185	.1407						.0223
5.4154	-38.8175	-3.6777	.1072						.0305
6.5824	-47.5182	-3.3044	.0795						.0462
7.8307	-55.7777	.4414	.0341						.0450
8.5000	-59.8318	.6824	.0595						.0482

RADIUS	STATION 5				NUMBER OF RACII= 6				THETA
	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE						
3.7385	-12.8574	-4.602	.1783						-.0379
4.5758	-20.6393	1.8174	.1366						.0403
5.5662	-32.2241	-.5642	.1076						-.0453
6.6591	-43.3122	-3.2075	.0847						-.0369
7.8455	-53.2632	-3.0393	.0707						-.0290
8.5000	-58.3035	-4.1035	.0674						-.0240

RADIUS	STATION 6				NUMBER OF RACII= 6				THETA
	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE						
4.0884	-.6510	3.8432	.1186						-.0610
4.8259	-8.6767	9.3017	.0958						-.0832
5.7147	-23.7341	6.1020	.0751						-.1076
6.7242	-38.5832	-1.5136	.0668						-.1115
7.8575	-50.1564	-4.9335	.0602						-.1033
8.5000	-56.4561	-7.4341	.0613						-.0948

	STATION 7	NUMBER OF RADII= 6		
RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
4.4612	38.0404	21.8205	.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 '2'

SECTION NUMBER 1 '2' = 2.5000

SECTION PROPERTIES

SECTION AREA = 4.3539E-01
 LOCATION OF CENTROID
 RELATIVE TO STACK AXIS
 XEAR = -6.1846E-02
 YEAR = 8.9764E-02
 SECOND MOMENTS OF AREA
 ABOUT CENTROID
 IXX = 1.3782E-02
 IYY = 1.5176E-01
 IXY = -6.5456E-03
 PRINCIPAL SECOND MOMENTS
 OF AREA ABOUT CENTROID
 IFX = 1.3204E-02 (AT -3.69 DEGREES TO 'X' AXIS)
 IFY = 1.5234E-01 (AT -3.69 DEGREES TO 'Y' AXIS)
 TORSIONAL CONSTANT = 5.2463E-03

SECTION COORDINATES

PCINT NO	XS	YS	XF	YP
1	-1.4401E+00	6.6206E-01	-1.4451E+00	6.5277E-01
2	-1.3622E+00	6.2333E-01	-1.3926E+00	6.0377E-01
3	-1.3249E+00	5.8562E-01	-1.3400E+00	5.5575E-01
4	-1.2670E+00	5.4904E-01	-1.2873E+00	5.0866E-01
5	-1.2396E+00	5.1347E-01	-1.2344E+00	4.6249E-01
6	-1.1523E+00	4.7881E-01	-1.1814E+00	4.1724E-01
7	-1.0551E+00	4.4507E-01	-1.1281E+00	3.7292E-01
8	-1.0380E+00	4.1220E-01	-1.0747E+00	3.2954E-01
9	-9.8097E-01	3.8015E-01	-1.0211E+00	2.8704E-01
10	-9.2400E-01	3.4885E-01	-9.6724E-01	2.4538E-01
11	-8.6712E-01	3.1824E-01	-9.1317E-01	2.0456E-01
12	-8.1030E-01	2.8925E-01	-8.5899E-01	1.6456E-01
13	-7.6113E-01	2.6314E-01	-8.1144E-01	1.3067E-01
14	-7.1253E-01	2.3881E-01	-7.6406E-01	9.7691E-02
15	-6.6452E-01	2.1535E-01	-7.1673E-01	6.5679E-02
16	-6.1715E-01	1.9287E-01	-6.6943E-01	3.4782E-02
17	-5.7047E-01	1.7162E-01	-6.2219E-01	5.2116E-03
18	-5.2450E-01	1.5185E-01	-5.7483E-01	-2.2864E-02
19	-4.7930E-01	1.3357E-01	-5.2756E-01	-4.9410E-02
20	-4.3491E-01	1.1686E-01	-4.8023E-01	-7.4121E-02
21	-3.9135E-01	1.0211E-01	-4.3287E-01	-9.6726E-02
22	-3.4870E-01	8.9602E-02	-3.8544E-01	-1.1688E-01
23	-3.0699E-01	7.9437E-02	-3.3757E-01	-1.3448E-01
24	-2.6481E-01	7.0952E-02	-2.8969E-01	-1.4995E-01
25	-2.2302E-01	6.4764E-02	-2.4183E-01	-1.6252E-01
26	-1.8138E-01	6.0442E-02	-1.9448E-01	-1.7209E-01
27	-1.3989E-01	5.7800E-02	-1.4774E-01	-1.7902E-01
28	-9.8522E-02	5.6980E-02	-1.0167E-01	-1.8363E-01
29	-5.7226E-02	5.7292E-02	-5.6368E-02	-1.8617E-01
30	-1.5591E-02	5.8573E-02	-1.1898E-02	-1.8661E-01
31	2.5215E-02	6.0622E-02	3.1669E-02	-1.8533E-01
32	6.6006E-02	6.3293E-02	7.4271E-02	-1.8272E-01
33	1.0756E-01	6.5907E-02	1.1565E-01	-1.7919E-01
34	1.4672E-01	6.8309E-02	1.5637E-01	-1.7494E-01

FCINT NO	XS	YS	XP	YP
35	1.87827E-01	7.07226E-02	1.94538E-01	-1.69955E-01
36	2.29336E-01	7.29277E-02	2.32328E-01	-1.64692E-01
37	2.62043E-01	7.50131E-02	2.69747E-01	-1.58903E-01
38	2.95151E-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	3.75642E-01	-1.35235E-01
41	4.01631E-01	8.92567E-02	4.15544E-01	-1.24240E-01
42	4.33945E-01	9.57912E-02	4.50406E-01	-1.10735E-01
43	4.65432E-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	6.45067E-01	1.98633E-01	6.85914E-01	5.62132E-02
49	6.84044E-01	2.33723E-01	7.24558E-01	1.07248E-01
50	7.22652E-01	2.75563E-01	7.70158E-01	1.66419E-01
51	7.63492E-01	3.25882E-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	9.70161E-01	7.63431E-01	9.80319E-01	7.59971E-01

FCINT 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	-1.44658E+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	6.61753E-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	-1.44001E+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,TAFES=INPUT,TAPE6=OUTPUT,
1TAPE7=PUNCH)
DIMENSION AIRANG(10,15), YPFME(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), F137E(8), F137S(5), F161C(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), SORARR(51), ROMIN(51)
COMMON EPZ(100,3), R(10,15), ZOUT(15), SS(100), X(100), YFRIME(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), CELX(15), DELY(15), XSTA(15,10), RSTA(15,10), K
5PTS(15), SIGMA(100), TANFHI(10,15), ZCAMB(15,10), YCAMB(15,10), IFANGS(
610), THETA(15,10), ALFHA(15,10)
REAL IX,IY,IXY,IPX,IPY,IXN,IYN,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/0.0,0.009,0.017,0.029,0.042,0.059,0.079,1.05,0.0,0.12,0.30,0
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/0.0,0.161,0.331,0.521,0.74,1.0,1.300/
LOG1=5
LOG2=6
LOG3=7
PI=3.1415926536
C1=180.0/PI
READ (LCG1,5) TITLE
FORMAT (7A10,A2)
WRITE (LOG2,10) TITLE
FORMAT (1H1,38X,44HUSAF - ARL(LF) ARBITRARY CAMBER LINE PROGRAM,/,
139X,44(1H*),/,10X,5HTITLE,25X,1H=,7A10,A2)
READ (LCG1,15) NLines,ASTAS,NZ,NSPEC,ISEGFT,NBLADE,ISTAK,IPUNCH,IF
1PLOT,IPRINT
FORMAT (12I3)
WRITE (LOG2,20) NLines,NSINS,NZ,NSPEC,ISEGPT,NBLADE,ISTAK,IPUNCH,I
1FFLOT,IPRINT

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20  FORMAT (10X,24HNUMBER OF STREAMSURFACES,6X,1H=,I3,/,10X,18HNUMBER
    10F STATIONS,12X,1H=,I3,/,10X,27HNUMBER OF CCNSTANT-Z PLANES,3X,1H=
    2,I3,/,10X,27HNUMBER OF BLADE DATA PCINTS,3X,1H=,I3,/,10X,31HNUMBER
    3 OF PCINTS 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,6HIPLOT,24X,1H=,I3,/,10X,6HIPRINT,24X,1H=,I3)
    READ (LCG1,25) ZINNER,ZOUTER,SCALE,STACKX,PLTSZ
    WRITE (LOG2,30) ZINNER,ZOUTER,SCALE,STACKX,PLTSZ
    FORMAT (5F12.0)
25  FORMAT (/,10X,6HZINNER,24X,1H=,F8.4,/,10X,6HZOUTER,24X,1H=,F8.4,/,
30  110X,5HSCALE,25X,1H=,F8.4,/,10X,6HSTACKX,24X,1H=,F8.4,/,10X,6HPLTSZ
    2E,24X,1H=,F8.4,/,2CX)
    READ (LCG1,15) IRLE,IRTE,NRADEV,NINC,ASIGN,IFCA,IPASS
    WRITE (LCG2,35) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
35  FORMAT (10X,27HLEADING EDGE STATION NUMBER,3X,1H=,I3,/,10X,26HRADII SPECIFYING DEVI
    1LING EDGE STATION NUMBER,2X,1H=,I3,/,10X,26HRADII SPECIFYING DEVI
    2TION,4X,1H=,I3,/,10X,26HRADII SPECIFYING INCIDENCE,4X,1H=,I3,/,10X,2
    37HSENSE OF ROTATION INCIDATOR,3X,1H=,I3,/,10X,27HDEVIATION CALCULA
    4TION INDEX,3X,1H=,I3,/,10X,28HNUMBER OF INITIAL S/R TRIALS,2X,1H=,
    5I3,/,2X)
    READ (LCG1,25) XKSHFE,SCLTOL
    WRITE (LCG2,40) XKSHFE,SCLTOL
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 (LCG2,45) K,NPTS(K),RADEV(K)
45  FORMAT (5X,16HDEVIATION CURVE ,I2,5X,18HNUMBER OF PCINTS =,I2,5X,8
    1HRADIUS =,F8.4,/,2X)
    NPT=NPTS(K)
    READ (LCG1,50) (SM(J,K),DEVCRV(J,K),J=1,NPT)
    FORMAT (2F12.0)
50  WRITE (LOG2,60) (J,SM(J,K),DEVCRV(J,K),J=1,NPT)
55  FORMAT (10X,5HPCINT,5X,22HNCORMALIZED MERIDIONAL,5X,20HNCORMALIZED
60  1DEVIATION,/,28X,5HCFORD,18X,12HDISTRIBUTION,/(11X,I2,14X,F6.4,20X
    2,F6.4)
    READ (LCG1,65) (RINC(J),XINC(J),DEDEV(J),J=1,NINC)
    FORMAT (3F12.0)
65  WRITE (LCG2,70) (RINC(J),XINC(J),DEDEV(J),J=1,NINC)

