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AEC RESEARCH AND DEVELOPMENT REPORT

524

Y-1620

Mathematics and
Computers

MASTER

COMPUTER PROGRAMS FOR DETERMINING PAYOUT-EYE
POSITIONS FOR LAYING FILAMENTS ALONG
GEODESIC PATHS ON SURFACES
OF REVOLUTION

T. W. Bookhart
A. H. Fowler

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the ATOMIC ENERGY COMMISSION under U. S. GOVERNMENT Contract W-7405 eng 26

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Date Issued: November 13, 1968

Document Y-1620

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TID-4500

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Nuclear Division

Y-12 PLANT

Contract W-7405-eng-26
With the US Atomic Energy Commission

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ABSTRACT

Fortran computer programs have been written for determining a geodesic path on an arbitrary surface of revolution. For this geodesic path on the surface, the corresponding payout-eye locations are calculated so that a machine will lay the filament along this geodesic path. Mandrel geometry and eye clearance are considered in locating the payout eye. The output of the program is a listing of points along the surface and the corresponding payout-eye positions. This information is then processed by an APT postprocessor to produce a punched tape for a numerically controlled filament winder.

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SUMMARY

Computer routines have been written for determining a geodesic path on an arbitrary surface of revolution and for calculating the filament feed-eye locations so that a machine will lay a filament along the geodesic path. The routines for determining the geodesic path are identical to those reported previously.⁽¹⁾ The method used in determining the geodesic path is to approximate the arbitrary surface by a series of conical and cylindrical sections and compute the path on the individual section. It has been shown⁽²⁾ that this path converges to the true geodesic path on the original surface as the surface approximation converges.

For a given point (r_1, z_1, θ_1) of the geodesic on the surface, the corresponding feed-eye position (r_2, z_2, θ_2) is found to be:

$$r_2 = \sqrt{\left[r_1 \pm \left(k_n \rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right]^2 + (\rho \sin \alpha)^2},$$

$$z_2 = z_1 \pm \rho \sin \alpha / \sqrt{1 + k_n^2}, \text{ and}$$

$$\theta_2 = \theta_1 + \tan^{-1} \left\{ \rho \sin \alpha / \left[r_1 \pm \left(k_n \rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right] \right\},$$

where:

k_n represents the slope (dr/dz) of the surface at (r_1, z_1, θ_1) ,

ρ the length of the vector from the surface to the eye, and

α the helix angle at (r_1, z_1, θ_1) . In the $\pm$ expressions,

+

 is used when z is increasing (going up part);

- is used for decreasing z (going down part).

The other dimension of interest, the A angle (rotation of the eye about the r axis), is:

$$A = \tan^{-1} [r_1 \sin(\theta_2 - \theta_1) / (z_2 - z_1)] .$$

As can be noted from these equations, there is an infinite number of eye positions (one for each value of ρ) corresponding to a point of the geodesic on the surface. To uniquely locate the eye position, the clearance of the eye from the mandrel is

considered. The minimum value of ρ which will allow the eye to clear the mandrel by the desired amount, produces a positive rotation of the mandrel and results in a positive feed of filament from the eye that is used.

An interpolation scheme is utilized for spacing points along the geodesic on the surface so that the machine path will not deviate more than a prescribed tolerance from the geodesic path. This interpolation would be adequate if the eye were located on the surface. However, since the eye is positioned in space and the vector length from the surface to the eye is continually changing, additional measures are required to better space the eye points. Therefore, routines are included which add additional eye points when a large eye motion occurs and delete points when too closely spaced.

The output of the computer program is a listing of surface points along the geodesic path and the corresponding eye coordinates. These coordinates are also written on magnetic tape in a format of APT GO TO points. This tape can be converted to punched cards and utilized as APT input for a filament-winder postprocessor.

INTRODUCTION

Manufacturing techniques for filament winding have advanced from machines mechanically controlled by cams and chains to highly versatile numerically controlled machines. However, to utilize the capabilities of a numerically controlled machine, algorithms must be developed for computing those machine motions that are necessary to lay a filament along the desired paths. This capability is not currently available in APT or any of the other powerful numerical-control computer systems.

One large class of filament-winding applications involve shapes which are surfaces of revolution. Since a geodesic path on any surface is a stable path, geodesics are often chosen as the desired filament paths. Algorithms and computer routines were developed earlier⁽¹⁾ for determining a geodesic path on an arbitrary surface of revolution. These routines are useful in designing filament-wound structures and analyzing their properties. The routines can be extended, however, to compute the machine feed-eye positions for laying a filament along these surface paths. The additional algorithms for determining these feed-eye positions are developed in this report. The computer program for making the calculations is included. These computer routines have also been incorporated in the APT system as a pre-postprocessor.⁽³⁾

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COMPUTER PROGRAM DEVELOPMENT

GEODESIC PATH ON A SURFACE OF REVOLUTION

The approach used in determining a geodesic path on an arbitrary surface of revolution has been reported previously.⁽¹⁾ A brief outline of this approach is as follows: First, approximate the contour of the surface of revolution by a series of short, straight-line segments. When rotated about the axis of revolution, these straight-line segments generate a series of conical and cylindrical sections which approximate the original surface of revolution. Then, by determining the geodesic on the individual conical and cylindrical sections and deriving criteria for crossing from one section to another, the geodesic for the overall surface can be determined. (It has been shown that as the approximated surface converges to the original surface, the geodesic on the approximation converges to the geodesic on the original.)⁽²⁾

Computer programs have been written to compute a geodesic path on a surface of revolution.⁽¹⁾ The necessary input for computing the geodesic path is:

1. Points along the contour of the surface to be wrapped (the straight line joining these points form the approximation of the surface).
2. Initial helix angle at an initial point.
3. Number of circuits per pattern and number of mandrel revolutions per pattern (optional).
4. Advance per circuit (optional).
5. Flag indicating whether to adjust or distort the geodesic to produce one having the desired revolutions per circuit.

Given an initial helix angle at an initial point, a geodesic path is computed. If the circuits per pattern and revolution per pattern are specified, the rotation of the path is linearly distorted (if distort is specified) or a new geodesic having this rotation (if adjust is wanted) is computed to produce a path having the desired rotation.

PAYOUT-EYE POSITION

Once the path on the surface has been found, the problem then is to determine the location of the payout eye so that the filament pulled from the eye is laid along this path on the surface. This information will be procured by computing, for a given point on the surface, the corresponding eye coordinates. The eye axes are shown schematically in Figure 1.

Figure 1. A VERTICAL FILAMENT WINDING MACHINE.

As was done in the previous work,⁽¹⁾ it will be assumed that, locally, the surface to be wrapped is a cone. Let the equation of the surface be (in cylindrical coordinates):

$$r = k_n z + b,$$

where k_n and b are constants. (Here k_n is the slope of the cone dr/dz .) Let the geodesic pass through point P_1 whose coordinates are (r_1, z_1, θ_1) .

Point P_2 lies along the vector which is tangent to the geodesic at P_1 , as shown in Figures 2 and 3. A coordinate frame can be established at P_1 such that the basis is composed of three orthogonal unit vectors, $\bar{e}_1$, $\bar{e}_2$, and $\bar{N}$, where:

$$\bar{e}_1 = \left(k_n / \sqrt{1 + k_n^2} \right) \bar{i} + 0 \bar{j} + \left(1 / \sqrt{1 + k_n^2} \right) \bar{k},$$

vector along meridian,

$$\bar{N} = \left(1 / \sqrt{1 + k_n^2} \right) \bar{i} + 0 \bar{j} - \left(k_n / \sqrt{1 + k_n^2} \right) \bar{k},$$

vector normal to surface, and

Figure 2. POINT ON THE SURFACE OF A CONE AND CORRESPONDING POINT IN THE TANGENT PLANE.

$$\bar{e}_2 = \bar{N} \times \bar{e}_1 = 0\bar{i} + \bar{j} + 0\bar{k}.$$

Then, the vector from P_1 to P_2 is

$$\bar{V} = (\rho \cos \alpha) \bar{e}_1 + (\rho \sin \alpha) \bar{e}_2 + 0\bar{N}, \quad (1)$$

where:

ρ represents the length of the vector from P_1 to P_2 , and

α the helix angle to P_1 .

Figure 3. VECTOR FROM THE SURFACE TO THE EYE IN THE TANGENT PLANE - POSITIVE Z DIRECTION.

Thus, the position vector is:

$$\begin{aligned}
 \bar{R}_2 &= \bar{R}_1 + \bar{V} , \\
 &= [r_1 \bar{i} + 0 \bar{j} + z_1 \bar{k}] + [(\rho \cos \alpha) \bar{e}_1 + (\rho \sin \alpha) \bar{e}_2] , \\
 &= (r_1 \bar{i} + z_1 \bar{k}) + (\rho \cos \alpha) \left[\left(k_n / \sqrt{1 + k_n^2} \right) \bar{i} + \left(1 / \sqrt{1 + k_n^2} \right) \bar{k} \right] + \\
 &\quad (\rho \sin \alpha) \bar{j}, \text{ or} \\
 &= \left[r_1 + \left(k_n \rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right] \bar{i} + (\rho \sin \alpha) \bar{j} + \\
 &\quad \left[z_1 + \left(\rho \sin \alpha / \sqrt{1 + k_n^2} \right) \right] \bar{k}. \quad (2)
 \end{aligned}$$

If the path were being traced in a negative z direction, as shown in Figure 4, Equation 1 would become:

$$\bar{V} = (-\rho \cos \alpha) \bar{e}_1 + (\rho \sin \alpha) \bar{e}_2, \quad (3)$$

Figure 4. VECTOR FROM THE SURFACE TO THE EYE -
NEGATIVE Z DIRECTION.

and Equation 2 would be changed to :

$$\begin{aligned} \vec{R}_2 = & \left[r_1 - \left(k_n \rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right] \vec{i} + (\rho \sin \alpha) \vec{j} + \\ & \left[z_1 - \left(\rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right] \vec{k}. \end{aligned} \quad (4)$$

In any case, $P_2 = (r_2, z_2, \theta_2)$,

where:

$$\begin{aligned} r_2 &= \sqrt{x_2^2 + y_2^2}, \text{ or} \\ r_2 &= \sqrt{\left[r_1 \pm \left(k_n \rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right]^2 + (\rho \sin \alpha)^2}, \end{aligned} \quad (5)$$

$$z_2 = z_1 \pm \rho \cos \alpha / \sqrt{1 + k_n^2}, \text{ and} \quad (6)$$

$$\begin{aligned} \theta_2 &= \theta_1 + \tan^{-1} (y_2 / x_2), \text{ or} \\ \theta_2 &= \theta_1 + \tan^{-1} \left\{ \rho \sin \alpha / \left[r_1 \pm \left(k_n \rho \cos \alpha / \sqrt{1 + k_n^2} \right) \right] \right\}. \end{aligned} \quad (7)$$

In the expression $\pm$, + is for increasing z , and - is for decreasing z .

Thus, corresponding to (r_1, z_1, θ_1) on the surface, as shown in Figure 5, the corresponding eye location is (r_2, z_2, θ_2) whose value is given by Equations 5, 6, and 7.

Figure 5. VECTOR FROM THE SURFACE TO THE EYE ON A SURFACE OF REVOLUTION.

The fourth axis of interest is the rotation of the payout eye about its axis. The filament band is to be fed through a slit which will be normal to the vector from surface to eye. With P_2 located in the X-Z plane (axis of the feed eye along the $\bar{i}$ vector), the vector from surface to eye becomes (Figure 6 shows the projection of this vector into the X-Y plane):

$$\begin{aligned}\bar{V} &= (x_2 - x_1)\bar{i} + (y_2 - y_1)\bar{j} + (z_2 - z_1)\bar{k}, \\ &= [r_2 - r_1 \cos(-\Delta\theta)]\bar{i} + [0 - r_1 \sin(-\Delta\theta)]\bar{j} + (z_2 - z_1)\bar{k}, \text{ or} \\ &= [r_2 - r_1 \cos(\Delta\theta)]\bar{i} + [r_1 \sin(\Delta\theta)]\bar{j} + (z_2 - z_1)\bar{k},\end{aligned}$$

where:

$$\Delta\theta = \theta_2 - \theta_1.$$

Figure 6. PROJECTION OF A FILAMENT VECTOR INTO THE X-Y PLANE.

Let $\bar{w}$ be the vector along the slit in the payout eye. Then $\bar{w}$ will be perpendicular to $\bar{V}$ and $\bar{i}$, or:

$$\begin{aligned}\bar{w} &= \bar{V} \times \bar{i}, \\ &= (z_2 - z_1) \bar{i} - (r \sin \Delta\theta) \bar{k}.\end{aligned}$$

The angle the eye makes with the X-Y plane (the "A" angle) can then be found by:

$$\begin{aligned}\cos A &= \bar{w} \cdot \bar{i} / (|\bar{w}| |\bar{i}|), \\ &= (z_2 - z_1) / \sqrt{(z_2 - z_1)^2 + (r_1 \sin \Delta\theta)^2}.\end{aligned}$$

Thus, Angle A can be found by:

$$A = \tan^{-1} \{ [r_1 \sin (\theta_2 - \theta_1)] / (z_2 - z_1) \}. \quad (8)$$

INTERPOLATING ALONG THE GEODESIC ON THE SURFACE

A numerically controlled machine moves from one commanded position to another such that the motion along each axis is linear within that axis. For the winder, the motion the eye makes will be linear in r , z , and θ in moving from one point to another. Hence, the path traced will not follow a geodesic except in the special case where the surface is cylindrical. To ensure that the path will not deviate more

than some preset tolerance from the geodesic, it may be necessary to interject additional points along the geodesic.

