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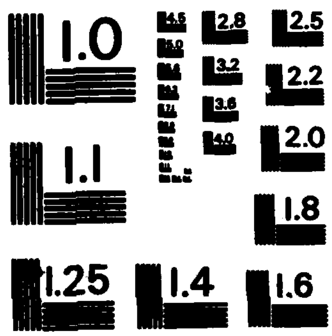

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A COMPUTER PROGRAM FOR THE DETERMINATION OF THE FLAT PLANE PROJECTION OF A PRINTED CIRCUIT TYPE STRAIN GAGE LEAD

Steven L. Puterbaugh
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Technology Branch
Turbine Engine Division

September 1982

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A computer program is discussed which calculates and plots the flat plane projection of a printed circuit type strain gage lead which is to be attached to an axial compressor rotor or stator blade. The input required includes lead path descriptive coordinates and blade descriptive coordinates.

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FOREWORD

This report contains the results of an effort to create a computer program to define the pattern of a flat printed circuit for a strain gage lead which is to be mounted on an axial flow compressor blade. The program was developed by the Compressor Research Group, Technology Branch, Turbine Engine Division, Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories at Wright-Patterson Air Force Base, Ohio. All debugging and code evaluation was done on a CDC 6600 system, utilizing CALCOMP plotting software. The effort was conducted by Steven L. Puterbaugh and C. Herbert Law from January 1980 to January 1981 under Project 2307, Task S1, Work Unit 27, "Turbomachinery Fluid Mechanics."

Requests for the FORTRAN code may be made in writing to Compressor Research Group, AFWAL/POTX, Wright-Patterson AFB OH 45433. Requests must include the Statement of Terms and Conditions contained in Atch 21 to AFR 300-6.

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SECTION I

INTRODUCTION

Strain gages are used to monitor compressor blade deformation during testing of aircraft turbine engines. The signal from the strain gage is conveyed to either a telemetry system or slip ring assembly through leads which are cemented to the blade surface for use up to about 500°F.

An improved application technique, developed by R. D. DeRose (AFWAL/POTX, WPAFB) (Reference 1), replaces conventional wire leads with printed circuit-type material. This technique significantly reduces aerodynamic interference due to the presence of leads, and offers great economy in installation labor.

The shape of the lead path when developed onto a flat plane must be determined in order to produce the printed circuit sheet. The computer program described in this report produces a plot of the flat path, along with other views of the lead on the blade, given blade surface coordinates and lead path descriptive coordinates.

SECTION II
APPROACH

The major consideration in the development of LEDOUT was to minimize the amount and complexity of required input data. It was assumed that the typical user might have minimal computer experience and, therefore, much emphasis was placed on user ease.

An obvious requirement was that the plot of the "flat path" must be of such quality that either a tracing done by a draftsman, or the plot itself, could be used in producing the printed circuit sheet. This requirement was met first by interpolating a sufficient number of points on the path so that a continuous, smooth curve could be generated. Secondly, a plot subroutine was written that actually "draws" a two-conductor lead in the flat plane. The code discussed in this report incorporates California Computer Inc. (CALCOMP) software for all plotting purposes.

The last primary requirement was that there was to be no restriction on the shape of the input lead path. This was done by developing the appropriate functions for interpolation purposes. The functions which were used were coordinates as a function of path length.

The general logic of LEDOUT is discussed below. A more detailed summary of subroutines C1, C1A, and C2 can be found in the "Program and Subroutine Description" section.

1. The input data is read, which includes user data and blade/hub geometric descriptive coordinates.
2. Three hundred points are then interpolated from the input curves, and represent the blade and hub paths.
3. A 30 X 30 coordinate mesh is then calculated which describes the surface on which the path will be "laid." The mesh consists of three smaller sections; a 15 X 30 mesh on the blade surface, a 10 X 30 mesh on the fillet surface, and a 5 X 30 mesh on the hub surface.

4. The path is then smoothed at the blade/hub "plane" intersection, and then translated onto the 30 X 30 mesh calculated in (3) above. The path is now fully specified from the strain gage on the blade to the exit point on the platform by six hundred sets of coordinates in three dimensions.