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70  FORMAT (2X,/,5X,42+INCIDENCE AND EXTRA DEVIATION DISTRIBUTION,/,
110X,12HINLET RADIUS,4X,9HINCIDENCE,4X,15HEXTRA DEVIATION,/(F19.4,
2F14.3,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,KFT)
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
LNCT=LNCT+IDUM+6
90  WRITE (LOG2,95) I,KPTS(I),I,IFANGS(I)
95  FORMAT (2X,/,10X,17+COMPUTING STATION,I3,5X,28HNUMBER OF DESCRIBIN
1G PCINTS=,I3,6X,7HIFANGS(,I2,2H)=,I3,/,6X,11HDESCRIPTION,9X,10HSTR
2EAMLINE,5X,5HRAIDII,11X,5HAIIR ANGLE,/,6X,11X,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)
CONTINUE
100
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,F8.4,5X,F8.4)
120  CONTINUE

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125 IF (LNCT.LE.54-NSPEC) GC TO 125
    WRITE (LOG2,85)
    LNCT=1
    LNCT=LNCT+NSPEC+6
    READ (LCG1,130) (ZR(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J),
130 1ZZ(J),SDIVR(J),DELY(J),DELY(J),J=1,NSPEC)
    FORMAT (6F12.0)
    WRITE (LCG2,135) (ZF(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J),
135 1ZZ(J),SDIVR(J),DELY(J),DELY(J),J=1,NSPEC)
    FORMAT (2X,/,20X,30+SECTION GEOMETRY SPECIFICATION,/,10X,10+STREA
1MLINE,2X,5HSLD,5X,6HIN.CEL,4X,6HCONSIG,4X,6+NO.ALD,3X,48HLE RADI
2US MAX THICK TE THICK FOINT OF START VAL,3X,7HX STACK,3X,7HY STAC
3K,/,11X,6HNUMBER,5X,5HCL FT,5X,5H S/R,3X,15HLE 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,6HCOFFSET,/,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,-PLTSE,-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,PLTSE,1,TITLE,IKDU
1M,IFPLOT)
140 DO 465 J=1,NLINES
    DO 145 I=IRLE,IRTE
    KPT=KPTS(I)
    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
    X(I)=X(I-1)+AX
150 ICORIT=IRTE-IRLE+1
    CALL CQ (XHERE(IRLE),R(IRLE,J),ICORIT,X,XGUM,YPRIME,100,1)
    SS(1)=0.0
    DO 155 I=2,100
    SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)-YPRIME(I-1))/2.0)**2)
    XJ=J
155 CALL D1 (ZR,RLE,NSPEC,XJ,YZERO,1,0)
    CALL D1 (ZR,TC,NSPEC,XJ,T,1,0)
    CALL D1 (ZR,TE,NSPEC,XJ,YCNE,1,0)

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A 805
A 810
A 815
A 820
A 825
A 830
A 835
A 840
A 845
A 850
A 855
A 860
A 865
A 870
A 875
A 880
A 885
A 890
A 895
A 900
A 905
A 910
A 915
A 920
A 925
A 930
A 935
A 940
A 945
A 950
A 955
A 960
A 965
A 970
A 975
A 980
A 985
A 990
A 995
A1000

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CALL D1 (ZR,DELX,NSPEC,XJ,XDEL,1,0)
CALL D1 (ZR,DELY,NSPEC,XJ,YDEL,1,0)
CALL D1 (ZR,ZZ,NSPEC,XJ,Z,1,0)
CALL D1 (ZR,YA,NSPEC,XJ,SSOLID,1,0)
CALL D1 (ZR,SDIVR,NSPEC,XJ,SDR,1,0)
CALL D1 (ZR,YE,NSPEC,XJ,DELSDR,1,0)
CALL D1 (ZR,YC,NSPEC,XJ,RELEMN,1,0)
CALL D1 (ZR,YE,NSPEC,XJ,ACCIFF,1,0)
IJ=IPASS-1
LMN=0
IJK=-1
PRNT=0.
XSIGN=NSIGN
STAGER=(AIRANG(IRLE,J)+AIRANG(IRTE,J))/2.
RINSCL=(R(IRLE,J)+R(IRTE,J))/2.
SOR1=SOR
CHORC=SS(100)/COS(STAGER/C1)
IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TC 170
IF (IJK.EQ.3) WRITE (LOG2,165) SDR
160 165 170 175 180
FORMAT (1H1,9X,15HOFTIMAL SECTION,/,1CX,15(1H*),/,10X,11HFINAL S/
1R =,F8.4,/,10X,23HITERATIONS ON SOLICITY )
SOLID=CHORC/RINSOL/2./PI*FLAG(NBLADE)
CALL D1 (RING,XINC,AINC,R(IRLE,J),TEMP2,1,0)
CALL D1 (RING,DELDEV,NINC,R(IRLE,J),TEMP3,1,0)
BETHET(1)=AIRANG(IRLE,J)-XSIGN*TEMP2(1)
BETS=AIRANG(IRLE,J)*XSIGN
DO 175 K=1,5
CALL D1 (F137B,F161C(1,K),8,BETS,EXB(K),1,0)
CALL D1 (F137E,F195P(1,IFCA),8,BETS,XPS,1,0)
CALL D1 (F137B,F161C(1,K),8,BETS,XTEMP,1,0)
CALL D1 (ZR,TC,NSPEC,XJ,X1,1,0)
CALL D1 (F142TC,F172K,7,X1,XKOT,1,0)
BETS=BETHET(1)*XSIGN
NN=0
NN=NN+1
IF (NN.GT.20) GO TO 700
CALL C1 (F137S,EXB,5,SCLIC,CO,1,1)
XMM=XMS/SOLID+XTEMP(1)
DEV={CO*XKOT*XKSHPE+XMM*(BETS-XSIGN*AIRANG(IRTE,J))+TEMP3(1))*1.0/
1(1.-XMM)

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185 IF (IJK.EQ.3.AND.IPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SCLIC
    FORMAT (33X,10HITERATION ,I2,3X,11HDEVIATION =,F7.3,3X,10HSOLIDITY
1    =,F7.4)
    HN=IRTE-IRLE+1
    BETMET(MN)=AIRANG(IRTE,J)-DEV*XSIGN
    S1(1)=0.
    DO 205 I=1,NSTNS
190 IF (I-IRLE) 205,205,190
195 IF (IRTE-I) 205,205,195
    L=I-IRLE+1
    CALL C1 (X,SS,100,XPERE(I),S1(L),1,1)
    S1(L)=S1(L)/SS(100)
    DO 200 K=1,NRADEV
200 CALL C1 (SH(1,K),DEVCRV(1,K),NPTS(K),S1(L),DEVVRAD(K),1,0)
    CALL C1 (RADEV,DEVVRAD,NRADEV,R(IRTE,J),DEVVPT,1,0)
    BETMET(L)=AIRANG(I,J)-DEV*DEVVPT*XSIGN
205 CONTINUE
    S1(MN)=1.
    YP1=TAN(BETMET(1)/C1)
    YMPRME(1)=YP1
    YU(1)=0.
    IPOINT=1
    SU(1)=0.
    Y1=0.
    YPP1=SDR/2./PI/R(IRLE,J)*FLOAT(NBLADE)*(1.+YP1*YP1)**(1.5)
    YPPME(1)=YPP1
    IF (YPP1.NE.0.) GO TO 210
    YPRIME(1)=1000.
    GC TC 215
210 CONTINUE
    YPRIME(1)=(1.+YMPRME(1)*YMPRME(1))**(1.5)/YPPME(1)
215 CONTINUE
    S11=0.
    S12=0.
    LL(1)=0
    DO 230 K=2,MN
    YP2=TAN(BETMET(K)/C1)
    LL(K)=0
    S2=S1(K)
    S22=S2*S2

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A1205 A=(YF2-YF1-YPP1*(S2-S11))/3./(S22-S12-2.*S11*(S2-S11))
A1210 B=(YPP1-6.*A*S11)/2.
A1215 C=YF1-3.*A*S12-2.*B*S11
A1220 D=Y1-A*S12*S11-B*S12-C*S11
A1225 SDIFF=(S2-S11)/FLOAT(ISEGFT-1)
A1230 KL=IFPOINT+1
A1235 KJ=IFPOINT+ISEGFT-1
A1240 DO 225 L=KL,KJ
A1245 SU(L)=SU(L-1)+SDIFF
A1250 YU(L)=D+SU(L)*(C+SU(L)*(B+A*SU(L)))
A1255 YMPRME(L)=C+SU(L)*(E*2.+A*3.*SU(L))
A1260 YPPME(L)=6.*A*SU(L)+2.*E
A1265 IF (YPPME(L).EQ.0.) YPRIME(L)=1000.
A1270 IF (YFPME(L).EQ.0.) GO TO 225
A1275 YPRIME(L)=(1.+YMPRME(L)*YMPRME(L))*((1.5)/YFPME(L))
A1280 SLPE=ABS(YPPME(L)-YFPME(L-1))
A1285 IF (SLPE.GE.ABS(YPPME(L)).AND.SLPE.GE.ABS(YFPME(L-1))) GO TO 220
A1290 GO TO 225
A1295 LL(K)=L
A1300 CONTINUE
A1305 IPOINT=KJ
A1310 Y1=YU(IPOINT)
A1315 YPP1=YPPME(KJ)
A1320 S11=S2
A1325 S12=S22
A1330 YF1=YF2
A1335 IS=0
A1340 DO 235 K=1,MN
A1345 IF (LL(K).NE.0) IS=IS+1
A1350 CONTINUE
A1355 CHORD1=SQRT(YU(IPOINT)**2+1.)*SS(100)
A1360 CALL D1 (SU,YU,IPOINT,SSOLID,YSSOLID,1,1)
A1365 CHORDC=SQRT((SU(IPOINT)-SSCLID)**2+(YU(IPOINT)-YSOLID)**2)*SS(100)
A1370 SOLIC1=CHORD/RINSOL/2./PI*FLOAT(NBLADE)
A1375 C1FF=SCOLID-SOLIE1
A1380 IF (ABS(DIFF).LT.SOLTOL*SCOLID) GO TO 240
A1385 SOLIC=SOLID1
A1390 GO TO 180
A1395 IF (IJK.EQ.3.AND.IPPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SOLID1
A1400 IF (IJK.EQ.3) GC TO 305