In determining an interpolation scheme, the developed surface is utilized (Figure 7).⁽¹⁾ The geodesic path from P_1 to P_2 is a straight line on the developed

Figure 7. MACHINE MOTION SHOWN ON A DEVELOPED SURFACE.

surface while the machine path will be that of a spiral $\rho = A\phi + B$. The radius of curvature of the spiral is computed at P_1 and used to determine the maximum step that can be taken. If the allowable step is less than the distance from P_1 to P_2 , then a new point, P_3 , is added and the process is continued.

The radius of curvature of the spiral can be found by:

$$R_c = [\rho^2 + (d\rho/d\phi)^2]^{3/2} / [\rho^2 + 2(d\rho/d\phi)^2 - \rho(d^2\rho/d\phi^2)] .$$

Here,

$$d\rho/d\phi = \rho \cos \alpha / \sin \alpha,$$

$$d^2\rho/d\phi^2 = 0, \text{ and}$$

$$\rho = (f_n / |k_n|) r_1,$$

where:

α represents the helix angle,

k_n the slope of the cone,

$$f_n = \sqrt{1 + k_n^2}$$

r_1 the radius of surface at P_1 .

Then, the radius of curvature becomes:

$$R_c = \rho \{1 / [\sin \alpha (1 + \cos^2 \alpha)]\} , \quad (9)$$

$$= f_n r_1^4 / [|k_n| c (2r_1^2 - c^2)] , \quad (10)$$

where:

$$c = r_0 \sin \alpha_0 \quad (\alpha_0 \text{ is the helix angle at some point whose radius is } r_0).$$

The maximum step that can be taken with the distance between a circle of radius, R_c , and the line not exceeding some tolerance, t , is found (see Figure 8) to be:

$$d = 2 \sqrt{2R_c t - t^2} . \quad (11)$$

Figure 8. DISTANCE BETWEEN THE CIRCLE OF RADIUS R_c AND A CORD THAT EQUALS t .

The distance, d , can be used to determine the point P_3 , thus:

$$\begin{aligned} d/\sin \Delta\varphi &= \left[\left(f_n / |k_n| \right) r_1 / \sin (\alpha - \Delta\varphi) \right] , \\ \tan \Delta\varphi &= \left\{ d \sin \alpha / \left[\left(f_n / |k_n| \right) r_1 + d \cos \alpha \right] \right\} , \text{ or} \\ \Delta\varphi &= \tan^{-1} \left\{ dc / \left[\left(f_n / |k_n| \right) r_1^2 + d \sqrt{r_1^2 - c^2} \right] \right\} . \end{aligned} \quad (12)$$

From $\Delta\varphi$, the point $P_3 = (r_3, z_3, \theta_3)$ can be found:

$$\theta_3 = \theta_1 + (f_n / |k_n|) \Delta\varphi , \quad (13)$$

$$r_3 = c / \sin (\alpha - \Delta\varphi) , \text{ and} \quad (14)$$

$$z_3 = (r_1 - r_n) / k_n - z_n . \quad (15)$$

Equations 12 - 15 are derived for the cone when $r_1 < r_2$ (see Figure 7). When going the other direction, $r_1 > r_2$, the equation becomes:

$$\Delta\varphi = \tan^{-1} \left\{ dc / \left[\left(f_n / |k_n| \right) r_1^2 - d \sqrt{r_1^2 - c^2} \right] \right\} , \text{ and} \quad (16)$$

$$r_3 = c / \sin (\alpha + \Delta\varphi) . \quad (17)$$

LOCATING THE PAYOUT EYE TO CLEAR THE MANDREL

In a previous section, equations were developed for locating the payout eye corresponding to a point on the surface. Equations 5 - 8 showed that the eye could be located anywhere along the tangent vector and that the filament would lay on the surface at the desired point. To uniquely locate a position for the eye, another factor must be taken into consideration — the clearance of the eye from the mandrel.

For a tangent vector of length p , the coordinates of the eye can be found. With the payout geometry as shown in Figures 9 and 10, the coordinates of P_2 and P_3 (P_4 and P_5 are used when P_1 is located below the maximum diameter of the part) are then

Figure 9. RELATION OF THE PAYOUT EYE TO THE MANDREL.

Figure 10. ENLARGED VIEW OF THE PAYOUT EYE AND MANDREL.

determined. Using these coordinates, the horizontal clearances d_1 , d_2 , and d_3 can be calculated. If a point defining the mandrel is located between P_2 and P_3 , the horizontal distance from the point on the mandrel and a line connecting P_2 and P_3 is also computed (distance d_4 , as shown in Figure 10). If any of these distances are less than the desired clearance, the vector length, ρ , is increased by an amount $\Delta\rho$ and the procedure continued until all points clear by the desired amount. If all points clear initially, the vector length, ρ , is decreased by $\Delta\rho$ until a further reduction in ρ would produce a clearance less than desired, produce a negative $\Delta\theta$ of the eye, or produce a negative feed of filament through the eye.

This procedure defines the payout point for a given surface point and allows the eye to remain as close as possible to the surface while maintaining a specified horizontal clearance. Staying close to the surface in most cases results in a minimum motion of the eye. There have been cases, however, where this procedure has resulted in a sudden large lengthening of the vector, producing large delta motions of the eye.

Most of these cases were results of wrapping with a low helix angle where shaft interference became a problem. In these cases it would have been desirable to have some of the points preceding this large change with vector lengths greater than that of minimum clearance. This condition could be accomplished by reworking the previous information when a situation such as this arises. At this time, no such routine has been developed to rework the information.

A routine has been written, however, for interjecting additional eye points when a large $\Delta\theta$ of the eye is encountered. If the $\Delta\theta$ from one computed eye position to the next is greater than DTMAX (DTMAX is initialized in subroutine FLWNDR and is currently set at 45°), then subroutine BLKADD is called to add additional eye positions. Additional eye points are computed for $\Delta\theta$ (eye) in increments of 18 degrees (increments of DBA which is currently set at 18° in subroutine BLKADD). This calculation is accomplished by determining the vector length (surface to eye) which will produce the desired θ (eye) coordinate. The remaining eye coordinates are then computed using this vector length. If this eye position will not produce the desired clearance, the r coordinate is set to the minimum value which will give the clearance. Thus, the points added by this routine, if the r coordinate is altered, may not lie along the proper tangent vector. Hence, points added by this routine are preceded by an asterisk in the output listing.

Another undesirable situation which can occur by using the shortest length vector is that of point spacing. The interpolation scheme, previously described, spaces the points along the geodesic on the surface to assure a given tolerance. This scheme would be adequate if the eye were located on the surface. However, since the eye is located in space, equally spaced surface points can produce unequally spaced eye location points. When using a numerically controlled machine, points too closely spaced can slow down the operation since there is a finite minimum block execution time (tape-read time or interpolation time).

A routine, BLKDLT, was written to eliminate points whose eye positions are too closely spaced. This adjustment is accomplished by defining a five-dimensional motion vector whose components are in a sense normalized, that is:

$$\overline{\Delta V} = (\Delta r, \Delta z, \Delta l, \Delta \theta / 15, \Delta A / 25),$$

where:

Δr represents the delta motion of the r axis,

Δz the delta motion of the z axis,

Δl the filament fed,

$\Delta \theta$ the delta mandrel rotation (degrees), and

ΔA the delta eye rotation (degrees).

The norm of this motion vector is defined to be:

$$|\overline{\Delta V}| = |\Delta r| + |\Delta z| + |\Delta l| + |\Delta \theta / 15| + |\Delta A / 25|.$$

The eye positions, as shown on the output listing, are examined and points eliminated until the resulting motion is such that:

$$|\overline{\Delta V}| \geq 1.$$

These remaining points are then written on magnetic tape in the format of APT GO TO points. This tape can be converted to punch card and the cards processed by an APT postprocessor.

FILAMENT FEED

In trying to maintain a constant rate of filament being fed from the eye, it is necessary to compute the length of filament fed as the eye moves from one point to another. If the eye moves from P_1 to P_2 , as shown in Figure 11, then the filament that is fed can be determined, that is:

$$l + \rho_2 = fl + \rho_1, \text{ or}$$

$$fl = l + (\rho_2 - \rho_1),$$

Figure 11. FEED-EYE POSITIONS BEFORE AND AFTER MOTION.

where:

fl represents the filament fed from the eye,

l the filament laid on the surface,

ρ_1 the vector length at the start of motion, and

ρ_2 the vector length at the end of motion.

The filament laid on the surface is computed in the routines which determine the path on the surface. ⁽¹⁾

PLOT OF THE EYE POSITION

In order to better visualize the wrap, computer routines have been written to draw two-dimensional plots of the surface path and the corresponding path of the payout eye. Figures 12 and 13 are illustrations of this type of plot. Shown in Figure 12 is Z (the carriage position) versus θ (the mandrel rotation) for one circuit. The inside plot is the path on the surface and the outer plot is the payout eye, with a line joining corresponding surface and eye points. Figure 13 shows R (the cross carriage) versus Z . These plots are for a 55-degree helix-angle wrap pattern on the mandrel shown in Figure 14.

Figure 12. Z- θ PLOT FOR A WRAP ON THE MANDREL SHOWN IN FIGURE 14.

Figure 13. R-Z PLOT FOR A WRAP ON THE MANDREL SHOWN IN FIGURE 14.

COMPUTER PROGRAM

The computer program consists of a main program and 10 subroutines written in Fortran II language. These routines are described in the Appendix. In addition, several plotting routines for the Gerber Scientific Plotter⁽⁴⁾ are utilized in constructing the plots previously mentioned.

Program Input

The input to the computer program consists of the following:

1. The number of points used in defining the surface.
2. Coordinates of the points defining the surface (straight lines joining these points form the approximation of the surface) in order of increasing z .
3. Desired clearance (eye to mandrel).
4. Tolerance for surface interpolation (allowable deviation of spiral to geodesic).
5. Shaft radii.
6. The number of geodesics to be wrapped, and for each geodesic: (a) coordinates of the initial point, (b) initial helix angle, (c) advance per circuit (revolutions), (d) number of circuits to be wrapped, (e) number of circuits per pattern, (f) number of revolutions per pattern, (g) flag indicating whether to adjust the helix angle or distort the geodesic, (h) flag indicating if plot is wanted, and (i) scale of plot (if desired).

The format for the program input is shown in the Appendix.

If the number of circuits per pattern and revolution per pattern are not specified (left blank), the geodesic wrapped will be that determined by the initial conditions. However, if the circuits per pattern and revolutions per pattern are specified, a new geodesic (if an adjustment is wanted) will be found or the rotation of the computed geodesic distorted (if a distort is wanted) to obtain a path having the desired number of revolutions per circuit.

Program Output

There are two listings for each geodesic computed. The first list shows the input data specifying the geodesic. Also shown on the first list is the total mandrel rotation (degrees) for a circuit, the length of filament laid on the surface during a circuit, and the distortion factor (the computed rotation is multiplied by this factor to achieve the desired number of revolutions per circuit).

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Figure 14. TEST MANDREL WOUND ON A NUMERICALLY CONTROLLED WINDER.

The second listing shows the eye positions corresponding to points along the geodesic on the surface. This list includes the coordinates of the surface point (r_1, z_1, θ_1), the corresponding eye coordinates (r_2, z_2, θ_2), the A angle of the eye, the length of the vector from the surface point to the eye, the filament fed as the eye moves from the previous to the present position, the filament laid on the surface during this motion, and the angular positions, θ and A, in revolutions. Interpolated eye positions (interjected by subroutine BLKADD) are preceded by asterisks.

The first surface point and eye position shown in the list will be located at the maximum diameter of the mandrel. The second eye position shown is the point in space corresponding to that same surface point; that is, the first motion of the eye is from a starting point on the surface to a point in space. This motion is for setup purposes. The eye starts at a known point on the surface and then proceeds through the circuit. The final point listed for the circuit is the same as that of the first space point.

An example of the program output is included in the Appendix.

REFERENCES

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APPENDIX

COMPUTER PROGRAM

The computer program consists of a main program and ten subroutines written in Fortran II. Also, certain plotting routines⁽⁴⁾ for the Gerber Scientific Plotter are utilized in constructing the plots described earlier. The input format is shown in Figure A-1; the deck arrangement is presented in Figure A-2. The Fortran routines are described in the sections that follow.