5. The path from (4) above is then used in a procedure which evaluates three adjacent points and differentiates the absolute turning of the path into two components. One component is that turning due to surface curvature; this angle is ignored. The other component is that turning due to the curvature of the lead path itself; this angle is calculated and, subsequently, used in plotting the flat plane path. The area to be evaluated then indexes one point, and the above procedure is repeated.

6. The final procedure is to print and plot the appropriate data.

SECTION III

PROGRAM IMPLEMENTATION

The following is a step-wise procedure which would be typical in using the computer program.

1. The stream surface or z-plane airfoil coordinates must first be available, either on permanent disk file, magnetic tape, or computer cards. (This data may be generated by program UD0300.)

2. The plot selection indicator (ISTEP) is set to 1 and the appropriate values are set on the "user data" card; the program is then executed to generate an r-x and x-y plot.

3. The plots from (2) are used to lay out the lead paths and determine the coordinates to be input.

4. The coordinates determined in (3) are then input and the program is executed once again; by varying the value of ISTEP, different sets of plots may be selected. This allows the user to confirm and/or correct the input coordinates without using the computer time required to generate the flat projection plot.

5. After the path has been confirmed, a flat projection plot may be obtained alone or along with other plots, again depending on the value of ISTEP.

It is best to keep the path as gently curving as possible to allow the spline fit subroutine to generate a smooth curve with no erratic bends. Sharp bends in any one section of the path described by the input data points could adversely affect the entire path.

The remaining point to be made is with respect to computer time. The plot selection indicator, ISTEP, was added to the program to allow for as efficient use of computer time as possible. ISTEP instructs the program as to how much information (number and type of plots) has been requested by the user and, so, which subroutines are to be called. Different subroutines of the program require different amounts of time to complete their calculations, depending on the complexity of the calculations. The user should keep this in mind when setting up his deck, and make efficient use of each run.

Typically, the maximum amount of time required for the entire plot sequence is 180 computer seconds. If the flat projection plot is not requested, the required time can be reduced significantly. A run with ISTEP = 1 or 2 can be made in less than 10 computer seconds.

SECTION IV

INPUT DATA

The input data may be divided into two groups: a geometric description of the blading (i.e. blade surface coordinates) and the user data. The program reads these two groups from separate units. With appropriate job control language (JCL), one or both sets of data may be read from the card reader or "attached" from permanent disk files or magnetic tapes.

Two input data formats are used: integer and real. The integer values are numbers without decimal points and the real are numbers with decimal points. Each record, or card, contains only one type of data, and those variables whose first letter occurs in the alphabet between "i" and "n", inclusive, are integer values. The integers are entered in fields of five characters, and the values must reside in the right-most position in its field. The real numbers are entered in fields of 12, and a decimal point should be used for correct interpretation of the data. The real number may be placed anywhere in its field.

The following chart illustrates the general input format.

(UNIT)		
(LOG1)	ISTEP	
(LOG1)	IBTYPE NPOINT NLE NZ ISURF IROTAT NHUB NTIP NBLADE NVIEW IPRINT IOPRNT	
(LOG2)	ZVALUE (only if IBTYPE = 2)	occurs NZ times
(LOG2)	ZB XB YB (only if IBTYPE = 1)	occurs NZ times
(LOG2)	XB YB (only if IBTYPE = 2)	occurs NZ times
(LOG2)	ZSEMI XSEMI YSEMI (occurs NLE times)	occurs NZ times
(LOG2)	XH RH (occurs NHUB times)	only if IBTYPE = 2
(LOG2)	XT RT (occurs NTIP times)	only if IBTYPE = 2
(LOG1)	XGAGE RGAGE AGAGE (only if ISTEP > 1)	

(LOG1)	NPATH	only if ISTEP > 2
(LOG1)	XPATH RPATH	
(LOG1)	NPHUB	
(LOG1)	XPHUB YPHUB	
(LOG1)	FILRAD	
(LOG1)	DF W WL (only if ISTEP ≥ 5)	

VARIABLE DEFINITIONS

ISTEP plot selection indicator

ISTEP = 1: r-x, x-y plots

= 2: r-x w/gage location, x-y plot

= 3: r-x, x-y, x-z, y-z plots

= 4: x-z, y-z plots

= 5: r-x, x-y, x-z, y-z, flat plane plots

= 6: x-z, y-z, flat plane plots

= 7: flat plane plot

IBTYPE blade coordinate type indicator; if IBTYPE = 1, stream surface coordinates are given; if IBTYPE = 2, manufacturing section coordinates are given.