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A1405 LMN=LMN+1
A1410 NOINF(LMN)=IS
A1415 SDRARR(LMN)=SDR
A1420 SDR=SDR+DELSDR
A1425 RDMIN(LMN)=1000.
A1430 DO 245 L=1,IPCINT
A1435 IF (L.EQ.1.ANG.ROLE+N.EQ.1.0) GO TO 245
A1440 IF (ABS(YPRIME(L)).LT.RCHIN(LMN)) RDMIN(LMN)=ABS(YPRIME(L))
A1445 CONTINUE
A1450 IF (LMN.LE.IJ.AND.IJK.LE.0) GO TO 160
A1455 IF (LMN.GT.IJ.AND.IJK.LE.0) GO TO 250
A1460 IF (LMN.GT.19) GO TC 250
A1465 GO TO 160
A1470 IF (LMN.EQ.20.OR.LMN.EQ.IPASS) IJK=IJK+1
A1475 IF (IJK.EQ.20.OR.IJK.EQ.3) GC TO 290
A1480 NMNINF=20
A1485 DO 255 LMN=1,IPASS
A1490 IF (NOINF(LMN).LT.NMNINF) IFIRST=LMN
A1495 IF (NCINF(LMN).LT.NMNINF) NMNINF=NOINF(LMN)
A1500 CONTINUE
A1505 IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TC 275
A1510 WRITE (LOG2,85)
A1515 IF (FLOAT(NMNINF).GE.(ACG2+1.)).AND.IPRINT.NE.2) WRITE (LOG2,260)
A1520
A1525
A1530
A1535
A1540
A1545
A1550
A1555
A1560
A1565
A1570
A1575
A1580
A1585
A1590
A1595
A1600

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245

250

255

260

265

270

275

280

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285 IF (IJK.EQ.0) IFIRST=IFIRST-1
    IF (IFIRST.EQ.0) IFIRST=1
    IF (IFIRST.EQ.IPASS) IFIRST=IJ
    IF (IJK.EQ.1.ANC.NCINF(IPASS).GT.NMNINF) ILAST=ILAST-1
    IF (ILAST.EQ.0) IFIRST=ILAST+1
    IF (ILAST.EQ.(IPASS+1).CR.ILAST.EQ.0) ILAST=IPASS
    IF (IJK.EQ.0) LJ=IPASS-1
    IF (IJK.EQ.1) LJ=19
    DELSCR=(SDRARR(ILAST)-SCRARR(IFIRST))/FLOAT(LJ)
    SDR=SDRARR(IFIRST)
    SDR1=SDR
    LMN=0
    GO TC 160
    RADMX=0.
    DO 295 L=1,20
    IF (RDMIN(L).GT.RADMX.AND.NCINF(L).EQ.NMNINF) LMN=L
    IF (RDMIN(L).GT.RADMX.AND.NCINF(L).EQ.NMNINF) RADMX=RDMIN(L)
    CONTINUE
295 IF (LMN.EQ.1.ANC.IPRINT.NE.2) WRITE (LOG2,300)
    IF (LMN.EQ.20.AND.IPRINT.NE.2) WRITE (LOG2,300)
    FORMAT (//101H THE MAXIMUM VALUE OF THE MINIMUM RADIUS CF CURVATUR
300 1E OCCURS AT AN END POINT CF THE PRESENT S/R RANGE)
    IF (IJK.EQ.3) SDR=SCRARR(LMN)
    IF (IJK.EQ.3) PRNT=1.
    IF (IJK.EQ.3) GC TO 160
    SDR=SDRARR(LMN)-3.0*DELSDR
    DELSCR=6.*DELSDR/20.
    LMN=0
    GO TC 160
305 IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TC 320
    WRITE (LOG2,310)
310 FORMAT (/10X,5HPOINT,5X,22HNORMALIZED MERIDIONAL,5X,10HTANGENTIAL
1,5X,11HCHAMBER LINE,7X,6HSECND,7X,9HRADIUS CF,/,26X,10HCOORDINATE,
211X,10HCOORDINATE,8X,5HSLCPE,8X,10HDERIVATIVE,5X,9HCURVATURE,/2X)
    IP=IPOINT
    IF (IPOINT.GE.49) IF=48
    WRITE (LOG2,315) (L,SU(L),YU(L),YMPRME(L),YFFME(L),YFRIME(L),L=1,I
1P)
    IF (IPOINT.GE.49) WRITE (LOG2,85)
    IF (IPCINT.GE.49) WRITE (LOG2,315) (L,SU(L),YU(L),YMPRME(L),YPPME(

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A1605
A1610
A1615
A1620
A1625
A1630
A1635
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A1800

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1L),YPRIME(L),L=49,IFPOINT)
315  FORMAT (12X,I2,14X,F6.4,14X,F7.4,6X,F8.4,5X,F8.4,7X,F8.3)
320  NPOINT=IPGINT
      XNORMC=CHORE1/SS(10C)
      AXIALC=SS(100)
      DO 325 I=1,NSTNS
      KPT=KPTS(I)
325  CALL D1 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
      X(1)=XHERE(1)
      X(10C)=XHERE(NSTNS)
      AX=(X(100)-X(1))/99.0
      DO 330 I=2,99
330  X(I)=X(I-1)+AX
      CALL CQ (XHERE,R(1,J),NSTNS,X,XDUM,YPRIME,100,1)
      CALL CQ (XHERE,R(1,J),NSTNS,XHERE,XDUM,TANPI(1,J),NSTNS,1)
      C(1)=0.0
      DO 335 I=2,100
335  SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)+YPRIME(I-1))/2.0)**2)
      CALL D1 (X,SS,100,STACKX,EX,1,1)
      CALL BQ (J,YS,YP,XS,XP,YSEMI,XSEMI,LOG2,IFPOINT,IPRINT,BETMET(1),BE
1THET(MN),YZERC,I,YCNE,XCEL,YDEL,Z,XNORMC,LNCT,XTEMP,YPRIME,RAD,SIG
2HA,EPZ,XHERE,X,SS,NSTNS,R,BX,SU,YU,YMFRME,AXIALC,ISTAK)
      CALL D1 (X,SS,100,STACKX,EX,1,1)
      DO 340 I=1,100
340  X(I)=X(I)-STACKX
      SS(I)=SS(I)-BX
      DO 345 I=1,NSTNS
345  XHERE(I)=XHERE(I)-STACKX
      IF (IFPLCT.EQ.0.OR.IFPLCT.EQ.2.OR.IFPLCT.EQ.4) GO TO 365
      XPLCT=XS(J,1)*SCALE
      YPLCT=YS(J,1)*SCALE
      CALL PLCT (XPLCT,YPLCT,3)
      DO 350 I=2,NPOINT
350  XPLCT=XS(J,I)*SCALE
      YPLCT=YS(J,I)*SCALE
      CALL PLCT (XPLCT,YPLCT,2)
      DO 355 II=1,NPOINT
      I=NPICINT-II+1
      XPLCT=XP(J,I)*SCALE
      YPLCT=YP(J,I)*SCALE

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355	CALL FLCT (XPLOT,YPLOT,2)	A2005
	DO 360 I=2,30	A2010
	XPLOT=XSEMI(J,I)*SCALE	A2015
	YPLOT=YSEMI(J,I)*SCALE	A2020
360	CALL FLCT (XPLOT,YPLOT,2)	A2025
	XPLOT=XS(J,1)*SCALE	A2030
	YPLOT=YS(J,1)*SCALE	A2035
365	CALL FLCT (XPLOT,YPLOT,2)	A2040
	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
375	ZCAME(J,I)=R(I,J)*CCS(THETA(J,I))	A2090
	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,NPCINT	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,NPCINT	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,NPCINT	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

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)*CCS(EFS)	A2235
	YSEMI(J,I)=RAD(I)*SIN(EFS)	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,38+CARTESIAN COORDINATES ON STREAMSURFACE,I3,/,1	A2280
	10X,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),XF(J,I)	A2300
430	FORMAT (10X,I5,3X,1F3E14.5,4X,1P3E14.5)	A2305
	I=I+1	A2310
	LNCT=LNCT+1	A2315
	IF (I.GT.NFCINT) 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,5IYSEMI,/,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,1F3E14.5)	A2395
	I=I+1	A2400

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A2405 LNCT=LNCT+1
A2410 IF (I.GT.31) GO TO 465
A2415 IF (LNCT.LE.59) GO TO 455
A2420 WRITE (LOG2,85)
A2425 WRITE (LOG2,450)
A2430 LNCT=4
A2435 GO TO 455
A2440 CONTINUE
A2445 IF (IPRINT.EQ.1) GO TO 530
A2450 VOL=0.0
A2455 DO 470 J=2,NLINES
A2460 VOL=VOL+((XS(J,1)-XP(J,1))*2+(YS(J,1)-YF(J,1))*2)+(XS(J-1,1)-X
A2465 1P(J-1,1))*2+(YS(J-1,1)-YF(J-1,1))*2)*(ZS(J,1)+ZP(J,1)-ZS(J-1,1)
A2470 2-ZP(J-1,1))*PI/32.0
A2475 DO 470 I=2,NPCINT
A2480 VOL=VOL+((SQRT((XS(J,I)-XF(J,I))*2+(YS(J,I)-YF(J,I))*2)+SQRT((XS
A2485 1(J,I-1)-XP(J,I-1))*2+(YS(J,I-1)-YP(J,I-1))*2)*(SQRT((XS(J,I-1)-
A2490 2XS(J,I))*2+(YS(J,I-1)-YP(J,I-1))*2)+SQRT((XP(J,I-1)-XP(J,I))*2+(Y
A2495 3P(J,I-1)-YF(J,I))*2)+(SQRT((XS(J-1,I)-XF(J-1,I))*2+(YS(J-1,I)-Y
A2500 4P(J-1,I))*2)+SQRT((XS(J-1,I-1)-XF(J-1,I-1))*2+(YS(J-1,I-1)-YP(J-
A2505 5I,I-1))*2)*(SQRT((XS(J-1,I-1)-XS(J-1,I))*2+(YS(J-1,I-1)-YS(J-1,
A2510 6I))*2)+SQRT((XP(J-1,I-1)-XF(J-1,I))*2+(YP(J-1,I-1)-YP(J-1,I))*2
A2515 7))*2*(ZS(J,I)+ZS(J,I-1)+ZP(J,I)+ZP(J,I-1)-ZS(J-1,I)-ZS(J-1,I-1)-ZP(
A2520 8J-1,I)-ZP(J-1,I-1))/32.0
A2525 IF (LNCT.LE.56) GO TO 475
A2530 LNCT=1
A2535 WRITE (LOG2,85)
A2540 LNCT=LNCT+4
A2545 WRITE (LOG2,480) VOL
A2550 FORMAT (2X,/,2X,/,4CX,25HVOLUME OF BLADE SECTION =,1FE11.4,/,40X,3
A2555 15(1H*))
A2560 IF (IJDUM.EQ.0) GO TO 530
A2565 WRITE (LOG2,85)
A2570 WRITE (LOG2,485)
A2575 FORMAT (43X,43HBLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS,/,43X,4
A2580 13(1H*))
A2585 IDUM=7
A2590 LNCT=3
A2595 DO 525 I=1,NSINS
A2600 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)
XTMF(K)=XP(J,K)
X(K)=YP(J,K)
XDUM=XDUM-STACKX
CALL D1 (SS,RAD,NPOINT,XDUM,YY1,1,1)
CALL D1 (XTMF,X,NPCINT,XCUM,YY2,1,1)
W1=YY1/R(I,J)
W2=YY2/R(I,J)
TC(J)=ABS(ATAN(W1/SCRT(1.-W1**2))-ATAN(W2/SCRT(1.-W2**2)))/(2.*PI)
1*FLOAT(NBLADE)
CONTINUE
CALL CQ (ZCAME(1,I),YCAMP(1,I),NLINES,ZCAME(1,I),XDUM,RLE,NLINES,1)
1)
IF (LNCT+IDUM+NLINES.LE.59) GO TO 500
WRITE (LOG2,85)
LCT=2
LNCT=LNCT+IDUM+NLINES
WRITE (LOG2,505) I,NLINES
FORMAT (//,48X,8HSTATION ,I2,5X,17HNUMBER OF RADII= ,I2,/,36X,6H
1RADIUS,5X,7HSECTION,6X,4HLEAN,9X,5HBLADE,7X,5H-THETA,/,48X,5HANGLE,
26X,5HANGLE,7X,8HBLOCKAGE,/,2X)
DO 510 J=1,NLINES
EPS=(THETA(J,I)-ATAN(RLE(J)))*C1
ALPH5=ALPHA(J,I)
ALP=(ATAN((TANPHI(I,J)*TAN(EPS/C1)+ALPH5*SCRT(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 (IFUNCH.EQ.0) GO TO 510
WRITE (LOG3,520) R(I,J),ALP,EPS,TC(J),THETA(J,I),I,J
CONTINUE
FORMAT (30X,5F12.4)
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525
530
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530
IF (IFPLCT.LT.2.OR.IFPLCT.EG.4) GC TO 535
CALL FQ (ISTAK,PLTSE,2,TITLE,IKDUM,IFPLOT)