Main Program WNMAIN

This is the main computer program for determining the winder-eye locations. Payout-eye and vector parameters are initialized here and the input data are read in. Routines for computing the geodesic on the surface and determining the payout-eye location are then called. If plots are wanted, the plotting routine is called.

Subroutine PARMET

This routine computes various parameters for the conical and cylindrical sections that make up the surface. These parameters are stored and used by the other routines called.

Subroutine DELTHA

This routine determines the delta theta (mandrel rotation) on the surface for each section and the total rotation for one circuit. The length of filament laid is also computed. The subroutine argument is the geodesic number.

Subroutine ADJUST

This routine is called to adjust the initial helix angle in order to obtain a geodesic having a predetermined number of revolutions per circuit. The first argument of ADJUST is the geodesic number, the second is the desired number of revolutions per pattern, the third is the desired number of circuits per pattern, the fourth is the number of revolutions per circuit of the geodesic as initially specified, the fifth is the maximum difference that will be allowed between the number of revolutions per circuit of a new geodesic and the revolutions per circuit desired, and the sixth is a flag indicating to the calling program whether or not a geodesic could be found having the desired number of revolutions per circuit.

Subroutine FLWNDR

In this routine, the path on the surface as computed in DELTHA is followed and the routine for computing payout-eye location is called when desired. Path interpolation is performed when the spiral path and geodesic deviate by more than the

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
First Card	Identification Information (to be punched in leader of plot tape)																																																																															
Second Card	M																																																																															
Third Card	R Coordinate of First Defining Point										Z Coordinate of First Defining Point										R Coordinate of Second Defining Point										Z Coordinate of Second Defining Point										R Coordinate of Third Defining Point										Z Coordinate of Third Defining Point																													
Fourth Card	R Coordinate of Fourth Defining Point										Z Coordinate of Fourth Defining Point										R Coordinate of Fifth Defining Point										Z Coordinate of Fifth Defining Point										R Coordinate of Sixth Defining Point										Z Coordinate of Sixth Defining Point																													
...																																																																																
Etc																																																																																
One Card for Every Three Points																																																																																
Next Card	Desired Clearance										Wrap Tolerance										Shaft Radius (bottom of mandrel)										Shaft Radius (top of mandrel)																																																	
Next Card	I	Number of Geodesics to be Wrapped																																																																														
Next Card	R Coordinate of Initial Point										Z Coordinate of Initial Point										Initial Helix Angle										Advance per Circuit (revolutions)										Number of Circuits					Circuits per Pattern					Revolutions per Pattern					J	K	Scale of Plot																						
Next Card	R Coordinate of Initial Point										Z Coordinate of Initial Point										Initial Helix Angle										Advance per Circuit (revolutions)										Number of Circuits					Circuits per Pattern					Revolutions per Pattern					J	K	Scale of Plot																						
...																																																																																
Etc																																																																																
One Card for Each Geodesic	$J = \begin{cases} 0, & \text{Adjust helix angle to produce wrap with desired revolutions per circuit;} \\ 1, & \text{distort geodesic to produce wrap with desired revolutions per circuit.} \end{cases}$ $K = \begin{cases} 0, & \text{No plot wanted;} \\ 1, & \text{plot wanted.} \end{cases}$																																																																															

Figure A-1. PROGRAM INPUT FORMAT.

Figure A-2. PROGRAM DECK ARRANGEMENT.

desired tolerance. If the point on the surface corresponding to a payout-eye position is a defining point of the surface, the average slope is computed and used in locating the eye. It is in this routine that the surface and eye positions are printed as output. The first argument of FLWNDR is the geodesic number. The next four arguments are the cylindrical coordinates and the A angle of the eye at the finish of the previous geodesic (if $I > 1$). (This information can be utilized in transitioning from one geodesic to another.) The fifth argument is the vector length at the last computed eye position. The final argument is the tolerance desired, spiral to geodesic.

Subroutine EYELOC

This routine is called by FLWNDR to determine the position of the payout eye corresponding to a wrap point on the surface. The payout eye is located so that the eye clears the mandrel by the desired amount. It is also in the routine that the A angle of the eye is computed. The first argument of EYELOC is the geodesic number; the next three arguments are the cylindrical coordinates of the point on the surface (r, z, θ); the fifth argument is the last used vector length; the next argument is a flag indicating increasing or decreasing Z (going up or down part); the next two arguments are the average slope, k_n , and $\sqrt{1 + k_n^2}$ for that slope; and the ninth argument is the theta coordinate of the previous eye position. The routine returns with the next four arguments which are the coordinates and the A angle of the payout eye. The final argument is the length of filament laid on the surface in making the present motion.

Subroutine BLKADD

This routine is called when a large $\Delta\theta$ of the eye is encountered. Additional eye positions are computed for $\Delta\theta$ (eye) in increments of DBA, which is currently set in this routine at 18 degrees. The first argument of BLKADD is the geodesic number; the next five arguments are the surface coordinates (r, z, θ), the surface slope, and the θ coordinate of the eye at the beginning of the motion; the next five arguments are the surface coordinates (r, z, θ), the surface slope, and the θ coordinate at the end of the motion; the twelfth argument is the length of filament fed from the eye during the motion, and the thirteenth is the length of filament laid on the surface. The final argument is a flag indicating increasing or decreasing Z (going up or down part).

Subroutine BLKDLT

This routine is called by subroutine FLWNDR when all of the eye positions for a geodesic have been computed. The function of the routine is to eliminate eye points which are too closely spaced. A normalized five-dimensional motion vector is constructed. The eye positions, as shown on the output listing, are examined and points eliminated until the resulting motion is greater than the established minimum. The remaining points are written on magnetic tape in APT format as GO TO points. The single argument of this routine is the number of computed eye positions for the geodesic.

Subroutine RMANDL

This routine determines the mandrel radius for a given Z coordinate. This radius is used to compute eye clearance. If Z is less than z_1 , or greater than z_m , the appropriate shaft radius is used. The first argument is the Z coordinate and the routine returns with the second argument, the radius of the mandrel.

Subroutine TZZPPT

This is the routine used in making the Z- θ and R-Z plots. The first two arguments are the coordinates of the origin for the plots. The routine produces two plots each having their origin at (XO, YO). The third argument is the scale for the Z axis of Z- θ plot and the fourth argument is the length for the theta axis. The fifth argument of TZZPPT is the scale for the R-Z plot.

Subroutine AXPLLOT

This routine, called by TZZPPT, is an axis generator. Its purpose is to draw and label the axes for a plot.

EXAMPLE OF PROGRAM USAGE

As Example 1, two geodesics are computed for the mandrel shown in Figure 14. This mandrel is basically a cylinder joined on each end by cones having considerably different slopes. The ends of the mandrel are flat plates. Twenty-one points were used in defining the contour of the surface as shown in Figure A-3. The program input is presented in Figure A-4. The program output for this example is outlined in Table A-1.

Figure A-3. CONTOUR OF SURFACE USED IN EXAMPLE.

Table A-1
PRINTOUT FOR EXAMPLE

GEODESIC	HELIX ANGLE	AT R	POINT Z	TOTAL ROTATION	DISTORT FACTOR	FILMNT LENGTH	NO. OF CIRCUITS	CIRC PER PATTERN	REV PER PATTERN	ADVANCE PER CIR	WRAP TOLERANCE	CLEAR- ANCE
:	18.03	18.0000	20.0000	495.66	1.0000	145.50	897	69	95	0.00002	0.050	1.000

** WRAP POINT ON MANDREL	THETA	** EYE LOCATION IN SPACE	** VECTOR	FILMT	FILMT	B ANGLE	A ANGLE
R Z		R Z THETA	LENGTH	FED	DOWN	(REV)	(REV)
18.0000	14.3604	0.	18.0000	14.3604	0.	180.00	0.50000
18.0000	14.3604	0.	18.0000	24.6478	10.20	162.79	0.45217
18.0000	15.3153	0.99	18.3486	26.2505	12.18	162.29	0.45081
18.0000	16.2702	1.98	18.2988	26.3877	12.35	162.25	0.45068
18.0000	17.2251	2.97	18.2517	26.5058	12.50	162.20	0.45056
18.0000	18.1800	3.96	18.2086	26.6239	12.64	162.16	0.45045
18.0000	19.1348	4.95	18.1687	26.7229	12.76	162.12	0.45035
18.0000	20.0897	5.94	18.1329	26.8220	12.88	162.09	0.45026
18.0000	21.0446	6.93	18.1007	26.9021	12.97	162.06	0.45018
18.0000	21.9995	7.92	18.0729	26.9822	13.06	162.04	0.45010
18.0000	22.9544	8.90	18.0491	27.0432	13.13	162.02	0.45004
18.0000	23.9093	9.89	17.8140	27.6679	13.84	161.76	0.44934
17.9854	24.0295	10.02	16.7057	30.6281	17.58	160.26	0.44517
17.9682	24.0849	10.08	14.1738	37.3774	28.94	156.39	0.43442
16.0156	29.2917	16.61	12.2274	42.5648	42.09	152.57	0.42380
14.2913	33.8899	23.98	11.2963	45.0473	50.51	150.23	0.41731
12.7712	37.9437	32.30	10.4534	47.2958	59.89	147.68	0.41023
11.4341	41.5091	41.69	9.6952	49.3259	70.40	144.90	0.40250
10.2620	44.6347	52.28	9.0199	51.1139	82.02	141.85	0.39402
9.2395	47.3615	64.25	8.4244	52.7096	95.08	138.48	0.38466
8.3537	49.7235	77.77	7.9079	54.0909	109.64	134.72	0.37422
7.5948	51.7472	93.02	7.4703	55.2597	125.85	130.47	0.36242
6.9560	53.4508	110.21	7.1130	56.2089	143.85	125.59	0.34887
6.4748	54.7341	127.72	6.7209	56.6613	158.87	119.92	0.33311
6.1217	55.6756	145.24	6.3915	57.0134	175.51	113.44	0.31511
6.0645	55.7847	147.86	6.3363	57.0817	183.51	110.15	0.30597
5.9846	55.8747	150.64	6.4154	56.9941	193.87	105.28	0.29243
5.8855	55.9429	153.81	6.6850	56.7037	203.46	99.63	0.27674
5.7729	55.9855	157.68	7.0825	56.2630	210.67	93.45	0.25957
5.6535	56.0000	163.13	7.1997	56.0000	212.20	90.00	0.25000
5.5714	56.0000	172.90	7.2122	56.0000	212.33	90.00	0.25000
5.6535	56.0000	182.68	7.2248	56.0000	212.45	90.00	0.25000
5.7729	55.9855	188.13	7.2585	55.8359	212.97	86.47	0.24019
5.8855	55.9429	192.00	7.3780	55.5074	215.27	79.39	0.22054
5.9846	55.8747	195.17	7.5283	55.1015	218.94	72.23	0.20064
6.0645	55.7847	197.95	7.7228	54.5780	224.37	65.90	0.18307
6.1217	55.6756	200.57	7.9272	54.0279	230.61	61.73	0.17148
6.5446	54.5478	220.98	8.6875	52.0129	251.36	52.55	0.14596
7.0705	53.1454	239.09	9.5306	49.7672	268.07	45.40	0.12611
7.6956	51.4785	255.07	10.5163	47.1381	282.63	39.36	0.10933

Table A-1 (Continued)

