

A COMPUTATIONAL MODEL FOR GEOMAGNETICALLY TRAPPED PARTICLE SHELLS AND KINEMATIC PARAMETERS

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SHELLS AND KINEMATIC PARAMETERS

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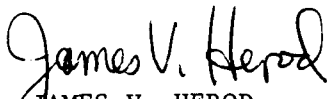
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FOREWORD

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Inclusive dates of research were October 1965 to June 1966. The report was submitted 14 July 1966 by the AFWL Project Officer, Captain James V. Herod, U.S. Army, (WLRTH).

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ABSTRACT

A computer program has been constructed which calculates a model for geomagnetically trapped particle shells and the associated kinematic parameters. Included is the calculation of longitude-dependent drift velocities and bounce paths. This document explains the methods used in constructing the program as well as the input and output of the code.

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SECTION I

INTRODUCTION

The detailed study of time and longitude dependence of energetic particle fluxes injected at low altitudes into geomagnetically trapped orbits requires an accurate description of the geometry of the magnetic shells populated by these particles, as well as the determination of the longitude dependence of all intervening kinetic variables, such as drift velocities and bounce periods.

For particles mirroring at low altitudes in the South American Anomaly, where interactions with the atmosphere are the dominant processes governing particle diffusion and loss, changes of a few kilometers in altitude of magnetic shells may induce quite appreciable changes in the numerical results of theoretical diffusion and loss calculations. Considerable accuracy is therefore required. Of course, there will always be a "natural" limitation imposed by the degree of accuracy in the geomagnetic field description. However, there are other more or less controllable sources of errors, both systematic and random, which are inherent to the numerical methods used in shell geometry and particle kinematics computations, and which must be reduced to a minimum.

Particle shell calculations require lengthy computations, consisting mainly of field line tracings, calculations of the second adiabatic invariant, and search for B-L points. This last procedure, in particular, is the most critical one for the geometric determination of a particle shell, and is where the problem of precision is most acute. Furthermore, exact determination of drift velocities and bounce periods, and their longitude dependence, also implies lengthy computations. All this makes the problem of speed a most critical one.

In the present paper, a computer code is described which meets to some degree all these requirements of accuracy and speed, furnishing complete information about particle shells, drift velocities, and bounce periods, and which is flexible enough to be easily used under varying initial conditions or output requirements.

SECTION II

PARTICLE SHELL GEOMETRY

A charged particle moves in a time independent, trapping magnetic field conserving two invariants (references 1 and 2): the mirror point field intensity B_m , and the value of the integral I between conjugate mirror points; i.e.,

$$B_m = \text{const.} \quad (1a)$$

$$I = \int \sqrt{1 - \frac{B(s)}{B_m}} ds = \text{const.} \quad (1b)$$

To each point in space, a pair of values, B_m and I , can be attached, such that a particle mirroring there has the value I for the integral (equation 1b), B_m being the field intensity at that point. In a trapping field configuration, like the geomagnetic field, we can trace constant I and constant B surfaces (see sketch in figure 1). A given particle will therefore always spiral along the field lines passing through the ring-shaped intersections of such a pair of B_m , I surfaces, mirroring on the intersection and drifting in azimuth.

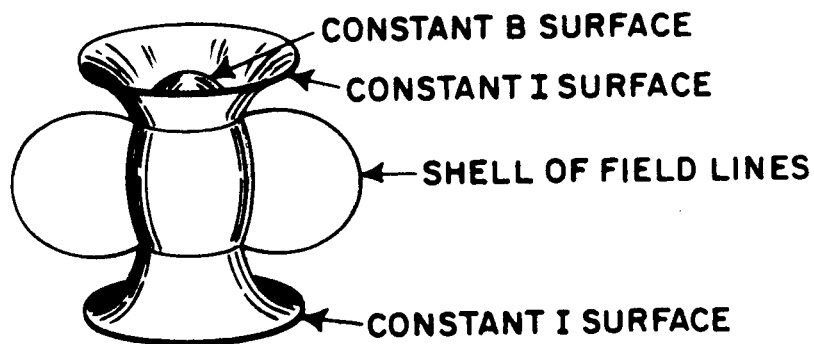


Figure 1. Geometric Definition of a Particle Shell.

McIlwain (reference 2) has shown that, in the real geomagnetic field, azimuthal asymmetry is small enough so that, to a fair approximation, particles initially mirroring on a common field line will always spiral along the same field lines at other longitudes, irrespective of their initial mirror points (or equatorial pitch angles). In other words, they will populate one and the same shell. McIlwain has found a relation $L = L(I, B_m)$ such that it has nearly the same value for all points along a given field line, and, therefore, for all field lines belonging to the shell generated by particles mirroring on the initial line. This parameter identifies this shell, and is taken as its proper geometric label. Physically, it gives the average distance in earth radii of the equatorial (minimum B) points of the shell to the geomagnetic center.

When there is a strong azimuthal asymmetry, as in the outer magnetosphere (reference 3), this shell "degeneracy" is removed (references 4 and 5), and particles initially mirroring on the same field line will populate different shells (shell splitting) according to their different mirror points or equatorial pitch angles. This shell splitting, of course, also does occur in the inner magnetosphere; however, it amounts to only a few kilometers at the equator, for L-shells of the order of 1.2. Nevertheless, following the discussion above, such a difference of a few kilometers may be of importance to mechanisms of atmospheric interactions, where it may compete with the scale height of atmospheric density. Special care must be taken, therefore, when a particle shell is to be defined for atmospheric scatter studies. For instance, if one is interested in the evolution of a group of particles mirroring far away from the equator, i.e., at high B-values or low altitudes in the Anomaly, the field lines on which these particles will mirror must be defined by the proper B_m , L (or B_m , I) ring, and not, for example, by the equatorial ring of the corresponding L-shell. The differences which result from picking shells by their equatorial points instead of some higher B-value points may be as much as 10-20 kilometers in the region of the Anomaly. The corresponding differences in the longitude dependence of drift velocities and bounce periods are, percentage wise, even higher (6 to 10 percent for $L = 1.25$); finally, the equatorial B value of a shell picked at a high B value becomes quite appreciably longitude-dependent (up to 6 to 7 percent for $L = 1.25$), as does the equatorial pitch angle of a given particle (although this is constant on a dipole shell).

Most of the longitude variations occur in the South American Anomaly (reference 6), where most of the atmospheric interactions also take place. Unfortunately, this is the region where the higher multipoles of the field expansion are felt most intensely, being therefore more exposed to the systematic errors in the particular field description used.

SECTION III

DETERMINATION OF PARTICLE SHELLS AND KINEMATIC PARAMETERS

The following procedure was adopted in the computer code to determine a given L-shell. First, a convenient B-value was chosen, which was centered in the B region to be explored. In general, for the study of atmospheric interactions of trapped particles, it is recommended to take a B value such that the corresponding southern B-L ring dips to about 250 to 300 kilometers in the Anomaly (for $L = 1.25$, choose $B = 0.22$).

The main numerical problem then is to find a point of prefixed B and L values, at any given longitude. An iteration method must be used, for in the case of a nondipole expansion there is no known analytical expression of L as a function of space (nor as an expansion in terms of the Gauss coefficients). The determination of L (or, really, I) always implies an integration along the field line; therefore, this is the critical part of the entire program with regard to speed and accuracy.

Once a B-L point is determined at a given longitude, information about the field line going through it must be provided. For particular atmospheric scattering problems, this field line must be traced to the intersection with a prefixed altitude level, say 100 kilometers, below which no trapping is possible. Coordinates of points of this field line may be needed either at a prefixed mesh of B-values, or at prefixed altitudes on the lower end of the field line (and their conjugate points on the other side). All this is usually wanted at many different longitudes until a grid of field lines of the shell is completed around the world. The present code was designed to provide this information.

As to the drift velocity and bounce period calculations, the following procedures were adopted. The most general expression for the average equatorial drift velocity u_o was given by Northrop and Teller (reference 7). Using a slightly different notation, we have

$$u_o = \frac{m \cdot v}{e \cdot B_o} \cdot \frac{\nabla_o I}{S_b} \quad (2)$$

where m is the particle's mass, e its electric charge, and v its velocity. B_o is the field intensity at the equatorial point of the shell, and $\nabla_o I$ is the gradient

of I (equation 1b) calculated for a fixed mirror point field B_m . S_b is the rectified path of the particle between mirror points:

$$S_b = \int \frac{ds}{\sqrt{1 - \frac{B(s)}{B_m}}}$$

For the angular equatorial drift velocity $\dot{\phi}_o$, we have

$$\dot{\phi}_o = \frac{\partial \phi}{\partial x} \cdot u_o' \quad (3)$$

where $\partial \phi / \partial x$ is computed along the equatorial ring (dx is the element of arc of this ring). In the real geomagnetic field, all quantities B_o , $\nabla_o I$, and S_b are longitude dependent. Though S_b is defined by an integration (with an integrand which diverges at the limits of integration), one can easily show, by taking the derivative of equation (1b) with respect to B_m , that

$$S_b = I + 2 B_m \frac{\partial I}{\partial B_m} \quad (4)$$

The derivative is to be taken along a given field line. This relation is far more convenient for computational purposes than the integral expression for S_b .

For particles mirroring on a given field line, drift velocities and bounce paths depend on their mirror points. It was found that, within the degree of accuracy wanted, this dependence can always be expressed in the form

$$\begin{aligned} u_o' &= d(L, \phi) + \sigma_u(L, \phi) \left[1 - \sqrt{\frac{B_o}{B_m}} \right] \\ S_b &= p(L, \phi) + \sigma_s(L, \phi) \left[1 - \sqrt{\frac{B_o}{B_m}} \right] \end{aligned} \quad (5)$$

provided that B_o/B_m is greater than about 0.5. The coefficients d , p , σ_u , and σ_s are all longitude-dependent. However, their longitude averages are remarkably close to the corresponding dipole values (reference 8). Care must be taken in interpreting d and p as drift and bounce path values for particles mirroring close to the equator. If the field lines of the shell for which the quantities in equation (5) are computed are picked at a point with a high B value, d and p would not represent exactly the drift and bounce parameters of equatorial particles, because these, even for the same L value, would be drifting along a slightly different shell. This slight difference in altitude may result in quite considerable longitude variations of u_o and S_b .

SECTION IV

EXPLANATION OF THE PROGRAM

In what follows, the computer code will be briefly described in a logical order, starting with the key subroutine, rather than with the main program. A listing is given in the appendix.

1. SEARCH

Subroutine SEARCH provides the foundation for the entire program. It consists of an iteration process which finds a point P with a prefixed B and L value at a specified longitude. In addition, this subroutine gives detailed information about the field line which passes through the point P. Input for the subroutine are the geodetic coordinates of the starting point for the iteration process, the specified B and L values, and the prefixed tolerances for each of B and L. Outputs are the geodetic coordinates of the desired B-L point, and the geocentric coordinates of a series of points along the field line between the point P and its conjugate. The entire calculation is done in geocentric coordinates.

There are two basic processes in this subroutine: one varies altitude searching along a constant latitude and longitude line for a point of given B; the other searches along a nearly constant B line in a given meridian plane for a point of prefixed L. The first of these processes is very fast; it involves only calling the subroutine NEWMAG which computes the intensity of the magnetic field at each point. The second process is much more complicated and involves the use of subroutine INVAR, which traces a field line through each point at which it is called. The program was constructed in such a manner as to minimize the number of times INVAR is used.

Figure 2 shows a simplified flow chart for subroutine SEARCH. Geometrically, the procedure used is as follows (see figure 3): starting at the input point P, the program iterates the altitude to a point S where the prefixed B-value (called SB) is reached within a prefixed, gross tolerance designated by ERRB. The L value is then determined for this point S. If it is not equal to the prefixed L-value (called SL) within the tolerance designated by ERRL, the latitude is changed by a small, prefixed amount DV in the correct direction. At this new latitude, a point T is found with the prefixed B-value; L is calculated at the point T.

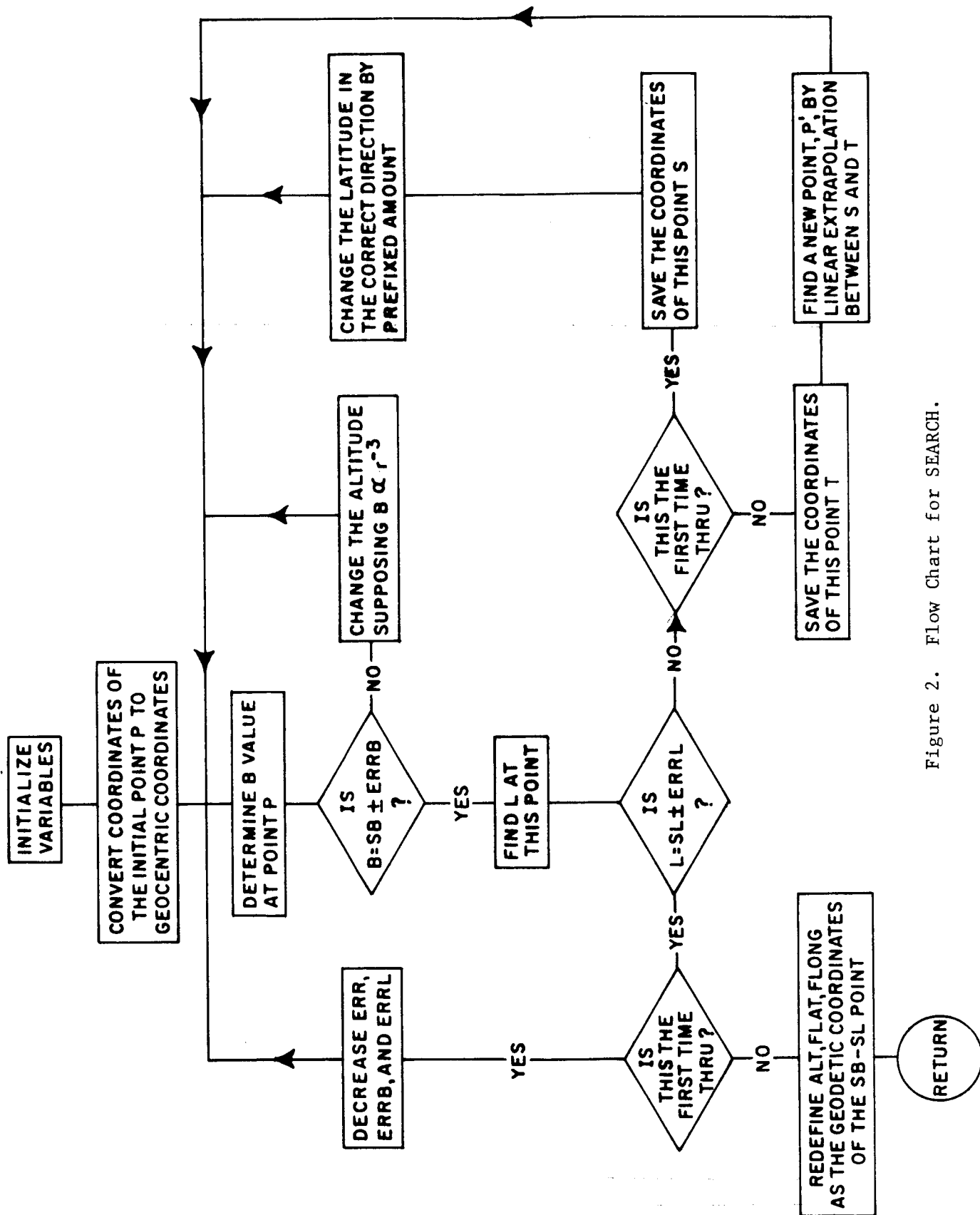


Figure 2. Flow Chart for SEARCH.

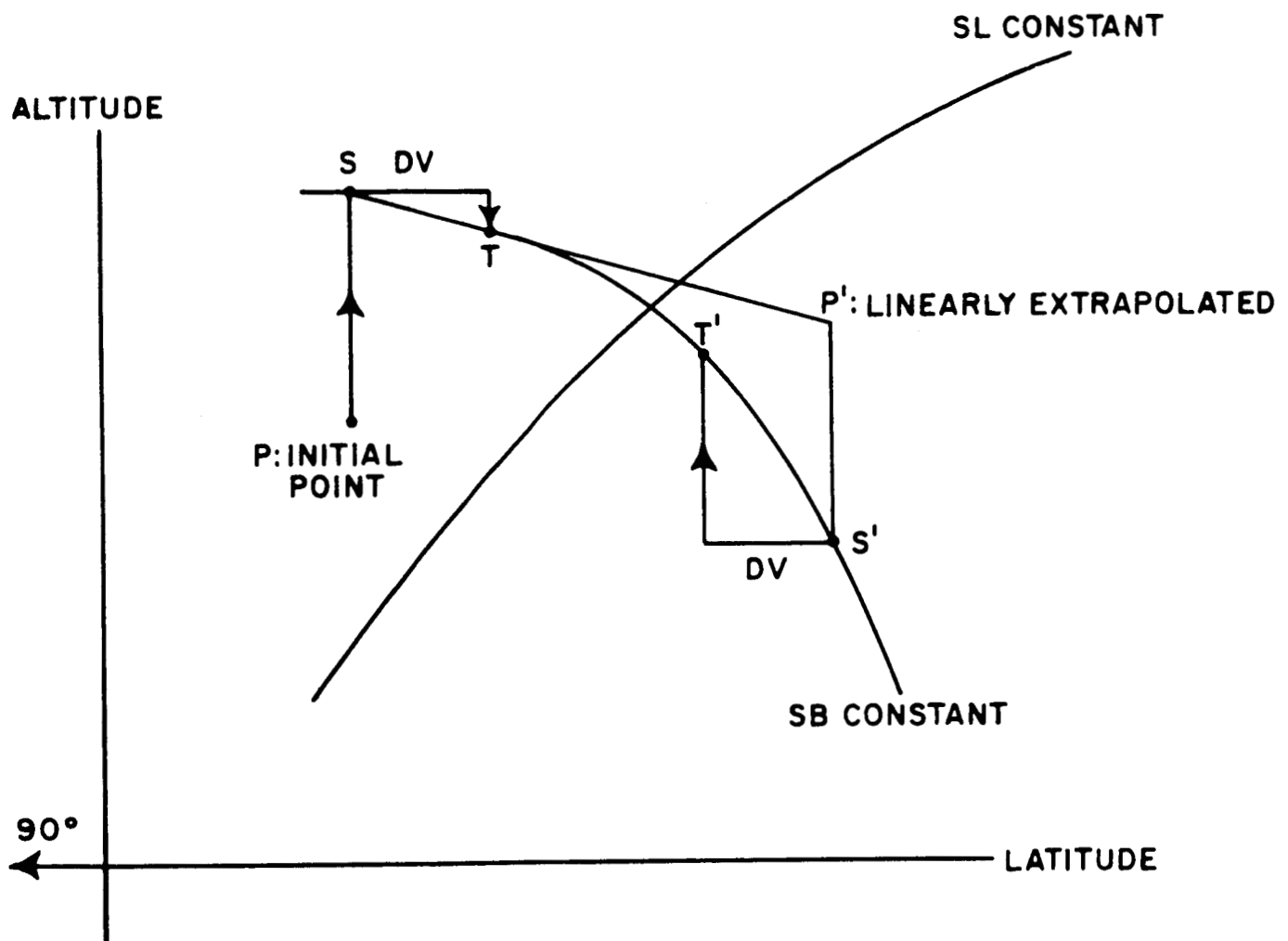


Figure 3. Iteration Procedure Followed in Subroutine SEARCH.

Points S and T lie, approximately, on a constant B line in the meridian plane. A linear extrapolation is then used to find the point on this line which would have the specified value SL. This extrapolation is made as though the L-dependence were linear along the constant B line. This extrapolated point 'P' is now taken as a second approximation and is used as the starting point of the next iteration cycle. If the new point 'P' is close enough to the points S and T, the step size in latitude is reduced by one-tenth. The iteration is continued until a point is found which lies in the interval $SB \pm \text{ERRB}$ and $SL \pm \text{ERRL}$. When this is accomplished, all tolerances are reduced two orders of magnitude and the entire procedure is repeated until a point is found whose B and L values agree with the prefixed ones within the new, reduced tolerance intervals.