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535 IF (IPRINT.EQ.1) GO TO 545
    LNCT=2
    WRITE (LOG2,540)
540 FORMAT (1H1,27X,74HBLADE SURFACE GEOMETRY IN CARTESIAN COORDINATES
1 AT SPECIFIED VALUES OF '2',/28X,74H*****
2 *****
545 IF (IPRINT.EQ.1.AND.IFPL01.LE.1) GO TC 695
    XZ=NZ-1
    OZ=(ZOUTER-ZINNER)/XZ
    ZOUT(1)=ZINNER
    DO 550 J=3,NZ
550 ZOUT(J-1)=ZOUT(J-2)+OZ
    ZOUT(NZ)=ZCUTER
    DO 555 I=1,NPCINT
    CALL O1 (ZS(1,I),XS(1,I),NLINES,ZOUT,TEMP1,NZ,0)
    CALL C1 (ZS(1,I),YS(1,I),NLINES,ZCUT,TEMP2,NZ,0)
    CALL D1 (ZP(1,I),XP(1,I),NLINES,ZCUT,TEMP3,NZ,0)
    CALL O1 (ZP(1,I),YP(1,I),NLINES,ZOUT,TEMP4,NZ,0)
    DO 555 J=1,NZ
    XS(J,I)=TEMP1(J)
    YS(J,I)=TEMP2(J)
    XP(J,I)=TEMP3(J)
    YP(J,I)=TEMP4(J)
555 DO 560 I=1,31
    CALL C1 (ZSEMI(1,I),XSEMI(1,I),NLINES,ZCUT,TEMP1,NZ,0)
    CALL O1 (ZSEMI(1,I),YSEMI(1,I),NLINES,ZCUT,TEMP2,NZ,0)
    DO 560 J=1,NZ
    XSEMI(J,I)=TEMP1(J)
    YSEMI(J,I)=TEMP2(J)
560 DO 650 J=1,NZ
    RD=SGRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)/2.0
    AREA=PI*RD**2/2.0
    BETA1=ATAN((YS(J,2)+YP(J,2)-YS(J,1)-YP(J,1))/(XS(J,2)+XF(J,2)-XS(J,1)-XP(J,1)))
    XINT=AREA*((XP(J,1)+XS(J,1))/2.0-COS(BETA1))*4.0/(3.0*PI)*RD)
    YINT=AREA*((YP(J,1)+YS(J,1))/2.0-SIN(BETA1))*4.0/(3.0*PI)*RC)
    DO 565 I=2,NPCINT
    DELA=(SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)+SQRT((XS(J,I)-XP(J,I)-1)-XF(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2)*SQRT((XS(J,I)-XP(J,I)-1)-XF(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2)+SQRT((XF(J,I)-XP(J,I))**2+(YP(J,I)-

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3 I-1) -YP(J,I))**2))/4.0
AREA=AREA+DELA
XINT=XINT+DELA*(XS(J,I)+XS(J,I-1)+XP(J,I)+YP(J,I-1))/4.0
YINT=YINT+DELA*(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0
YINT=YINT/AREA
XINT=XINT/AREA
X1=(XS(J,1)+XP(J,1))/2.
Y1=(YS(J,1)+YP(J,1))/2.
T1=SGRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)
F=0.
U=0.
DO 570 I=2,NPCINT
T2=SGRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)
X2=(XS(J,I)+XP(J,I))/2.
Y2=(YS(J,I)+YP(J,I))/2.
DELU=SGRT((X2-X1)**2+(Y2-Y1)**2)
U=U+DELU
TAV3=(T1**3+T2**3)/2.
F=F+TAV3*DELU
X1=X2
Y1=Y2
T1=T2
570 TORCCN=((1./3.)*F)/(1.+(4./3.)*F,AREA/U**2)
IX=0.0
IY=0.0
IXY=0.0
DO 575 I=2,NPCINT
XD=(SGRT((XS(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2)+SGRT((
1 XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2))/2.0
YD=(SGRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)+SGRT((XP(J
1,I)-XP(J,I-1))**2+(YP(J,I)-YP(J,I-1))**2))/2.0
IXD=YD*YD*YC*XD/12.0
IYD=XD*XD*XC*YD/12.0
ANG=ATAN((YS(J,I)+YP(J,I)-YS(J,I-1)-YP(J,I-1))/(XP(J,I)+XS(J,I)-XP
1 (J,I-1)-XS(J,I-1))
COSANG=COS(2.0*ANG)
IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
IXYN=0.0
IF (ANG.NE.0.0) IXYN=((IXN-IYN)*COSANG-IXC+IYD)/(2.0*SIN(2.0*ANG))
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610      LNCT=4
        WRITE (LOG2,85)
        WRITE (LOG2,605)
        WRITE (LOG2,615) I,XS(J,I),YS(J,I),XP(J,I),YP(J,I)
615      FORMAT (31X,I5,3X,1F2E14.5,4X,2E14.5)
        IF (LNCT.LE.55) GO TO 620
        LNCT=1
        WRITE (LOG2,85)
        LNCT=LNCT+3
        WRITE (LOG2,625)
625      FORMAT (2X,/,31X,8HPOINT NO,5X,5HXSEMI,9X,5+YSEMI,/,2X)
        CO 630 I=1,31
        LNCT=LNCT+1
        IF (LNCT.LE.60) GO TO 630
        WRITE (LOG2,85)
        WRITE (LOG2,625)
        LNCT=4
630      WRITE (LOG2,635) I,XSEMI(J,I),YSEMI(J,I)
635      FORMAT (31X,I5,3X,1F2E14.5)
640      IF (IFPLCT.LT.2) GO TO 690
        IF (IFPLCT.EQ.4) GO TO 660
        XPLCT=XS(J,1)*SCALE
        YPLCT=YS(J,1)*SCALE
        CALL PLCT (XPLCT,YPLCT,3)
        DO 645 I=2,NPCINT
        XPLCT=XS(J,I)*SCALE
        YPLCT=YS(J,I)*SCALE
        CALL PLCT (XPLCT,YPLCT,2)
645      DO 650 II=1,NPOINT
        I=NPICINT+1-II
        XPLCT=XP(J,I)*SCALE
        YPLCT=YF(J,I)*SCALE
        CALL PLCT (XPLCT,YPLCT,2)
650      DO 655 I=2,30
        XPLCT=XSEMI(J,I)*SCALE
        YPLCT=YSEMI(J,I)*SCALE
        CALL PLCT (XPLCT,YPLCT,2)
655      XPLCT=XS(J,1)*SCALE
        YPLCT=YS(J,1)*SCALE
        CALL PLCT (XPLCT,YPLCT,2)

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660 GO TC 690
CALL SYMBOL (19.9,2.0,.175,22HCARTESIAN SECTION NO. ,0.0,22)
XJ=J
CALL NUMBER (23.75,2.,.175,XJ,0.0,-1)
CALL SYMBOL (20.6,1.0,.175,10HSTAGGER = ,0.0,10)
STAGER=ATAN((YS(J,NPOINT)+YF(J,NPOINT)-YS(J,1))-YP(J,1))/(XS(J,NPOI
1NT)+XP(J,NPCINT))-XS(J,1)-XP(J,1))*C1
CALL NUMBER (22.35,1.,.175,STAGER,0.0,3)
CALL FLCT (22.0,5.25,-3)
SINSTG=SIN(STAGER/C1)
COSSTG=COS(STAGER/C1)
YPL0T=4.75
XPL0T=4.75*SINSTG/COSSTG
IF (ABS(XPL0T).LE.22.0) GO TO 665
XPL0T=22.0
YPL0T=-22.0/SINSTG*COSSTG
CALL FLCT (XPL0T,YPL0T,3)
XPL0T=-XPLCT
YPL0T=-YPLCT
CALL FLCT (XPL0T,YPL0T,2)
XPL0T=22.0
YPL0T=-22.0*SINSTG/COSSTG
IF (ABS(YPL0T).LE.4.75) GC TO 670
YPL0T=-4.75
XPL0T=4.75/SINSTG*COSSTG
CALL FLCT (XPL0T,YPL0T,3)
XPL0T=-XPLCT
YPL0T=-YPLCT
CALL FLCT (XPL0T,YPL0T,2)
XPL0T=SCALE*(XS(J,1)*COSSTG+YS(J,1)*SINSTG)
YPL0T=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)
CALL FLCT (XPL0T,YPL0T,3)
DO 675 I=2,NPCINT
XPL0T=SCALE*(XS(J,I)*COSSTG+YS(J,I)*SINSTG)
YPL0T=SCALE*(YS(J,I)*COSSTG-XS(J,I)*SINSTG)
CALL FLCT (XPL0T,YPL0T,2)
DO 680 II=1,NPOINT
I=NPCINT+1-II
XPL0T=SCALE*(XP(J,I)*COSSTG+YP(J,I)*SINSTG)
YPL0T=SCALE*(YP(J,I)*COSSTG-XP(J,I)*SINSTG)