NPOINT number of points describing a single blade section (NPOINT ≤ 80).

NLE number of points describing the LE radius (0 ≤ NLE ≤ 31).

NZ number of stream surfaces/constant-z planes (NZ ≤ 11).

ISURF pressure/suction surface indicator; if ISURF = 1, the pressure side is specified; if ISURF = 2, the suction side is specified.

IROTAT rotor rotation direction indicator; if IROTAT = 1, rotation is CW; if IROTAT = -1, rotation is CCW. For stator, if associated rotor rotates CW, IROTAT = -1; if CCW, IROTAT = 1.

NHUB number of points describing the hub (mfg section only) (0 ≤ NHUB ≤ 25).

NTIP — number of points describing the tip (mfg section only) ($0 \leq NTIP \leq 25$).

NBLADE — number of blades in the row

NVIEW — number of x-z views of the blade to be plotted

IPRINT — plot point print indicator; if IPRINT = 1, all points are printed on the output file; if IPRINT = 0, the coordinates are not printed.

IOPRNT — output printout indicator; if IOPRNT = 1, the stream surface/z-plane coordinates (input data) are printed; if IOPRNT = 0, this information is deleted from the printout.

ZVALUE — the z coordinate of the constant-z plane (mfg section only)

ZB — a-z coordinate of the set of points defining the blade surface

XB — an x coordinate of the set of points defining the blade surface

YB — a-y coordinate of the set of points defining the blade surface

ZSEMI — a-z coordinate of the set of points defining the arc which defines the LE

XSEMI — an x coordinate of the set of points defining the arc which defines the LE

YSEMI — a-y coordinate of the set of points defining the arc which defines the LE

XH — an x coordinate of the set of points which defines the hub

RH — an r coordinate of the set of points which defines the hub

XT — an x coordinate of the set of points which defines the tip

RT — an r coordinate of the set of points which defines the tip

XGAGE — the x coordinate of the strain gage location

RGAGE — the r coordinate of the strain gage location

AGAGE — the angle orientation of the strain gage itself (measured CW from the positive x-axis).

NPATH — the number of points input to define the lead path on the blade ($NPATH \leq 25$).

XPATH	an x coordinate of the set defining the lead path on the blade
RPATH	an r coordinate of the set defining the lead path on the blade
NPHUB	the number of points input to define the lead path on the hub (NPHUB $\leq$ 15).
XPHUB	an x coordinate of the set defining the lead path on the hub
YPHUB	a-y coordinate of the set defining the lead path on the hub
FILRAD	the fillet radius (must be > 0)
DF	distance from the centerline of the lead to the conductor
W	plotter line width
WL	overall lead width

SECTION V

OUTPUT DATA

The output data consists of two parts, the printed output and the plotted output. Within the printed output is "user" input data (output options, etc.), input blade coordinates (optional), input lead path coordinates, and calculated lead path coordinates. The calculated coordinates consist of the x-y-z-r coordinates of the centerline of the strain gage lead. The plotted output is the most important and informative, and is discussed below.

1. The r-x plane plot: This plot shows the blade in the radial plane; that is, all y and z coordinates have been converted to radial coordinates ($r^2 = y^2 + z^2$). These are the coordinates in which the lead path on the blade are given. If ISTEP = 1, 2, or 3, the plot is made twice the actual size; this facilitates plotting the input path and checking the path once the program has been executed.

2. The x-y plane plot: This plot gives the x-y view of the hub and the blade roots. These are the coordinates in which the lead path on the hub are given. Similar to the r-x plane plot, if ISTEP = 1, 2, or 3, the plot is made twice the actual size. This plot is also used for path layout and confirmation.