To avoid the possibility of infinite cycling in case the tolerances were too small, a cutoff is introduced and a diagnostic is printed. The process is begun again at a slightly different value of SB (see section IV,11).

It should be noted that the input coordinates of the starting point P determine the longitude of the desired B-L point as well as the hemisphere in which it will lie. Indeed, the value of the longitude is never changed in this subroutine. It is recommended, in general, that the initial guess or starting point for the iteration process should not differ in latitude by more than 10 or 15 degrees from the real B-L point. This may be accomplished by consulting the usual B-L maps (references 9 and 10).

2. INVAR, START, LINES, INTEG, CARMEL, AND NEWMAG

This group of subroutines is slightly modified and implemented versions of McIlwain's program INVAR (reference 11). Their purpose is to trace a field line (START, LINES, and NEWMAG) and to determine the second invariant (equation (1b)) (INTEG) and the associated L-value (CARMEL). Input for INVAR is a point P in space given by geocentric coordinates; output are the B and L values at P and the geocentric coordinates of a sequence of points along the field line beginning at P and progressing to its conjugate.

INVAR controls the rest of the above-listed programs. When called from INVAR, subroutine START picks the first three points of a sequence along the field line which are such that the second point is P and the B-value of the three are in decreasing order. LINES is a tracing routine which continues the sequence of points along the field line in the direction defined by START. This sequence progresses to the first point for which the B-value equals or exceeds that at P.

The arc length between consecutive points in the sequence is, in general, a linear function of the geocentric altitude of the two points, initially being directly controlled by the prefixed value of the parameter called ERR. During the tracing, the arc length keeps doubling until an error control (dependent on ERR) levels it off at a value which is usually eight or ten times greater than the initial value. The result is speed and accuracy at the expense of a nonconstant and sometimes unpredictable cell size.

INTEG and CARMEL are straightforward programs which were left intact from McIlwain's code. NEWMAG is also practically unchanged; it contains the latest Cain et al. (reference 12) field coefficients (truncated to 48) with an option for January 1960 or November 1966.

3. EQUAT

This subroutine traces a field line from a given point to the geomagnetic equator, i.e., to the point on the field line with minimum B-value. Usually, the starting point is one defined in a previous INVAR call and is already close to the equator. This starting point is called VNEAR in the program. EQUAT is always used for a more accurate determination of the equatorial point and is called with a much smaller value of ERR than the one used in the original field tracing. When called from EQUAT, the cell-doubling mechanism in LINES is bypassed to ensure highest precision.

4. BESECT

This subroutine operates similarly to EQUAT, but traces a field line downwards, i.e., in the direction opposite to the direction of the equatorial point, until a prefixed B-value is reached.

5. INSECT

This subroutine traces a field line from a given point downwards to the intersection with a geodetic altitude. It should be noted that this subroutine can be used for the determination of geomagnetically conjugate points.

All operations mentioned in connection with subroutines EQUAT, BESECT, and INSECT are actually executed by START, LINES, and NEWMAG. Information about the particular type of tracing wanted is transferred by a parameter called MMM which is defined to be 0 in INVAR, 1 in EQUAT, 2 in BESECT, and 3 in INSECT.

6. BLRING

This subroutine finds the B-L point for a given longitude, gives the geocentric coordinates of a sequence of points along the field line between this point and its conjugate, and computes all geometric factors required for the determination of the longitude and B dependence of the particle drift velocity and the bounce period.

To accomplish this, the subroutine actually determines four field lines m, n, o, and p going through the points M, N, O, and P labeled $M(B', L + \delta L)$, $N(B', L)$, $O(B, L + \delta L)$, and $P(B, L)$, where $B' < B$ and $\delta L \ll L$ (see figure 4). The last point P is the true B-L ring point; the other three are needed in the calculation of the drift and bounce factors given in equations (2), (4), and (5). The procedure is as follows: for a given longitude, the field line through the point M is determined by calling SEARCH and EQUAT. Then the field line through the point N is determined, as well as the value of $\partial I / \partial B$, by calling INVAR at a point of the field line very close to N. Exactly the same procedure is repeated for the pair of points O and P. (Of course, the field line pairs m, o and n, p will be almost superposed.) The gradient of the second invariant is then computed for the pairs of field lines m,n and o,p. A correction for the longitude displacement of the equatorial point at the two different L shells is made to obtain a better estimate of the perpendicular distance between the equatorial rings of the two shells L and $L + \delta L$. Finally, the geomagnetic quantities appearing in equations (2) and (4) are calculated for the B-values B and B' , and the factors d , p , σ_u , and σ_s , giving the mirror dependence (5), from these.

7. TRACE

This subroutine completes the field line tracing done in BLRING down to point R at a prefixed geodetic altitude level called ALTO, in one hemisphere (see figure 5). In the other hemisphere, it continues the tracing to the point C which is conjugate to R (i.e., which has the same B-value).

After calling BLRING, the first operation in TRACE is to insert the equatorial point which has been accurately determined in EQUAT. If P and Q are the end points of the field line traced in BLRING, TRACE chooses the one, say P, with the lowest altitude and traces the field line from there on downwards by calling INSECT. Special provision is made for the case that the lower of P and Q should fall below ALTO. Subroutine BESECT is then called at the point Q at the other end of the field line. The field line is then traced to a point C where the field intensity

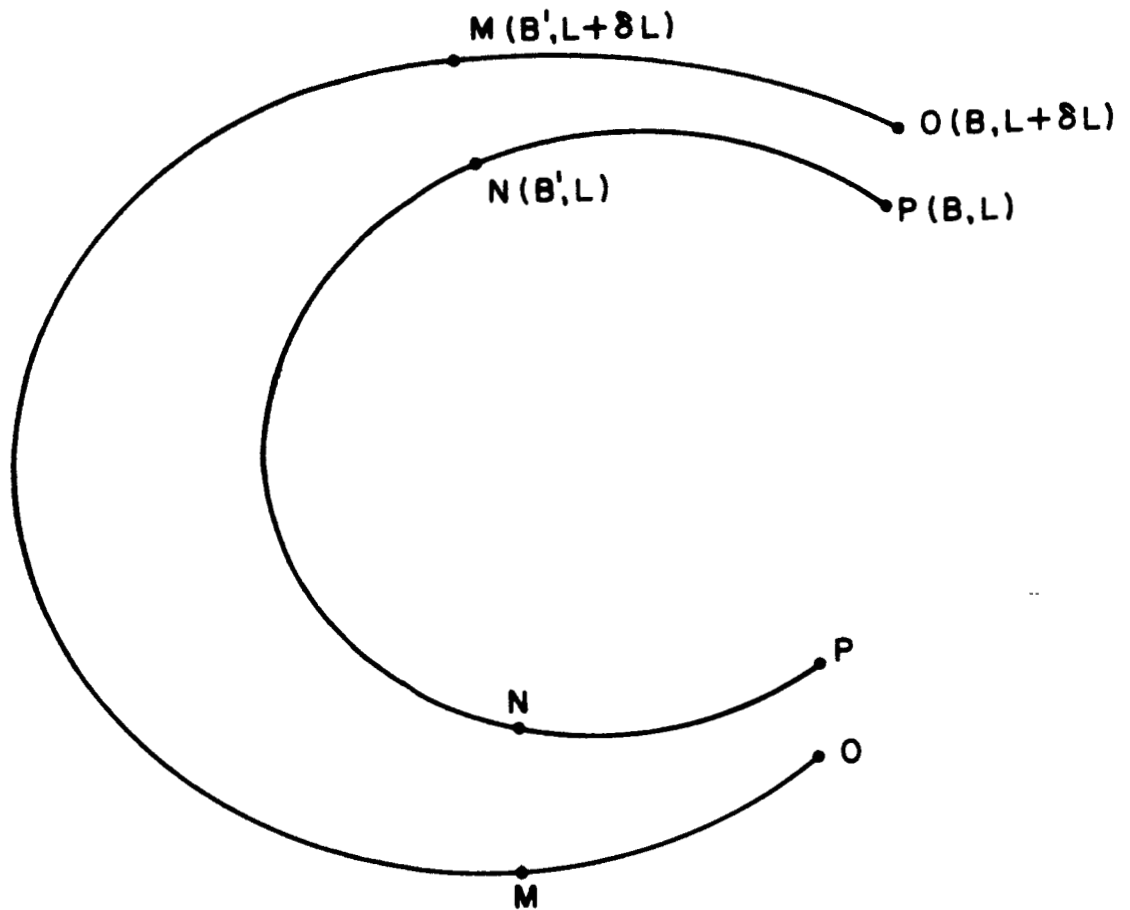


Figure 4. Pairs of Field Lines Traced for the Computation of Drift Velocity and Bounce Path.

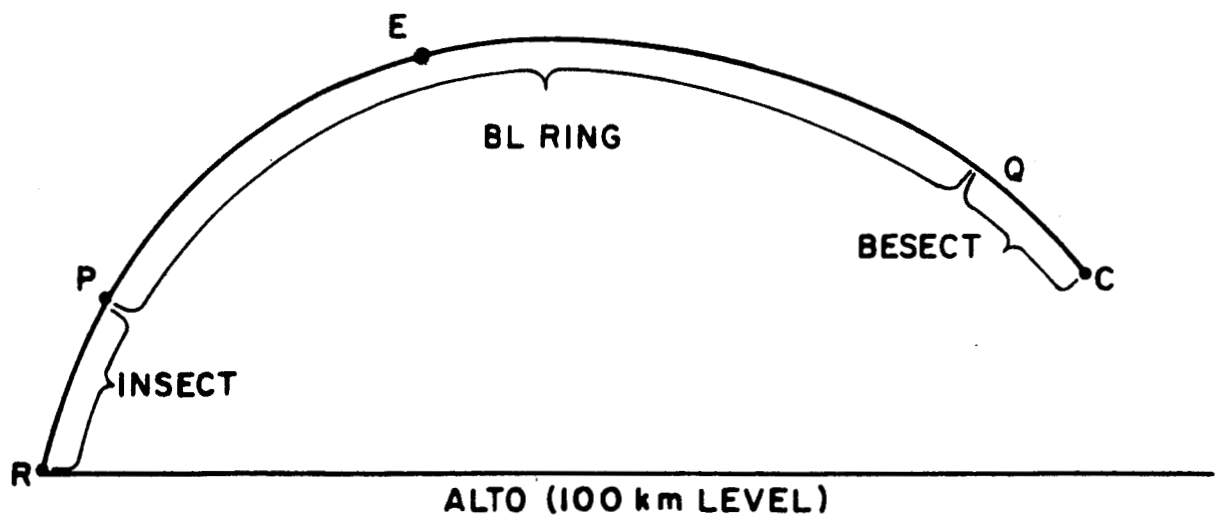


Figure 5. Portions of the Field Line Assembled by Subroutine Trace.

is the same as at R. In some cases, the point C may fall below ALTO; in that case, the points from which INSECT and BESECT trace are reversed, and the entire procedure is repeated.

In TRACE, all field line point coordinates are converted into geodetic coordinates. A flow chart for this subroutine is given in figure 6.

This subroutine can be modified conveniently to obtain tracing of the field line to the ALTO level in both the northern and the southern hemisphere (reference 14).

8. SHELL

SHELL is the first subroutine in the program and has five primary purposes: (1) read data and initialize the necessary parameters, (2) serialize the three portions of the field line data obtained in TRACE, (3) define the sequence in B (called the X-mesh) at which the field line data is desired, (4) interpolate the field line data onto this X-mesh, and (5) after editing the results, advance in longitude to the next field line until the shell is completed.

Data which are read into the program are the B-L coordinates (called SB and SL, respectively) of the point through which the field lines of the shell are to be traced, the altitude, latitude, and longitude of the point used as the starting point in the iteration technique of subroutine SEARCH, the step in longitude between successive field lines, the frequency of printing a detailed edit, and the controls for the B-mesh to be used. A full explanation of the input data may be found in section IV, 10.

Subroutine TRACE is called and the field line geometry is computed. Included in this geometry are the three sequences of points along three distinct portions of the field line (see figure 5). These three sequences do not advance in the same direction along the field line. Subroutine SHELL rearranges these three sequences of points into one monotonic sequence from point R to point C.

Two options for the X-mesh are provided. One defines a mesh of prefixed B-values, equally spaced. The other, though more complicated in conception, is specifically designed for studies of longitude dependence of trapped particles interacting with the atmosphere. In this option, the X-mesh is defined in such a way as to give B-values which correspond to points of prefixed altitudes, roughly proportional to the scale height, on the lower portion of the field line (portion E-P-R in figure 5). However, due to the longitude dependence of the

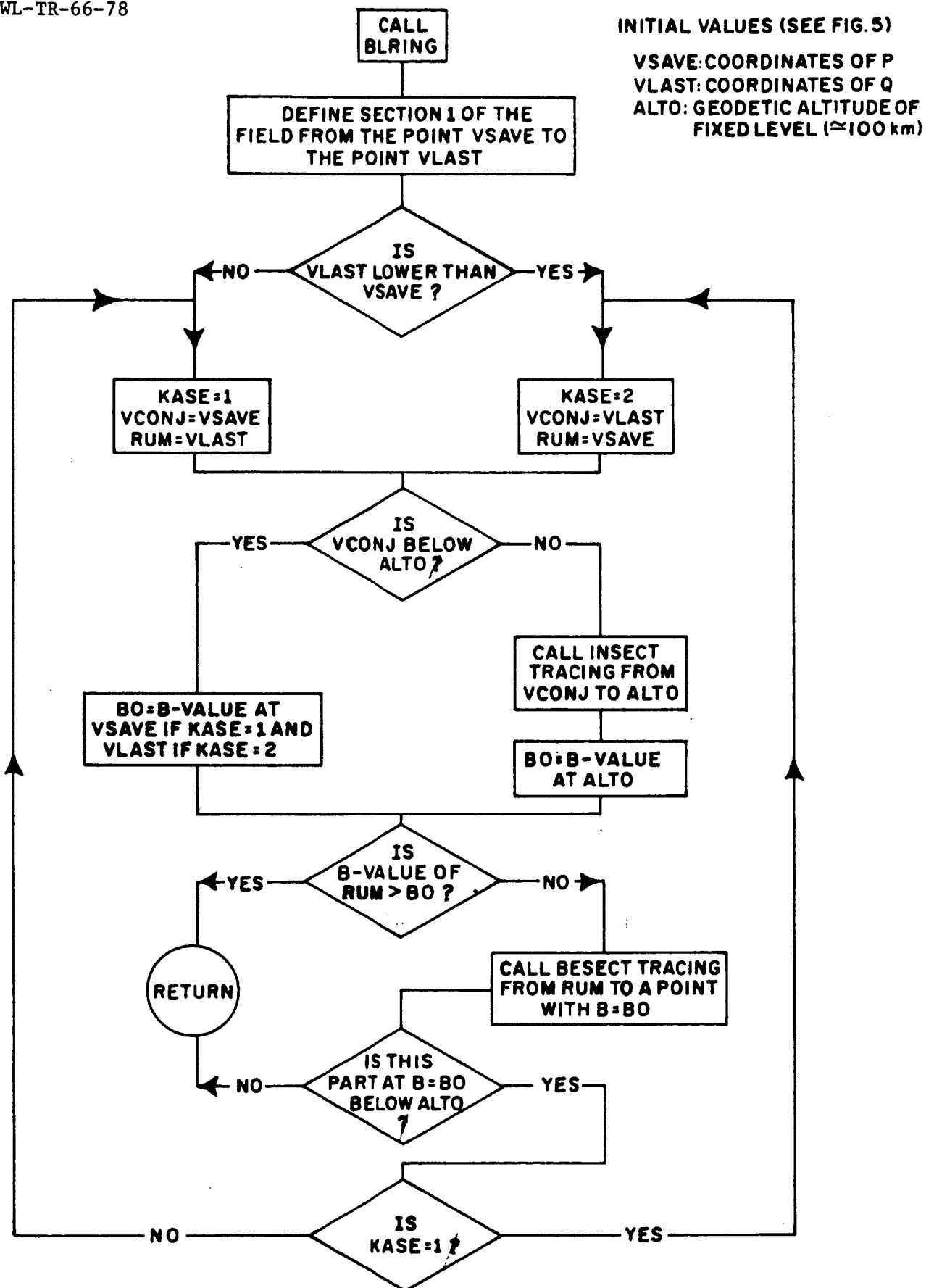


Figure 6. Flowchart for TRACE.

shell geometry, not all points of the mesh can be fixed in this way. Some mesh points have to be defined in a different manner. In the present code, this is done as follows: the first mesh point is always the equatorial point.* The third through twelfth points have prefixed, longitudinally independent B-values which are conveniently arranged as a function of the shell parameter L; the second point is inserted according to the actual value of the equatorial point. For the section of the X-mesh with prefixed altitudes, the user can select the number of points and the maximum and minimum altitudes between which these points should be placed. All remaining mesh points will be filled in between the twelfth point and the highest of the prefixed altitude points (see figure 7). This latter section of the mesh varies with longitude; its points have an accordion-like behavior, expanding and contracting as a function of longitude. The total number of mesh points is constant for the entire shell. Special care should be taken to avoid too big, sudden changes in step size. It should be noted that, for atmospheric scattering problems, a change in step size is less harmful if it occurs at higher altitudes.

9. SPLINE and YSPLN

These subroutines provide a very fast and accurate interpolation scheme (reference 13).

Let (x_i, y_i) , $i=1,2,\dots,n$ be a sequence of number pairs having the property that $x_1 < x_2 < \dots < x_n$. Subroutines SPLINE and YSPLN determine a function f defined on the number interval $[x_1, x_n]$ such that $f(x_i) = y_i$ and, on the interval $[x_{i-1}, x_i]$, the function f is a cubic polynomial. Moreover, each of the derivatives f' and f'' exists and is continuous on $[x_1, x_n]$. Input for SPLINE is the sequence x , the sequence y , and the number of points in these sequences. SPLINE returns the sequence Y2DOT which is f'' evaluated at each value of x_i . If z is a number, subroutine YSPLN evaluates $f(z)$. Input for YSPLN is the sequence x , the sequence y , the number of points, the sequence Y2DOT, and the number z . Subroutine YSPLN finds an integer j such that $x_{j-1} < z \leq x_j$ and then determines $f(z)$ by using the cubic equation defining f on the interval $[x_{j-1}, x_j]$.

* Remember that in the real field, the B-value at the equator of a shell defined by a B-L ring off the equator depends on the longitude.