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```

680 CALL PLCT (XPLOT,YPLOT,2)
DO 685 I=2,30
  XPLOT=SCALE*(XSEMI(J,I)*CCSSTG+YSEMI(J,I)*SINSTG)
  YPLOT=SCALE*(YSEMI(J,I)*CCSSTG-XSEMI(J,I)*SINSTG)
685 CALL PLOT (XPLOT,YPLOT,2)
  XPLOT=SCALE*(XS(J,1)*CCSSTG+YS(J,1)*SINSTG)
  YPLOT=SCALE*(YS(J,1)*CCSSTG-XS(J,1)*SINSTG)
  CALL PLCT (XPLOT,YPLOT,2)
  CALL PLOT (23.0,-5.25,-3)
690 CCNTINUE
695 IF (IFPLOT.NE.0) CALL PLOTE
  GO TO 710
700 WRITE (L062,705) J
705 FORMAT (10X,8HFAILEC ,I2)
710 CCNTINUE
  STOP
  END

```

A3805
 A3810
 A3815
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 A3825
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 A3845
 A3850
 A3855
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 A3875
 A3880
 A3885-

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SUBROUTINE BQ (IBL,YS,YF,XS,XP,YSEMI,XSEMI,LOG2,N,IFPRINT,BETA1,BET
1A2,YZERO,T,YONE,XDEL,YDEL,Z,XNORMC,LNCT,DX,Y,CY,SIGMA,SS1,XHERE,X,
2SS,NSINS,R,BX,XM,YM,AM,AXIALC,ISTAK)
REAL IX,IY,IXY,IPX,IPY,IXC,IYD,IXN,IYA,IXYN
DIMENSION YS(15,81), YF(15,81), XS(15,81), XP(15,61), 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,
33), SIGMA(100)
5 FORMAT (1H1)
PI=3.1415926535
C1=180.0/PI
IF (IFPRINT.EQ.2) GO TO 15
WRITE (LCG2,10) IBL,BETA1,BETA2,YZERO,T,YCNE,Z,AXIALC
10 FORMAT (1H1,44X,43HSTREAMSURFACE GEOMETRY ON STREAMLINE NUMBER,13,
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 FRACTION CF MEAN
8LINE.),//,20X,4HCORD,12X,1H=,F7.4,6X,36H(MERIDIONAL 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=1.0/99.
DX(1)=0.
DO 20 IK=2,100
OX(1K)=OX(1K-1)+AX
CALL D1 (XM,YM,N,DX,DY,100,1)
SIGMA(1)=0.
DO 25 K=2,100
SIGMA(K)=SIGMA(K-1)+SQRT((DX(K)-OX(K-1))**2+(DY(K)-OY(K-1))**2)
CALL D1 (OX,SIGNA,100,XP,S,N,1)
YZERO=YZERC*CHORD/FCSLMN
YONE=YONE*CHORD/FCSLMN
T=T*CHORD/FCSLMN
S(1)=0.0
AT=(YZERO-T/2.0)/(2.0+Z**2)
CT=((1/2.0-YZERO)*3.0/(2.0+Z)

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30 OT=YZERO
   ET=(YGNE-T/2.0)/(1.0-Z)**3-1.5*(YZERO-T/2.0)/(Z**2*(1.0-Z))
   FT=1.5*(YZERO-T/2.0)/Z**2
   HT=T/2.0
   DO 40 J=1,N
   SN=S(J)/S(N)
   IF (SN.GT.Z) GO TO 30
   THICK2(J)=(AT*SN**2+CT)*SN+CT
   GO TC 35
35 SN=SN-Z
   THICK2(J)=(ET*SN+FT)*SN**2+FT
   FYPR=1./SQRT(1.+AM(J)**2)
   YPRIME=AM(J)
   XS(1BL,J)=(XM(J)-THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
   YS(1BL,J)=(YM(J)+THICK2(J)*FYPR)*FCSLMN
   XP(1BL,J)=(XM(J)+THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
   YP(1BL,J)=(YM(J)-THICK2(J)*FYPR)*FCSLMN
   AM(J)=ATAN(AM(J))*C1
   XM(J)=(XM(J)+YZERO)*FCSLMN
   YM(J)=YM(J)*FCSLMN
   THICK2(J)=THICK2(J)*FCSLMN
   S(J)=S(J)*FCSLMN
   YZERC=YZERC*FCSLMN
   AREA=PI/2.0*YZERO**2
   XINT=YZERO*(1.0-COS(BETA1/C1)*4.0/(3.0*PI))*AREA
   YINT=-4.0/(3.0*PI)*YZERO*AREA*SIN(BETA1/C1)
   DO 45 J=2,N
   DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
   AREA=AREA+DELA
   XINT=XINT+DELA*(XM(J)+XM(J-1))/2.0
   YINT=YINT+DELA*(YM(J)+YM(J-1))/2.0
   XBAR=XINT/AREA
   YBAR=YINT/AREA
   XBAR8=XBAR
   YBAR8=YBAR
   YBAR=YBAR+YDEL/AXIALC
   XBAR=XBAR+XDEL/AXIALC
   CALL D1 (XM,AM,N,DX,SS1(1,1),100,1)
   DO 50 IK=1,100
   SS1(IK,1)=TAN(SS1(IK,1)/C1)
40
45

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50      Y(IK)=DY(IK)*FCSLMN
      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,XEAR,XBC,1,1)
      XBAR=XBARB
      YBAR=YBARB
      IX=0.0
      IY=0.0
      IXY=0.0
      CO 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
      CCSANG=CCS((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.C.()) IXYN=((IXN-IYN)*CCSANG-IXD+IYD)/(2.0*S
1      1IN((AM(J)+AM(J-1))/C1))
      IX=IX+IXN+CELA*((YM(J)+YM(J-1))/2.0-VEAR)**2
      IY=IY+IYN+CELA*((XM(J)+XM(J-1))/2.0-XEAR)**2
      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*CCS(ANG)-IXY*SIN(ANG)
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*CCS(ANG)+IXY*SIN(ANG)
      ANG=ANG/2.0*C1
      STAGER=ATAN(YM(N)/XP(N))*C1
      XNL=XM(N)
      YNL=YM(N)
      CAMBER=BETA1-BETA2
      IF (IPRINT.EQ.2) GO TO 95
      LNCI=47
      WRITE (LCG2,60) CHORD,STAGER,CAMBER,AREA,XBAR,YEAR,IX,IY,IXY,ANG,I
1PX,ANG,IPY,ANG
      FORMAT (/,16X,100HNCRMALISED RESULTS - ALL THE FOLLOWING REFER TO
1ABLADE HAVING A MERIDICNAL CHORD PROJECTION OF UNITY,/,16X,100(1H*
2),/,20X,11HBLADE CHORD,4X,1P=,F7.4,/,20X,16HSTAGGER ANGLE =,F7.3
60

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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 CF 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 ,Y, AXIS),/,
$,6HIY =,F7.5,6X,3H(AT,F7.3,15H WITH ,Y, AXIS),/,
FORMAT (27X,5HPCINT,8X,24H E A N L I N E C 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
TH=THICK2(J)*2.0
75 WRITE (LOG2,80) J,XM(J),YM(J),AM(J),TM,XS(IBM,J),YS(IBM,J),XF(IBM,
1J),YF(IBM,J)
FORMAT (27X,I3,F13.5,F8.5,F7.3,F8.5,F16.5,3F8.5)
DO 85 J=1,N
XM(J)=XS(IBM,J)
YM(J)=YS(IBM,J)
AM(J)=XF(IBM,J)
THICK2(J)=YF(IBM,J)
85 WRITE (LOG2,90) IBM
FORMAT (1H1,45X,33HNORMALISED PLOT OF SECTION NUMBER,I3,/,2X)
90 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.

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100      IF (ISTAK.EQ.1) YBAR=YML
      RLE=YZERO*AXIALC
      CHORD=CHORD*AXIALC
      AREA=AREA*A2
      XC=RLE-XBAR*AXIALC-XOEL
      YC=-YBAR*AXIALC-YOEL
      IF (IPRINT.EQ.2) GO TO 120
      WRITE (LOG2,105) CHORD,RLE,XC,YC,AREA,IX,IY,IXY,IFX,ANG,IPY,ANG
      FORMAT (1H1,31X,69HCIMENSIONAL RESULTS - ALL RESULTS REFER TO A BL
105      1ADE CF SPECIFIED CHORD,/,32X,69H*****
      2*****
      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 MMENTS OF AREA ABOUT CENTROID,/,30X,6HIX =,1PE12.5,/,30X
      6,6HIY =,1PE12.5,/,30X,6FIY =,1PE12.5,/,20X,47HPRINCIPAL SECON
      7D MOMENTS OF AREA ABOUT CENTROID,/,30X,6FIPX =,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      FT      SUCTION-----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(1EL,J)=(XS(1EL,J)-XBAR)*AXIALC-XOEL
      YS(1EL,J)=(YS(1EL,J)-YBAR)*AXIALC-YOEL
      XP(1EL,J)=(XP(1EL,J)-XBAR)*AXIALC-XOEL
      YP(1EL,J)=(YP(1EL,J)-YBAR)*AXIALC-YOEL
      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 (LOG2,5)
      WRITE (LOG2,110)
      WRITE (LOG2,115)
      LNCT=LNCT+1
125      JM1=J-1

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130 WRITE (LOG2,130) JM1,XS( IBL,JM1),YS( IEL,JM1),XP( IBL,JM1),YP( IBL,JM
135 11),J,XS( IBL,J),YS( IBL,J),XP( IBL,J),YP( IBL,J)
      FORMAT (3X,I3,4(2X,1PE12.5),6X,I3,4(2X,1PE12.5))
      CONTINUE
140 IF (IPRINT.EQ.2) GO TO 150
      IF (LNCT.GT.24) WRITE (LOG2,140)
      FORMAT (1H1)
      IF (LNCT.GT.24) LNCT=2
      LNCT=LNCT+5
      WRITE (LOG2,145)
145 FCRMAT (2X,/,48X,37+POINTS DESCRIBING LEACING EDGE RADIUS,/,48X,9
      1HPOINT NO.,6X,1HX,13X,1HY,/,2X)
150 EPS=BETA1+180.0
      DO 160 J=1,31
      XSEMI( IBL,J)=XC-RLE*SIN(EPS/C1)
      YSEMI( IBL,J)=YC+RLE*COS(EPS/C1)
      EPS=EPS-6.0
      IF (IPRINT.EQ.2) GO TO 160
      WRITE (LOG2,155) J,XSEMI( IBL,J),YSEMI( IBL,J)
      LNCT=LNCT+1
155 FCRMAT (48X,I5,1PE17.5,1PE14.5)
160 CONTINUE
      SSURF=AXIALC
      SS2=EX-AXIALC*XBAR-XDEL
      SBAR=SS2+AXIALC*XBARB+XDEL
      DO 165 IK=1,100
      SS( IK)=SS( IK)-SBAR
165 CALL D1 (SS,X,100,0.,SBAR,1,1)
      CALL D1 (XHERE,R(1, IBL),NSTNS,SBAR,RXEAR,1,0)
      XBARC=XBAR
      YBARC=YBAR
      XBAR=XBARB+XDEL/AXIALC
      YBAR=YBARB+YDEL/AXIALC
      SS1(1,1)=SS(1)
      SS2=AXIALC/99.
      SS(1)=SS(1)+SS2
      DO 170 IK=2,100
      SS( IK,1)=SS( IK)
      SS( IK)=SS( IK-1)+S23
170 SIGMAC=(XAB-YBAR)/RXBAR*AXIALC

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175	DO 175 IK=2,100	81205
180	IF (XBAR.EQ.OX(IK)) GO TO 185	81210
185	IF (XBAR.GT.OX(IK-1).AND.XBAR.LT.OX(IK)) GC TO 190	81215
	CONTINUE	81220
	WRITE (LOG2,180)	81225
180	FORMAT (1H1,23H XBAR CANNOT BE LOCATED)	81230
185	SIGMA(IK)=SIGMAC	81235
	KL=IK+1	81240
	GO TC 195	81245
190	KL=IK	81250