3. The x-z plane plot: This plot gives a view of the blade and lead path in the x-z plane. Two or more of these views may be generated, depending on the value of NVIEW. This plot may be used in verification of the desired path or determination of a possible bad data point.

4. The y-z plane plot: This plot gives a view of the blade and lead path in the y-z plane (a "front" view). Its function is much the same as the x-z plane plot.

5. The flat projection plot: This plot is, of course, the most valuable of all the plots as it can form the pattern for producing the printed circuit sheet. It is a plot of the two-conductor lead and

its associated border. The width of the lead and the spacing of the conductors are specified by DF and WL.

Three examples will now be discussed which, hopefully, will illustrate some pitfalls and adequate solutions. The gage location and orientation is the same for each example: (-1.2750, 6.0000) @ 100.0°. An integral rotor design was used in these examples.

The first case employed a gently curving lead path on the blade (Figure 1) and a typical curved path on the hub (Figure 2).

The flat plot which was developed from this specification was obviously an unacceptable one. The combination of the curvature of the path and the curvature of the blade caused the path to cross over itself (Figure 3).

The transition point from blade to hub was moved further back on the blade, and the amount of curvature on the blade was reduced to produce the second example. This was done in an attempt to alleviate the unacceptable condition in the first example. An erroneous radial coordinate was input for the first point on the blade lead path. This error adversely affects all of the plots (Figures 4, 5, 6, 7), and is fairly obvious and easily corrected.

Finally, the correction was made and the results are shown in Figures 8, 9, and 10. The slightly irregular shape in the path near the exit of the fillet is a result of the path smoothing routine used in the fillet area.

SECTION VI

PROGRAM AND SUBROUTINE DESCRIPTION

Main program (MAIN)	The main program which controls the job flow of the calculation and plot subroutines.
Subroutine D1	Subroutine D1 retrieves all information (option switches) and required data that will be used in subsequent subroutines.
Subroutine D2	Subroutine D2 prints information and calculated data in an organized format.
Subroutine C1	Subroutine C1 calculates the blade and hub leadout path coordinates.
Subroutine C1A	Subroutine C1A calculates the 10 X 30 array which describes the fillet surface.
Subroutine C1B	Subroutine C1B calculates local blade and hub coordinates in preparation of the fillet surface calculation (C1A).
Subroutine C2	Subroutine C2 calculates the flat projection path of the leadout.
Subroutine C3	Subroutine C3 rotates coordinates into the proper planes for plotting purposes.
Subroutine C4	Subroutine C4 converts manufacturing section coordinates into "psuedo" streamsurface coordinates.

Subroutine C5	Subroutine C5 interfaces the x-y plot subroutine with the available blade coordinates for plotting purposes.
Subroutine G1	Subroutine G1 spline fits a series of points and calculates a y-value given an x-value or the slope of the function at a given x-value.
Subroutine G2	Subroutine G2 rotates the coordinate system about the origin, first about the z-axis, then about the new x-axis.
Subroutine G3	Subroutine G3 rotates a coordinate system about a single axis.
Subroutine G4	Subroutine G4 converts a single set of Cartesian coordinates into polar coordinates.
Subroutine RXP	Subroutine RXP plots the blade in the radial plane. Strain gage location and/or the lead path may be plotted depending on the value of ISTEP.
Subroutine XYP	Subroutine XYP plots the hub and blade root in the x-y plane.
Subroutine YZP	Subroutine YZP plots the blade and leadout path in the y-z plane.
Subroutine FP	Subroutine FP plots the flat projection path using the parameters calculated in C2.
Subroutine DP	Subroutine DP is the general plot subroutine which is accessed by the specific plot subroutines.

1. CALCULATION PROCEDURE

The major calculations of the program are contained within three of the subroutines: C1, C1A, and C2. These subroutines are described below.

a. SUBROUTINE C1

Subroutine C1 returns 600 sets of coordinates which describe the path of the strain gage lead on the blade surface in three dimensions. Eight distinct steps are used in the calculation and are described below:

(1) The 300 r-x path coordinates on the blade are calculated. This is done by creating two functions which will be evaluated for r and x values, respectively. The two functions are x as a function of absolute length of the path, and r as a function of absolute length of the path. The spline subroutine is then used to interpolate r and x values at 300 increments of length.