8.4205	49.5455	269.19	11.6553	44.0975	295.33	34.25	7.76	3.903	2.863	0.82036	0.09514
9.2492	47.3357	281.68	12.9600	40.6092	306.41	29.91	9.00	4.285	3.045	0.85115	0.08308
10.1883	44.8312	292.76	14.4635	36.6001	316.15	26.17	10.50	4.767	3.267	0.87820	0.07269
11.2468	42.0026	302.60	16.1888	32.0043	324.71	22.93	12.30	5.331	3.531	0.90198	0.06371
12.4354	38.8391	311.37	18.1507	26.7683	332.22	20.14	14.42	5.958	3.838	0.92283	0.05594
13.7667	35.2888	319.19	19.0013	23.5415	336.18	18.90	13.72	3.491	4.191	0.93382	0.05251
15.2554	31.3191	326.17	19.0061	22.3237	337.61	18.59	10.32	1.153	4.593	0.93780	0.05163
16.4940	28.0162	330.95	19.0072	21.7239	338.24	18.40	7.14	0.588	3.768	0.93955	0.05110
17.9682	24.0849	335.73	19.0064	21.1351	338.80	18.05	3.28	0.577	4.437	0.94110	0.05015
17.9854	24.0295	335.79	19.0026	19.5872	340.26	17.51	4.78	1.561	0.061	0.94516	0.04864
18.0000	23.9093	335.92	18.9269	13.6018	346.15	17.23	10.86	6.207	0.127	0.96151	0.04786
18.0000	22.9544	336.90	18.2955	12.8941	347.22	17.76	10.58	0.724	1.004	0.96449	0.04933
18.0000	21.9995	337.89	18.2456	12.8331	347.31	17.80	9.64	0.064	1.004	0.96474	0.04945
18.0000	21.0446	338.88	18.1994	12.7910	347.37	17.85	8.68	0.044	1.004	0.96492	0.04957
18.0000	20.0897	339.87	18.1579	12.7490	347.43	17.88	7.72	0.044	1.004	0.96510	0.04968
18.0000	19.1348	340.86	18.1212	12.7070	347.49	17.92	6.76	0.044	1.004	0.96526	0.04977
18.0000	18.1800	341.85	18.0893	12.6650	347.55	17.95	5.80	0.044	1.004	0.96541	0.04985
18.0000	17.2251	342.84	18.0617	12.6419	347.58	17.97	4.82	0.024	1.004	0.96550	0.04992
18.0000	16.2702	343.83	18.0392	12.6189	347.61	17.99	3.84	0.024	1.004	0.96558	0.04998
18.0000	15.3153	344.82	18.0218	12.5959	347.64	18.01	2.86	0.024	1.004	0.96565	0.05003
18.0000	14.3604	345.81	17.8916	12.4525	347.79	18.17	2.00	0.144	1.004	0.96609	0.05046
17.9845	14.2369	345.94	17.4063	11.9359	348.49	19.17	2.50	0.631	0.131	0.96802	0.05326
17.9391	14.1211	346.07	15.8780	10.3002	351.23	22.90	4.60	2.231	0.131	0.97564	0.06361
17.8664	14.0202	346.20	10.7677	5.9158	366.18	36.99	11.80	7.331	0.131	1.01717	0.10276
** 17.8318	13.9911	346.25	8.0091	4.4259	384.18	48.89	15.76	2.715	0.048	1.06717	0.13581
** 17.8014	13.9657	346.29	6.8691	4.3027	399.94	56.02	17.68	2.378	0.042	1.11095	0.15562
17.7711	13.9402	346.33	6.4115	4.4701	415.70	60.34	19.14	2.378	0.042	1.15474	0.16762
** 17.7296	13.9203	346.38	6.4765	5.0734	433.70	63.46	20.59	2.110	0.048	1.20474	0.17627
** 17.6939	13.9032	346.42	7.1771	5.3552	449.23	63.64	22.23	1.821	0.042	1.24787	0.17679
17.6581	13.8860	346.46	8.8727	5.2862	464.76	61.05	24.76	1.821	0.042	1.29101	0.16959
14.5255	12.8418	350.85	10.9116	5.9615	474.94	60.23	23.56	2.322	3.522	1.31928	0.16731
12.0027	12.0009	356.23	11.3128	6.1022	476.45	60.37	21.06	0.434	2.934	1.32347	0.16770
9.9868	11.3289	362.82	11.8762	6.2902	478.41	60.78	19.20	0.610	2.470	1.32892	0.16882
8.3989	10.7596	370.88	12.4585	6.6113	480.42	62.11	17.70	0.612	2.112	1.33449	0.17254
7.1822	10.3541	380.70	12.9391	7.1334	482.29	65.13	16.34	0.487	1.847	1.33970	0.18093
6.5225	10.1742	388.92	13.3945	7.6060	483.99	68.43	15.62	0.483	1.203	1.34440	0.19009
6.0767	10.0256	397.14	13.9749	8.2515	486.09	73.72	15.24	0.638	1.018	1.35025	0.20478
6.0297	10.0124	398.23	14.4522	8.7533	487.50	78.20	15.64	0.525	0.125	1.35418	0.21723
5.9816	10.0040	399.39	15.1079	9.4573	488.99	84.78	16.22	0.711	0.131	1.35832	0.23549
5.9185	10.0000	401.01	15.6108	10.0000	489.82	90.00	16.58	0.540	0.180	1.36062	0.25000
5.6550	10.0000	410.87	15.6189	10.0000	489.84	90.00	15.56	0.009	1.029	1.36065	0.25000
5.5714	10.0000	420.73	15.6266	10.0000	489.85	90.00	14.60	0.008	0.968	1.36068	0.25000
5.6550	10.0000	430.59	15.6344	10.0000	489.86	90.00	13.64	0.008	0.968	1.36071	0.25000
5.9185	10.0000	440.45	15.6424	10.0000	489.87	90.00	12.62	0.009	1.029	1.36075	0.25000
5.9816	10.0040	442.08	16.0034	10.4368	490.43	95.53	12.84	0.400	0.180	1.36232	0.26536
6.0297	10.0124	443.24	16.6252	11.0944	491.56	103.51	13.44	0.731	0.131	1.36545	0.28752
6.0767	10.0256	444.32	17.1449	11.6507	492.61	109.71	13.96	0.645	0.125	1.36837	0.30475
6.7984	10.2662	456.38	18.1571	12.7523	494.64	120.56	13.72	1.309	1.549	1.37399	0.33490
7.7814	10.5938	466.19	18.8121	13.4548	495.75	126.70	12.96	0.860	1.620	1.37707	0.35195
9.0209	11.0070	474.18	19.0169	13.8769	496.20	130.33	11.54	0.332	1.752	1.37832	0.36202
10.5364	11.5121	480.74	19.0133	14.1047	496.32	132.49	9.66	0.068	1.948	1.37868	0.36802
12.3636	12.1212	486.16	19.0177	14.2383	496.39	133.94	7.50	0.048	2.208	1.37887	0.37205

Table A-1 (Continued)

14.5050	12.8350	490.58	19.0181	14.3064	496.42	134.90	5.04	0.023	2.483	1.37895	0.37473
17.6581	13.8860	495.00	19.0061	14.4138	496.45	139.84	1.52	0.026	3.546	1.37902	0.38843
17.7711	13.9402	495.14	19.0087	14.6921	496.57	149.36	1.52	0.132	0.132	1.37937	0.41489
17.8664	14.0202	495.27	19.0030	15.2013	496.89	156.88	1.72	0.331	0.131	1.38024	0.43579
17.9321	14.1211	495.40	19.0057	16.0147	497.53	160.56	2.28	0.651	0.131	1.38204	0.44501
17.9845	14.2369	495.53	19.0035	18.0105	499.36	162.33	4.10	1.951	0.131	1.38711	0.45093
18.0000	14.3604	495.66	18.9450	24.6478	505.86	162.78	10.84	6.871	0.131	1.40516	0.45217

GEODESIC	HELIX ANGLE	AT R	POINT Z	TOTAL ROTATION	DISTORT FACTOR	FILMNT LENGTH	NO. OF CIRCUITS	CIRC PER PATTERN	REV PER PATTERN	ADVANCE PER CIR	WRAP TOLERANCE	CLEAR- ANCE
2	55.56	18.0000	20.0000	360.71	1.0000	114.46	510	1	1	0.00197	0.050	1.000

**	WRAP POINT ON MANDREL			**	EYE LOCATION IN SPACE			**	VECTOR	FILMT	FILMT	B ANGLE	A ANGLE
R	Z	THETA	R	Z	THETA	A ANGLE	LENGTH	FED	DOWN	(REV)	(REV)		
18.0000	14.3604	0.	18.9450	24.6478	0.	162.78				0.	0.45217		
18.0000	14.3604	0.	19.0021	18.0290	16.39	125.85	6.50	-4.340	0.	0.04552	0.34957		
18.0000	15.3153	4.43	19.0012	19.4888	23.12	125.90	7.38	2.569	1.689	0.06421	0.34972		
18.0000	16.2702	8.87	19.0012	20.4436	27.55	125.90	7.38	1.689	1.689	0.07652	0.34972		
18.0000	17.2251	13.30	19.0012	21.3985	31.98	125.90	7.38	1.689	1.689	0.08884	0.34972		
18.0000	18.1800	17.73	19.0012	22.3534	36.41	125.90	7.38	1.689	1.689	0.10115	0.34972		
18.0000	19.1348	22.16	19.0012	23.3083	40.85	125.90	7.38	1.689	1.689	0.11346	0.34972		
18.0000	20.0897	26.60	19.0012	24.2632	45.28	125.90	7.38	1.689	1.689	0.12578	0.34972		
18.0000	21.0446	31.03	18.8583	24.9014	48.38	125.69	6.82	1.129	1.689	0.13440	0.34915		
18.0000	21.9995	35.46	18.6678	25.3926	50.83	125.42	6.00	0.869	1.689	0.14121	0.34838		
18.0000	22.9544	39.90	18.4924	25.8611	53.15	125.16	5.14	0.829	1.689	0.14763	0.34767		
18.0000	23.9093	44.33	18.2439	26.5171	56.38	124.75	4.62	1.169	1.689	0.15662	0.34653		
17.9854	24.0295	44.89	17.9575	27.2962	60.68	123.72	5.92	1.514	0.214	0.16856	0.34367		
17.9682	24.0849	45.16	17.6966	27.9860	65.15	122.43	7.32	1.503	0.103	0.18096	0.34008		
17.1567	26.2488	57.13	17.0732	29.6471	78.66	118.36	7.24	4.255	4.335	0.21850	0.32878		
16.4598	28.1074	69.94	16.6105	30.8736	91.74	114.35	6.84	3.848	4.248	0.25484	0.31763		
15.8805	29.6520	83.57	16.2583	31.8268	105.66	110.01	6.54	3.865	4.185	0.29351	0.30559		
15.4238	30.8699	97.98	16.0159	32.4703	120.23	105.33	6.30	3.904	4.144	0.33398	0.29257		
15.0956	31.7453	113.07	15.8961	32.7878	135.39	100.30	6.14	3.962	4.122	0.37608	0.27862		
14.9072	32.2475	127.94	15.9030	32.7641	150.24	95.22	6.06	3.850	3.930	0.41734	0.26449		
14.8453	32.4126	142.82	16.0345	32.4126	165.02	90.00	6.06	3.865	3.865	0.45840	0.25000		
14.9153	32.2259	158.64	16.3120	31.6695	180.64	84.31	6.14	4.191	4.111	0.50177	0.23420		
15.1235	31.6709	174.16	16.7391	30.5412	195.92	78.60	6.32	4.291	4.111	0.54421	0.21835		
15.4644	30.7618	189.15	17.3055	29.0361	210.55	73.00	6.58	4.374	4.114	0.58487	0.20278		
15.9307	29.5182	203.40	17.9974	27.1743	224.33	67.62	6.90	4.444	4.124	0.62315	0.18782		
16.5149	27.9605	216.83	18.8373	24.9493	237.33	62.50	7.34	4.587	4.147	0.65925	0.17361		
17.1657	26.2248	228.65	19.0050	23.3384	244.88	58.96	6.14	2.738	3.938	0.68021	0.16377		
17.9682	24.0849	240.48	19.0016	21.9319	250.59	55.70	4.04	2.184	4.284	0.69609	0.15472		
17.9854	24.0295	240.75	19.0047	21.3256	253.03	54.76	4.90	0.963	0.103	0.70287	0.15212		
18.0000	23.9093	241.31	19.0003	20.2290	257.75	54.15	6.52	1.834	0.214	0.71597	0.15043		
18.0000	22.9544	245.74	19.0012	18.7810	264.43	54.10	7.38	2.549	1.689	0.73452	0.15028		

Table A-1 (Continued)

18.0000	21.9995	250.18	19.0012	17.8261	268.86	54.10	7.38	1.689	1.689	0.74683	0.15028
18.0000	21.0446	254.61	19.0012	16.8712	273.29	54.10	7.38	1.689	1.689	0.75914	0.15028
18.0000	20.0897	259.04	19.0012	15.9163	277.72	54.10	7.38	1.689	1.689	0.77146	0.15028
18.0000	19.1348	263.47	19.0012	14.9614	282.16	54.10	7.38	1.689	1.689	0.78377	0.15028
18.0000	18.1800	267.91	19.0012	14.0065	286.59	54.10	7.38	1.689	1.689	0.79608	0.15028
18.0000	17.2251	272.34	18.8194	13.4588	289.31	54.36	6.66	0.969	1.689	0.80364	0.15101
18.0000	16.2702	276.77	18.5547	13.1825	290.82	54.75	5.46	0.469	1.689	0.80783	0.15207
18.0000	15.3153	281.21	18.3303	12.9402	292.10	55.07	4.20	0.429	1.689	0.81138	0.15299
18.0000	14.3604	285.64	18.0656	12.6559	293.56	55.52	3.02	0.509	1.689	0.81545	0.15422
17.9845	14.2369	286.22	17.7263	12.2915	295.76	56.87	3.56	0.760	0.220	0.82155	0.15798
17.9391	14.1211	286.80	17.0723	11.5798	301.34	60.57	5.18	1.841	0.221	0.83706	0.16824
17.8664	14.0202	287.39	16.2154	10.6577	312.75	66.28	8.36	3.403	0.223	0.86876	0.18412
17.7711	13.9402	287.99	15.8815	10.2969	329.99	72.96	12.72	4.565	0.225	0.91663	0.20268
17.6581	13.8860	288.62	16.3481	10.8060	341.66	77.69	15.54	3.050	0.230	0.94907	0.21580
16.4476	13.4825	296.29	16.9589	11.4595	348.56	81.16	14.86	1.935	2.615	0.96823	0.22544
15.5617	13.1872	304.78	17.3826	11.9125	352.30	83.66	13.44	1.124	2.544	0.97862	0.23240
15.0203	13.0068	313.95	17.8549	12.4253	355.91	86.69	12.08	1.150	2.510	0.98864	0.24080
14.8453	12.9484	323.17	18.3464	12.9484	359.16	90.00	10.78	1.110	2.410	0.99766	0.25000
15.0336	13.0112	332.74	18.8305	13.4761	362.00	93.62	9.32	1.040	2.500	1.00555	0.26006
15.5849	13.1949	341.85	19.0102	13.8976	363.31	97.03	7.30	0.481	2.501	1.00919	0.26952
16.4140	13.4713	349.79	19.0084	14.1512	363.67	99.80	5.04	0.121	2.381	1.01019	0.27722
17.6581	13.8860	357.73	19.0105	14.3735	363.98	104.24	2.46	0.118	2.698	1.01105	0.28956
17.7711	13.9402	358.35	19.0031	14.6276	364.41	110.14	2.40	0.170	0.230	1.01225	0.30593
17.8664	14.0202	358.96	19.0083	15.0820	365.58	117.25	2.64	0.465	0.225	1.01551	0.32569
17.9391	14.1211	359.55	19.0056	15.7008	367.61	122.13	3.22	0.803	0.223	1.02113	0.33926
17.9845	14.2369	360.13	19.0058	16.7288	371.55	124.98	4.56	1.561	0.221	1.03209	0.34716
18.0000	14.3604	360.71	19.0021	18.0290	377.10	125.85	6.50	2.160	0.220	1.04749	0.34957