	SIGMA(IK-1)=SIGMA0	81255
195	SSDUM=SS(KL-1)	81260
	SS(KL-1)=0.	81265
	YP1=XEC	81270
	RX1=RXBAR	81275
	DO 200 IK=KL,100	81280
	XSURF=SS2+OX(IK)*SSURF+SS1(1,1)	81285
	CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)	81290
	CALL D1 (SS1(1,1),X,130,XSURF,XDUM,1,1)	81295
	CALL C1 (SS1(1,1),X,100,XSURF,XDUM,1,1)	81300
	CALL D1 (XHERE,R(1,IBL),NSTNS,XCUM,RX2,1,0)	81305
	SIGMA(IK)=SIGMA(IK-1)+(Y(IK)/RX2+YP1/RX1)/2.*(SS(IK)-SS(IK-1))	81310
	YP1=Y(IK)	81315
200	RX1=RX2	81320
	SS(KL-1)=SSDUM	81325
	SSDUM=SS(KL)	81330
	SIGDUM=SIGMA(KL)	81335
	SIGMA(KL)=SIGMAC	81340
	SS(KL)=0.	81345
	RX1=RXEAR	81350
	YP1=XEC	81355
	KP=KL-1	81360
	CO 205 IK=1,KM	81365
	KJ=KL-1K	81370
	XSURF=SS2+OX(KJ)*SSURF+SS1(1,1)	81375
	CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)	81380
	CALL D1 (XPERE,R(1,IBL),NSTNS,XDUM,RX2,1,0)	81385
	SIGMA(KJ)=SIGMA(KJ+1)-(Y(KJ)/RX2+YP1/RX1)/2.*(SS(KJ+1)-SS(KJ))	81390
	YP1=Y(KJ)	81395
205	RX1=RX2	81400

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210      SIGMA(KL)=SIGDUM
      SS(KL)=SSDUM
      DO 210 IK=1,100
      SS(IK)=SS1(IK,1)
      XBAR=XBARC
      YBAR=YBARC
      DO 215 IK=1,N
      SS1(IK,1)=SS2+((XS(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
      SS1(IK,2)=SS2+((XP(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
      DO 220 IK=1,31
      SS1(IK,3)=SS2+((XSEMI(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
      CALL G1 (SS,X,100,SS1(1,1),SS1(1,1),N,1)
      CALL G1 (SS,X,100,SS1(1,2),SS1(1,2),N,1)
      CALL G1 (SS,X,100,SS1(1,3),SS1(1,3),31,1)
      IF (ISTAK.GT.1) GO TO 230
      IF (ISTAK.EQ.1) SIGMA0=SIGMA(100)
      IF (ISTAK.EQ.0) SIGMA0=SIGMA(1)
      DO 225 IK=1,100
      SIGMA(IK)=SIGMA(IK)-SIGMAC
      DO 235 IK=1,100
      DX(IK)=(OX(IK)-XBAR)*AXIALC-XDEL
      DY(IK)=(OY(IK)-YBAR)*AXIALC-YDEL
      DO 245 MK=1,3
      IF (MK.EQ.3) NNN=31
      IF (MK.EQ.1.OR.MK.EQ.2) NNN=N
      DO 240 IK=1,NNN
      IF (MK.EQ.1) YP1=YS(IBL,IK)
      IF (MK.EQ.2) YP1=YP(IBL,IK)
      IF (MK.EQ.3) YP1=YSEMI(IBL,IK)
      IF (MK.EQ.1) RX1=XS(IBL,IK)
      IF (MK.EQ.2) RX1=XP(IBL,IK)
      IF (MK.EQ.3) RX1=XSEMI(IBL,IK)
      CALL G1 (OX,DY,100,RX1,RXEAR,1,1)
      DELLY=YP1-RXBAR
      CALL G1 (XHERE,R(1,IBL),NSTNS,SS1(IK,MK),RAB,1,0)
      DELSIG=CELLY/RAB
      CALL G1 (OX,SIGMA,100,RX1,XAB,1,1)
      SS1(IK,MK)=XAB+DELSIG
240      CONTINUE
245      RETURN
      END

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70	IF (XIN(I)-XDATA(NDATA)) 75,110,110	C 205
75	CX=XDATA(J+1)-XDATA(J)	C 210
80	IF (NWCT-1) 80,85,85	C 215
	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))/CX-(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 TC 90	C 290
110	YDASH=(YDATA(NDATA)-YDATA(N))/(XDATA(NDATA)-XDATA(N))+ (M(NDATA)/3.0	C 295
	+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-

5	SUBRCUTINE G1 (XDATA,YDATA,NDATA,XIN,YOUT,NXY,NTYPE)	0	5
10	REAL M	0	10
15	DIMENSION P(15), A(15), B(15), C(15), XDATA(1), YDATA(1), XIN(1),	0	15
20	YOUT(1)	0	20
25	IF (NDATA-1) 5,5,15	0	25
30	DO 10 I=1,NXY	0	30
35	YOUT(I)=YDATA(1)	0	35
40	RETURN	0	40
45	IF (NDATA-2) 25,25,20	0	45
50	IF (NTYPE) 90,90,25	0	50
55	J=1	0	55
60	I=1	0	60
65	IF (XIN(I)-XDATA(2)) 65,65,35	0	65
70	IF (XIN(I)-XDATA(NDATA-1)) 40,70,70	0	70
75	IF (XIN(I)-XDATA(J)) 50,60,45	0	75
80	IF (XIN(I)-XDATA(J+1)) 60,60,50	0	80
85	J=J+1	0	85
90	IF (J-NDATA) 40,55,55	0	90
95	J=1	0	95
100	GO TC 40	0	100
105	YOUT(I)=YDATA(J)+(YDATA(J+1)-YDATA(J))/(XDATA(J+1)-XDATA(J))*(XIN(	0	105
110	1I)-XDATA(J))	0	110
115	GO TC 75	0	115
120	YOUT(I)=YDATA(1)+(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))*(XIN(I)-X	0	120
125	DATA(1))	0	125
130	GO TC 75	0	130
135	YOUT(I)=YDATA(NDATA-1)+(YDATA(NDATA)-YDATA(NDATA-1))/(XDATA(NDATA)	0	135
140	1-XDATA(NDATA-1))*(XIN(I)-XDATA(NDATA-1))	0	140
145	IF (I-NXY) 80,85,85	0	145
150	I=I+1	0	150
155	GO TC 30	0	155
160	RETURN	0	160
165	A(1)=1.0	0	165
170	B(1)=0.0	0	170
175	D(1)=0.0	0	175
180	N=NDATA-1	0	180
185	DO 95 I=2,N	0	185
190	A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*E(I-1)/(6.0	0	190
195	1*A(I-1))	0	195
200	B(I)=(XDATA(I+1)-XDATA(I))/6.0	0	200

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95      D(I)=(YDATA(I+1)-YDATA(I))/(XD(I)-XD(I-1))-XDATA(I)-(YDATA(I)-YDATA(I-1))/
1-1)/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))/6.0/A(I-1)
      M(NDATA)=0.0
      DO 100 II=2,N
      I=NDATA+1-II
      M(I)=(D(I)-B(I)*M(I+1))/A(I)
      N(I)=0.0
      J=1
      I=1
      IF (XIN(I)-XDATA(1)) 115,130,110
      IF (XIN(I)-XDATA(NDATA)) 140,135,120
      JP=1
      KP=2
      GO TC 125
      JP=NCATA
      KP=NCATA-1
      YPRIME=(YDATA(KP)-YDATA(JP))/(XDATA(KP)-XDATA(JP))-M(KP)/6.0*(XDATA
1A(KP)-XDATA(JP))
      YOUT(I)=YDATA(JP)+(XIN(I)-XDATA(JP))*YPRIME
      GO TC 175
      YOUT(I)=YDATA(1)
      GO TC 175
      YOUT(I)=YDATA(NCATA)
      GO TC 175
      IF (XIN(I)-XDATA(J)) 150,160,145
      IF (XIN(I)-XDATA(J+1)) 170,165,150
      J=J+1
      IF (J-NCATA) 140,155,155
      J=1
      GO TC 140
      YOUT(I)=YDATA(J)
      GO TC 175
      YOUT(I)=YDATA(J+1)
      GO TC 175
      DX=XDATA(J+1)-XDATA(J)
      YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))*3+M(J+1)/(6.0*DX)*(XIN(
1I)-XDATA(J))*3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN
2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)
      IF (I-NXY) 180,185,185
      I=I+1
      GO TC 105
      RETURN
      END

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SUBROUTINE EQ (IX,LCG1,X1,Y1,X2,Y2)
REAL LINE
DIMENSION X1(1), Y1(1), X2(1), Y2(1), LINE(121), XNUP(13)
DATA SYMBOL/1H+/,DASH/1H-/,CROSS/1H+/,BLANK/1H /,XI/1HI/
YMIN=Y1(1)
XMIN=X1(1)
YMAX=YMIN
XMAX=XMIN
DO 5 I=1,IX
IF (Y2(I).LT.YMIN) YMIN=Y2(I)
IF (Y2(I).GT.YMAX) YMAX=Y2(I)
IF (X2(I).LT.XMIN) XMIN=X2(I)
IF (X2(I).GT.XMAX) XMAX=X2(I)
IF (Y1(I).GT.YMAX) YMAX=Y1(I)
IF (X1(I).GT.XMAX) XMAX=X1(I)
CONTINUE
IF (XMAX.EQ.XMIN.OR.YMIN.EQ.YMAX) GO TO 85
YH=YMAX+(YMAX-YMIN)/25.0
YL=YMIN-(YMAX-YMIN)/25.0
XH=XMAX+(XMAX-XMIN)/38.3333
XL=XMIN-(XMAX-XMIN)/38.3333
IF ((YH-YL)/(XH-XL).GT.0.75) XH=1.3333*(YH-YL)+XL
IF ((YH-YL)/(XH-XL).LT.0.75) YH=0.75*(XH-XL)+YL
XMAX=(XMIN+XMAX-XH+XL)/2.0
XH=XH-XL+XMAX
XL=XMAX
XMAX=(YMIN+YMAX-YH+YL)/2.0
YH=YH-YL+XMAX
YL=XMAX
XMAX=ABS(XH)
XMIN=ABS(XL)
YMIN=ABS(YL)
YMAX=ABS(YH)
IF (XMIN.GT.XMAX) XMAX=XMIN
IF (YMIN.GT.YMAX) YMAX=YMIN
XMAX=ALCG10(XMAX)
YMAX=ALCG10(YMAX)
IF (XMAX.LT.0.0) XMAX=XMAX-1.0
IF (YMAX.LT.0.0) YMAX=YMAX-1.0
MX=-XMAX

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10	MY=-YMAX	E 205
	WRITE (LOG1,10) MX,MY	E 210
	FORMAT (20X,46HSCALES - 'X' IS SHOWN TIMES 10 TO THE POWER OF,I3,4	E 215
	10H 'Y' IS SHOWN TIMES 10 TO THE POWER OF,I3,/))	E 220
	YINC=(YH-YL)/54.0	E 225
	YINC2=YINC/2.0	E 230
	XRANGE=XH-XL	E 235
	DO 70 KLINE=1,55	E 240
	IF (KLINE.EQ.1.OR.KLINE.EG.55) GO TO 25	E 245
	DO 15 L=2,120	E 250
	LINE(L)=BLANK	E 255
15	IF (KLINE.EQ.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLINE.EQ.25.OR.KLI	E 260
	1NE.EG.31.OR.KLINE.EG.37.OR.KLINE.EQ.43.OR.KLINE.EQ.49) GC TO 20	E 265
	LINE(1)=XI	E 270
	LINE(121)=XI	E 275
	GO TO 40	E 280
20	LINE(1)=DASH	E 285
	LINE(121)=DASH	E 290
	GO TO 40	E 295
25	DO 30 L=2,120	E 300
30	LINE(L)=DASH	E 305
	LINE(1)=CRCSS	E 310
	LINE(121)=CROSS	E 315
35	DO 35 L=11,111,10	E 320
	LINE(L)=XI	E 325
	GO TO 60	E 330
40	DO 50 I=1,IX	E 335
	IF (Y2(I).GT.YH+YINC2.OR.Y2(I).LE.YH-YINC2) GC TO 45	E 340
	L=(X2(I)-XL)/XRANGE*120.0+1.5	E 345
	LINE(L)=SYMBOL	E 350
45	IF (Y1(I).GT.YH+YINC2.OR.Y1(I).LE.YH-YINC2) GC TO 50	E 355
	L=(X1(I)-XL)/XRANGE*120.0+1.5	E 360
	LINE(L)=SYMBOL	E 365
50	CONTINUE	E 370
	IF (KLINE.EQ.1.OR.KLINE.EG.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLIN	E 375
	1E.EQ.25.OR.KLINE.EQ.31.CR.KLINE.EQ.37.OR.KLINE.EQ.43.OR.KLINE.EQ.4	E 380
	29.OR.KLINE.EQ.55) GC TO 60	E 385
	WRITE (LOG1,55) LINE	E 390
55	FORMAT (8X,121A1)	E 395
	GO TO 70	E 400