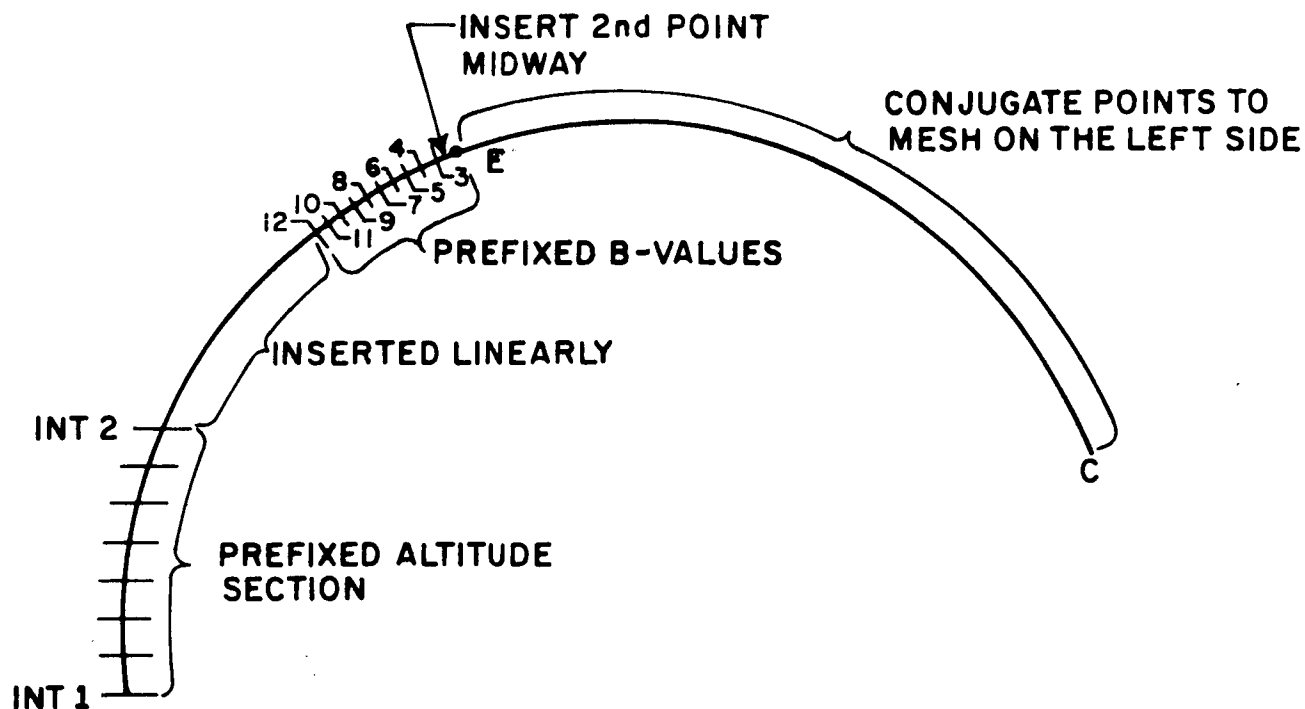


Figure 7. Definition of the X-mesh When Altitudes are Prefixed.

10. DATA

Below is a list of the input data together with a brief explanation of their functions and limitations:

- | | |
|------------------|--|
| SB, SL | The field line which is to be traced shall go through a point whose field intensity is SB and shall belong to the shell for which the McIlwain parameter has the value SL. The units for SB are gauss and the units for SL are Earth radii. In principle there are no restrictions for the values of SB and SL, except that the SB-SL point should lie above the altitude of ALTO. Of course, beyond a value of about 5 for SL, external sources of the field must be taken into consideration, and shell splitting invalidates the entire program (see section II). |
| ALT, FLAT, FLONG | These are the geodetic coordinates of a point, in kilometers and degrees, respectively. The positive direction for longitude is east of Greenwich. Subroutine SEARCH will use this point as the initial value in the iteration technique to find a point in the meridian FLONG for which $B = SB$ and $L = SL$. The value of FLAT determines the |

hemisphere in which the B-L point shall lie. It was found that, in view of the considerable field distortions in the South American Anomaly, it is convenient to define the L-shells by the B-L ring points in the Northern hemisphere. FLAT should have absolute value different from 90 degrees; it should also be more than 5 to 10 degrees away from the geomagnetic equator. In general, it should not differ by more than 10 to 15 degrees from the real SB-SL point. Standard B-L maps (reference 9 and 10) can aid the user of the programmer in selecting the initial value of ALT and FLAT.

SLONG1,
SLONG2,
SLONG3,
SLONG4

These are the longitudes at which the longitude step size is changed.

DLONG1,
DLONG2,
DLONG3

These are the increments for the longitude step in degrees. After the geometry for a field line is calculated, the new field line is determined by changing the value of FLONG. The increment for FLONG is DLONG1 between SLONG2 and SLONG3, DLONG2 in the region between SLONG1 and SLONG2 and between SLONG3 and SLONG4, and DLONG3 elsewhere.

NPR

NPR is a positive integer which controls the frequency of printing. Detailed edit is given every NPR field lines of the shell.

MESHB

MESHB is used as a control for the choice of mesh of B-values to be used. If MESHB = 1, the mesh at which the field line data are to be interpolated is given as B-values of prefixed altitude points at one end of the field line. If MESHB = 0, then the mesh is prefixed with a constant step size in B.

BIN, DELB

If MESHB = 0, then the mesh of prefixed B-values begins at BIN, i.e., $X(1) = \text{BIN}$. Furthermore, the step size for this mesh is DELB. Of course, BIN must not be so large that the point on the field line with B-value equal to BIN is below ALT0, nor so small that $\text{BIN} + 99 * \text{DELB}$ is less than the equatorial value. Care must be taken to ensure that these latter restrictions are true for all longitudes.

INT1, INT2
ALT1, ALT2

If MESHB = 1, then the altitudes of the points whose field intensities are $X(\text{INT1})$ and $X(\text{INT2})$ on the lower end of the field line are ALT1 and ALT2 kilometers, respectively. INT1 must not be greater than

100, which is the dimension of X, H, etc. INT2 should not be less than 12 for X(j), j = 3,4,...,12 is prefixed in B. ALT1 is the altitude of the lowest point on the field line. It can be equal to, but never less than, ALTO. ALT2 should be chosen so that the variations of the X-mesh size should be as small as possible (see figure 7).

11. DIAGNOSTICS

Below is a list of the possible diagnostics followed by an explanation of why they were printed:

SORRY, BUT I CANNOT FIND THAT POINT IN ICHECK

If this diagnostic is given, then subroutine SEARCH has completed 15 iterations trying to find the point at longitude FLONG with L value SL and B value SB. In the printout, the diagnostic is followed by the number of iterations performed to find the correct value of L, the number of iterations performed to find the correct value of B, the altitude, latitude, and longitude of the point at which the iteration process began, and the desired B,L value. The program chooses a new value for B; namely, SB becomes SB + .005, and the search process begins again.

There are three primary reasons why this diagnostic can be given. The first is that an error was made by the user: the initial value for the altitude, latitude, and longitude (ALT, FLAT, FLONG) of the desired B,L point (SB,SL) was too far from the correct value. The usual B,L maps can be consulted to prevent this problem.

The second reason that this diagnostic can occur appears to be caused by an inherent error in INVAR. Take a point P whose conjugate point P' lies below the surface of the earth. To calculate the value of L at P, INVAR uses subroutine LINES to trace the field line from P to the point P'. As has been described in section IV, b, LINES begins at P and determines a sequence of points along the field line through P until some point of the sequence has a B-value at least as large as that of P. However, the geometric field expansion used in LINES is strictly valid only for points above the surface of the earth, and a peculiar behavior must be expected in a forced tracing well below sea level. A region for which such peculiar behavior was found to affect the calculated value of L is shown in figure 8. When field lines are traced from this European region, one finds a B-dependence along the field line as sketched in figure 9. It is quickly realized, then, that whenever I (or L) is computed in INVAR for this field line,

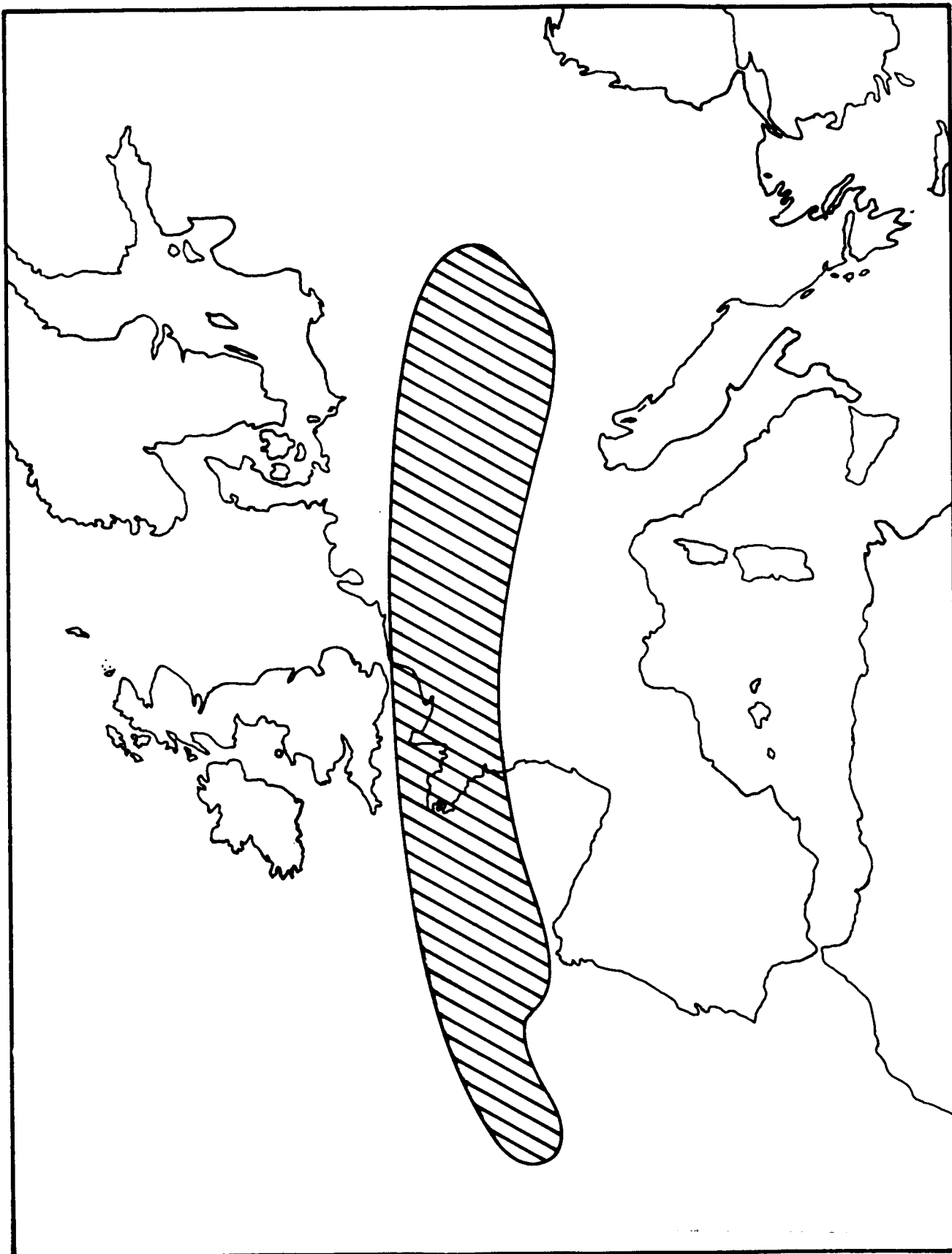


Figure 8. Region Over Europe for Which L Values Calculated in INVAR are not Accurate.

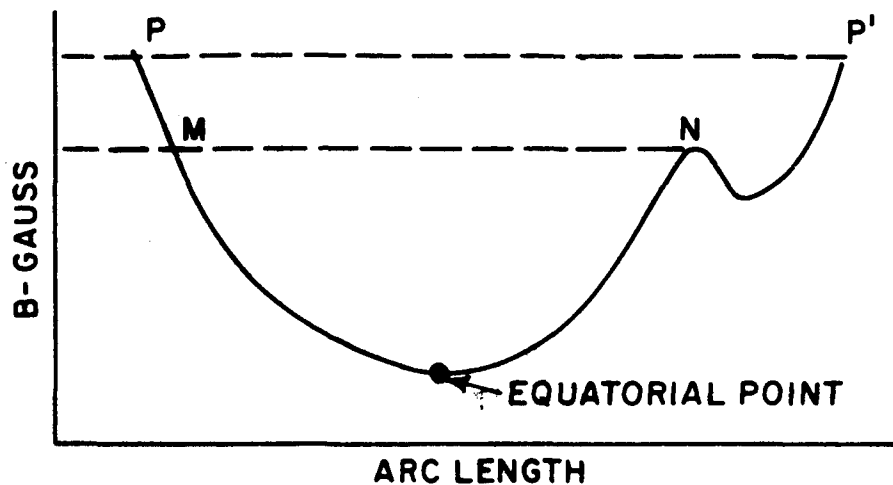


Figure 9. Sketch of B-dependence Along Field Lines
Traced from the Area Shown in Figure 8.

only the section between M and N yields correct values of L. The value of L at M may differ by as much as 3.5 percent from that of a point on the same field line, but at a slightly higher B value. It is easily seen that the points iterated by the technique used in SEARCH may fail to converge to a point with the correct value of L because of the discontinuity. There, an inherently incorrect value of L may be computed.

The third reason why it is possible for this diagnostic to occur is that the tolerance $ERRL$ may be changed to a value too small with respect to ERR (or ERR may be increased to a value too big). In this case, the iterated points may never fall in the interval $SL \pm ERRL$.

SORRY, BUT I CANNOT FIND THAT POINT IN MCHECK

If this diagnostic is given in the output, then subroutine SEARCH has completed 15 iterations trying to find the point at longitude FLONG with B-value SB. It is not expected that this diagnostic will ever occur for the geomagnetic field within the magnetosphere; it is programmed into the subroutine to prevent any possibility of an infinite iteration. The printout which follows the diagnostic, as well as the action taken by the program after printing the diagnostic, is exactly the same as that described in the discussion above.

INCREASE OF ERR IN EQUAT, or
 INCREASE OF ERR IN BESECT, or
 INCREASE OF ERR IN INSECT, or
 INCREASE OF ERR IN INVAR

This diagnostic is given if, after calling LINES for the subroutine indicated in the diagnostic, more than 200 points are found in the tracing of the field line. The diagnostic is followed by the increased value of ERR which will be used in the recall of LINES. If, after increasing ERR and recalling LINES, it is found that less than 200 points were required to complete the section of the field line trace in question, the program will reset ERR to its original small value and proceed. This check on the number of points permitted in the trace is necessary to prevent an overflow of the dimension of B, VN1, VN2, VN3, BX, etc. Since ERR controls the maximum step size of the arc length along the field line, then an increase of ERR will allow a larger step size and, consequently, a smaller number of points in the determination of the field line.

X SHOULD BE INCREASING IN SPLINE

If this diagnostic is given, then the independent variable sequence with which the interpolation subroutine SPLINE is called is not an increasing sequence. Following the diagnostic is a list of the pair of sequences X and Y--the independent variable and the dependent variable. The subroutine continues its calculation but the results in the neighborhood of the section where the values of X are not increasing will likely not be correct. It is very unlikely that this diagnostic will ever be given when SPLINE is used as a subroutine to SHELL. The check is included mostly for users of SPLINE in other interpolation problems.

INCREASE THE DIMENSION OF ALL DIMENSIONED VARIABLES IN SPLINE AND YSPLN

This diagnostic occurs if the number of points in the sequence X is greater than the maximum dimension of the dimensioned variables in these two subroutines. The program will stop and the user must increase the dimension of X, Y, D, P, E, A, B, and Y2DOT in subroutines SPLINE and YSPLN. They are presented in this document as dimensioned 400 places merely to save on storage requirements.

AT LEAST FOUR POINTS ARE NEEDED IN THIS ROUTINE

The technique used in SPLINE requires at least four points. If there are not four values of the independent variable, the program stops. Should this diagnostic occur, the user can either decrease the value of ALTO or decrease the value of ERR. In either case, the number of points along the field line will increase.

PROGRAM HALT IN SUBROUTINE YSPLN----SEARCH LIST CONTAINS LESS THAN TWO POINTS

The technique used in YSPLN requires at least two points. Since a call of this subroutine logically follows a call of SPLINE, the diagnostic should never occur and is included only for logical completeness.

SECTION V

RESULTS

Tables I and II show typical printouts for the $L = 1.25$ shell. In the first table, the X-mesh was one of prefixed B-value; in the second table, the X-mesh was defined according to prefixed altitudes (see section IV,8).

Computer time for a complete run around the world, defining 72 field lines on the shell, was 2.56 minutes on a Control Data Corporation 6600 computer, and roughly four times more on an IBM 7094, for $L = 1.25$. The same run, without the calculation of drift velocity and bounce period takes 0.73 minute on the CDC 6600. Tracing of a given B-L ring, without any additional information other than giving the coordinates of the B-L point on 72 different longitudes around the world, requires only 20 seconds on the 6600, for $L = 1.25$. All these computer times increase with increasing L .

In figures 10 and 11 the longitude dependence of angular drift velocities and bounce paths, respectively, is shown, for $L = 1.25$ and $B = 0.18$ and 0.22 . Notice that the bounce path (and, therefore, the bounce period) varies considerably less with longitude than does the drift velocity. This is to be expected according to expression (4), in which I and B_m are invariant, and should vary only a little with longitude.

When the curves in figures 10 and 11 are to be compared with those previously calculated, one has to bear in mind that longitude dependence of drift velocities and bounce paths depends very critically on how the shell was originally defined. The correct calculation requires picking the L-shell at precisely the B_m points for which these quantities are to be determined.

Table I

AT LONG = -35.00 THE COORDINATES OF THE POINT AT L = 1.25 AND B = .2200 ARE ALT = 787.46 AND LAT = .37
 THE EQUATORIAL POINT OF THE FIELD LINE IS AT EALT = 1118.84 ELAT = -14.94 ELONG = -52.30 AND HAS 3 VALJE = .1616
 THE DRIFT PARAMETERS ARE DRIFT = 1.149 SLOPE = -.612 PATH = 1.915 PSLOPE = 1.628 DPHIDX = 9.694 = .01

YESH POINTS (GAUSS)	ALTITUDES(KM)		ARC LENGTH FROM EQUATOR(KM)		LATITUDES		LONGITUDES	
	NORTH	SOUTH	NORTH	SOUTH	NORTH	SOUTH	NORTH	SOUTH
17	1114.5	935.4	865.7	892.5	-8.48	-21.64	-53.39	-51.19
18	1052.6	784.8	1256.9	1328.8	-5.56	-24.84	-53.97	-50.65
19	985.5	649.5	1539.4	1655.6	-3.47	-27.21	-54.23	-50.25
20	918.2	523.7	1767.3	1928.1	-1.79	-29.18	-54.53	-49.92
21	851.9	405.6	1961.7	2165.5	-.37	-30.88	-54.73	-49.63
22	787.5	293.3	2132.1	2379.0	.87	-32.41	-55.00	-49.38
23	724.9	186.9	2284.4	2573.0	1.96	-33.80	-55.20	-49.14

Table II

AT LONG = -95.00 THE COORDINATES OF THE POINT AT L = 1.25 AND B = .2200 ARE ALT = 787.46 AND LAT = .87
 THE EQUATORIAL POINT OF THE FIELD LINE IS AT EALT = 1118.84 ELAT = -14.94 ELONG = -52.30 AND HAS B VALUE .1616
 THE DRIFT PARAMETERS ARE DRIFT = 1.149 SLOPE = -.612 PATH = 1.915 PSLOPE = 1.628 DPHIDX = 8.683E-01