(2) The 300 x-y path coordinates on the hub are then calculated by converting the input path coordinates into polar coordinates, with respect to four points lying halfway between the first and last input points. The spline subroutine is then used to interpolate magnitude (radius) values at 300 increments of angular displacement values. The 300 sets of polar coordinates are then converted back to rectangular coordinates.

(3) The required x-range of the surface coordinate mesh is then determined by a simple max-min search algorithm, and the range is "sliced" by 30 constant-x planes.

(4) The coordinates describing the fillet surface are then calculated in subroutine C1A.

(5) The remaining blade and hub surface coordinates are then calculated. This is done at each constant-x slice by spline interpolation. The blade section is determined by spline

fitting y coordinates as a function of z coordinates, and evaluating the function at 10 evenly spaced z intervals. The hub section is determined by spline fitting z coordinates as a function of y coordinates, and evaluating at 5 evenly spaced y intervals.

(6) The existence of single point functions in the x, y, z-r, x plane relationship is checked; if single point functions are not found, the coordinates are rotated in the proper direction until the desired condition is attained.

(7) The discontinuity due to the blade/hub corner is removed. Since the input coordinates for the blade and hub reside in two intersecting surfaces, it is highly unlikely that a discontinuity will not be present. This is remedied by spline fitting the path coordinates in the r-x plane, x as a function of r. The coordinates in the vicinity of the fillet are removed in the function so that the spline subroutine will generate a smooth curve. The new function is then evaluated at each of the removed r values to find the corresponding new x value.

(8) The final x-y-z-r coordinates are determined by using the 30 X 30 mesh calculated above. This is done through multiple uses of the spline subroutine.

b. SUBROUTINE C1A

Subroutine C1A returns 300 sets of coordinates which describe the fillet surface over the required x-range. Five steps are used in the calculation, and are described below.

(1) 600 local surface coordinates which describe the blade/hub interface are determined in subroutine C1B.

(2) The local hub pitch and blade angles are determined by evaluating the slopes of the hub streamline for the pitch and the blade surface at each of the 30 constant-x slices.

(3) The local surface coordinates found in (1) are transferred to a coordinate system whose x-axis is tangent to the blade root. This is done for each of the 30 slices.

(4) The y-z plane profile of the coordinates from (3) is then evaluated to determine the center of the arc which will define the shape of the fillet at each of the 30 slices. Two curves parallel to the blade and hub profiles are determined, which are one fillet radius from the blade and hub profiles, respectively. The intersection of these curves defines the center of the arc.

(5) 10 radial increments, beginning at the point tangent with the hub and ending with the point tangent with the blade at each slice, are evaluated to give the required 300 points.

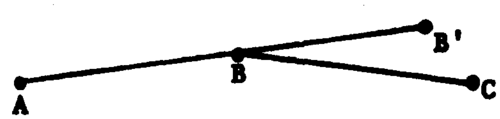
c. SUBROUTINE C2

Subroutine C2 returns flat path projection "direction parameters" for use in subroutine FP. The direction parameters are length, the true length between adjacent points; and angle, the angular deviation from a "straight" line on the blade surface. The method through which the parameters are calculated is as follows:

(1) The length values are calculated for all 600 points.

(2) The following procedure is repeated for each point:

(a) Given 4 points, A, B, C, and B', in the radial plane:



(b) The equation of line AB is determined.

(c) Points A and C are converted to polar coordinates with respect to B, and CB'BC is determined.

(d) The coordinates of B' are determined in the radial plane, and then the coordinates of B' are determined on the blade surface. BB' represents the straight line reference for determination of the "bend" in the lead due to direction change vs. surface contour change.

(e) The law of cosines is used to determine the angle B'BC in the original Cartesian coordinate system.

SECTION VII

CONCLUSIONS

The computer program discribed in this report is an easy-to-use method of determining the "flat plane" path of a printed circuit type strain gage lead. Since the trial and error method used previously in this determination is eliminated, an increase in speed is an obvious result through use of the program. Accuracy is also improved, as the analytical approach more closely approximates the blade surface and the required path shape.