TOTAL FILAMENT LENGTH # 5246.75 YARDS

PROGRAM LISTING

Main Program WNMAIN

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CWNMAIN      MAIN PROGRAM FOR WINDER CALCULATIONS
      DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
      1RO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
      2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
      COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHA0,CONS,W,D,THICK,NC,RT,ZT,
      1SMAX,RMAX,ZMAX,THMAX,-J,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
      2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
      COMMON AA,BB,CC,DEL,DELRHO,NSTART
      COMMON LLL , RHOMIN , FR , TMIN
      10 READ INPUT TAPE 5 , 4050, ( TITLE(K) , K # 1 , 6 )
      4050 FORMAT ( 6A6 )
      C READ NUMBER OF DEFINING POINTS
      READ INPUT TAPE 5 , 4000 , M
      4000 FORMAT ( 14 )
      C READ IN COORDINATES OF DEFINING POINTS
      READ INPUT TAPE 5 , 4010 , ( R(N) , Z(N) , N # 1 , M )
      4010 FORMAT ( 6F12.6 )
      C READ CLEARANCE , TOLERANCE , AND SHAFT RADII
      READ INPUT TAPE 5 , 4010 , DEL , TOL , SHAFT1 , SHAFT2
      C INITIALIZE EYE DIMENSIONS A , B , C
      AA # .5
      BB # 6.5
      CC # 7.0
      C INITIALIZE INCREMENT DELTA RHO
      DELRHO # .020
      C INITIALIZE MINIMUM VECTOR LENGTH
      RHOMIN # .5
      PI # 3.1415927
      FLTOTL # 0.0
      C COMPUTE SECTION PARAMETERS
      CALL PARMET
      C READ NUMBR OF GEODESICS
      READ INPUT TAPE 5 , 4000 , NOGEOD
      REWIND 8
      C START OF LOOP FOR EACH GEODESIC TO BE WRAPPED
      DO 500 I # 1 , NOGEOD
      DISTRT # 1.0
      C READ GEODESIC DEFINING INFORMATION
      READ INPUT TAPE 5 , 4020 , RO(I),ZO(I),ALPHA0(I),ADVNCE,NC(I),
      1 NCPERP, NREVPT, LA , IPLOT , ZSCALE
      4020 FORMAT ( 4F12.6 , 3I6 , 2I3 , F4.2 )
      IF ( ZO(I) ) 12 , 12 , 27
      12 DO 15 N # 2 , M
      IF ( RO(I) - R(N) ) 25 , 20 , 15
      15 CONTINUE
      WRITE OUTPUT TAPE 6 , 2050 , I , RO(I)
      2050 FORMAT ( 44H3 COULD NOT LOCATE INITIAL POINT OF GEODESIC , 13 ,
      1 25H USING INITIAL RADIUS OF , F7.3 , 18H THIS ONE SKIPPED )
      GO TO 500
      20 N # N + 1
      25 NSTART # N - 1
      IF ( AK(NSTART) ) 30 , 35 , 30
      30 ZO(I) # ( RO(I) - R(NSTART) ) / AK(NSTART) + Z(NSTART)
      GO TO 37
      35 ZO(I) # Z(NSTART)
      37 CONTINUE

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C  COMPUTE GEODESIC PATH ON THE SURFACE
      CALL DELTHA ( I )
      NLOW # NLOW
      NHIGH # NHIGH
C  ARE THE NUMBER OF CIRCUITS PER PATTERN SPECIFIED
      IF ( NCPERP ) 150 , 150 , 110
110 RVN # TSUM / 360.0
      FRACT # RVN
      NB # NCPERP
      NA # NREVPT
      IF ( LA ) 120 , 120 , 130
120 EPS # .000001
C  COMPUTE NEW GEODESIC HAVING DESIRED NUMBER OF REVOLUTIONS PER CIRCUIT
      CALL ADJUST ( I , NA , NB , FRACT , EPS , LL )
      NLOW # NLOW
      NHIGH # NHIGH
      IF ( LL ) 150 , 150 , 130
130 CONTINUE
      RVN2 # FLOATF(NA) / FLOATF(NB) + ADVNCE
      DISTRT # RVN2 / RVN
      DO 140 N # NLOW , NHIGH
        DTHETA(N) # DTHETA(N) * DISTRT
140 CONTINUE
      TSUM # TSUM * DISTRT
150 CONTINUE
C  COMPUTE TURNAROUND PARALLELS
      ZLOW # ( CONS(I) - R(NLOW) ) / AK(NLOW) + Z(NLOW)
      ZHIGH # ( CONS(I) - R(NHIGH) ) / AK(NHIGH) + Z(NHIGH)
      WRITE OUTPUT TAPE 6 ; 5000
5000 FORMAT ( 120H1          HELIX          AT POINT          TOTAL  DISTOR
      IT FILMNT NO. OF CIRC PER REV PER ADVANCE          WRAP    CLEAR
      2- / 120H GEODESIC ANGLE      R      Z      ROTATION FACTOR  LE
      3NGTH CIRCUITS PATTERN PATTERN PER CIR  TOLERNCE  ANCE  )
      WRITE OUTPUT TAPE 6 , 5010 , I , ALPHA0(I) , RO(I) , ZO(I) , TSUM ,
      I DISTRT , FLSUM , NC(I) , NCPERP , NREVPT , ADVNCE , TOL , DEL
5010 FORMAT ( 1H0 , I4,F10.2,2F10.4,F10.2,F8.4,F9.2,2I8,I9,F12.5,2F10.3)
C  COMPUTE WINDER EYE COORDINATES FOR GEODESIC ON THE SURFACE
      CALL FLWNR ( I , RPI , ZPI , TPI , AANGLI , RHOI , TOL )
      FLTOTL # FLTOTL + FLSUM * FLOATF ( NC(I) )
C  PLOT WANTED
      IF ( IPLOT ) 500 , 500 , 170
C  CALL PLOTTING ROUTINE
170 CALL TZZPPT ( 0.0 , 0.0 , ZSCALE , 10.0 , ZSCALE )
500 CONTINUE
C  END LOOP
      FLTOT # FLTOTL / 36.0
      WRITE OUTPUT TAPE 6 , 5050 , FLTOT
5050 FORMAT ( 24H0TOTAL FILAMENT LENGTH # , F10.2 , 6H YARDS )
      GO TO 10
      END

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*LABEL

Subroutine PARMET

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CPARMET          COMPUTE SECTION PARAMETERS
      SUBROUTINE PARMET
      DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
      IRO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
      2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
      COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHAC,CONS,W,D,THICK,NC,RT,ZT,

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    ISMAX,RMAX,ZMAX,THMAX,JJ,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
    2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
    XI(1) # 0.0
    MM # M - 1
    RMAX # R(1)
    DO 1200 N # 1 , MM
    IF ( ABSF( Z(N) - Z(N+1) ) - .0001 ) 1010 , 1010 , 1040
1010 IF ( R(N+1) - R(N) ) 1020 , 1020 , 1030
1020 AK(N) # - ( 1.0E 20 )
    GO TO 1035
1030 AK(N) # 1.0 E 20
1035 F(N) # 1.0 E 20
    XI(N+1) # XI(N) + ABSF( R(N+1) - R(N) )
    GO TO 1200
1040 AK(N) # ( R(N+1) - R(N) ) / ( Z(N+1) - Z(N) )
    IF ( ABSF( AK(N) ) - .0001 ) 1050 , 1050 , 1100
1050 AK(N) # 0.0
1100 F(N) # SQRT( 1.0 + AK(N)**2 )
    XI(N+1) # XI(N) + ( Z(N+1) - Z(N) ) * F(N)
1200 RMAX # MAX( R(N+1) , RMAX )
    ZMAX # Z(M)
    RETURN
    END