MESH POINTS (GAUSS)	ALTITUDES(KM)		ARC LENGTH FROM EQUATOR(KM)		LATITUDES		LONGITUDES	
	NORTH	SOUTH	NORTH	SOUTH	NORTH	SOUTH	NORTH	SOUTH
1	1126.4	1108.4	90.0	87.1	-14.31	-15.64	-52.40	-52.18
2	1139.4	1052.2	434.0	431.7	-11.73	-18.22	-52.84	-51.76
3	1135.1	1012.6	603.1	609.4	-10.45	-19.54	-53.05	-51.54
4	1126.8	976.0	735.6	751.2	-9.46	-20.59	-53.21	-51.36
5	1116.8	942.4	844.1	869.0	-8.64	-21.47	-53.35	-51.22
6	1105.6	910.3	939.7	973.3	-7.93	-22.23	-53.47	-51.09
7	1093.7	879.2	1025.3	1068.1	-7.29	-22.93	-53.58	-50.97
8	1081.2	849.0	1103.3	1155.5	-6.70	-23.57	-53.68	-50.86
9	1068.5	819.6	1175.6	1236.7	-6.17	-24.17	-53.77	-50.76
10	1055.4	790.9	1242.9	1312.9	-5.66	-24.72	-53.86	-50.67
11	1042.2	762.8	1306.0	1385.0	-5.19	-25.25	-53.94	-50.58
12	1028.9	735.2	1365.8	1453.7	-4.75	-25.75	-54.01	-50.50
13	1019.5	716.2	1405.9	1500.0	-4.45	-26.08	-54.06	-50.44
14	1010.0	697.4	1444.6	1544.8	-4.17	-26.41	-54.11	-50.39
15	1000.6	678.8	1482.0	1588.4	-3.89	-26.73	-54.16	-50.33
16	991.1	660.4	1518.2	1630.8	-3.62	-27.03	-54.21	-50.28
17	981.7	642.2	1553.3	1672.1	-3.36	-27.33	-54.25	-50.23
18	972.2	624.1	1587.4	1712.5	-3.11	-27.62	-54.30	-50.18
19	962.8	606.3	1620.6	1752.0	-2.87	-27.91	-54.34	-50.13
20	953.4	588.6	1652.9	1790.6	-2.63	-28.19	-54.38	-50.09
21	944.0	571.0	1684.4	1828.4	-2.40	-28.46	-54.42	-50.04
22	934.6	553.7	1715.2	1865.4	-2.17	-28.73	-54.46	-49.99
23	925.2	536.4	1745.3	1901.6	-1.95	-28.99	-54.50	-49.95
24	915.8	519.4	1774.7	1937.1	-1.73	-29.24	-54.54	-49.91
25	906.5	502.5	1803.5	1971.9	-1.52	-29.49	-54.57	-49.87
26	897.1	485.7	1831.7	2006.1	-1.32	-29.74	-54.61	-49.82
27	887.8	469.1	1859.3	2039.7	-1.12	-29.98	-54.65	-49.78
28	878.6	452.6	1886.4	2072.8	-.92	-30.22	-54.68	-49.74
29	869.3	436.2	1912.9	2105.3	-.72	-30.45	-54.71	-49.70
30	860.1	420.0	1938.9	2137.3	-.54	-30.68	-54.75	-49.67
31	851.0	403.9	1964.4	2168.8	-.35	-30.91	-54.78	-49.63
32	842.4	388.9	1987.9	2197.9	-.18	-31.11	-54.81	-49.59
33	834.4	374.9	2009.6	2224.9	-.02	-31.31	-54.84	-49.56
34	826.9	361.8	2029.7	2250.0	.12	-31.49	-54.87	-49.53
35	819.9	349.5	2048.4	2273.4	.26	-31.66	-54.89	-49.50
36	813.2	338.0	2065.9	2295.3	.39	-31.81	-54.91	-49.48

Table II (cont'd)

37	.21694	807.0	327.1	2082.1	2315.8	.50	-31.96	-54.93	-49.45
38	.21786	801.1	316.9	2097.4	2335.0	.62	-32.10	-54.95	-49.43
39	.21874	795.5	307.2	2111.7	2353.1	.72	-32.23	-54.97	-49.41
40	.21957	790.2	298.1	2125.2	2370.1	.82	-32.35	-54.99	-49.39
41	.22036	785.2	289.4	2137.8	2386.2	.91	-32.46	-55.01	-49.37
42	.22111	780.4	281.2	2149.8	2401.4	.99	-32.57	-55.02	-49.35
43	.22183	775.9	273.5	2161.2	2415.8	1.08	-32.67	-55.04	-49.33
44	.22251	771.6	266.1	2171.9	2429.4	1.15	-32.77	-55.05	-49.31
45	.22317	767.4	259.0	2182.1	2442.3	1.23	-32.86	-55.07	-49.30
46	.22379	763.5	252.3	2191.8	2454.6	1.30	-32.95	-55.08	-49.28
47	.22439	759.7	245.9	2201.0	2466.2	1.36	-33.04	-55.09	-49.27
48	.22497	756.1	239.9	2209.8	2477.4	1.43	-33.12	-55.10	-49.26
49	.22552	752.7	234.0	2218.2	2488.0	1.49	-33.19	-55.11	-49.25
50	.22604	749.4	228.5	2226.1	2498.1	1.54	-33.26	-55.12	-49.23
51	.22655	746.3	223.1	2233.6	2507.8	1.60	-33.33	-55.13	-49.22
52	.22703	743.3	218.0	2240.9	2517.0	1.65	-33.40	-55.14	-49.21
53	.22750	740.4	213.1	2247.8	2525.8	1.70	-33.46	-55.15	-49.20
54	.22794	737.6	208.4	2254.4	2534.3	1.75	-33.52	-55.16	-49.19
55	.22837	735.0	203.9	2260.7	2542.4	1.79	-33.58	-55.17	-49.18
56	.22879	732.4	199.6	2266.8	2550.2	1.84	-33.64	-55.18	-49.17
57	.22918	730.0	195.4	2272.6	2557.7	1.88	-33.69	-55.18	-49.16
58	.22957	727.6	191.4	2278.2	2564.9	1.92	-33.74	-55.19	-49.15
59	.22994	725.3	187.6	2283.6	2571.8	1.96	-33.79	-55.20	-49.15
60	.23030	723.1	183.8	2288.7	2578.5	1.99	-33.84	-55.21	-49.14
61	.23064	721.0	180.3	2293.7	2584.9	2.03	-33.89	-55.21	-49.13
62	.23098	718.9	176.8	2298.5	2591.1	2.06	-33.93	-55.22	-49.12
63	.23130	717.0	173.5	2303.1	2597.1	2.10	-33.97	-55.22	-49.12
64	.23161	715.0	170.2	2307.6	2602.8	2.13	-34.01	-55.23	-49.11
65	.23192	713.2	167.1	2311.9	2608.4	2.16	-34.05	-55.24	-49.10
66	.23221	711.4	164.1	2316.0	2613.7	2.19	-34.09	-55.24	-49.10
67	.23249	709.7	161.2	2320.1	2618.9	2.22	-34.13	-55.25	-49.09
68	.23277	708.0	158.4	2323.9	2623.9	2.25	-34.17	-55.25	-49.08
69	.23303	706.4	155.6	2327.7	2628.8	2.27	-34.20	-55.26	-49.08
70	.23329	704.8	153.0	2331.3	2633.4	2.30	-34.23	-55.26	-49.07
71	.23354	703.3	150.4	2334.8	2638.0	2.32	-34.27	-55.27	-49.07
72	.23379	701.8	147.9	2338.2	2642.4	2.35	-34.30	-55.27	-49.06
73	.23402	700.4	145.5	2341.5	2646.7	2.37	-34.33	-55.28	-49.06
74	.23425	699.0	143.2	2344.7	2650.8	2.40	-34.36	-55.28	-49.05
75	.23447	697.6	140.9	2347.8	2654.8	2.42	-34.39	-55.28	-49.05
76	.23469	696.3	138.7	2350.8	2658.7	2.44	-34.42	-55.29	-49.04
77	.23490	695.0	136.6	2353.7	2662.5	2.46	-34.44	-55.29	-49.04
78	.23511	693.8	134.5	2356.5	2666.2	2.48	-34.47	-55.30	-49.03
79	.23531	692.6	132.4	2359.2	2669.7	2.50	-34.49	-55.30	-49.03
80	.23550	691.4	130.5	2361.9	2673.2	2.52	-34.52	-55.30	-49.03

Table II (cont'd)

81	.23549	690.3	128.6	2364.5	2676.6	2.54	-34.54	-55.31	-49.02
82	.23588	689.2	126.7	2367.0	2679.9	2.56	-34.57	-55.31	-49.02
83	.23606	688.1	124.9	2369.5	2683.1	2.57	-34.59	-55.31	-49.02
84	.23623	687.0	123.1	2371.9	2686.2	2.59	-34.61	-55.32	-49.01
85	.23640	686.0	121.4	2374.2	2689.2	2.61	-34.63	-55.32	-49.01
86	.23657	685.0	119.7	2376.4	2692.2	2.62	-34.66	-55.32	-49.00
87	.23673	684.0	118.1	2378.6	2695.0	2.64	-34.68	-55.32	-49.00
88	.23689	683.1	116.5	2380.8	2697.8	2.65	-34.70	-55.33	-49.00
89	.23704	682.1	114.9	2382.9	2700.6	2.67	-34.72	-55.33	-48.99
90	.23720	681.2	113.4	2384.9	2703.2	2.68	-34.73	-55.33	-48.99
91	.23734	680.4	111.9	2386.9	2705.8	2.70	-34.75	-55.34	-48.99
92	.23749	679.5	110.4	2388.8	2708.4	2.71	-34.77	-55.34	-48.99
93	.23763	678.6	109.0	2390.7	2710.9	2.72	-34.79	-55.34	-48.98
94	.23777	677.8	107.7	2392.5	2713.3	2.74	-34.81	-55.34	-48.98
95	.23790	677.0	106.3	2394.3	2715.6	2.75	-34.82	-55.35	-48.98
96	.23803	676.2	105.0	2396.1	2717.9	2.76	-34.84	-55.35	-48.97
97	.23816	675.5	103.7	2397.8	2720.2	2.78	-34.86	-55.35	-48.97
98	.23829	674.7	102.4	2399.5	2722.4	2.79	-34.87	-55.35	-48.97
99	.23841	674.0	101.2	2401.1	2724.5	2.80	-34.89	-55.35	-48.97
100	.23853	673.3	100.0	2402.7	2726.6	2.81	-34.90	-55.36	-48.96

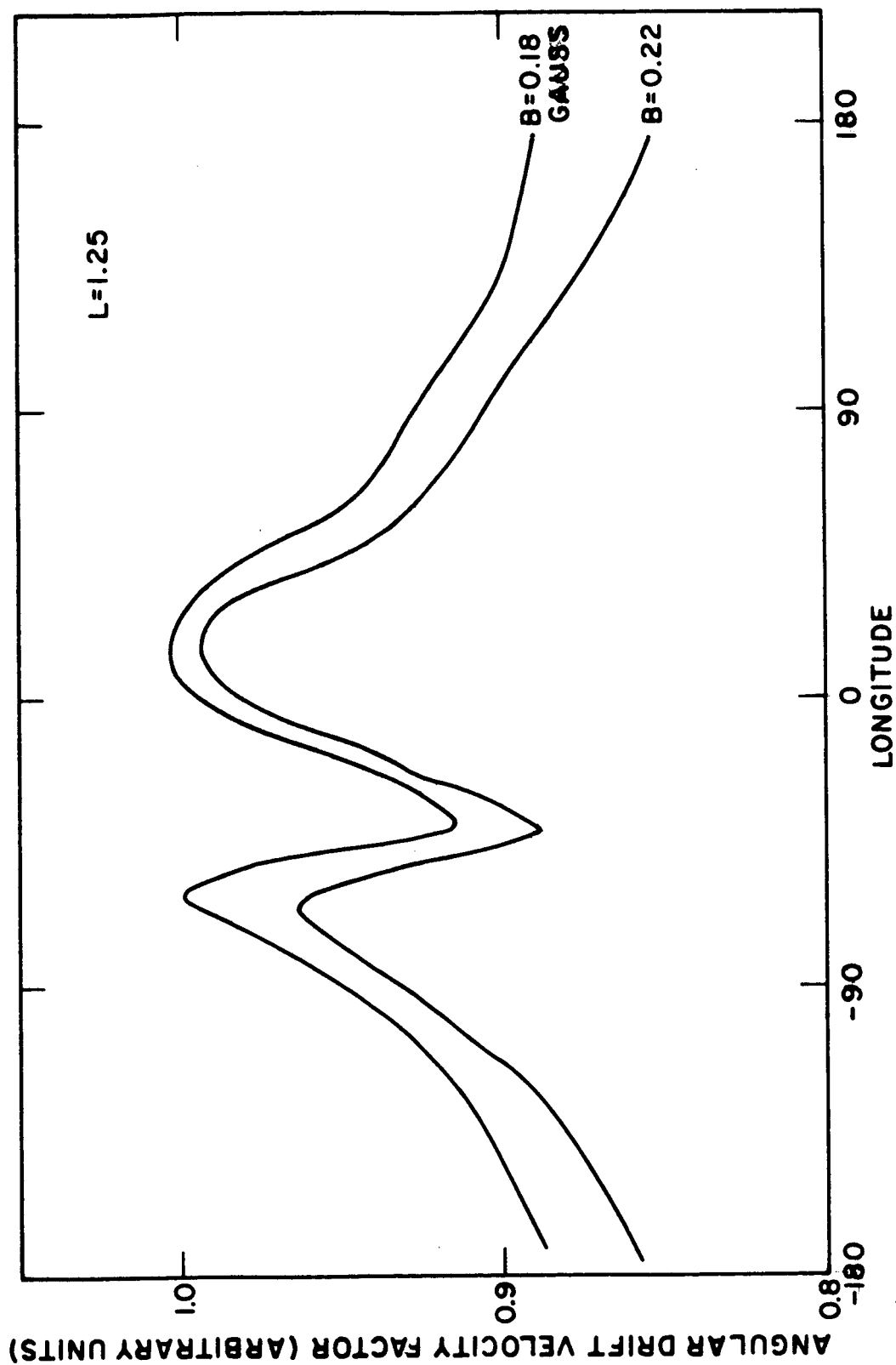


Figure 10. Longitude Dependence of Angular Drift Factor for $B = .18$ and $B = .22$ at $L = 1.25$.

In order to obtain the angular drift velocity in degrees/sec, multiply by

$$L * \gamma * \beta^2 * 2.31759 \times 10^{-2} * (\text{mass in electron masses}) \text{ where } \gamma = \text{total energy and } \beta = v/c.$$

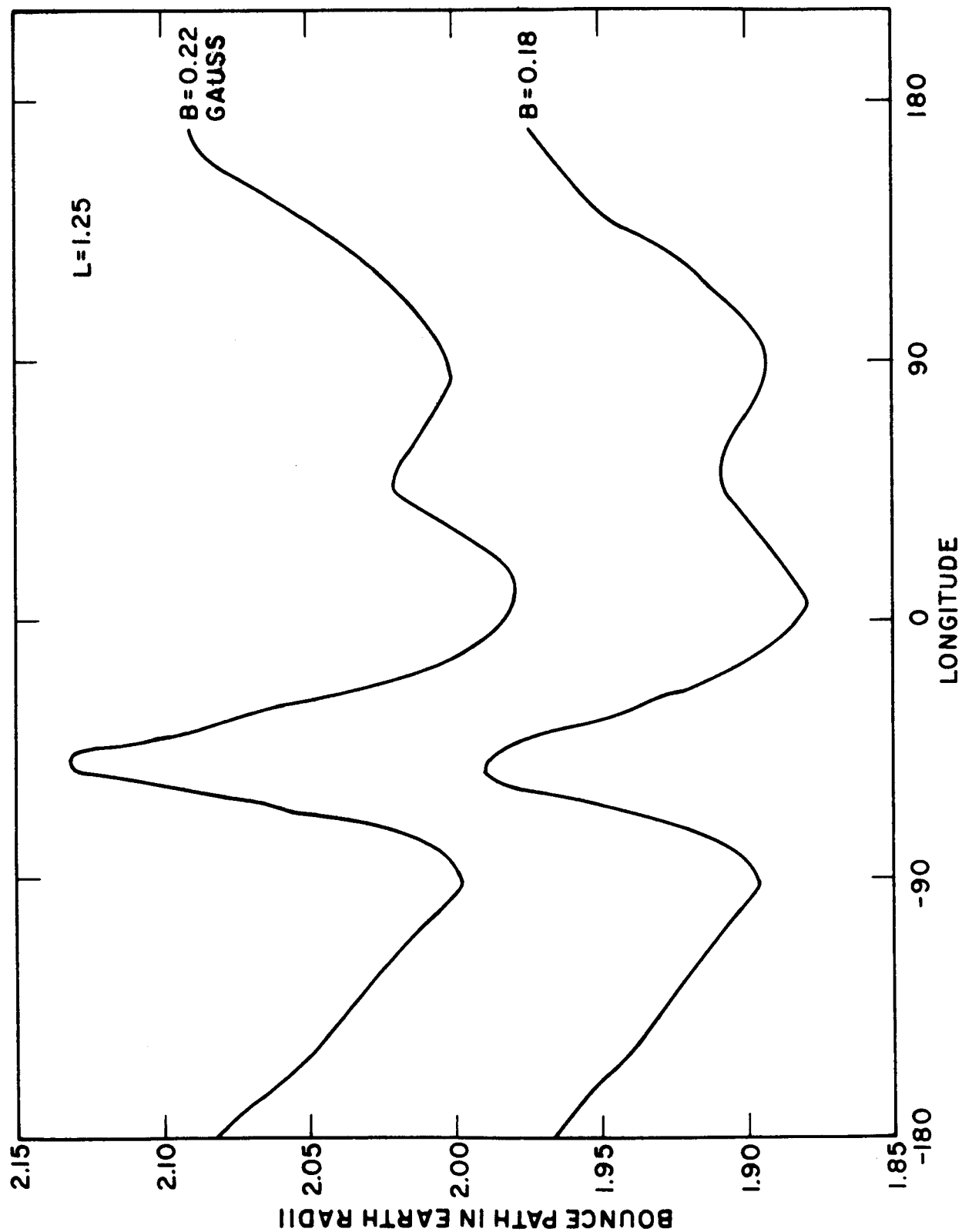


Figure 11. Bounce Path in Earth Radii for $B = .22$ and $B = .18$ at $L = 1.25$

APPENDIX I
PROGRAM DICTIONARY

In this appendix, some of the most important variables are defined for the principal subroutines.

<u>Variable</u>	DICTIONARY FOR SHELL	<u>Units</u>
ABX	arc length to the preceding point in the mesh along the field line.	earth radii
ALT	initial altitude value for the iteration process used by subroutine SEARCH. After TRACE is called, ALT is the altitude of the B-L point through which the field line has been traced and will be used as the initial value for the iteration at the next field line.	km
ALTO	minimum altitude level to which the field line will be traced.	km
ALT1	altitude of the lowest point in the prefixed altitude section of the field line. This is used only in case MESHB = 1.	km
ALT2	altitude of the highest point in the prefixed altitude section of the field line. This is used only in case MESHB = 1.	km
BIN	B-value of the first point of the sequence of prefixed B's. This is used only in case MESHB = 0.	gauss
BX	B-value of the sequence of points along the field line.	gauss
CLONG	longitude of the point on the field line at ALTO km.	degrees
DARC	arc length between successive points along the field line. DARC(j,1) is computed in BLRING, DARC(j,2) in INSECT, and DARC(j,3) in BESECT.	earth radii
DB	B-value of points along the field line. DB(j,1), DB(j,2), and DB(j,3) are calculated in BLRING, INSECT, and BESECT, respectively.	gauss

DELB	increment in B-value for the sequence of prefixed B's. This is used only in case MESHB = 0.	gauss
DEQ	distance between the equatorial points of successive field lines.	earth radii
DH	altitude of points along the field line. The calculation is done in the same order as that of DARC and DB.	km
DLAT	latitude of points along the field line. The calculation is done in the same order as that of DARC and DB.	degrees
DLONG	longitude of points along the field line. The calculation is done in the same order as that of DARC and DB.	degrees
DLONG1	increment in longitude in the region containing the anomaly for the SB-SL point through which the field line is to be traced.	degrees
DLONG2	same as DLONG1 except the region is outside the anomaly, but still not far from it.	degrees
DLONG3	same as DLONG1 except the region is away from the anomaly.	degrees
DPHIDX	change of equatorial longitude per unit equatorial distance.	radian/ earth radii
DRIFT	see dictionary for BLRING.	
EALT	altitude of the equatorial point.	km
ELAT	latitude of the equatorial point.	degrees
ELONG	longitude of the equatorial point.	degrees
ENC	increment for the X mesh for the small region of prefixed B (approximately X(3) through X(12)). This is used only in case MESHB = 1.	gauss
ERR	see dictionary for SEARCH.	
ERRB	see dictionary for SEARCH.	
ERRL	see dictionary for SEARCH.	
EVN	geocentric coordinates of the equatorial point.	
FLAT	initial value of latitude for the iteration used by SEARCH. See definition of ALT.	degrees

FLAX	latitude of the sequence of points along the field line.	degrees
FLONG	longitude of the B-L point through which the field is to be traced.	degrees
FLOX	longitude of the sequence of points along the field line.	degrees
H	prefixed altitude sequence.	km
HXN	altitude of points in the final X-mesh for which the arc length to the equator has been defined to be negative.	km
HXP	altitude of points in the final X-mesh for which the arc length to the equator has been defined to be positive.	km
INT1	number of points in the X-mesh if MESHB = 1.	
INT2	subscript for the highest point in the section of prefixed altitude section of the X-mesh.	
JLAST	number of points in the sequences BX, HBX, FLAT, FLOX, ABX, and S.	
JUP	(JUP(1) - 1) is the number of points calculated by BLRING; (JUP(2) - 1) is the number of points calculated by INSECT; and (JUP(3) - 1) is the number of points calculated by BESECT.	
KASE	see dictionary for TRACE.	
KEQ	subscript for the equatorial point.	
LATN	latitude of points in the final X-mesh for which the the arc length to the equator has been defined to be positive.	degrees
LINE	number of field line calculations completed.	
LONGN	longitude of the points indicated in the definition of LATP.	degrees
MESHB	control for the type of X-mesh to be used (see section IV,8).	
NPR	edit control. Detailed printing occurs every NPR cycles.	
S	arc length from the equatorial point to a point in the sequence along the field line.	earth radii
SB	B-value of the point through which the field line will be traced.	gauss

SFLONG	longitude of the point through which the initial field line was traced.	degrees
SL	L value of the shell to be determined.	earth radii
SLONG1, SLONG2, etc.	longitude at which the longitude step size changes.	degrees
SLOPE	see dictionary for BLRING.	
SXN	arc length to the equator of points in the X-mesh as indicated in the definition of LATN.	earth radii
SXP	arc length to the equator of points in the X-mesh as indicated in the definition of LATP.	earth radii
X	B-value of points in the final mesh.	gauss

DICTIONARY FOR TRACE

ALT	see dictionary for SHELL.	
BALT	altitude of the last point calculated in BESECT. The B-value on the field line at this altitude will equal or be slightly higher than BO.	km
BO	B-value on the field line at the ALTO km level.	gauss
BCONJ	B-value to which BESECT must trace.	gauss
CLONG	longitude of the lowest point in the final X-mesh.	degrees
DARC	see dictionary for SHELL.	
DB	see dictionary for SHELL.	
DH	see dictionary for SHELL.	
DLONG	see dictionary for SHELL.	
DLAT	see dictionary for SHELL.	
DRIFT	see dictionary for BLRING.	
EALT	altitude of the equatorial point.	km
EB	B-value of the equatorial point.	gauss
ERR	see dictionary for SEARCH.	
EVN	geodetic coordinates of the equatorial point.	
FLAT	see dictionary for SEARCH.	degrees
FLONG	see dictionary for SEARCH.	
JNEAR	see dictionary for BLRING.	
JUP	see dictionary for SHELL.	
KASE	this has value 1 or 2 depending on which end of the field line is lower in the tracing of BLRING.	
KEQ	see dictionary for SHELL.	
PATH	see dictionary for BLRING.	