The plot of the two-conductor lead is suitable for production of the printed circuit sheet, given the step size of the plotter is sufficiently small.

Finally, this program gives the instrumentation engineer an opportunity to consider several paths without actually producing the printed circuit sheet. High stress or high fatigue areas may be avoided, for example.

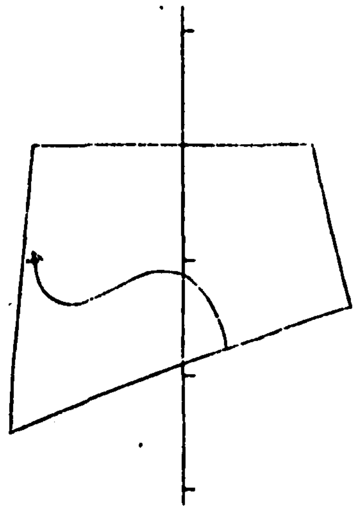


Figure 1. R-X Plane Plot

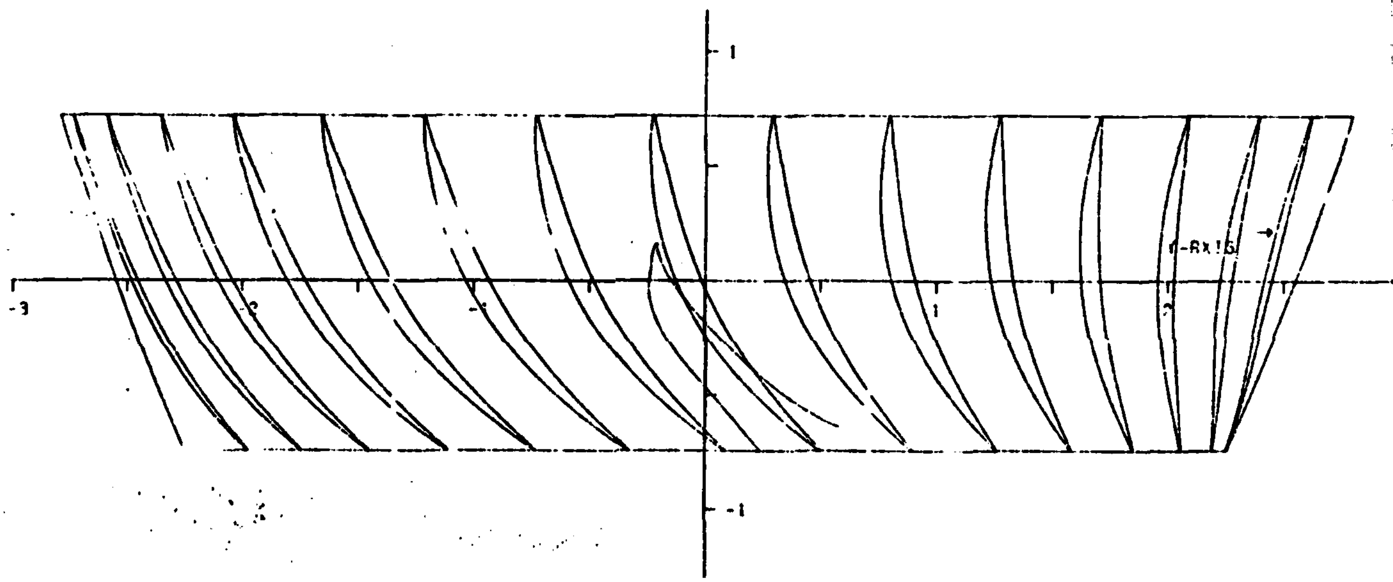


Figure 2. X-Y Plane Plot

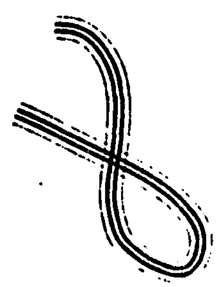


Figure 3. Flat Projection Plot

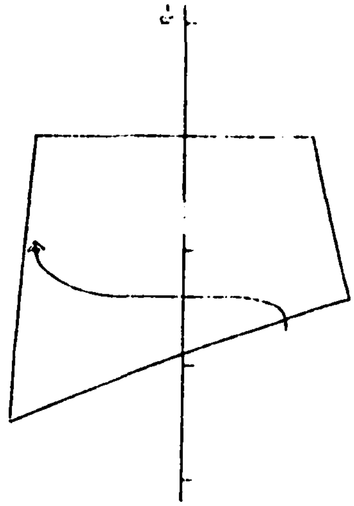


Figure 4. R-X Plane Plot

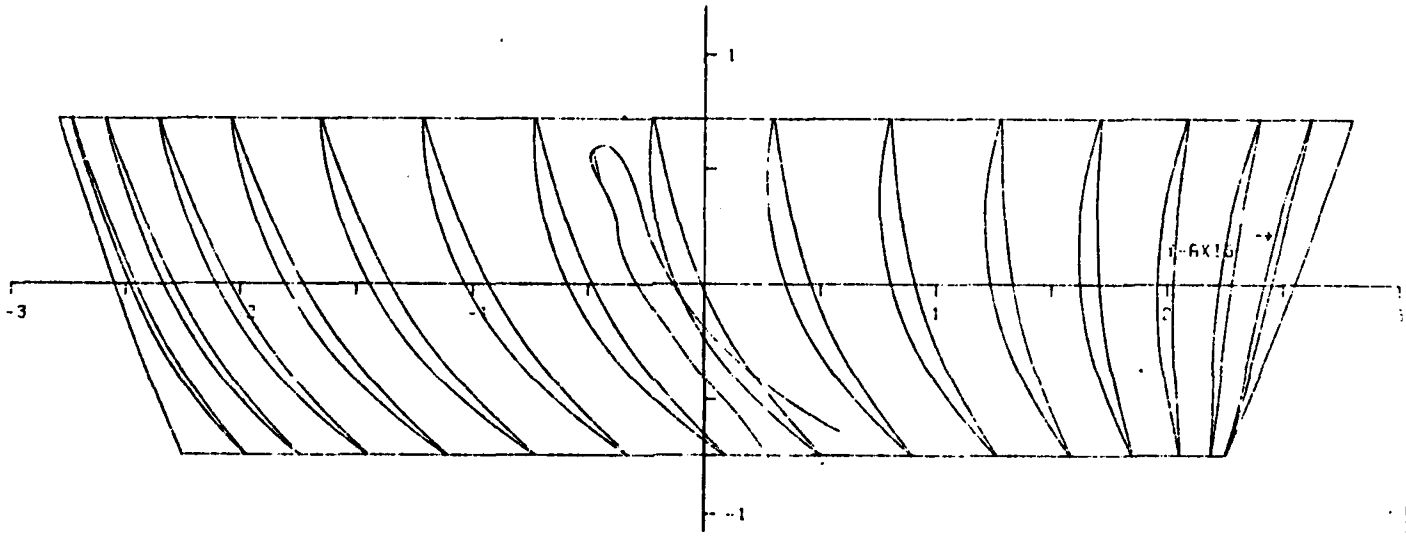


Figure 5. X-Y Plane Plot

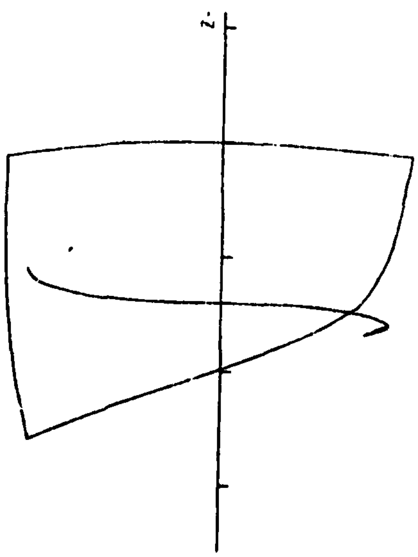