```

5      SUBROUTINE FQ (ISTAK,PLTSZ,ITRIG,TITLE,IKDUM,IFPLOT)
10     DIMENSION TITLE(8)
15     IF (ITRIG.EQ.2.AND. IFPLCT.NE.2) CALL FLCT (PLTSZ,0.,-3)
20     PLTTIT=PLTSZ*.1
25     IF (ISTAK.LT.2) GO TO 5
30     BAL=.35*PLTSZ
35     XLEN1=.3*PLTSZ
40     XLEN2=XLEN1
45     YLEN1=.25*PLTSZ
50     YLEN2=-1.*YLEN1
55     XBACK1=-1.9
60     XBACK2=-6.2
65     GO TO 25
70     IF (ISTAK.EQ.0) GO TO 10
75     XLEN1=.70*PLTSZ
80     XLEN2=.15*PLTSZ
85     XBACK1=-1.9-.20*PLTSZ
90     XBACK2=-6.2-.20*PLTSZ
95     IF (IKDUM.EQ.1) GO TO 15
100    GO TO 20
105    CONTINUE
110    XLEN1=.15*PLTSZ
115    XLEN2=.70*PLTSZ
120    XBACK1=-1.9+.20*PLTSZ
125    XBACK2=-6.2+.20*PLTSZ
130    IF (IKDUM.EQ.1) GO TO 20
135    BAL=.25*PLTSZ
140    YLEN1=.50*PLTSZ
145    YLEN2=-.15*PLTSZ
150    GO TO 25
155    BAL=.50*PLTSZ
160    YLEN1=.15*PLTSZ
165    YLEN2=-.50*PLTSZ
170    CONTINUE
175    YBACK1=-(.35+BAL)
180    YBACK2=YBACK1-.01*PLTSZ-.175
185    CALL FLOT (0.0,-PLTSZ,-3)
190    CALL FLCT (7.0,PLTTIT,-3)
195    CALL PLCT (0.0,BAL,3)
200    CALL FLCT (XLEN1,BAL,-2)

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5      F
10     F
15     F
20     F
25     F
30     F
35     F
40     F
45     F
50     F
55     F
60     F
65     F
70     F
75     F
80     F
85     F
90     F
95     F
100    F
105    F
110    F
115    F
120    F
125    F
130    F
135    F
140    F
145    F
150    F
155    F
160    F
165    F
170    F
175    F
180    F
185    F
190    F
195    F
200    F

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

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F 205
F 210
F 215
F 220
F 225
F 230
F 235
F 240
F 245
F 250
F 255-

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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_0 . 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_0 parameter. (A1400-A1450)
16. The range of S/R_0 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_0 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_0 on either side of the S/R_0 value which produced the maximum value of the minimum radius of curvature in 17 are examined to find the optimal S/R_0 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)