RUM	geodetic coordinates of the point at which BESECT begins to trace the field line.	
SB	see dictionary for SEARCH.	
SL	see dictionary for SEARCH.	
SLOPE	see dictionary for BLRING.	
VCONJ	after the call of INSECT, this is the geodetic coordinates of the intersection of the field line with ALTO.	
VLAST	geodetic coordinates of the last point in the section of the field line traced in SEARCH.	
VNEAR	see dictionary for BLRING.	
VN1	geodetic altitude of points in the section of field line traced in the last call of LINES.	earth radii
VN2	geodetic latitude of points in the section of the field line traced in the last call of LINES.	co-latitude
VN3	geodetic longitude of points in the section of the field line traced in the last call of LINES.	radians
VSAVE	geodetic coordinates of the first point in the section of the field line traced by SEARCH.	

DICTIONARY FOR BLRING

ALT	see dictionary for SEARCH.	
ARC	arc length between consecutive points of the field line.	earth radii
BB	see dictionary for SEARCH.	
BZERO	equatorial field intensity for a pure dipole at the given L-shell.	gauss
CORR	longitude correction for a parallel displacement of field lines.	radians
DRIFT	drift factor--see SLOPE.	
EB	equatorial B-value.	gauss
ERR	see dictionary for SEARCH.	
EALT	altitude of the equatorial point.	km
FLAT	see dictionary for SEARCH.	
FLONG	see dictionary for SEARCH.	
JU	(JU - 1) is the total number of points in the field as traced by BLRING.	
JNEAR	see VNEAR.	

PATH	rectified trajectory of a particle from one mirror point to its conjugate.	earth radii
PSLOPE	factor which gives the B-dependence of PATH in the expression (5).	
SB	see dictionary for SEARCH.	
SL	see dictionary for SEARCH.	
SLOPE	factor which gives the B-dependence of the drift velocity in the expression (5). To obtain the drift velocity in cm/sec, see comment cards.	
VINEAR	when determined in SEARCH, VNEAR is the geodetic coordinates of the first point in the field line tracing for which B increases again, i.e., VNEAR is the geodetic coordinates of the first point after the equatorial point. JNEAR - 1 is the number of points between the origin of the tracing and VNEAR. When determined in EQUAT, VNEAR is the geocentric coordinates of the equatorial point.	
VN1	see dictionary for SEARCH.	
VSAVE	see dictionary for SEARCH.	

DICTIONARY FOR SEARCH

ALT	geodetic altitude of the initial point in the iteration process--becomes the geodetic altitude of the SB-SL point.	km
BB	magnitude of the geomagnetic field intensity.	gauss
BP	east component of the geomagnetic field.	
BR	radial component of the geomagnetic field.	
BT	south component of the geomagnetic field.	
B1	field intensity at point T (see figure 3).	gauss
B2	field intensity at point S (see figure 3).	gauss
DV	initial increment in latitude.	radians
ERR	control parameter for the step size in line tracing.	
ERRB	relative gross tolerance in B; final tolerance is 1/20 of the initial value.	
ERRL	relative gross tolerance in L; final tolerance is 1/100 of the initial value.	

FLAT	geodetic latitude of the initial starting point in the iteration process--becomes the geodetic latitude of the SB-SL point.	
FLONG	geodetic longitude of the initial point in the iteration process.	
JUP	(JUP - 1) is the total number of points in the field line tracing.	
SB	prefixed B-Value of the point sought in SEARCH.	gauss
SL	prefixed L-value of the point sought in SEARCH.	earth radii

APPENDIX II
PROGRAM LISTING

	PROGRAM SHELL	A	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNLPR(3),VCONJ(3),VLAST(3)	A	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALT1,MESH,UNEAD,BNEAR,BSAVE	A	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	A	4
	DIMENSION ABX(600), BX(600), HBX(600), H(100), S(600), SKN(300)	A	5
	DIMENSION X(100), SXN(100), GXP(100), HXN(100), HXP(100), SKN(300)	A	6
	DIMENSION BARC(200,3), DB(200,3), DH(200,3), JUP(3), V2DOT(600)	A	7
	DIMENSION DLONG(200,3), DLAT(200,3), FLAX(600), FLOX(600)	A	8
	DIMENSION LATN(100), LONGN(100), LATP(100), LONGP(100)	A	9
	DIMENSION EVN(3), EVN1(3)	A	10
	REAL LATN,LONGN,LATP,LONGP	A	11
	ERR=.02	A	12
	ERRB=.01	A	13
	ERRL=.01	A	14
	LINE=0	A	15
	DEQ=0.	A	16
C		A	17
C	ALTO IS THE MINIMUM ALTITUDE IN KM TO WHICH FIELD LINES SHOULD	A	18
C	BE TRACED	A	19
C		A	20
	ALTO=100.	A	21
C		A	22
C	FLONG IS THE PREFIXED LONGITUDE OF THE B-L POINT WHICH DETERMINES	A	23
C	THE FIELD LINE	A	24
C	ALT AND FLAT ARE APPROXIMATE COORDINATES OF THE B-L POINT	A	25
C	SL IS THE L-VALUE OF THE SHELL	A	26
C	SB (GAUSS) IS THE B-VALUE OF THE POINT WHICH DETERMINES EACH	A	27
C	FIELD LINE OF THAT SHELL	A	28
C	ALTITUDE IN KM ABOVE SEA LEVEL	A	29
C	EAST LONGITUDE IS POSITIVE	A	30
C		A	31
	READ (5,52) ALT,FLAT,FLONG	A	32
	SFLONG=FLONG	A	33
	READ (5,52) SB,SL	A	34
	WRITE (6,56) ALT,FLAT,FLONG,ERR,ERRB,ERRL,SB,SL	A	35
C		A	36
C	DLONG1 - - LONGITUDE STEP BETWEEN SLONG2 AND SLONG3	A	37
C	DLONG2 - - LONGITUDE STEP BETWEEN SLONG1 AND SLONG2 AND	A	38
C	BETWEEN SLONG3 AND SLONG4	A	39
C	DLONG3 - - LONGITUDE STEP ELSEWHERE	A	40
C	(NPR-1) - - NUMBER OF LINES SKIPPED BETWEEN DETAILED PRINTING	A	41
C		A	42
	READ (6,53) SLONG1,SLONG2,SLONG3,SLONG4	A	43
	WRITE (6,53) SLONG1,SLONG2,SLONG3,SLONG4	A	44
	READ (5,52) DLONG1,DLONG2,DLONG3,NPR	A	45
	WRITE (6,52) DLONG1,DLONG2,DLONG3,NPR	A	46
C		A	47
C	MESHB CONTROLS THE MESH FOR THE MAGNETIC FIELD ALONG THE LINE	A	48
C	SET MESHB EQUAL TO ONE IF THE MESH SHOULD BE DEFINED AT	A	49
C	FIXED ALTITUDES. IN THAT CASE, ALT1 AND ALT2 ARE END POINTS	A	50
C	OF THE PREFIXED ALTITUDES. SET MESHB EQUAL TO ZERO IF THE	A	51
C	MESH SHOULD BE DEFINED AT PREFIXED B-VALUES. IN THAT CASE, FIN	A	52
C	IS THE MINIMUM B-VALUE OF THE MESH, DELP IS THE INCREMENT. FIELD	A	53
C	MESH POINTS ARE CALLED X(J).	A	54
C	INT2 SHOULD BE LESS THAN 12.	A	55
C	INT1 MUST ALWAYS BE NOT GREATER THAN 100.	A	56
C		A	57

C	DEFINE PREFIXED X-MESH	A	58
C		A	59
	READ (5,54) MESHB,BIN,DELB	A	60
	IF (MESHB.EQ.1) GO TO 2	A	61
	X(1)=BIN	A	62
	DO 1 J=2,100	A	63
1	X(J)=X(J-1)+DELB	A	64
	GO TO 4	A	65
C		A	66
C	DEFINE PREFIXED ALTITUDE MESH	A	67
C		A	68
2	READ (5,55) INT1,INT2	A	69
	READ (5,52) ALT1,ALT2	A	70
	ENT1=INT1	A	71
	ENT2=INT2	A	72
	WRITE (6,52) ENT1,ENT2	A	73
	WRITE (6,52) ALT1,ALT2	A	74
	JMIN=1	A	75
	JMAX=INT1	A	76
	E=ALOG(ALT1/ALT2)/ALOG(ENT1/ENT2)	A	77
	EN=-E	A	78
	A=ALT2*ENT2**EN	A	79
	DO 3 I=INT2,INT1	A	80
	FI=1	A	81
3	H(I)=A*FI**E	A	82
C		A	83
C	DEFINE FIELD LINE GEOMETRY	A	84
C		A	85
4	CALL TRACE (DB,DARC,DH,KEQ,ALT,FLAT,FLONG,ERR,ERRB,ERRL,SB,SL,KASE	A	86
	1,JUP,DRIFT,CLONG,SLOPE,EVN,DLONG,DLAT,PATH,PSLOPE)	A	87
	IF (LINE.EQ.0) GO TO 5	A	88
	DR=ABS(EVN1(1)-EVN(1))	A	89
	DTHE=ABS(EVN1(2)-EVN(2))	A	90
	DPHI=ABS(EVN1(3)-EVN(3))	A	91
	RO=(EVN1(1)+EVN(1))*0.5	A	92
	SIT=ABS(SIN((EVN1(2)+EVN(2))*0.5))	A	93
	SSQ=SIT*SIT	A	94
	DEQ=SQRT(DR*DR+RO*RO*(DTHE*DTHE+DPHI*DPHI*SSQ))	A	95
	DPHIDX=DPHI/DEQ	A	96
5	CONTINUE	A	97
	SIT=ABS(SIN(EVN(2)))	A	98
	SSQ=SIT*SIT	A	99
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	A	100
	AER=EVN(1)-OER	A	101
	EALT=AER*6371.2	A	102
	ELAT=90.-EVN(2)*57.2957795	A	103
	ELONG=EVN(3)*57.2957795	A	104
	IF (ELONG.GT.180.) ELONG=ELONG-360.	A	105
	IF (ELONG.LT.-180.) ELONG=ELONG+360.	A	106
C		A	107
C	EQUATORIAL DRIFT VELOCITY IN DEGREES PER SECOND IS GIVEN BY	A	108
C	DRIFT VELOCITY (IN CM/SEC) * DPHIDX	A	109
C		A	110
	WRITE (6,57) FLONG,SL,SB,ALT,FLAT,EALT,ELAT,ELONG,DB(KEQ,1),DRIFT,	A	111
	1SLOPE,PATH,PSLOPE,DPHIDX	A	112
C		A	113
C	ARRANGE IN ORDER ALL PORTIONS OF FIELD LINE	A	114

C	ABX(1)=0.0	A 115
	IF (JUP(2).EQ.0) GO TO 10	A 116
	JEND=JUP(2)-1	A 117
	DO 6 J=2,JEND	A 118
	JJ=2-J+JUP(2)	A 119
	JM1=J-1	A 120
	BX(JM1)=DB(JJ,2)	A 121
	FLOX(JM1)=DLONG(JJ,2)	A 122
	FLAX(JM1)=DLAT(JJ,2)	A 123
	HBX(JM1)=DH(JJ,2)	A 124
6	ABX(J)=DARC(JJ,2)	A 125
	IF (KASE.EQ.2) GO TO 8	A 126
	JEND=JUP(1)-1	A 127
	DO 7 J=2,JEND	A 128
	JPJ=JUP(2)-3+J	A 129
	BX(JPJ)=DB(J,1)	A 130
	FLAX(JPJ)=DLAT(J,1)	A 131
	FLOX(JPJ)=DLONG(J,1)	A 132
	HBX(JPJ)=DH(J,1)	A 133
7	ABX(JPJ+1)=DARC(J+1,1)	A 134
	KEQ=JUP(2)-3+KEQ	A 135
	GO TO 14	A 136
8	JEND=JUP(1)-1	A 137
	DO 9 J=2,JEND	A 138
	JPJ=JUP(2)-3+J	A 139
	JJ=2-J+JUP(1)	A 140
	BX(JPJ)=DB(JJ,1)	A 141
	FLAX(JPJ)=DLAT(JJ,1)	A 142
	FLOX(JPJ)=DLONG(JJ,1)	A 143
	HBX(JPJ)=DH(JJ,1)	A 144
9	ABX(JPJ+1)=DARC(JJ,1)	A 145
	KEQ=JUP(1)+JUP(2)-1-KEQ	A 146
	GO TO 14	A 147
10	IF (KASE.EQ.2) GO TO 12	A 148
	JEND=JUP(1)-1	A 149
	DO 11 J=2,JEND	A 150
	JM1=J-1	A 151
	BX(JM1)=DB(J,1)	A 152
	FLAX(JM1)=DLAT(J,1)	A 153
	FLOX(JM1)=DLONG(J,1)	A 154
	HBX(JM1)=DH(J,1)	A 155
11	ABX(J)=DARC(J+1,1)	A 156
	KEQ=KEQ-1	A 157
	GO TO 14	A 158
12	JEND=JUP(1)-1	A 159
	DO 13 J=2,JEND	A 160
	JJ=JUP(1)-J+2	A 161
	JM1=J-1	A 162
	BX(JM1)=DB(JJ,1)	A 163
	FLAX(JM1)=DLAT(JJ,1)	A 164
	FLOX(JM1)=DLONG(JJ,1)	A 165
	HBX(JM1)=DH(JJ,1)	A 166
13	ABX(J)=DARC(JJ,1)	A 167
	KEQ=JUP(1)+1-KEQ	A 168
14	IF (JUP(3).EQ.0) GO TO 16	A 169
	JEND=JUP(3)-1	A 170
		A 171

	DO 15 J=2,JEND	A 172
	JPJ=JUP(1)+JUP(2)-5+J	A 173
	IF (JUP(2).EQ.0) JPJ=JPJ+2	A 174
	BX(JPJ)=DB(J,3)	A 175
	FLOX(JPJ)=DLONG(J,3)	A 176
	FLAX(JPJ)=DLAT(J,3)	A 177
	HBX(JPJ)=DH(J,3)	A 178
15	ABX(JPJ+1)=DARC(J+1,3)	A 179
	JLAST=JUP(1)+JUP(2)+JUP(3)-5	A 180
	IF (JUP(2).EQ.0) JLAST=JLAST+2	A 181
	JU=JUP(3)	A 182
	BX(JLAST)=DB(JU,3)	A 183
	FLOX(JLAST)=DLONG(JU,3)	A 184
	FLAX(JLAST)=DLAT(JU,3)	A 185
	HBX(JLAST)=DH(JU,3)	A 186
	GO TO 17	A 187
16	JLAST=JUP(1)-1	A 188
	IF (JUP(2).NE.0) JLAST=JLAST+JUP(2)-2	A 189
	JU=2	A 190
	IF (KASE.EQ.1) JU=JUP(1)	A 191
	BX(JLAST)=DB(JU,1)	A 192
	FLOX(JLAST)=DLONG(JU,1)	A 193
	HBX(JLAST)=DH(JU,1)	A 194
	FLAX(JLAST)=DLAT(JU,1)	A 195
17	CONTINUE	A 196
	S(KEQ)=0.0	A 197
	IEND=KEQ-1	A 198
	DO 18 I=1,IEND	A 199
	II=KEQ-I	A 200
18	S(II)=S(II+1)-ABX(II+1)	A 201
	IEND=JLAST-1	A 202
	DO 19 I=KEQ,IEND	A 203
19	S(I+1)=S(I)+ABX(I+1)	A 204
C		A 205
C	DEFINE X-MESH IN CASE OF PREFIXED ALTITUDES (MESH.B.EQ.1)	A 206
C		A 207
	IF (MESH.B.EQ.0) GO TO 28	A 208
	ISTAR=3	A 209
	FSTAR=ISTAR	A 210
	ENC=.002*SL*SL*SL/(1.25*1.25*1.25)	A 211
20	IF (BX(KEQ).LT.(.311653/(SL*SL*SL)+FSTAR*ENC)) GO TO 21	A 212
	ISTAR=ISTAR+1	A 213
	FSTAR=FSTAR+1.	A 214
	GO TO 20	A 215
21	X(1)=BX(KEQ)	A 216
	DO 22 I=ISTAR,12	A 217
	EI=I	A 218
22	X(I)=.311653/(SL*SL*SL)+EI*ENC	A 219
	ISM1=ISTAR-1	A 220
	FIS=ISM1	A 221
	DEL=(X(ISTAR)-X(1))/FIS	A 222
	DO 23 I=2,ISM1	A 223
23	X(I)=X(I-1)+DEL	A 224
	CALL SPLINE (HBX,BX,Y2DOT,KEQ)	A 225
	DO 24 J=INT2,100	A 226
24	CALL YSPLN (HBX,BX,KEQ,Y2DOT,H(J),X(J))	A 227
	ISTAR=12	A 228