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*LABEL

Subroutine DELTHA

```

CDELTHA      COMPUTE DELTA THETAS FOR GEODESIC I
SUBROUTINE DELTHA ( I )
    DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
    IRO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
    2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
    COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHA0,CONS,W,D,THICK,NC,RT,ZT,
    ISMAX,RMAX,ZMAX,THMAX,JJ,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
    2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
    CONV # 100.0 / PI
    CONS(1) # RO(1) * SINF ( ALPHA0(1) / CONV )
    DO 20 N # 2 , M
    IF ( ZO(1) - Z(N) ) 40 , 30 , 20
20 CONTINUE
30 IF ( ALPHA0(1) - 90.7 ) 30 , 33 , 38
33 IF ( AK(N) ) 40 , 40 , 38
38 N # N + 1
40 NSTART # N - 1
    IF ( CONS(1) - R(1) ) 150 , 45 , 45
45 J # NSTART + 1
50 J # J - 1
    IF ( R(J) - CONS(1) ) 60 , 60 , 50
60 NLOW # J
    IF ( CONS(1) - R(M) ) 150 , 70 , 70
70 J # NSTART
80 J # J + 1
    IF ( R(J) - CONS(1) ) 90 , 90 , 80
90 NHIGH # J - 1
    FOK # F(NLOW) / AK(NLOW)
    NLI # NLOW + 1
    TERM # ( R(NLI) / CONS(1) )**2 - 1.0
    IF ( TERM ) 92 , 92 , 95
92 ASEC2 # 0.0

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      GO TO 98
95  ASEC2 # ATANF ( SQRTF ( TERM ) )
98  DBETA # ASEC2
     DTHETA(NLOW) # FOK * DBETA * CONV
     FLNGTH(NLOW) # R(NLI) * FOK * SIN( DBETA )
     NHI # NHIGH - 1
     IF ( NHI - NLI ) 135 , 100 , 100
100 DO 130 N # NLI , NHI
     IF ( AK(N) ) 120 , 110 , 120
110 DBETA#CONS(I)*(Z(N+1)-Z(N)) / (R(N)*SQRTF(R(N)**2 - CONS(I)**2))
     DTHETA(N) # DBETA * CONV
     FLNGTH(N) # SQRTF(( Z(N+1)-Z(N))**2 + (R(N)*DBETA)**2 )
     GO TO 130
120 FOK # ABSF( F(N) / AK(N) )
     ASEC1 # ASEC2
     TERM # ( R(N+1) / CONS(I) )**2 - 1.0
     IF ( TERM ) 122 , 122 , 125
122 ASEC2 # 0.0
     GO TO 126
125 ASEC2 # ATANF ( SQRTF ( TERM ) )
126 DBETA # ABSF ( ASEC2 - ASEC1 )
     DTHETA(N) # FOK * DBETA * CONV
     RN2 # R(N) * FOK
     RN3 # R(N+1) * FOK
     TERM # RN2**2 + RN3**2 - 2.0 * RN2 * RN3 * COSF ( DBETA )
     IF ( TERM ) 127 , 127 , 129
127 FLNGTH(N) # 0.0
     GO TO 130
129 FLNGTH(N) # SQRTF ( TERM )
130 CONTINUE
135 CONTINUE
     FOK # ABSF ( F(NHIGH) / AK(NHIGH) )
     DBETA # ABSF ( ASEC2 )
     DTHETA(NHIGH) # FOK * DBETA * CONV
     FLNGTH(NHIGH) # FOK * R(NHIGH) * SIN( DBETA )
     TSUM # 0.0
     FLSUM # 0.0
     DO 140 N # NLOW , NHIGH
     TSUM # TSUM + DTHETA(N)
140 FLSUM # FLSUM + FLNGTH(N)
     TSUM # 2.0 * TSUM
     FLSUM # 2.0 * FLSUM
     GO TO 160
150 CONS(I) # MAXIF ( R(I) , R(M) )
     ALPHA0(I) # ATANF( CONS(I)/ SQRTF( RO(I)**2 - CONS(I)**2) ) * CONV
     WRITE OUTPUT TAPE 6 , 8000 , I , ALPHA0(I)
8000 FORMAT ( 33H0 TURN-AROUND RADIUS FOR GEODESIC ,I3 , 56H IS LESS T
     HAN R(I) OR R(M) - STARTING ANGLE CHANGED TO , F10.6 )
     GO TO 45
160 CONTINUE
     RETURN
     END

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*LABEL

Subroutine ADJUST

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CADJUST  ADJUST STARTING HELIX ANGLE
          SUBROUTINE ADJUST ( I, NA , NB , FRACT , EPS , LL )
          DIMENSION R(1000),Z(1000),AK(1000),F(1000),X1(1000),TITLE(12),
          RO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),

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```

2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHAO,CONS,W,D,THICK,NC,RT,ZT,
ISMAR,RMAX,ZMAX,THMAX,JJ,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
CONV # 180.0 / PI
ITER # 0
AZERO # ALPHAO(1)
RZERO # RO(1)
ZZERO # ZO(1)
C # CONS(1)
IF ( ALPHAO(1) - 89.0 ) 30 , 30 , 20
20 RO(1) # RMAX
ALPHAO(1) # ATANF( CONS(1) / SQRTF( RO(1)**2 - CONS(1)**2 ) ) * CONV
DO 22 N # 2 , M
IF ( RO(1) - R(N) ) 24 , 24 , 22
22 CONTINUE
24 ZO(1) # Z(N)
30 FRC# FRCT
RV # FLOATF( NA ) / FLOATF ( NB ) + ADVNCE
AAZERO # ALPHAO(1)
40 CONTINUE
DELA# RV - FRC
IF ( ABSF( DELA ) - EPS ) 110 , 110 , 50
50 DTDA # 0.0
CSQ # CONS(1)**2
RCOS # RO(1) * COSF ( ALPHAO(1) / CONV )
NLI # NLOW + 1
NHI # NHIGH - 1
SQ2 # 1.0 / SQRTF ( R(NLI)**2 - CSQ )
DTDA # DTDA - F(NLOW) * RCOS * SQ2 / AK(NLOW)
IF ( NHI - NLI ) 85 , 55 , 55
55 DO 80 N # NLI , NHI
IF ( AK(N) ) 60 , 70 , 60
60 SQ1 # SQ2
SQ2 # 1.0 / SQRTF ( R(N+1)**2 - CSQ )
DTDA # DTDA + F(N) * RCOS * ( - SQ2 + SQ1 ) / AK(N)
GO TO 80
70 DTDA # DTDA + RCOS * R(N) * ( Z(N+1) - Z(N) ) * ( SQ2 **3 )
80 CONTINUE
85 DTDA # DTDA + F(NHIGH) * RCOS * SQ2 / AK(NHIGH)
DTDA # 2.0 * DTDA
IF ( ABSF( DTDA ) - .01 ) 140 , 140 , 90
90 DALPHA # DELA* 360.0 / DTDA
ALPHAO(1) # ALPHAO(1) + DALPHA
IF ( ITER - 10 ) 100 , 150 , 150
100 ITER # ITER + 1
CONS(1) # RO(1) * SINF ( ALPHAO(1) / CONV )
CALL DELTHA ( 1 )
NLOW # NLOW
NHIGH # NHIGH
FRC # TSUM / 360.0
GO TO 40
110 DALPHA # ALPHAO(1) - AAZERO
IF ( ARSF ( DALPHA ) - 5.0 ) 120 , 130 , 130
120 LL # 0
GO TO 170
130 WRITE OUTPUT TAPE 6 , 1000 , DALPHA
1000 FORMAT ( 20H0 CHANGE IN ALPHA , , F10.6 , 43H , TOO GREAT - GEOD
IESIC DISTORTED INSTEAD )
GO TO 160
140 WRITE OUTPUT TAPE 6 , 1010 , DTDA
1010 FORMAT ( 22H0 D THETA / D ALPHA # , F9.6 , 71H , LARGE CHANGE IN

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```

      ALPHA WOULD BE REQUIRED - GEODESIC DISTORTED INSTEAD )
      GO TO 160
150 WRITE OUTPUT TAPE 6, 1020
1020 FORMAT ( 7H0 ALPHA DID NOT CONVERGE IN 10 ITERATIONS - GEODESIC
      IDISTORTED INSTEAD )
160 LL # 1
      CONS(I) # C
      RO(I) # RZERO
      ZO(I) # ZZERO
      ALPHAO(I) # AZERO
      CALL DELTHA ( I )
170 CONTINUE
      RETURN
      END

```

*LABEL

Subroutine FLWNDR

```

CFLWNDR    FILAMENT WINDER SUBROUTINE
      SUBROUTINE FLWNDR ( I,RPI,ZPI,TPI,AANGLI,RHOI,TOL )
      DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
      1RO(100),ZO(100),ALPHAO(100),CONS(100),W(100),D(100),THICK(100),
      2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
      COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHAO,CONS,W,D,THICK,NC,RT,ZT,
      1SMAX,RMAX,ZMAX,THMAX,JJ,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
      2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
      COMMON AA,BB,CC,DEL,DELRHO, NSTART
      COMMON LLL , RHOMIN , FR , TMIN
      CONV # 180.0 / PI
      DTMAX # 45.0
      REWIND 1
      DO 100 N # 1 , M
      IF ( RMAX - R(N) ) 110 , 110 , 100
100 CONTINUE
110 NSTART # N
      RHO # RHOMIN
      UPDOWN # 1.0
      AKN # ( AK(N) + AK(N-1) ) / 2.0
      IF ( ABSF ( AKN ) - 1.0 E 10 ) 114 , 114 , 112
112 FN # ABSF ( AKN )
      GO TO 116
114 FN # SQRTF ( 1.0 + AKN**2 )
116 THETA # 0.0
      FL # 0.0
      TPI # 0.0
      IF ( I - 1 ) 120 , 120 , 125
120 RPI # R(NSTART)
      ZPI # Z(NSTART)
      TPI # 0.0
      AANGLI # 180.0
      RHOI # 0.0
      RHO # RHOMIN
      RHO # 2.0 * DEL
      GO TO 130
125 RHO # RHOI
130 CONTINUE
      NOSEQ # ( I-1 ) * 10 + 5
      WRITE OUTPUT TAPE 10 , 2050 , NOSEQ
2050 FORMAT ( 16H          SEQNO / , I3 , 6IX )
      NREPET # 2

```



```

WRITE OUTPUT TAPE 10 , 2060 , NREPET
2060 FORMAT ( 17H REPEAT / , I4 , 59X )
WRITE OUTPUT TAPE 6 , 1000
1000 FORMAT ( 122HI** WRAP POINT ON MANDREL ** EYE LOCATION
1IN SPACE ** VECTOR FILMT FILMT B ANGLE A ANG
2LE / 123H R Z THETA R Z
3THETA A ANGLE LENGTH FED DOWN ( REV ) ( REV )
4 )
RR # R(N)
ZZ # Z(N)
AREV # AANGLI / 360.0
TREV # TPI / 360.0
WRITE OUTPUT TAPE 6 , 1010 , RR, ZZ, THETA, RPI, ZPI, TPI, AANGLI,
I TREV, AREV
1010 FORMAT ( 1H0 , 2F10.4,F10.2,2F10.4,2F10.2,30X,2F10.5 )
WRITE OUTPUT TAPE 10 , 2030 , RPI , ZPI , AREV , TREV
2000 FORMAT ( 13H FROM / , F10.4 , 2H , , F10.4 , 6H , 0 , ,
I F10.6 , 2H , , F10.6 , 5H , 0 , 12X )
CALL EYELOC ( I,RR,ZZ,THETA,RHO,UPDOWN,AKN,FN,TPI,RPRIME,ZPRIME,
I TP2 , AANGL , FL )
DELR # RPRIME - RPI
DELZ # ZPRIME - ZPI
DELT # TP2 - TPI
DAA # AANGL - AANGLI
RDEL # RPI + DELR / 2.0
ZDEL # ZPI + DELZ / 2.0
TDEL # TREV + DELT / 720.0
ADEL # AREV + DAA / 720.0
WRITE OUTPUT TAPE 10 , 2020 , RDEL, ZDEL, ADEL, TDEL, FL
2020 FORMAT ( 14H GO TO / , F10.4 , 2H , , F10.4 , 6H , 0 , ,
I F10.6 , 2H , , F10.6 , 2H , , F6.2 , 8X )
WRITE OUTPUT TAPE 10 , 2070
2070 FORMAT ( 15H SWITCH , 65X )
NOSEQ # 10 * I
WRITE OUTPUT TAPE 10 , 2050 , NOSEQ
WRITE OUTPUT TAPE 10 , 2060 , NC(I)
DIST # FL + RHO - RHOI
TREV # TP2 / 360.0
AREV # AANGL / 360.0
WRITE OUTPUT TAPE 6 , 1020, RR, ZZ, THETA, RPRIME, ZPRIME, TP2,
I AANGL, RHO, DIST, FL, TREV, AREV
1020 FORMAT ( 1H , 2F10.4,F10.2,2F10.4,3F10.2,2F10.3,2F10.5 )
LLL # 1
WRITE TAPE 1 , RR,ZZ,THETA,RPRIME,ZPRIME,TP2 , AANGL , DIST
WRITE OUTPUT TAPE 10 , 2000 , RPRIME , ZPRIME , AREV , TREV
RPT # RPRIME
ZPT # ZPRIME
TPT # TP2
AAT # AANGL
RHOT # RHO
RPI # RPRIME
ZPI # ZPRIME
TPI # TP2
RRI # RR
ZZI # ZZ
TTI # THETA
AKI # AKN
TPRI # TP2
AANGLI # AANGL
RB # R(N)
140 CONTINUE
IF ( AK(N) ) 150 , 380 , 150
150 IF ( UPDOWN) 160 , 160 , 180

```

```

160 IF ( N - NLOW ) 200, 200, 170
170 RE # R(N)
    ZE # Z(N)
    AKE # ( AK(N) + AK(N-1) ) / 2.0
    GO TO 210
180 IF ( N - NHIGH ) 190, 200, 200
190 RE # R(N+1)
    ZE # Z(N+1)
    AKE # ( AK(N) + AK(N+1) ) / 2.0
    GO TO 210
200 RE # CONS(I)
    ZE # ( RE - R(N) ) / AK(N) + Z(N)
    AKE # AK(N)
210 CONTINUE
    AZERO # ATANF ( CONS(I) / SQRTF ( RB**2 - CONS(I)**2 ) )
218 AOF # ABSF ( AK(N) / F(N) )
    FOK # ABSF ( F(N) / AK(N) )
    BETA # AOF * DTHETA(N) / ( CONV * DISTRT )
    AKN # AK(N)
    FN # F(N)
    IF ( RB - RE ) 220, 220, 230
220 AR # -1.0
    GO TO 240
230 AR # 1.0
240 CONTINUE
    RA # RB
    RC # FOK * ( RA**4 / ( CONS(I) * ( 2.0*(RA**2) - CONS(I)**2 ) ) )
    DD# 2.0 * SQRTF ( TOL * ( 2.0 * RC - TOL ) )
    DPHI # ATANF ( DD*CONS(I) / ( FOK*(RB**2) - AR * DD * SQRTF ( RB**2
    - CONS(I)**2 ) ) )
    IF ( DPHI ) 242, 242, 246
242 DPHI # DPHI + PI
246 CONTINUE
    IF ( DPHI - BETA ) 250, 330, 330
250 IF ( 2.0 * DPHI - BETA ) 270, 260, 260
260 DPHI # .5 * BETA
    K # 1
    FL # FOK * RB * SIN ( DPHI ) / SIN ( AZERO + AR * DPHI )
    GO TO 275
270 K # 0
    FL # DD
275 DALPHA # AR * DPHI
    AONE # AZERO + DALPHA
    RR # CONS(I) / SIN ( AONE )
    ZZ # ( RR - R(N) ) / AK(N) + Z(N)
    THETA # THETA + FOK * DPHI * CONV * DISTRT
300 CONTINUE
    RHO1 # RHO
    CALL EYELOC ( I,RR,ZZ,THETA,RHO,UPDOWN,AKN,FN,TPI,RPRIME,ZPRIME,
    I TP2, AANGL, FL )
    DELT # TP2 - TPI
    IF ( DELT - DTMAX ) 308, 308, 302
302 FILFED # FL + RHO - RHO1
    CALL BLKADD ( I,RR1,ZZ1,TT1,AK1,TP1,RR,ZZ,THETA,AKN,TP2,
    I FILFED,FL,UPDOWN )
    DIST # FILFED
    GO TO 309
308 CONTINUE
    DIST # FL + RHO - RHO1
309 TREV # TP2 / 360.0
    AREV # AANGL / 360.0
    WRITE OUTPUT TAPE 6, 1020, RR, ZZ, THETA, RPRIME, ZPRIME, TP2,