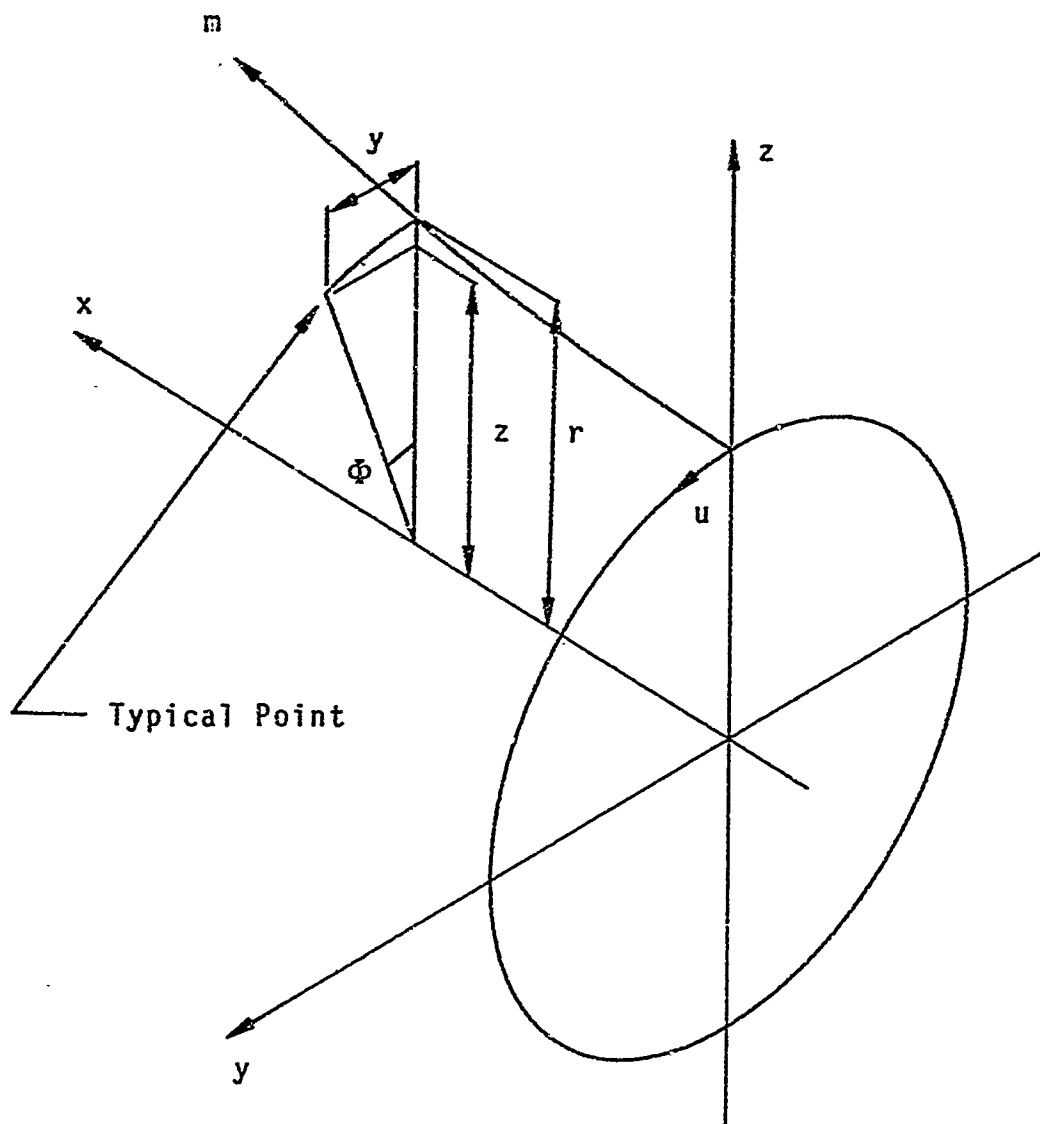


Figure 1. Cartesian and Streamsurface Coordinates of a Point

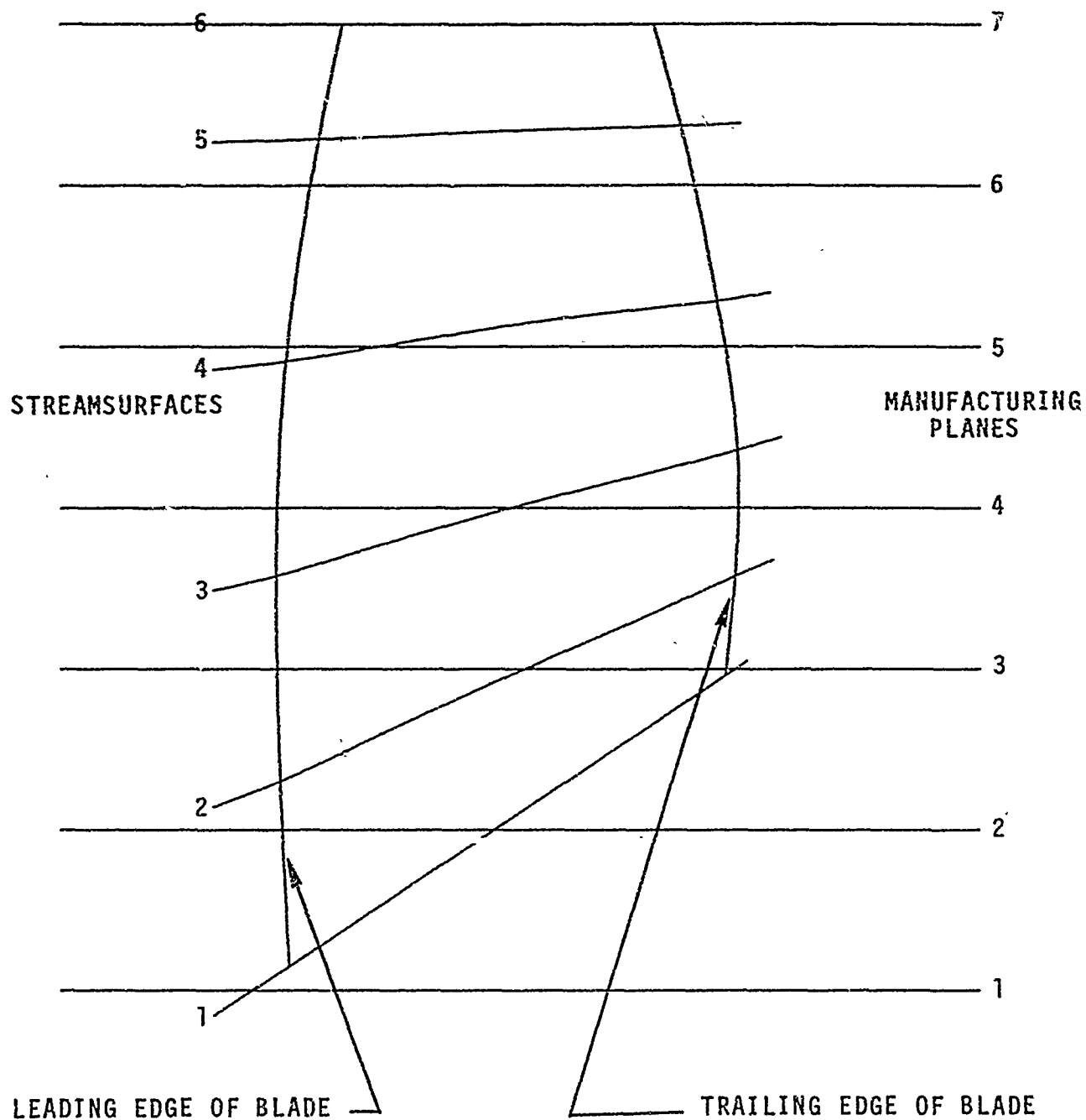


Figure 2. Locations of Streamsurfaces and Manufacturing Planes for Example Blade Design

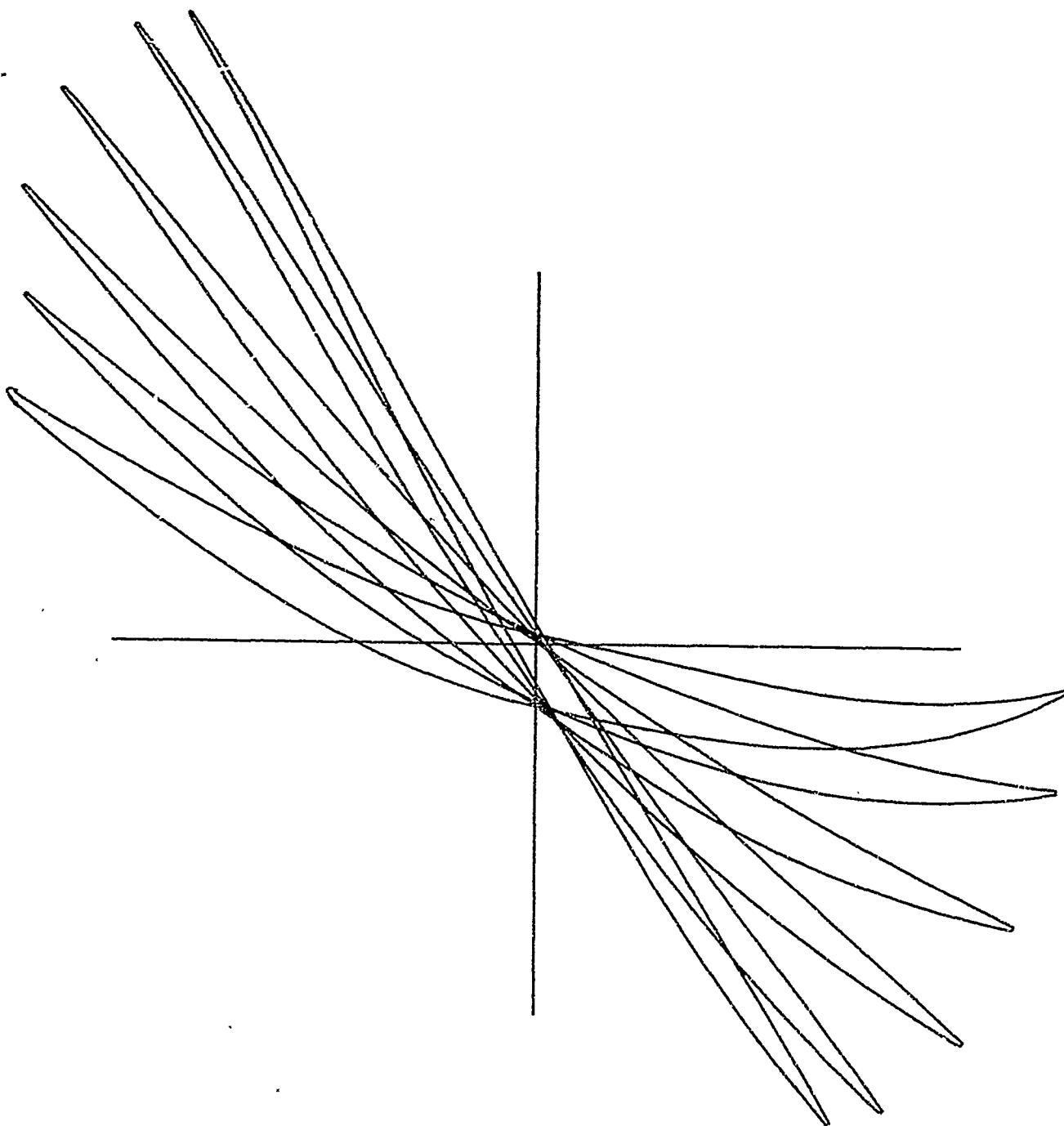


Figure 3, Example Blade Design:
Streamsurface Sections

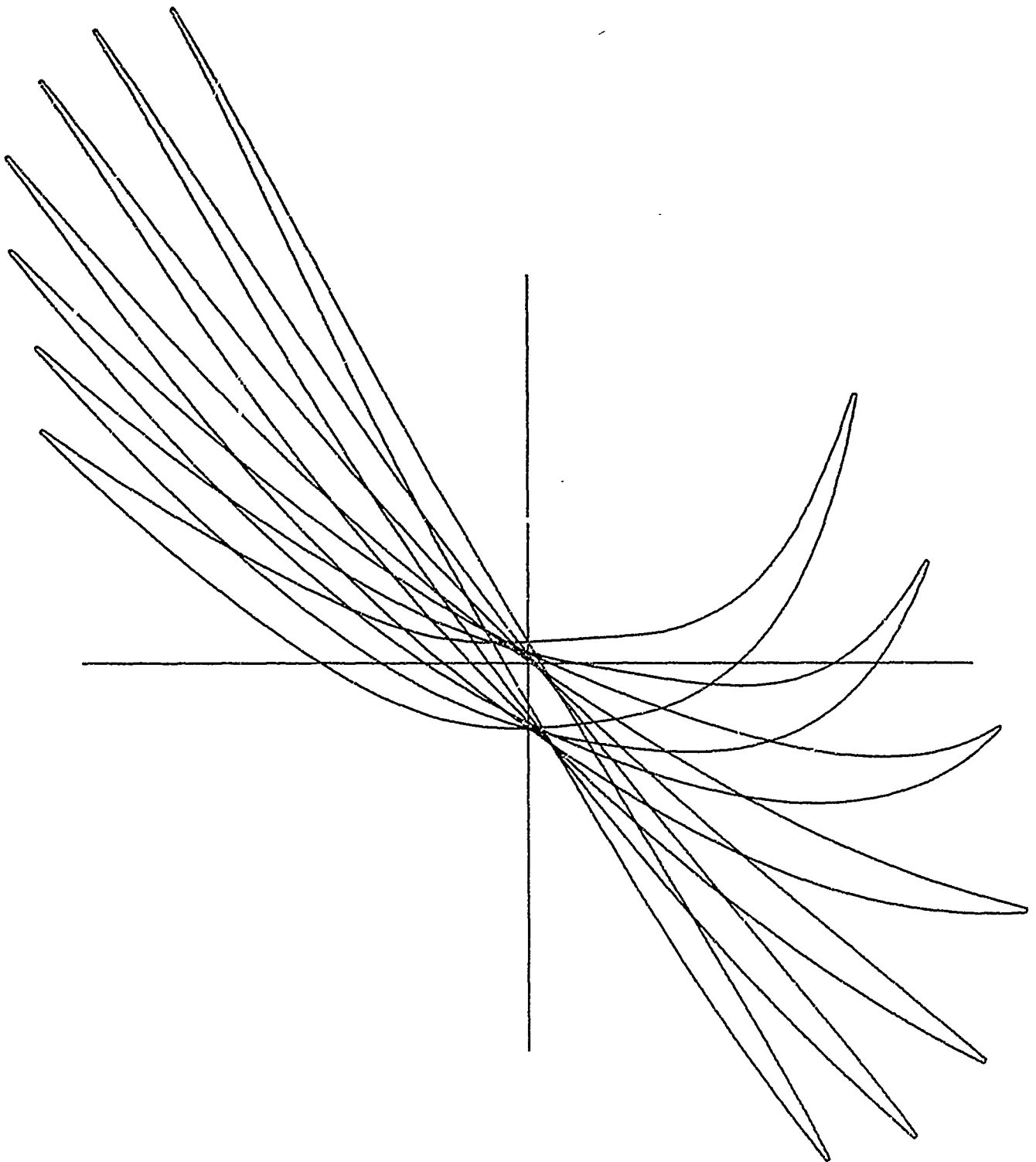


Figure 4. Example Blade Design:
Cartesian Sections

REFERENCES

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