25	IF (X(ISTAR).LT.X(INT2)) GO TO 26	A 229
	ISTAR=ISTAR-1	A 230
	IF (ISTAR.GT.0) GO TO 25	A 231
	STOP	A 232
26	N=INT2-ISTAR	A 233
	EN=N	A 234
	DEL=(X(INT2)-X(ISTAR))/EN	A 235
	LIMIT=INT2-2	A 236
	DO 27 I=ISTAR,LIMIT	A 237
27	X(I+1)=X(I)+DEL	A 238
	GO TO 33	A 239
C		A 240
C	DETERMINE THE BOUNDS OF THE X-MESH COMPATIBLE WITH AVAILABLE	A 241
C	POINTS ON THE FIELD LINES, IN CASE OF PREFIXED X-MESH (MESHB.EQ.0)	A 242
C		A 243
28	DO 29 J=1,100	A 244
	IF (BX(KEQ).LT.X(J)) GO TO 30	A 245
29	CONTINUE	A 246
	WRITE (6,58)	A 247
	STOP	A 248
30	JMIN=J	A 249
	DO 31 J=JMIN,100	A 250
	IF (BX(JLAST).LT.X(J)) GO TO 32	A 251
31	CONTINUE	A 252
	JMAX=101	A 253
32	JMAX=J-1	A 254
33	CONTINUE	A 255
C		A 256
C	INTERPOLATE ALTITUDES AND ARC LENGTHS ONTO X MESH	A 257
C		A 258
	IF (((FLOX(1).LE.100.).AND.(FLOX(JLAST).GT.250.)).OR.((FLOX(1).GT.	A 259
	1250.).AND.(FLOX(JLAST).LE.100.))) GO TO 34	A 260
	GO TO 36	A 261
34	DO 35 I=1,JLAST	A 262
	IF (FLOX(I).GT.180.) FLOX(I)=FLOX(I)-360.	A 263
35	CONTINUE	A 264
36	CONTINUE	A 265
	KEQ1=KEQ-1	A 266
	DO 37 I=1,KEQ1	A 267
	II=KEQ-I	A 268
	SKN(I)=S(II)	A 269
37	BKN(I)=BX(II)	A 270
	CALL SPLINE (BKN,SKN,Y2DOT,KEQ1)	A 271
	JJ=JMIN	A 272
	IF (MESHB.GT.0)) JJ=2	A 273
	DO 38 J=JJ,JMAX	A 274
	CALL YSPLN (BKN,SKN,KEQ1,Y2DOT,X(J),SXN(J))	A 275
38	CONTINUE	A 276
	NPTS=IEND+1-KEQ	A 277
	DO 39 J=1,NPTS	A 278
	JK1=J+KEQ	A 279
	SKN(J)=S(JK1)	A 280
39	BKN(J)=BX(JK1)	A 281
	CALL SPLINE (BKN,SKN,Y2DOT,NPTS)	A 282
	DO 40 J=JJ,JMAX	A 283
40	CALL YSPLN (BKN,SKN,NPTS,Y2DOT,X(J),SXP(J))	A 284
	NPTS=IEND+1	A 285

	CALL SPLINE (S,HBX,Y2DOT,NPTS)	A 286
	DO 41 J=JMIN,JMAX	A 287
	CALL YSPLN (S,HBX,NPTS,Y2DOT, SXN(J),HXN(J))	A 288
41	CALL YSPLN (S,HBX,NPTS,Y2DOT, SXP(J),HXP(J))	A 289
	CALL SPLINE (S,FLAX,Y2DOT,NPTS)	A 290
	DO 42 J=JMIN,JMAX	A 291
	CALL YSPLN (S,FLAX,NPTS,Y2DOT, SXN(J),LATN(J))	A 292
42	CALL YSPLN (S,FLAX,NPTS,Y2DOT, SXP(J),LATP(J))	A 293
	CALL SPLINE (S,FLOX,Y2DOT,NPTS)	A 294
	DO 43 J=JMIN,JMAX	A 295
	CALL YSPLN (S,FLOX,NPTS,Y2DOT, SXN(J),LONGN(J))	A 296
43	CALL YSPLN (S,FLOX,NPTS,Y2DOT, SXP(J),LONGP(J))	A 297
C		A 298
C		A 299
C	OUTPUT - - COORDINATES OF X-MESH POINTS ALONG THE NORTH AND THE	A 300
C	SOUTH PORTIONS OF THE FIELD LINE	A 301
C		A 302
	DO 44 J=JMIN,JMAX	A 303
	IF (LONGN(J).GT.180.) LONGN(J)=LONGN(J)-360.	A 304
	IF (LONGP(J).GT.180.) LONGP(J)=LONGP(J)-360.	A 305
	IF (LONGN(J).LT.-180.) LONGN(J)=LONGN(J)+360.	A 306
	IF (LONGP(J).LT.-180.) LONGP(J)=LONGP(J)+360.	A 307
	SXN(J)=ABS(SXN(J))*6371.2	A 308
44	SXP(J)=SXP(J)*6371.2	A 309
	IF (LATN(JMAX).LT.LATP(JMAX)) GO TO 45	A 310
	IF (MOD(LINE,NPR).EQ.0) WRITE (6,59) (I,X(I),HXN(I),HXP(I),SXN(I),	A 311
	1SXP(I),LATN(I),LATP(I),LONGN(I),LONGP(I),I=JMIN,JMAX)	A 312
	GO TO 46	A 313
45	IF (MOD(LINE,NPR).EQ.0) WRITE (6,59) (I,X(I),HXP(I),HXN(I),SXP(I),	A 314
	1SXN(I),LATP(I),LATN(I),LONGP(I),LONGN(I),I=JMIN,JMAX)	A 315
46	CONTINUE	A 316
	DRIFT=DRIFT*PATH	A 317
	PHI=EVN(3)	A 318
	BACKSPACE 10	A 319
	WRITE (10) SL,FLONG,LINE,SLOPE,DRIFT,CLONG,DPHIDX,PHI,(X(I),HXN(I)	A 320
	1,HXP(I),SXN(I),SXP(I),I=JMIN,JMAX)	A 321
	END FILE 10	A 322
C		A 323
C	INITIALIZE FOR THE NEXT LINE	A 324
C		A 325
	DO 47 I=1,3	A 326
47	EVN1(I)=EVN(I)	A 327
	IF ((FLONG.LT.SLONG2).OR.(FLONG.GT.SLONG3)) GO TO 48	A 328
	FLONG=FLONG+DLONG1	A 329
	IF (ABS(FLONG-SFLONG).LT.(DLONG1*.99)) GO TO 51	A 330
	GO TO 50	A 331
48	IF ((FLONG.LT.SLONG1).OR.(FLONG.GT.SLONG4)) GO TO 49	A 332
	FLONG=FLONG+DLONG2	A 333
	IF (ABS(FLONG-SFLONG).LT.(DLONG2*.99)) GO TO 51	A 334
	GO TO 50	A 335
49	FLONG=FLONG+DLONG3	A 336
	IF (ABS(FLONG-SFLONG).LT.(DLONG3*.99)) GO TO 51	A 337
50	LINE=LINE+1	A 338
	GO TO 4	A 339
51	CONTINUE	A 340
C		A 341
52	FORMAT (3F10.4,I10)	A 342

53	FORMAT (4F10.2)	A 343
54	FORMAT (110,2F10.3)	A 344
55	FORMAT (2110)	A 345
56	FORMAT (3F10.2,5F10.5)	A 346
57	FORMAT (//1X8HAT LONG=,F8.2,1X,34HTHE COORDINATES OF THE POINT AT	A 347
	1L=,F6.2,1X,7HAND B =,F7.4,1X,9HARE ALT =,F10.2,1X,9HAND LAT =,F6.2	A 348
	2/1X,51HTHE EQUATORIAL POINT OF THE FIELD LINE IS AT EALT =,F10.2,1	A 349
	3X,6HELAT =,F6.2,1X,7HELONG =,F8.2,1X,15HAND HAS B VALUE,F7.4/1X,32	A 350
	4HTHE DRIFT PARAMETERS ARE DRIFT =,F7.3,2X,7HSLOPE =,F7.3,2X,6HPATH	A 351
	5 =,F8.3,2X,8HPSLOPE =,F7.3,2X,8HDPHIDX =,E12.3,///)	A 352
58	FORMAT (20H CHOOSE ANOTHER MESH)	A 353
59	FORMAT (5X,11HMESH POINTS,11X,13HALTITUDES(KM),7X,27HARC LENGTH FR	A 354
	10M EQUATOR(KM),7X,9HLATITUDES,15X,10HLONGITUDES//7X,7H(GAUSS),10X,	A 355
	25HNORTH,7X,5HSOUTH,12X,5HNORTH,7X,5HSOUTH,9X,5HNORTH,5X5HSOUTH,9X,	A 356
	35HNORTH,6X,5HSOUTH// (14,F10.5,4X,2F12.1,4X,2F12.1,4X,2F10.2,4X,2F1	A 357
	41.2))	A 358
	END	A 359-

	SUBROUTINE TRACE (DB,DARC,DH,KEQ,ALT,FLAT,FLONG,ERR,ERRB,ERRL,SB,S	B 1
	1L,KASE,JUP,DRIFT,CLONG,SLOPE,EVN,DLONG,DLAT,PATH,PSLOPE)	B 2
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	B 3
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	B 4
	2,BRSAVE,RPSAVE,BTSAVE,VN3(200),JSTOP	B 5
C		B 6
C	THIS SUBROUTINE COMPLETES TRACING OF THE FIELD LINE DEFINED	B 7
C	IN BLRING, TO THE ALTITUDE LEVEL GIVEN BY ALTO, AND TO ITS	B 8
C	CONJUGATE POINT (WHERE THE SAME B-VALUE IS ATTAINED IN THE	B 9
C	OPPOSITE HEMISPHERE). THE HEMISPHERE IN WHICH TRACING TO ALTO IS	B 10
C	PERFORMED, IS SELECTED SO THAT THE ALTITUDE OF THE CONJUGATE	B 11
C	POINT IS GREATER THAN ALTO	B 12
C		B 13
	DIMENSION V(3), DB(200,3), DARC(200,3), DH(200,3), JUP(3), EVN(3)	B 14
	DIMENSION DLONG(200,3), DLAT(200,3)	B 15
	ERR1=2.5E-04*ERR	B 16
	ERR2=2.5E-05*ERR	B 17
	KK=0	B 18
	CALL BLRING (ALT,FLAT,FLONG,ERR,ERRB,ERRL,SB,SL,JUP(1),DRIFT,SLOPE	B 19
	1,AEQ,EB,EALT,PATH,PSLOPE)	B 20
	JU=JUP(1)	B 21
	DO 1 J=1,JU	B 22
	DB(J,1)=B(J)	B 23
	DARC(J,1)=ABS(ARC(J))	B 24
	DLAT(J,1)=90.-VN2(J)*57.2957795	B 25
	DLONG(J,1)=VN3(J)*57.2957795	B 26
	SIT=ABS(SIN(VN2(J)))	B 27
	SSQ=SIT*SIT	B 28
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	B 29
	AER=VN1(J)-OER	B 30
1	DH(J,1)=AER*6371.2	B 31
	VSAVE(1)=VN1(2)	B 32
	VSAVE(2)=VN2(2)	B 33
	VSAVE(3)=VN3(2)	B 34
	VLAST(1)=VN1(JU)	B 35
	VLAST(2)=VN2(JU)	B 36
	VLAST(3)=VN3(JU)	B 37
	DO 2 I=1,3	B 38
2	EVN(I)=VNEAR(I)	B 39
C		B 40

C	INSERT EQUATORIAL POINT	B	41
C		B	42
3	IF (ABS(EB-DB(JNEAR,1)).LE.2.E-6) GO TO 6	B	43
	IF (AEQ.GE.DARC(JNEAR,1)) GO TO 5	B	44
	JU=JUP(1)	B	45
	DO 4 J=JNEAR,JU	B	46
	JJ=JUP(1)-J+JNEAR+1	B	47
	DB(JJ,1)=DB(JJ-1,1)	B	48
	DLAT(JJ,1)=DLAT(JJ-1,1)	B	49
	DLONG(JJ,1)=DLONG(JJ-1,1)	B	50
	DH(JJ,1)=DH(JJ-1,1)	B	51
4	DARC(JJ,1)=DARC(JJ-1,1)	B	52
	JUP(1)=JUP(1)+1	B	53
	KEQ=JNEAR	B	54
	DB(JNEAR,1)=EB	B	55
	DLAT(JNEAR,1)=90.-VNEAR(2)*57.2957795	B	56
	DLONG(JNEAR,1)=VNEAR(3)*57.2957795	B	57
	DH(JNEAR,1)=EALT	B	58
	DARC(JNEAR+1,1)=AEQ	B	59
	DARC(JNEAR,1)=DARC(JNEAR,1)-AEQ	B	60
	GO TO 8	B	61
5	IF (AEQ.EQ.DARC(JNEAR,1)) GO TO 7	B	62
	AEQ=AEQ-DARC(JNEAR,1)	B	63
	JNEAR=JNEAR-1	B	64
	GO TO 3	B	65
6	KEQ=JNEAR	B	66
	GO TO 8	B	67
7	KEQ=JNEAR-1	B	68
8	CONTINUE	B	69
C		B	70
C	COMPLETE THE TRACING OF THE FIELD LINE TO ALTO (USUALLY 100 KM)	B	71
C	AND TO THE CONJUGATE OF THIS POINT (WHERE THE SAME B-VALUE IS	B	72
C	ATTAINED).	B	73
C		B	74
	IF (VLAST(1).LT.VSAVE(1)) GO TO 11	B	75
9	KASE=1	B	76
	RUM1=VLAST(1)	B	77
	RUM2=VLAST(2)	B	78
	RUM3=VLAST(3)	B	79
	DO 10 I=1,3	B	80
10	VCONJ(I)=VSAVE(I)	B	81
	GO TO 13	B	82
11	DO 12 I=1,3	B	83
12	VCONJ(I)=VLAST(I)	B	84
	KASE=2	B	85
	RUM1=VSAVE(1)	B	86
	RUM2=VSAVE(2)	B	87
	RUM3=VSAVE(3)	B	88
13	CONTINUE	B	89
	CALL INSECT (CLONG,ERR2,JUP(2))	B	90
	IF (JUP(2).EQ.0) GO TO 15	B	91
	JU=JUP(2)	B	92
	DO 14 J=3,JU	B	93
	DB(J,2)=B(J)	B	94
	DLAT(J,2)=90.-VN2(J)*57.2957795	B	95
	DLONG(J,2)=VN3(J)*57.2957795	B	96
	DARC(J,2)=ABS(ARC(J))	B	97

	SIT=ABS(SIN(VN2(J)))	B 98
	SSQ=SIT*SIT	B 99
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	B 100
	AER=VN1(J)-OER	B 101
14	DH(J,2)=AER*6371.2	B 102
	BO=BCONJ	B 103
15	JU=JUP(1)	B 104
	IF (JUP(2).EQ.0) BO=DB(JU,1)	B 105
	IF ((JUP(2).EQ.0).AND.(KASE.EQ.1)) BO=DB(2,1)	B 106
	CALL BESECT (RUM1,PUM2,RUM3,BALT,ERR2,JUP(3))	B 107
	IF ((JUP(2).EQ.0).OR.(BALT.GT.100.).OR.(KK.EQ.1)) GO TO 16	B 108
	KK=1	B 109
	GO TO (11,9), KASE	B 110
16	IF (JUP(3).EQ.0) GO TO 18	B 111
	JU=JUP(3)	B 112
	DO 17 J=2,JU	B 113
	DB(J,3)=B(J)	B 114
	DLAT(J,3)=90.-VN2(J)*57.2957795	B 115
	DLONG(J,3)=VN3(J)*57.2957795	B 116
	DARC(J,3)=ABS(ARC(J))	B 117
	SIT=ABS(SIN(VN2(J)))	B 118
	SSQ=SIT*SIT	B 119
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	B 120
	AER=VN1(J)-OER	B 121
17	DH(J,3)=AER*6371.2	B 122
18	CONTINUE	B 123
	RETURN	B 124
	END	B 125-

	SUBROUTINE BLRING (ALT,FLAT,FLONG,ERR,ERRB,ERRL,SB,SL,JU,DRIFT,SLO	C	1
	1PE,AEQ,EB,EALT,PATH,PSLOPE)	C	2
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	C	3
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	C	4
	2,BRSAGE,BPSAVE,BTSAVE,VN3(200),JSTOP	C	5
	DIMENSION SVB(200), SV1(200), SV2(200), SV3(200)	C	6
	DIMENSION V(3), SARC(200)	C	7
C		C	8
C	THIS SUBROUTINE DEFINES THE FIELD LINE THROUGH AN SB-SL POINT,THE	C	9
C	GRADIENT OF THE SECOND INVARIANT, AND THE VARIATION OF THE DRIFT	C	10
C	FACTOR ALONG THE FIELD LINE	C	11
C		C	12
	ERR1=2.5E-04*ERR	C	13
	ITEST=1	C	14
	SSB=SB	C	15
	BZERO=.311653/(SL*SL*SL)	C	16
	SB=(SB+BZERO)*0.5	C	17
	SSL=SL	C	18
1	SL=SL*1.03	C	19
	CALL SEARCH (ALT,FLAT,FLONG,SB,SL,V,BB,FL,FI,ERR,ERRB,ERRL,JU)	C	20
	F11=FI	C	21
	VS12=VSAVE(2)	C	22
	CALL EQUAT (VNEAR(1),VNEAR(2),VNEAR(3),EB,SL,EALT,ERR1,AEQ)	C	23
	SL=SSL	C	24
	VN11=VNEAR(1)	C	25
	VN12=VNEAR(2)	C	26
	VN13=VNEAR(3)	C	27
	CALL SEARCH (ALT,FLAT,FLONG,SB,SL,V,BB,FL,FI,ERR,ERRB,ERRL,JU)	C	28
	C11=VSAVE(1)	C	29
	C12=VSAVE(2)	C	30
	C13=VSAVE(3)	C	31
	C21=VN1(4)	C	32
	C22=VN2(4)	C	33
	C23=VN3(4)	C	34
	VS22=VSAVE(2)	C	35
	SIT1=ABS(SIN(VSAVE(2)))	C	36
	FACT=BPSAVE/(BTSAVE*SIT1)	C	37
	IF (ITEST.EQ.1) GO TO 3	C	38
	IF (JSTOP.GT.0) JU=JSTOP	C	39
	JS=JNEAR	C	40
	DO 2 J=1,JU	C	41
	SARC(J)=ARC(J)	C	42
	SVB(J)=B(J)	C	43
	SV1(J)=VN1(J)	C	44
	SV2(J)=VN2(J)	C	45
2	SV3(J)=VN3(J)	C	46
3	CALL EQUAT (VNEAR(1),VNEAR(2),VNEAR(3),EB,SL,EALT,ERR1,AEQ)	C	47
	VN21=VNEAR(1)	C	48
	VN22=VNEAR(2)	C	49
	VN23=VNEAR(3)	C	50
	CALL INVAR (C21,C22,C23,ERR1,BIN2,DUM,F112,NO)	C	51
	CALL INVAR (C11,C12,C13,ERR1,BIN1,DUM,F111,NO)	C	52
	CORR=FACT*(VS12-VS22)	C	53
	DPHI=ABS(VN13-VN23+CORR)	C	54
	DTHE=ABS(VN22-VN12)	C	55
	DR=ABS(VN21-VN11)	C	56
	SSQ=SIT1*SIT1	C	57