```

```

I AANGL, RHO, DIST, FL, TREV, AREV
  LLL # LLL + 1
  WRITE TAPE 1, RR, ZZ, THETA, RPRIME, ZPRIME, TP2, AANGL, DIST
  RPI # RPRIME
  ZPI # ZPRIME
  TPI # TP2
  AANGLI # AANGL
  RRI # RR
  ZZI # ZZ
  TTI # THETA
  AKI # AKN
  TPRI # TP2
  RB # RR
  IF ( K - 1 ) 310, 320, 310
310 BETA # BETA - DPHI
  AZERO # AONE
  GO TO 240
320 BETA # DPHI
  AZERO # AONE
330 CONTINUE
  DTA # BETA * FOK * CONV * DISTRT
  FL # FOK * RB * SIN( BETA ) / SIN( AZERO + AR * BETA )
360 CONTINUE
  THETA # THETA + DTA
370 CONTINUE
  GO TO 420
380 IF ( UPDOWN ) 390, 390, 400
390 RE # R(N)
  ZE # Z(N)
  AKE # ( AK(N) + AK(N-1) ) / 2.0
  GO TO 410
400 RE # R(N+1)
  ZE # Z(N+1)
  AKE # ( AK(N) + AK(N+1) ) / 2.0
410 CONTINUE
  DZ # Z(N+1) - Z(N)
  NDZ # DZ
  NDZ # NDZ + 1
  IF ( NDZ - 1 ) 418, 418, 411
411 ANDZ # NDZ
  DDT # DTHETA(N) / ANDZ
  DDZ # DZ / ANDZ
  DFL # FLNGTH(N) / ANDZ
  IF ( UPDOWN ) 412, 412, 413
412 ZZ # Z(N+1)
  GO TO 414
413 ZZ # Z(N)
414 IK # 1
  RR # R(N)
415 IK # IK + 1
  ZZ # ZZ + DDZ * UPDOWN
  THETA # THETA + DDT
  FL # DFL
  AKN # 0.0
  FN # 1.0
  RHOI # RHO
  CALL EYELOC ( I, RR, ZZ, THETA, RHO, UPDOWN, AKN, FN, TPI, RPRIME, ZPRIME,
  I TP2, AANGL, FL )
  DIST # FL + RHO - RHOI
  LLL # LLL + 1
  TREV # TP2 / 360.0
  AREV # AANGL / 360.0
  WRITE OUTPUT TAPE 6, 1020, RR, ZZ, THETA, RPRIME, ZPRIME, TP2,

```

```

      I AANGL, RHO, DIST, FL, TREV, AREV
      WRITE TAPE 1, RR, ZZ, THETA, RPRIME, ZPRIME, TP2, AANGL, DIST
      RPI # RPRIME
      ZPI # ZPRIME
      TPI # TP2
      IF ( IK - NDZ ) 415, 416, 416
416 THETA # THETA + DDT
      FL # DFL
      GO TO 420
418 THETA # THETA + DTHETA(N)
      FL # FLNGTH(N)
420 CONTINUE
      AKN # AKE
      IF ( ABSF ( AKN ) - 1.0 E 10 ) 424, 422, 422
422 FN # ABSF ( AKN )
      GO TO 426
424 FN # SQRTF ( 1.0 + AKN**2 )
426 RR # RE
      ZZ # ZE
      IF ( N - NSTART + 1 ) 430, 500, 430
430 CONTINUE
      RHOI # RHO
      CALL EYELOC ( 1, RR, ZZ, THETA, RHO, UPDOWN, AKN, FN, TPI, RPRIME, ZPRIME,
      I TP2, AANGL, FL )
      DELT # TP2 - TPI
      IF ( DELT - DTMAX ) 438, 438, 432
432 IF ( AK(N) ) 434, 438, 434
434 FILFED # FL + RHO - RHOI
      CALL BLKADD ( 1, RRI, ZZI, TTI, AKI, TPRI, RR, ZZ, THETA, AKN, TP2,
      I FILFED, FL, UPDOWN )
      DIST # FILFED
      GO TO 439
438 CONTINUE
      DIST # FL + RHO - RHOI
439 TREV # TP2 / 360.0
      AREV # AANGL / 360.0
      WRITE OUTPUT TAPE 6, 1020, RR, ZZ, THETA, RPRIME, ZPRIME, TP2,
      I AANGL, RHO, DIST, FL, TREV, AREV
      LLL # LLL + 1
      WRITE TAPE 1, RR, ZZ, THETA, RPRIME, ZPRIME, TP2, AANGL, DIST
      RPI # RPRIME
      ZPI # ZPRIME
      TPI # TP2
      AANGLI # AANGL
      RRI # RR
      ZZI # ZZ
      TTI # THETA
      AKI # AKN
      TPRI # TP2
      IF ( UPDOWN ) 440, 440, 470
440 IF ( N - NLOW ) 450, 450, 460
450 UPDOWN # 1.0
      RB # CONS(1)
      AZERO # PI / 2.0
      RE # R(N+1)
      ZE # Z(N+1)
      AKE # ( AK(N) + AK(N+1) ) / 2.0
      GO TO 218
460 N # N - 1
      RB # R(N+1)
      GO TO 140
470 IF ( N - NHIGH ) 480, 490, 490
480 N # N + 1

```

```

      RB # R(N)
      GO TO 140
490  UPDOWN # - 1.0
      RB # CONS(I)
      AZERO # PI / 2.0
      RE # R(N)
      ZE # Z(N)
      AKE # ( AK(N) + AK(N-1) ) / 2.0
      GO TO 218
500  IF ( UPDOWN ) 430 , 430 , 510
510  CONTINUE
      RHOI # RHO
      RHO # RHOT
      RPRIME # RPT
      ZPRIME # ZPT
      TP2 # THETA + TPT
      AANGL # AAT
      DELT # TP2 - TPI
      DIST # FL + RHO - RHOI
      TREV # TP2 / 360.0
      AREV # AANGL / 360.0
      WRITE OUTPUT TAPE 6 , 1020, RR, ZZ, THETA, RPRIME, ZPRIME, TP2,
I  AANGL, RHO, DIST, FL, TREV, AREV
      LLL # LLL + 1
      WRITE TAPE 1 , RR,ZZ,THETA,RPRIME,ZPRIME,TP2 , AANGL , DIST
      RPI # RPRIME
      ZPI # ZPRIME
      TPI # TPT
      AANGLI # AANGL
      RHOI # RHO
      CALL BLKDLT (LLL)
      IF ( 1 - NOGEOD ) 530 , 535 , 535
530  WRITE OUTPUT TAPE 10 , 2070
      GO TO 540
535  WRITE OUTPUT TAPE 10 , 2080
2080  FORMAT ( 12H          STOP , 68X )
540  CONTINUE
      RETURN
      END

```

*LABEL

Subroutine EYELOC

```

CEYELOC  DETERMINE WINDER EYE LOCATION WHICH CLEARS MANDREL
SUBROUTINE EYELOC ( I,RR,ZZ,THETA,RHO,UPDOWN,AKN,FR,TPI,
I  RPRIME,ZPRIME,TP2 , AANGL , FL )
  DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
  IRO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
  2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
  COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHA0,CONS,W,D,THICK,NC,RT,ZT,
  1SMAX,RMAX,ZMAX,THMAX,J,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
  2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
  COMMON AA,RR,CC,DEL,DELRHO,NSTART
  COMMON LLL , RHOMIN , FR , TMIN
  CONV # 180.0 / PI
  RHOI # RHO
  SINA # CONS(I) / RR
  COSA # SQRTF ( RR**2 - CONS(I)**2 ) / RR
  K # 0

```

```

      L # 0
100 CONTINUE
      XX # RR + UPDOWN * AKN * RHO * COSA / FN
      YY # RHO * SINA
      RPRIME # SQRTF ( XX**2 + YY**2 )
      ZPRIME # ZZ + RHO * COSA * UPDOWN / FN
      IF ( XX ) 110 , 120 , 130
110 DELTAT # ATANF ( YY / XX ) * CONV + 180.0
      GO TO 140
120 DELTAT # 90.0
      GO TO 140
130 DELTAT # ATANF ( YY / XX ) * CONV
140 CONTINUE
      R1 # RPRIME
      R2 # RPRIME + BB
      IF ( ZPRIME - Z(NSTART) ) 150 , 150 , 160
150 Z1 # ZPRIME + AA
      Z2 # ZPRIME + AA + CC
      DRDZ # BB / CC
      DO 156 N # 1 , NSTART
      IF ( Z(N) - Z1 ) 156 , 156 , 152
152 IF ( Z(N) - Z2 ) 154 , 158 , 158
154 REYE # DRDZ * ( Z(N) - Z1 ) + R1
      IF ( REYE - R(N) - DEL ) 210 , 156 , 156
156 CONTINUE
158 CONTINUE
      GO TO 170
160 Z1 # ZPRIME - AA
      Z2 # ZPRIME - AA - CC
      DRDZ # - BB / CC
      DO 166 N # NSTART , M
      IF ( Z(N) - Z2 ) 166 , 166 , 162
162 IF ( Z(N) - Z1 ) 164 , 168 , 168
164 REYE # DRDZ * ( Z(N) - Z1 ) + R1
      IF ( REYE - R(N) - DEL ) 210 , 166 , 166
166 CONTINUE
168 CONTINUE
170 CALL RMANDL ( Z1 , RM1 )
      CALL RMANDL ( Z2 , RM2 )
      CALL RMANDL ( ZPRIME , RM3 )
      IF ( RPRIME - RM3 - DEL ) 210 , 175 , 175
175 IF ( R1 - RM1 - DEL ) 210 , 180 , 180
180 IF ( R2 - RM2 - DEL ) 210 , 185 , 185
185 IF ( RHO - RHOMIN ) 240 , 240 , 190
190 IF ( K - 1 ) 200 , 240 , 240
200 L # 1
      RHOTMP # RHO
      RPTMP # RPRIME
      ZPTMP # ZPRIME
      DELTMP # DELTAT
      RHO # RHO - DELRHO
      GO TO 100
210 IF ( L - 1 ) 220 , 230 , 230
220 K # 1
      IF ( RHO - 60.0 ) 225 , 222 , 222
222 TP2 # THETA + DELTAT
      GO TO 260
225 RHO # RHO + DELRHO
      GO TO 100
230 RHO # RHOTMP
      RPRIME # RPTMP
      ZPRIME # ZPTMP

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      DELTAT # DELTMP
240  CONTINUE
      TP2 # THETA + DELTAT
      DTP # TP2 - TP1
      IF ( DTP ) 250 , 242 , 242
242  IF ( RHO-RHO1+FL ) 244 , 244 , 260
244  IF ( THETA ) 260 , 260 , 250
250  K # 1
      IF ( RHO - 60.0 ) 255 , 260 , 260
255  RHO # RHO + DELRHO
      GO TO 100
260  CONTINUE
      RHOCOS # RHO * COSA * UPDOWN / FN
      IF ( ABSF(RHOCOS) - .000001 ) 270 , 280 , 280
270  AANGL # 90.0
      GO TO 300
280  AANGL # ATANF( ( RR*SINF(DELTAT/CONV) ) / ( - RHOCOS ) ) * CONV
      IF ( AANGL ) 290 , 300 , 300
290  AANGL # AANGL + 180.0
300  CONTINUE
      RETURN
      END

```

*LABEL

Subroutine BLKADD

```

CBLKADD  ADD BLOCKS WHEN CARGE MANDREL ROTATION OCCURS
      SUBROUTINE BLKADD ( I,RR1,ZZ1,TT1,AK1,TPR1,RR2,ZZ2,TT2,AK2,
1  TPR2,FILFED,FILDWN,UPDOWN )
      DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
1RO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
      COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHA0,CONS,W,D,THICK,NC,RT,ZT,
1SMAX,RMAX,ZMAX,THMAX,JJ,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
      COMMON AA,BB,CC,DEL,DELRHO,NSTART
      COMMON LLL , RHOMIN , FR , TMIN
      DBA # 18.0
      BANGLE # TPR1
      DENOM # TPR2 - TPR1
      DR # RR2 - RR1
      DZ # ZZ2 - ZZ1
      DK # AK2 - AK1
      DDD # 0.0
      DWN # 0.0
      DDSUM # 0.0
      DWNSUM # 0.0
      DTT # TT2 - TT1
100  CONTINUE
      BANGLE # BANGLE + DBA
110  CONTINUE
      FACTOR # ( BANGLE - TPR1 ) / DENOM
      RRS # RR1 + FACTOR * DR
      ZRS # ZZ1 + FACTOR * DZ
      TTS # TT1 + FACTOR * DTT
      AKK # AK1 + FACTOR * DK
      IF ( ABSF ( AKK ) - 1.0 E 10 ) 120, 130, 130
120  FI # SORTF ( 1.0 + AKK **2 )
      GO TO 140