Figure 6. X-Z Plane Plot

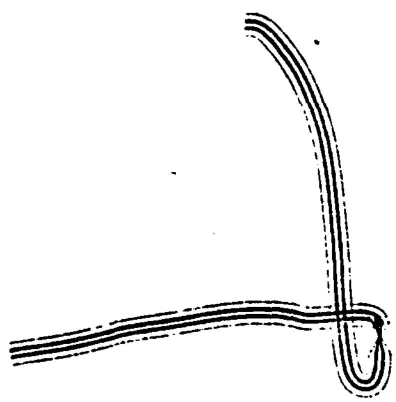


Figure 7. Flat Projection Plot

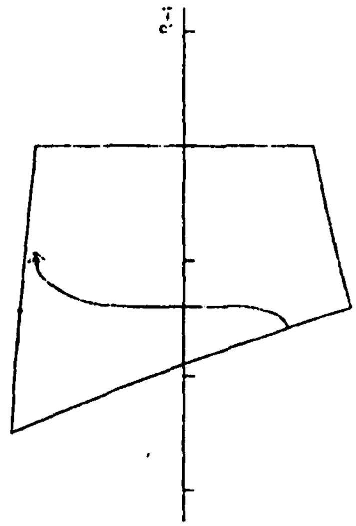


Figure 8. R-X Plane Plot

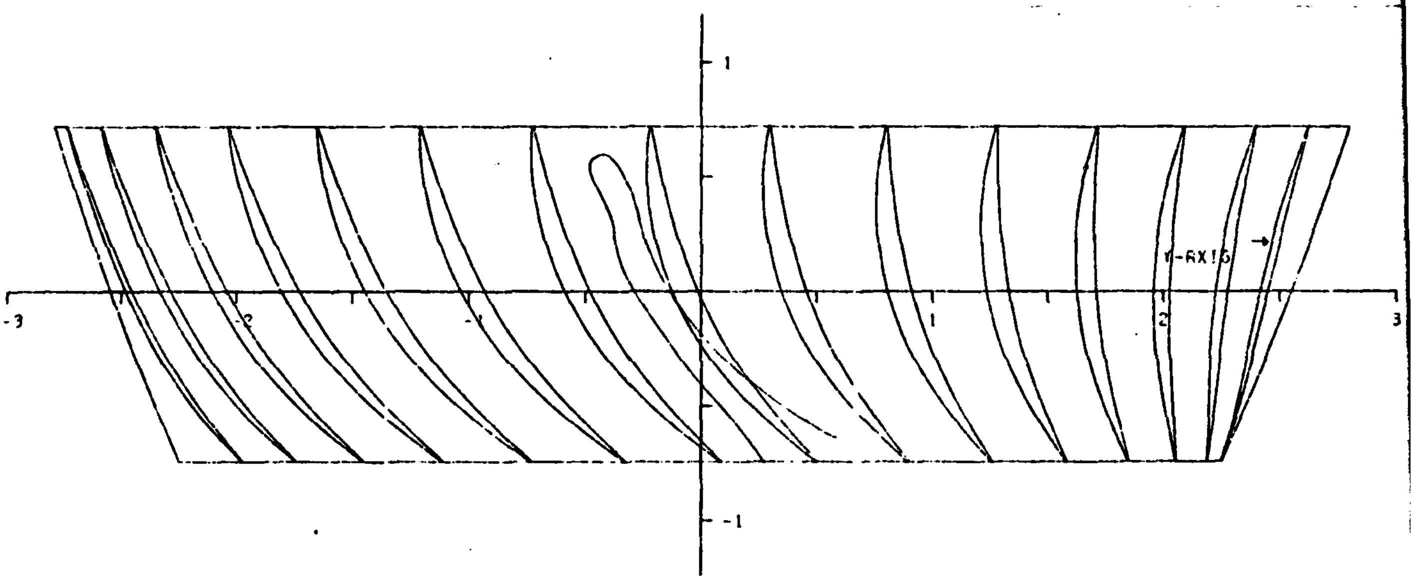


Figure 9. X-Y Plane Plot

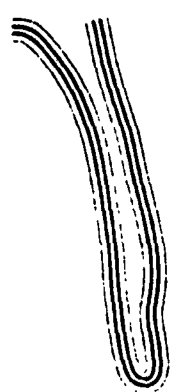


Figure 10. Flat Projection Plot

REFERENCES

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