	DIST=SQRT(DR*DR+VN21*VN21*(DTHE*DTHE+DPHI*DPHI*SSQ))	C	56
	QQQ=BZERO/SB	C	59
	QQ=BZERO/EB	C	60
	IF (ITEST.EQ.2) GO TO 4	C	61
	PATH1=FII1+2.*BIN1*(FII1-FII2)/(BIN1-BIN2)	C	62
	DRIFT1=(FII1-FI1)*QQ/(DIST*PATH1)	C	63
	ROOT1=SQRT(QQQ)	C	64
	SB=SSB	C	65
	ITEST=2	C	66
	GO TO 1	C	67
4	PATH=FII1+2.*BIN1*(FII1-FII2)/(BIN1-BIN2)	C	68
	DRIFT=(FII1-FI1)*QQ/(DIST*PATH)	C	69
	ROOT=SQRT(QQQ)	C	70
	SLOPE=(DRIFT-DRIFT1)/(ROOT1-ROOT)	C	71
	DRIFT=DRIFT-SLOPE*(1.-ROOT)	C	72
	PSLOPE=(PATH-PATH1)/(ROOT1-ROOT)	C	73
	PATH=PATH-PSLOPE*(1.-ROOT)	C	74
C		C	75
C	DRIFT IS THE GEOMETRIC FACTOR IN THE EQUATORIAL DRIFT VELOCITY	C	76
C	OF PARTICLES MIRRORING AT THE EQUATOR. DRIFT FOR PARTICLES	C	77
C	MIRRORING AT ANY OTHER POINT OF FIELD STRENGTH X IS OBTAINED	C	78
C	BY THE EXPRESSION DRIFT+SLOPE*(1.-SQRT(BZERO/X)).	C	79
C	TO OBTAIN THE REAL EQUATORIAL DRIFT VELOCITY IN CM/SEC, MULTIPLY	C	80
C	DRIFT BY 2.5766 E 05 * (SL**3) * (MASS) * (BETA**2) * (GAMMA)	C	81
C	MASS IN ELECTRON MASSES, BETA AND GAMMA USUAL RELATIVISTIC FACTOR	C	82
C	THE RECTIFIED LENGTH OF THE PARTICLES TRAJECTORY BETWEEN TWO	C	83
C	CONJUGATE MIRROR POINTS AT X, IS GIVEN BY	C	84
C	PATH + PSLOPE*(1.-SQRT(BZERO/X)). TO OBTAIN REAL PATH IN CM,	C	85
C	MULTIPLY PATH BY 6.3712E 08	C	86
C		C	87
	JNEAR=JS	C	88
	VNEAR(1)=VN21	C	89
	VNEAR(2)=VN22	C	90
	VNEAR(3)=VN23	C	91
	DO 5 J=1,JU	C	92
	ARC(J)=SARC(J)	C	93
	B(J)=SVB(J)	C	94
	VN1(J)=SV1(J)	C	95
	VN2(J)=SV2(J)	C	96
5	VN3(J)=SV3(J)	C	97
	RETURN	C	98
	END	C	99-

	SUBROUTINE SEARCH (ALT,FLAT,FLONG,SB,SL,V,BB,FL,FI,ERR,ERRB,ERRL,J	D	1
	1UP)	D	2
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	D	3
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	D	4
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	D	5
C		D	6
C	THIS SUBROUTINE FINDS A FIELD LINE THROUGH A POINT WITH A PREFIXED	D	7
C	B AND L VALUE FOR A GIVEN LONGITUDE.	D	8
C	SUBROUTINE IS CALLED WITH ALT,FLAT,FLONG = APPROXIMATE STARTING	D	9
C	COORDINATES WHICH SHOULD NOT BE TOO FAR AWAY FROM REAL B-L POINT	D	10
C	(E.G. NOT MORE THAN 20 DEGREES LATITUDE)	D	11
C	FLAT DETERMINES THE HEMISPHERE OF THE B-L POINT	D	12
C	FLONG REMAINS CONSTANT	D	13
C		D	14
	DIMENSION V(3), V1(3), V2(3)	D	15
	SERR=ERR	D	16
	SERRB=ERRB	D	17
	SERRL=ERRL	D	18
	SSB=SB	D	19
1	CONTINUE	D	20
	VO=0.	D	21
	DV=0.02	D	22
	MCHECK=0	D	23
	ICHECK=0	D	24
	V(1)=ALT/6371.2	D	25
	V(2)=(90.-FLAT)/57.2957795	D	26
	V(3)=FLONG/57.2957795	D	27
	DCLT=1.5708-0.2007*COS(V(3)+1.239)	D	28
	SIT=ABS(SIN(V(2)))	D	29
	SSQ=SIT*SIT	D	30
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	D	31
	V(1)=V(1)+OER	D	32
	VO=ALTO/6371.2+OER	D	33
	ICON=1	D	34
2	ILIT=1	D	35
	DEL V2=DV	D	36
	ICHECK=ICHECK+1	D	37
	IF (ICHECK.GT.15) GO TO 12	D	38
3	SIT=ABS(SIN(V(2)))	D	39
	CALL NEWMAG (V(1),SIT,V(3),BR,BP,BT,BB,V(2))	D	40
4	FAC=1.-(SB-BB)/(3.*SB)	D	41
	IF (FAC.GT.1.5) FAC=1.5	D	42
	IF (FAC.LT.0.666) FAC=0.666	D	43
	V(1)=V(1)*FAC	D	44
	V1(1)=V(1)	D	45
	V1(2)=V(2)	D	46
	MCHECK=MCHECK+1	D	47
	IF (MCHECK.GT.15) GO TO 13	D	48
	CALL NEWMAG (V(1),SIT,V(3),BR,BP,BT,BB,V(2))	D	49
	IF (ABS((BB-SB)/SB).GT.ERRB) GO TO 4	D	50
	MCHECK=0	D	51
	IF (ILIT.NE.1) GO TO 8	D	52
	ILIT=2	D	53
	CALL INVAR (V(1),V(2),V(3),ERR,BB,FL,FI,JUP)	D	54
	V2(1)=V(1)	D	55
	V2(2)=V(2)	D	56
	B2=BB	D	57

	FL2=FL	D	58
	IF (ABS((FL-SL)/SL).LE.ERRL) GO TO 9	D	59
	IF (ABS(V(2)-DCLT).LT.0.1) GO TO 7	D	60
	SGN=SIGN(1.,(FL-SL))	D	61
	IF (V(2).LT.DCLT) GO TO 5	D	62
	DELV2=-SGN*DELV2	D	63
	GO TO 6	D	64
5	DELV2=SGN*DELV2	D	65
6	V(2)=V(2)+DELV2	D	66
	GO TO 3	D	67
7	V(2)=V(2)+DELV2	D	68
	CALL INVAR (V(1),V(2),V(3),ERR,BB,FL,FI,JUP)	D	69
	IF ((FL-SL)*(FL-FL2).LE.0.) GO TO 3	D	70
	V(2)=V(2)-2.*DELV2	D	71
	GO TO 3	D	72
8	B1=BB	D	73
	CALL INVAR (V(1),V(2),V(3),ERR,BB,FL,FI,JUP)	D	74
	IF (ABS((FL-SL)/SL).LE.ERRL) GO TO 9	D	75
	FACT=(SL-FL)/(FL2-FL)	D	76
	IF (ABS(FACT).GT.3.) FACT=3.*SIGN(1.,FACT)	D	77
	V(1)=V1(1)+(V2(1)-V1(1))*FACT	D	78
	V(2)=V1(2)+(V2(2)-V1(2))*FACT	D	79
	Y=AMIN1(ABS(V(2)-V1(2)),ABS(V(2)-V2(2)))	D	80
	IF (Y.GT.ABS(V1(2)-V2(2))) GO TO 2	D	81
	DV=Y	D	82
	GO TO 2	D	83
9	CONTINUE	D	84
	IF (ICON.EQ.2) GO TO 10	D	85
	ICON=2	D	86
	DV=DV*0.1	C	87
	ERR=ERR*0.025	D	88
	ERRB=ERRB*0.05	D	89
	ERRL=ERRL*0.01	D	90
	GO TO 2	D	91
10	SIT=ABS(SIN(V(2)))	D	92
	SSQ=SIT*SIT	D	93
	OEP=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	D	94
	AER=V(1)-OEP	D	95
C		D	96
C	WHEN THE CALCULATION IS COMPLETED, ALT AND FLAT BECOME FINAL	D	97
C	COORDINATES OF THE B-L POINT. VSAVE ARE COORDINATES OF SAME	D	98
C	POINT IN GEOCENTRIC SYSTEM	D	99
C		D	100
	ALT=AER*6371.2	D	101
	FLAT=90.-V(2)*57.2957795	D	102
	FLONG=V(3)*57.2957795	D	103
	IF (FLONG.GT.180.) FLONG=FLONG-360.	D	104
	IF (FLONG.LT.(-180.)) FLONG=FLONG+360.	D	105
	DO 11 I=1,3	D	106
11	VSAVE(I)=V(I)	D	107
	GO TO 15	D	108
12	WRITE (6,16) ICHECK,MCHECK,ALT,FLAT,FLONG,SB,SL	D	109
	GO TO 14	D	110
13	WRITE (6,17) ICHECK,MCHECK,ALT,FLAT,FLONG,SB,SL	D	111
14	SB=SB+.005	D	112
	ERR=SEPR	D	113
	ERRB=SEPRB	D	114

	ERRL=SERRL		D 115
	GO TO 1		D 116
15	ERR=SERP		D 117
	ERRB=SERRB		D 118
	ERRL=SERRL		D 119
	SB=SSB		D 120
	RETURN		D 121
C			D 122
16	FORMAT (51H	SORRY,BUT I CANNOT FIND THAT DAMN POINT IN ICHECK/211	D 123
	10,5E15.5)		D 124
17	FORMAT (51H	SORRY,BUT I CANNOT FIND THAT DAMN POINT IN MCHECK/211	D 125
	10,5E15.5)		D 126
	END		D 127-

	SUBROUTINE EQUAT (DUM1,DUM2,DUM3,EB,SL,EALT,ERR,AEQ)	E	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	E	2
	1),VPLAST(3),VBO(3),VSAVE(3),RCONJ,VO,RO,ALTO,MMM,JNEAR,BNEAR,BSAVE	E	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	E	4
C		E	5
C	THIS SUBROUTINE TRACES THE FIELD LINE FROM AN INITIAL POINT	E	6
C	TO THE POINT OF MINIMUM INTENSITY.	E	7
C		E	8
	DIMENSION V(3,3), VN(3), VP(3), R1(3), R2(3), R3(3)	E	9
	ERR1=ERR	E	10
	MMM=1	E	11
	V(1,2)=DUM1	E	12
	V(2,2)=DUM2	E	13
	V(3,2)=DUM3	E	14
	ARC(1)=0.	E	15
	DCLT=1.5708-0.2007*COS(V(3,2)+1.239)	E	16
1	ARC(2)=V(1,2)*SQRT(ERR)*0.3	E	17
	IF (V(2,2)-DCLT) 2,3,3	E	18
2	ARC(2)=-ARC(2)	E	19
3	CALL START (R1,R2,R3,B,ARC,ERR,V)	E	20
	DO 4 I=1,3	E	21
	VP(I)=V(I,2)	E	22
4	VN(I)=V(I,3)	E	23
	CALL LINES (R1,R2,R3,B,ARC,ERR,J,VP,VN)	E	24
	IF (J.LT.200) GO TO 5	E	25
	ERR=4.*ERR	E	26
	WRITE (6,7) ERR	E	27
	GO TO 1	E	28
5	ERR=ERR1	E	29
	JUP=J	E	30
	AEQ=0.0	E	31
	DO 6 J=3,JUP	E	32
6	AEQ=AEQ+ABS(ARC(J))	E	33
	EB=BNEAR	E	34
	SIT=ABS(SIN(VNEAR(2)))	E	35
	SSQ=SIT*SIT	E	36
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	E	37
	AER=VNEAR(1)-OER	E	38
	EALT=AER*6371.2	E	39
	RETURN	E	40
C		E	41
7	FORMAT (28H INCREASE OF ERR IN EQUAT TO,E16.4)	E	42
	END	E	43-

	SUBROUTINE INSECT (CLONG,ERR,JUP)	F	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	F	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	F	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	F	4
C		F	5
C	THIS SUBROUTINE TRACES THE FIELD LINE FROM AN INITIAL POINT	F	6
C	DOWNWARDS TO A PREFIXED (LOWER) ALTITUDE	F	7
C		F	8
	DIMENSION V(3,3), VN(3), VP(3), R1(3), R2(3), R3(3)	F	9
	ERR1=ERR	F	10
	J=0	F	11
	SIT=ABS(SIN(VCONJ(2)))	F	12
	SSQ=SIT*SIT	F	13
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	F	14
	AER=VCONJ(1)-OER	F	15
	HR=6371.2*AER	F	16
	IF (HR.LE.ALTO) GO TO 5	F	17
	MMM=2	F	18
	V(1,2)=VCONJ(1)	F	19
	V(2,2)=VCONJ(2)	F	20
	V(3,2)=VCONJ(3)	F	21
	ARC(1)=0.	F	22
	DCLT=1.5708-0.2007*COS(V(3,2)+1.239)	F	23
1	ARC(2)=V(1,2)*SQRT(ERR)*0.3	F	24
	IF (V(2,2)-DCLT) 3,3,2	F	25
2	ARC(2)=-ARC(2)	F	26
3	CALL START (R1,R2,R3,B,ARC,ERR,V)	F	27
	DO 4 I=1,3	F	28
	VP(I)=V(I,2)	F	29
4	VN(I)=V(I,3)	F	30
	CALL LINES (R1,R2,R3,B,ARC,ERR,J,VP,VN)	F	31
	IF (J.LT.200) GO TO 5	F	32
	ERR=4.*ERR	F	33
	WRITE (6,6) ERR	F	34
	GO TO 1	F	35
5	ERR=ERR1	F	36
	JUP=J	F	37
	CLONG=VCONJ(3)*57.2957795	F	38
	IF (CLONG.GT.180.) CLONG=CLONG-360.	F	39
	IF (CLONG.LT.(-180.)) CLONG=CLONG+360.	F	40
	RETURN	F	41
C		F	42
6	FORMAT (29H INCREASE OF ERR IN INSECT TO,E16.4)	F	43
	END	F	44-

	SUBROUTINE BESECT (RUM1,RUM2,RUM3,BALT,ERR,JUP)	G	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	G	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	G	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	G	4
C		G	5
C	THIS SUBROUTINE TRACES THE FIELD LINE DOWNWARDS FROM AN INITIAL	G	6
C	POINT TO A PREFIXED (HIGHER) B-VALUE	G	7
C		G	8
	DIMENSION V(3,3), VN(3), VP(3), R1(3), R2(3), R3(3)	G	9
	ERR1=ERR	G	10
	J=0	G	11
	MMM=3	G	12
	V(1,2)=RUM1	G	13
	V(2,2)=RUM2	G	14
	V(3,2)=RUM3	G	15
	ARC(1)=0.	G	16
	DCLT=1.5708-0.2007*COS(V(3,2)+1.239)	G	17
1	ARC(2)=V(1,2)*SQRT(ERR)*0.3	G	18
	IF (V(2,2)-DCLT) 3,3,2	G	19
2	ARC(2)=-ARC(2)	G	20
3	CALL START (R1,R2,R3,B,ARC,ERR,V)	G	21
	IF (B(2).GT.BO) GO TO 5	G	22
	DO 4 I=1,3	G	23
	VP(I)=V(I,2)	G	24
4	VN(I)=V(I,3)	G	25
	CALL LINES (R1,R2,R3,B,ARC,ERR,J,VP,VN)	G	26
	IF (J.LT.200) GO TO 6	G	27
	ERR=4.*ERR	G	28
	WRITE (6,7) ERR	G	29
	GO TO 1	G	30
5	VBO(2)=RUM2	G	31
	VBO(1)=RUM1	G	32
6	EPR=ERR1	G	33
	JUP=J	G	34
	SIT=ABS(SIN(VBO(2)))	G	35
	SSQ=SIT*SIT	G	36
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	G	37
	AER=VBO(1)-OER	G	38
	BALT=AER*6371.2	G	39
	RETURN	G	40
C		G	41
7	FORMAT (29H INCREASE OF ERR IN BESECT TO,E16.4)	G	42
	END	G	43-

	SUBROUTINE INVAR (DUM1,DUM2,DUM3,ERR,BB,FL,FI,JUP)	H	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	H	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	H	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	H	4
C		H	5
C	SUBROUTINES INVAR,START,INTEGER,CARMEL, AND NEWMAG ARE BASED ON	H	6
C	ON MCILWAINS 1965 CODE.	H	7
C	INVAR MUST BE CALLED WITH GEOCENTRIC COORDINATES.	H	8
C	MMM IS A TRACING CONTROL PARAMETER DETERMINED IN EQUAT,INSECT,	H	9
C	BESECT AND INVAR.	H	10
C		H	11
	DIMENSION V(3,3), VN(3), VP(3), BEG(200), BEND(200), BLOG(200), EC	H	12
	10(200), R1(3), R2(3), R3(3)	H	13
	V(1,2)=DUM1	H	14
	V(2,2)=DUM2	H	15
	V(3,2)=DUM3	H	16
	ERR1=EPR	H	17
	MMM=0	H	18
	ARC(1)=0.	H	19
	DCLT=1.5708-0.2007*COS(V(3,2)+1.239)	H	20
1	ARC(2)=DUM1*SQR(ERR)*0.3	H	21
	IF (V(2,2)-DCLT) 2,3,3	H	22
2	ARC(2)=-ARC(2)	H	23
3	CALL START (R1,R2,R3,B,ARC,ERR,V)	H	24
	DO 4 I=1,3	H	25
	VP(I)=V(I,2)	H	26
4	VN(I)=V(I,3)	H	27
	CALL LINES (R1,R2,R3,B,ARC,ERR,J,VP,VN)	H	28
	IF (J.LT.200) GO TO 5	H	29
	ERR=ERR*4.	H	30
	WRITE (6,8) ERR	H	31
	GO TO 1	H	32
5	ERR=ERR1	H	33
	JUP=J	H	34
	DO 6 J=1,JUP	H	35
	ARC(J)=ABS(ARC(J))	H	36
6	BLOG(J)=ALOG(B(J))	H	37
	JEP=JUP-1	H	38
	DO 7 J=2,JEP	H	39
	ASUM=ARC(J)+ARC(J+1)	H	40
	DX=BLOG(J-1)-BLOG(J)	H	41
	DN=ASUM*ARC(J)*ARC(J+1)	H	42
	BCO=((BLOG(J-1)-BLOG(J+1))*ARC(J)**2-DX*ASUM**2)/DN	H	43
	CCO=(DX*ARC(J+1)-(BLOG(J)-BLOG(J+1))*ARC(J))/DN	H	44
	SA=.75*ARC(J)	H	45
	SC=SA+.25*ASUM	H	46
	DCO=BLOG(J-1)-CCO*SA*SC	H	47
	ECO(J)=BCO+CCO*(SA+SC)	H	48
	BEG(J)=EXP(DCO+ECO(J)*.5*ARC(J))	H	49
7	BEND(J)=EXP(DCO+ECO(J)*.5*(ASUM+ARC(J)))	H	50
	BEG(JUP)=BEND(JEP)	H	51
	BEND(JUP)=B(JUP)	H	52
	ECO(JUP)=(2.0/ARC(JUP))*ALOG(BEND(JUP)/BEG(JUP))	H	53
	CALL INTEG (ARC,BEG,BEND,B,JEP,ECO,FLINT)	H	54
	CALL CARMEL (B(2),FLINT,FL)	H	55
	FI=FLINT	H	56
	BB=B(2)	H	57
	RETURN	H	58
C		H	59
8	FORMAT (28H INCREASE OF ERR IN INVAR TO,E16.4)	H	60
	END	H	61-

	SUBROUTINE START (R1,R2,R3,B,ARC,ERR,V)	I	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	I	2
	1),VPLAST(3),VB0(3),VSAVE(3),RCONJ,VO,RO,ALTO,MMIM,JNEAR,BNEAR,BSAVE	I	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	I	4
	DIMENSION V(3,3), R1(3), R2(3), R3(3)	I	5
	M=MMM	I	6
	SIT=ABS(SIN(V(2,2)))	I	7
1	IF (V(3,2)) 2,3,3	I	8
2	V(3,2)=V(3,2)+6.283185307	I	9
	GO TO 1	I	10
3	CALL NEWMAG (V(1,2),SIT,V(3,2),BR,BT,BP,B(2),V(2,2))	I	11
	BSAVE=B(2)	I	12
	BRSAVE=BR	I	13
	BPSAVE=BP	I	14
	BTSAVE=BT	I	15
	R2(1)=BR/B(2)	I	16
	DN=B(2)*V(1,2)	I	17
	R2(2)=BT/DN	I	18
	R2(3)=BP/(DN*SIT)	I	19
	IS=0	I	20
4	DO 5 I=1,3	I	21
5	V(I,1)=V(I,2)-ARC(2)*R2(I)	I	22
	SIT=ABS(SIN(V(2,1)))	I	23
6	CALL NEWMAG (V,SIT,V(3,1),BR,BT,BP,B(1),V(2,1))	I	24
	IF (M.LT.2) GO TO 7	I	25
	IF (B(1)-B(2)) 9,9,8	I	26
7	IF (B(1)-B(2)) 8,9,9	I	27
8	ARC(2)=-ARC(2)	I	28
	GO TO 4	I	29
9	R1(1)=BR/B(1)	I	30
	ARC(3)=ARC(2)	I	31
	DN=B(1)*V(1,1)	I	32
	R1(2)=BT/DN	I	33
	R1(3)=BP/(DN*SIT)	I	34
	DO 10 I=1,3	I	35
10	V(I,1)=V(I,2)-ARC(2)*(R1(I)+R2(I))/2.	I	36
	SIT=ABS(SIN(V(2,1)))	I	37
	IS=IS+1	I	38
	GO TO (6,11), IS	I	39
11	DO 12 I=1,3	I	40
12	V(I,3)=V(I,2)+ARC(3)*((1.5)*R2(I)-.5*R1(I))	I	41
	RETURN	I	42
	END	I	43-