```

```

130 FI # ABSF ( AKK )
140 CONTINUE
   DDDSUM # DDDSUM + DDD
   DWNSUM # DWNSUM + DWN
   DDD # FACTOR * FILFED - DDDSUM
   DWN # FACTOR * FILDWN - DWNSUM
   SINA # CONS(I) / RRS
   COSA # SQRTF ( 1.0 - SINA ** 2 )
   B # ( BANGLE - TTS ) * PI / 180.0
   CB # COSF(B)
   IF ( ABSF ( CB ) - .001 ) 150 , 150 , 160
150 RHO # RRS / ( - UPDOWN * AKK * COSA / FI )
   GO TO 170
160 TANB # SINF(B) / CB
   RHO # ( RRS * TANB ) / ( SINA - UPDOWN * AKK * COSA * TANB / FI )
170 CONTINUE
   XXX # RRS + UPDOWN * AKK * RHO * COSA / FI
   YYY # RHO * SINA
   RHOCOS # RHO * COSA * UPDOWN / FI
   XX # SQRTF ( XXX ** 2 + YYY ** 2 )
   YY # ZS + RHOCOS
   IF ( ABSF ( RHOCOS ) - .00001 ) 180 , 180 , 190
180 AANGL # 90.0
   GO TO 220
190 AANGL # ATANF ( ( RRS * SINF(B) ) / ( - RHOCOS ) ) * 180.0 / PI
   IF ( AANGL ) 200 , 220 , 220
200 AANGL # AANGL + 180.0
220 CONTINUE
   CALL RMANDL ( YY , RMI )
   IF ( XX - RMI - DEL ) 230 , 240 , 240
230 XX # RMI + DEL
240 CONTINUE
   BREV # BANGLE / 360.0
   AREV # AANGL / 360.0
   WRITE OUTPUT TAPE 6,4000, RRS,ZS,TTS,XX,YY,BANGLE,AANGL,RHO,DDD,
   , DWN,BREV,AREV
4000 FORMAT ( 3H ** , F8.4,F10.4,F10.2,2F10.4,3F10.2,2F10.3,2F10.5 )
   LLL # LLL + 1
   WRITE TAPE 1 , RRS , ZS , TTS , XX , YY , BANGLE , AANGL , DDD
   IF ( BANGLE - TPR2 + DBA ) 250 , 300 , 300
250 IF ( BANGLE - TPR2 + 2.0 * DBA ) 100 , 100 , 260
260 DB # ( TPR2 - BANGLE ) / 2.0
   BANGLE # BANGLE + DB
   GO TO 110
300 CONTINUE
   FILFED # DDD
   FILDWN # DWN
   RETURN
   END

```

*LABEL

Subroutine BLKDLT

```

CBKDLT  DELETE BLOCKS THAT ARE TOO SMALL
SUBROUTINE BLKDLT ( NOPTS )
DELMIN # 5.0
REWIND 1
N # 1
READ TAPE 1 , RR,ZZ,TT,XOLD,YOLD,BOLD,AOLD

```



```

100 CONTINUE
   DSUM # 0.0
150 CONTINUE
   N # N + 1
   READ TAPE 1 , RR,ZZ,TT,XNEW,YNEW,BNEW,ANEW,DNEW
   DX # XNEW - XOLD
   DY # YNEW - YOLD
   DB # BNEW - BOLD
   DA # ANEW - AOLD
   DSUM # DSUM + DNEW
   FACTOR # 5.0 * ( ABSF(DX) + ABSF(DY) + DSUM ) + DB / 3.0
   1 + ABSF(DA) / 5.0
   IF ( FACTOR - DELMIN ) 200 , 200 , 170
170 BREV # BNEW / 360.0
   AREV # ANEW / 360.0
   WRITE OUTPUT TAPE 10,4000, XNEW,YNEW,AREV,BREV,DSUM
4000 FORMAT ( 14H          GO TO / , F10.4 , 1H , , F10.4 , 5H, 0 , ,
   F10.6 , 1H , , F10.6 , 1H , , F10.4 , 8X )
   IF ( N - NOPTS + 1 ) 180 , 190 , 220
180 XOLD # XNEW
   YOLD # YNEW
   BOLD # BNEW
   AOLD # ANEW
   GO TO 100
190 READ TAPE 1 , RR,ZZ,TT,XNEW,YNEW,BNEW,ANEW,DSUM
   GO TO 210
200 CONTINUE
   IF ( N - NOPTS ) 150 , 210 , 210
210 BREV # BNEW / 360.0
   AREV # ANEW / 360.0
   WRITE OUTPUT TAPE 10,4000,XNEW,YNEW,AREV,BREV,DSUM
220 CONTINUE
   REWIND 1
   RETURN
   END

```

*LABEL

Subroutine RMANDI

```

CRMANDL : DETERMINE RADIUS OF MANDREL FOR A GIVEN VALUE OF Z
SUBROUTINE RMANDL ( ZS , RM )
  DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
  IRO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
  2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
  COMMON M,R,Z,AK,F,XI,NOGEOD,RO,ZO,ALPHA0,CONS,W,D,THICK,NC,RT,ZT,
  ISMAX,RMAX,ZMAX,THMAX,PI,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
  2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
  IF ( ZS - Z(1) ) 10 , 10 , 20
10 RM # SHAFT1
   GO TO 60
20 DO 30 NN # 2 , M
   IF ( Z(NN) - ZS ) 30 , 40 , 50
30 CONTINUE
   RM # SHAFT2
   GO TO 60
40 RM # R(NN)
   GO TO 60
50 NN # NN - 1
   RM # AK(NN) * ( ZS - Z(NN) ) + R(NN)
60 CONTINUE

```

RETURN
END

*LABEL

Subroutine TZZPPT

```

CTZZPPT  PLOT GEODESIC AND EYE LOCATION  THETA VS Z AND Z VS R
SUBROUTINE TZZPPT ( XO,YO,ZSCALE,TLNGTH,RZSCLE )
  DIMENSION XAX(12) , YAX(12)
  DIMENSION R(1000),Z(1000),AK(1000),F(1000),XI(1000),TITLE(12),
  IRO(100),ZO(100),ALPHA0(100),CONS(100),W(100),D(100),THICK(100),
  2RT(100),ZT(100),NC(100),DTHETA(1000),FLNGTH(1000)
  COMMON M,R,Z,AK,F,XI,NOGEOD,RC,ZO,ALPHA0,CONS,W,D,THICK,NC,RT,ZT,
  ISMAX,RMAX,ZMAX,THMAX,JJ,TITLE,PI,DTHETA,FLNGTH,TSUM,FLSUM,NHIGH,
  2 NLOW , DISTRT , ADVNCE , SHAFT1 , SHAFT2
  COMMON AA,BB,CC,DEL,DELRHO,NSTART
  COMMON LLL , RHOMIN , FR , TMIN
B  XAX(1) # 633025632153
B  YAX(1) # 606060607153
B  TITLE(7) # 716060633025
B  TITLE(8) # 632160604743
B  TITLE(9) # 466353606060
  ZILNGH # ZMAX * ZSCALE
  DIVX # 10.0 / TLNGTH
  DIVY # 1.0 / ZSCALE
  XLD # .1
  YLD # 1.0
  NX # 5
  NY # 5
  II # 50
  REWIND 1
  CALL SETUP ( TITLE )
  CALL AXPLOT (XO,YO,TLNGTH,ZILNGH,DIVX,DIVY,XLD,YLD,NX,NY,II,
  1 XAX,YAX )
  TSCALE # TLNGTH / TSUM
  INK # 2
  DO 100 L # 1 , LLL
  READ TAPE 1 , RR,ZZ,THETA,RPRIME,ZPRIME,TP2
  ZZ # ZZ * ZSCALE + YO
  ZPRIME # ZPRIME * ZSCALE + YO
  TT # THETA * TSCALE + XO
  TTP # TP2 * TSCALE + XO
  CALL PLOT ( TT,ZZ,1,INK )
  CALL PLOT ( TTP,ZPRIME,1,1 )
  CALL PLOT ( TT,ZZ,1,2 )
100 INK # 1
  REWIND 1
  INK # 2
  DO 150 L # 1 , LLL
  READ TAPE 1 , RR,ZZ,THETA,RPRIME,ZPRIME,TP2
  ZPRIME # ZPRIME * ZSCALE + YO
  TTP # TP2 * TSCALE + XO
  CALL PLOT ( TTP,ZPRIME,1,INK )
150 INK # 1
  CALL FINISH ( 30,TITLE )
  END FILE 8
  REWIND 1
B  XAX(1) # 606060607153
B  YAX(1) # 606060605153

```

```

B   TITLE(7) # 516060716060
B   TITLE(8) # 474343635360
    Z2LNHG # ZMAX * RZSCLE
    RLNGTH # RMAX * RZSCLE
    DIVX # 1.0 / RZSCLE
    DIVY # DIVX
    XLD # 1.0
    CALL SETUP ( TITLE )
    CALL AXPLLOT ( XO,YO,Z2LNHG,RLNGTH,DIVX,DIVY,XLD,YLD,NX,NY,
1    II,XAX,YAX )
    INK # 2
    DO 200 L # 1 , LLL
    READ TAPE 1 , RR,ZZ,THETA,RPRIME,ZPRIME,TP2
    ZZ # ZZ * RZSCLE + XO
    ZPRIME # ZPRIME * RZSCLE + XO
    RR # RR * RZSCLE + YO
    RPRIME # RPRIME * RZSCLE + YO
    CALL PLOT ( ZZ,RR,1,INK )
    CALL PLOT ( ZPRIME,RPRIME,1,1 )
    CALL PLOT ( ZZ,RR,1,2 )
200 INK # 1
    CALL FINISH ( 30 , TITLE )
    END FILE 8
    REWIND 1
    RETURN
    END

```

Subroutine AXPLLOT

```

CAXPLOT          DRAW AXES FOR PLOTS
SUBROUTINE AXPLLOT ( XO,YO,XL,YL,DIVX,DIVY,XLD,YLD,NX,NY,II,XAX,
1 YAX )
C
C   XO , YO  IS THE ORIGIN
C   XL , YL  IS LENGTH OF AXES
C   DIVX,DIVY IS DIVISIONS PER INCH
C   XLD, YLD IS LENGTH DIVISION REPRESENTS
C   NX , NY  IS DIVISIONS TO BE LABELED ( 1,EVERY DIV , 2,EVERY OTHER)
C   II  IS SIZE OF LETTERS
C   XAX , YAX IS NAME OF AXES
C
    DIMENSION XAX(12) , YAX(12)
    XXL # XL + XO
    YYL # YO + YL
    CALL PLOT ( XO ,YYL , 1 , 2 )
    CALL PLOT ( XO , YO , 1 , 1 )
    IX # DIVX * XL + .05
    IY # DIVY * YL + .05
    YOFF1 # YO + .04
    YOFF2 # YO - .04
    XOFF1 # XO - .04
    XOFF2 # XO + .04
    DO 20 I # 1 , IY
    YI # I
    YYI # YI / DIVY + YO
    CALL PLOT ( XOFF1 , YYI , 1 , 2 )
20 CALL PLOT ( XOFF2 , YYI , 1 , 1 )
    CALL PLOT ( XXL, YO , 1 , 2 )
    CALL PLOT ( XO , YO , 1 , 1 )
    DO 10 I # 1 , IX

```

```

      XI # I
      XXI # XI / DIVX + XO
      CALL PLOT ( XXI , YOFF1 , 1 , 2 )
10  CALL PLOT ( XXI , YOFF2 , 1 , 1 )
      IF ( II - 51 ) 30 , 40 , 50
30  SIZE # .096
      GO TO 90
40  SIZE # .192
      GO TO 90
50  IF ( II - 53 ) 60 , 70 , 80
60  SIZE # .384
      GO TO 90
70  SIZE # .768
      GO TO 90
80  SIZE # 1.536
90  CONTINUE
      YOFF # YOFF2 - SIZE - .1
      DO 100 I # NX , IX , NX
      XI # I
      XXI # XI / DIVX
      XXXI # XI * XLD
      WRITE OUTPUT TAPE 0,1000,XXXI
1000 FORMAT ( F5.2 , IH$ )
      READ INPUT TAPE 0,1002, A
1002 FORMAT ( 'A6-' )
      XXI # XXI - 2.5 * SIZE + XO
110  CALL LETTER ( XXI , YOFF , II , 52 , A )
      YOFF # YOFF - SIZE - .1
      XX # XO + XL / 4.0
      CALL LETTER ( XX , YOFF , II , 52 , XAX )
      XOFF # XOFF1 - .05 - 5.0 * SIZE
      DO 110 I # NY , IY , NY
      YI # I
      YYI # YI / DIVY + YO - SIZE / 2.0
      YYYYI # YI * YLD
      WRITE OUTPUT TAPE 0,1000,YYYYI
      READ INPUT TAPE 0, 1002 , A
1110 CALL LETTER ( XOFF , YYI , II , 52 , A )
      XOFF # XOFF - SIZE - .1
      YY # YO + YL / 4.0
      CALL LETTER ( XOFF , YY , II , 53 , YAX )
      RETURN
      END

```

*LABEL