	SUBROUTINE LINES (R1,R2,R3,B,ARC,ERR,J,VP,VN)	J	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	J	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	J	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	J	4
	INTEGER FLAG1,FLAG2	J	5
	DIMENSION R1(3), R2(3), R3(3), VN(3), VP(3), RA(3)	J	6
	JSTOP=0	J	7
	M=MMM	J	8
	FLAG1=0	J	9
	FLAG2=0	J	10
	DEL=0.01	J	11
	CRE=0.25	J	12
	IF (ERR-0.15625) 1,2,2	J	13
1	CRE=(ERR**0.333333333)	J	14
2	A3=ARC(3)	J	15
	AAB=ABS(A3)	J	16
	SNA=A3/AAB	J	17
	A1=ARC(1)	J	18
	A2=ARC(2)	J	19
	A06=A3*A3/6.0	J	20
	VN1(2)=VP(1)	J	21
	VN2(2)=VP(2)	J	22
	VN3(2)=VP(3)	J	23
	J=3	J	24
	ILP=1	J	25
	IS=1	J	26
	GO TO 8	J	27
3	IS=1	J	28
	J=J+1	J	29
	A06=A3*A3/6.0	J	30
	ARCJ=A1+A2+A3	J	31
	AD=(ASUM+A1)/AA	J	32
	BD=ASUM/BB	J	33
	CD=A1/CC	J	34
4	DO 7 I=1,3	J	35
	DD=R1(I)/AA-R2(I)/BB+R3(I)/CC	J	36
	GO TO (5,6), IS	J	37
5	RT=R1(I)-(AD*R1(I)-BD*R2(I)+CD*R3(I)-DD*ARCJ)*ARCJ	J	38
	RA(I)=R1(I)	J	39
	R1(I)=R2(I)	J	40
	R2(I)=R3(I)	J	41
	R3(I)=RT	J	42
	VP(I)=VN(I)	J	43
6	RBAR=(R2(I)+R3(I))/2.-DD*A06	J	44
7	VN(1)=VP(1)+A3*RBAR	J	45
8	IF (VN(2)) 9,10,10	J	46
9	VN(2)=-VN(2)	J	47
10	IF (VN(2)-3.141592653) 12,12,11	J	48
11	VN(2)=6.283185307-VN(2)	J	49
	GO TO 10	J	50
12	IF (VN(3)) 13,14,14	J	51
13	VN(3)=VN(3)+6.283185307	J	52
	GO TO 12	J	53
14	IF (VN(3)-6.283185307) 16,16,15	J	54
15	VN(3)=VN(3)-6.283185307	J	55
	GO TO 14	J	56
16	GO TO (17,18), IS	J	57

17	SIT=ABS(SIN(VN(2)))	J	58
	PRE1=VN(1)	J	59
	PRE2=PRE1*VN(2)	J	60
	PRE3=PRE1*SIT*VN(3)	J	61
	CALL NEWMAG (VN,SIT,VN(3),BR,BT,BP,B(J),VN(2))	J	62
	R3(1)=BR/B(J)	J	63
	DN=B(J)*VN(1)	J	64
	R3(2)=BT/DN	J	65
	R3(3)=BP/(DN*SIT)	J	66
	ASUM=A3+A2	J	67
	AA=ASUM*A2	J	68
	BB=A3*A2	J	69
	CC=ASUM*A3	J	70
	IS=2	J	71
	GO TO 4	J	72
18	SIT=ABS(SIN(VN(2)))	J	73
	B(J)=B(J)*((PRE1/VN(1))*3)	J	74
C		J	75
C	WHEN CALLED FROM EQUAT,ARC LENGTH IS MAINTAINED CONSTANT	J	76
C		J	77
	IF (M.EQ.1) GO TO 22	J	78
	QRT=.5*ABS(R3(1))/(.1+ABS(R3(2)*VN(1)))	J	79
	X=(ABS(VN(1)-PRE1)+QRT*ABS(VN(1)*VN(2)-PRE2)+ABS(VN(1)*SIT*VN(3)-PRE3))/(AAB*ERR*SQRT(1.+QRT*QRT))	J	80
	GO TO (22,19,22), ILP	J	81
19	IF (X-3.3) 22,20,20	J	82
20	A3=A3*0.2*(8.0+X)/(0.8+X)	J	83
	J=J-1	J	84
	ILP=3	J	85
	ASUM=A2+A1	J	86
	AA=ASUM*A1	J	87
	BB=A2*A1	J	88
	CC=ASUM*A2	J	89
	DO 21 I=1,3	J	90
	VN(I)=VP(I)	J	91
	R3(I)=R2(I)	J	92
	R2(I)=R1(I)	J	93
21	R1(I)=RA(I)	J	94
	GO TO 38	J	95
22	VN1(J)=VN(1)	J	96
	VN2(J)=VN(2)	J	97
	VN3(J)=VN(3)	J	98
	IF (M.EQ.2) GO TO 28	J	99
	IF (M.EQ.3) GO TO 30	J	100
	IF (B(J-1).GT.B(J)) GO TO 32	J	101
	IF (M.EQ.1) GO TO 24	J	102
	IF (FLAG1.EQ.1) GO TO 26	J	103
	FLAG1=1	J	104
	DO 23 I=1,3	J	105
23	VNEAR(I)=VN(I)	J	106
	BNEAR=B(J)	J	107
	JNEAR=J	J	108
	GO TO 26	J	109
24	BNEAR=B(J-1)	J	110
	DO 25 I=1,3	J	111
25	VNEAR(I)=VP(I)	J	112
	GO TO 42	J	113
		J	114

26	IF (FLAG2.EQ.1) GO TO 32	J 115
	IF ((VO+DEL).LT.VN(1)) GO TO 32	J 116
	DO 27 I=1,3	J 117
27	VCONJ(I)=VP(I)	J 118
	JSTOP=J-1	J 119
	FLAG2=1	J 120
	GO TO 32	J 121
28	SIT=ABS(SIN(VN(2)))	J 122
	SSQ=SIT*SIT	J 123
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	J 124
	AER=VN(1)-OER	J 125
	HR=6371.2*AER	J 126
	IF (HR.GT.ALTO) GO TO 32	J 127
	SIT=ABS(SIN(VP(2)))	J 128
	SSQ=SIT*SIT	J 129
	OER=(6356.912+SSQ*(21.3677+.108*SSQ))/6371.2	J 130
	AER=VP(1)-OER	J 131
	HRP=6371.2*AER	J 132
	FAC=(ALTO-HRP)/(HR-HRP)	J 133
	DO 29 I=1,3	J 134
29	VCONJ(I)=VP(I)+(VN(I)-VP(I))*FAC	J 135
	ARC(J)=ARC(J)*FAC	J 136
	VN1(J)=VCONJ(1)	J 137
	VN2(J)=VCONJ(2)	J 138
	VN3(J)=VCONJ(3)	J 139
	SIT=ABS(SIN(VCONJ(2)))	J 140
	CALL NEWMAG (VCONJ,SIT,VCONJ(3).BR,BT,BP,BB,VCONJ(2))	J 141
	BCONJ=BB	J 142
	B(J)=BB	J 143
	GO TO 42	J 144
30	IF (B(J).LT.B0) GO TO 32	J 145
	FAC=(B0-B(J-1))/(B(J)-B(J-1))	J 146
	DO 31 I=1,3	J 147
31	VBO(I)=VP(I)+(VN(I)-VP(I))*FAC	J 148
	ARC(J)=ARC(J)*FAC	J 149
	B(J)=B0	J 150
	VN1(J)=VBO(1)	J 151
	VN2(J)=VBO(2)	J 152
	VN3(J)=VBO(3)	J 153
	GO TO 42	J 154
32	IF (J.GE.200) GO TO 42	J 155
	A1=A2	J 156
	IF (M.NE.0) GO TO 33	J 157
	IF (B(J)-B(2)) 33,33,39	J 158
33	ILP=2	J 159
	A2=A3	J 160
	IF (M.EQ.1) GO TO 38	J 161
	A3=A3*.2*(8.+X)/(8.+X)	J 162
	AM=(2.-R3(2)*VN(1))*VN(1)*CRE	J 163
	IF (ABS(A3)-AM) 35,35,34	J 164
34	A3=SNA*AM	J 165
35	IF (SNA*R3(1)+.5) 36,36,38	J 166
36	AM=-.5*SNA*VN(1)/R3(1)	J 167
	IF (ABS(A3)-AM) 38,38,37	J 168
37	A3=SNA*AM	J 169
38	ARC(J+1)=A3	J 170
	AAB=ABS(A3)	J 171
	GO TO 3	J 172
39	BLAST=B(J)	J 173
	DO 40 ILAST=1,3	J 174
	VPLAST(ILAST)=VP(ILAST)	J 175
40	VLAST(ILAST)=VN(ILAST)	J 176
	IF (FLAG2.NE.0) GO TO 42	J 177
	DO 41 I=1,3	J 178
41	VCONJ(I)=VLAST(I)	J 179
42	RETURN	J 180
	END	J 181

	SUBROUTINE INTEG (ARC,BEG,BEND,B,JEP,ECO,FI)	K	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VN1(3),VCONJ(3),VLAST(3	K	2
	1),VPLAST(3),V50(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	K	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	K	4
	DIMENSION BEG(200), BEND(200), ECO(200)	K	5
1	KK=JEP	K	6
	IF (KK-4) 3,2,4	K	7
2	KK=KK-1	K	8
3	A=B(KK-1)/B(2)	K	9
	X2=B(KK)/B(2)	K	10
	X3=B(KK+1)/B(2)	K	11
	ASUM=ARC(KK)+ARC(KK+1)	K	12
	DN=ARC(KK)*ARC(KK+1)*ASUM	K	13
	BB=(-A*ARC(KK+1)*(ARC(KK)+ASUM)+X2*ASUM**2-X3*ARC(KK)**2)/DN	K	14
	C=(A*ARC(KK+1)-X2*ASUM+X3*ARC(KK))/DN	K	15
	FI=1.570796326*(1.-A+BB*BB/(4.*C))/SQRT(ABS(C))	K	16
	RETURN	K	17
4	T=SQRT(1.-BEND(2)/B(2))	K	18
	FI=(2.*T-ALOG((1.+T)/(1.-T)))/ECO(2)	K	19
	IF (B(2)-BEND(KK)) 6,6,5	K	20
5	KK=KK+1	K	21
6	T=SQRT(ABS(1.0-BEG(KK)/B(2)))	K	22
	FI=FI-(2.*T-ALOG((1.+T)/(1.-T)))/ECO(KK)	K	23
	KK=KK-1	K	24
	DO 15 I=3, KK	K	25
	ARG1=1.-BEND(I)/B(2)	K	26
	IF (ARG1) 7,7,8	K	27
7	TE=1.E-5	K	28
	GO TO 9	K	29
8	TE=SQRT(ARG1)	K	30
9	ARG1=1.-BEG(I)/B(2)	K	31
	IF (ARG1) 11,11,10	K	32
10	TB=SQRT(ARG1)	K	33
	GO TO 12	K	34
11	TB=1.E-5	K	35
12	IF (ABS(ECO(I))-2.E-5) 13,13,14	K	36
13	FI=FI+((TE+TB)*(ARC(I)+ARC(I+1)))/4.	K	37
	GO TO 15	K	38
14	FI=FI+(2.*((TE-TB)-ALOG((1.+TE)*(1.-TB)/((1.-TE)*(1.+TB)))))/ECO(I)	K	39
15	CONTINUE	K	40
	RETURN	K	41
	END	K	42-

	SUBROUTINE CARMEL (B,XI,VL)	L	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	L	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,RO,ALTO,MMM,JNEAR,BNEAR,BSAVE	L	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	L	4
	IF (XI-1.0E-36) 1,1,2	L	5
1	VL=(0.311653/B)**(1./3.)	L	6
	RETURN	L	7
2	XX=3.0*ALOG(XI)	L	8
	XX=XX+ALOG(B/0.311653)	L	9
	IF (XX+22.) 7,7,3	L	10
3	IF (XX+3.) 8,8,4	L	11
4	IF (XX-3.) 9,9,5	L	12
5	IF (XX-11.7) 10,10,6	L	13
6	IF (XX-23.) 11,11,12	L	14
7	GG=.333338*XX+.30062102	L	15
	GO TO 13	L	16
8	GG=((((((-8.1537735E-14*XX+8.3232531E-13)*XX+1.0066362E-9)*XX+8.	L	17
	11048663E-8)*XX+3.2916354E-6)*XX+8.2711006E-5)*XX+1.3714667E-3)*XX+	L	18
	2.01501724E)*XX+.43432642)*XX+.62337691	L	19
	GO TO 13	L	20
9	GG=((((((2.6047023E-10*XX+2.3028767E-9)*XX-2.1997983E-8)*XX-5.39	L	21
	177642E-7)*XX-3.3408822E-6)*XX+3.0379917E-5)*XX+1.1784234E-3)*XX+1.	L	22
	24492441E-2)*XX+.43352763)*XX+.6222644	L	23
	GO TO 13	L	24
10	GG=((((((1.0.2271565E-10*XX-3.958306E-8)*XX+9.9766148E-07)*XX-1.25	L	25
	121037E-5)*XX+7.9451313E-5)*XX-2.2077032E-4)*XX+2.1680398E-3)*XX+1.	L	26
	22817956E-2)*XX+.43510529)*XX+.6222355	L	27
	GO TO 13	L	28
11	GG=((((((2.8212095E-8*XX-3.8049276E-6)*XX+2.170224E-4)*XX-6.7310339	L	29
	1E-3)*XX+.12038224)*XX-.12461796)*XX+2.0007187	L	30
	GO TO 13	L	31
12	GG=XX-3.0460681	L	32
13	VL=(((1.0+EXP(GG))*0.311653)/B)**(1./3.)	L	33
	RETURN	L	34
	END	L	35-

	SUBROUTINE NEWMAG (R,ST,PHI,BR,BT,BP,B,THET)	M	1
	COMMON B(200),VN1(200),VN2(200),ARC(200),VNEAR(3),VCONJ(3),VLAST(3	M	2
	1),VPLAST(3),VBO(3),VSAVE(3),BCONJ,VO,BO,ALTO,MMM,JNEAR,BNEAR,BSAVE	M	3
	2,BRSAVE,BPSAVE,BTSAVE,VN3(200),JSTOP	M	4
	DIMENSION G(7,7)	M	5
C	CAIN COEF.(SEE HENDRICKS,CAIN,JGR,71,JAN 1966,P346. EPOCH 1960	M	6
C	GSFC(9-65)- TRUNCATED	M	7
	DATAG/0,0,	M	8
C	3.042500E+04, 2.304000E+03, -3.252500E+03, -4.191250E+03,	M	9
C	1.795500E+03, -7.218750E+02, -5.775000E+03, 2.162000E+03,	M	10
C	-5.196152E+03, 6.083920E+03, -4.443791E+03, -3.659969E+03,	M	11
C	-1.153091E+03, 3.377499E+03, -1.766692E+02, -1.372650E+03,	M	12
C	-2.498074E+03, -1.968299E+03, -1.775284E+03, -7.472116E+01,	M	13
C	1.319663E+03, -4.473296E+02, 1.027740E+02, -6.885860E+02,	M	14
C	8.241101E+02, 1.458926E+02, 2.411003E+03, -8.411659E+02,	M	15
C	1.048716E+03, -6.274950E+00, 1.856170E+02, -2.004072E+02,	M	16
C	3.483092E+02, 5.456862E+00, -9.149923E+01, -9.299108E+02,	M	17
C	5.459207E+02, 2.440383E+02, -5.612486E+01, 4.560145E+01,	M	18
C	0, 2.268375E+02, -1.539256E+03, -6.077321E+02,	M	19
C	1.473353E+02, 2.792177E+01, 8.060319E+00, 7.321457E+01	M	20
	C/,J/0/,NMAX/7/	M	21
C	GSFC(9-65) FOR NOV.,1965	M	22
C	3.030346E+04, 2.561535E+03, -3.292325E+03, -4.168019E+03,	M	23
C	1.674698E+03, -6.622481E+02, -5.751990E+03, 2.126600E+03,	M	24
C	-5.208415E+03, 6.264570E+03, -4.505827E+03, -3.653971E+03,	M	25
C	-1.264619E+03, 3.517501E+03, -9.593829E+01, -1.369074E+03,	M	26
C	-2.516355E+03, -1.940594E+03, -1.843298E+03, -1.452579E+02,	M	27
C	1.202240E+03, -4.804629E+02, 1.456861E+02, -6.825223E+02,	M	28
C	8.302805E+02, 1.569993E+02, 2.287563E+03, -7.823949E+02,	M	29
C	1.083347E+03, -4.576530E+01, 2.096141E+02, -1.820821E+02,	M	30
C	3.574717E+02, -4.605592E+01, -2.714477E+02, -1.061405E+03,	M	31
C	5.986773E+02, 2.283311E+02, -5.943623E+01, 3.897872E+01,	M	32
C	1.372820E+00, 3.829773E+02, -1.548073E+03, -6.959031E+02,	M	33
C	1.698721E+02, 2.929459E+01, 6.475123E+00, 7.281827E+01	M	34
	C/,J/0/,NMAX/7/	M	35
1	P22=ST.	M	36
	P21=SQRT(1.-P22*P22)	M	37
	AR=R	M	38
	IF (THET-1.570796327) 3,3,2	M	39
2	P21=-P21	M	40
3	IF (J) 5,5,4	M	41
4	SSQ=P22*P22	M	42
	AR=AR+(14.288-SSQ*(21.3677+.108*SSQ))/6371.2	M	43
5	AR=1./AR	M	44
C	N= 2	M	45
	DP22=P21	M	46
	SP2=SIN(PHI)	M	47
	CP2=COS(PHI)	M	48
	DP21=-P22	M	49
	AOR=AR*AR*AR	M	50
	C2=G(2,2)*CP2+G(1,2)*SP2	M	51
	BR=-(AOR+AOR)*(G(2,1)*P21+C2*P22)	M	52
	BT=AOR*(G(2,1)*DP21+C2*DP22)	M	53
	BP=AOR*(G(1,2)*CP2-G(2,2)*SP2)*P22	M	54
	IF (NMAX-3) 11,6,6	M	55
6	SP3=(SP2+SP2)*CP2	M	56
	CP3=(CP2+SP2)*(CP2-SP2)	M	57

	P31=P21*P21-0.333333333	M	58
	P32=P21*P22	M	59
	P33=P22*P22	M	60
	DP31=-P32-P32	M	61
	DP32=P21*P21-P33	M	62
	DP33=-DP31	M	63
	AOR=AOR*AR	M	64
	C2=G(3,2)*CP2+G(1,3)*SP2	M	65
	C3=G(3,3)*CP3+G(2,3)*SP3	M	66
	BR=BR-3.0*AOR*(G(3,1)*P31+C2*P32+C3*P33)	M	67
	BT=BT+AOR*(G(3,1)*DP31+C2*DP32+C3*DP33)	M	68
	BP=BP-AOR*((G(3,2)*SP2-G(1,3)*CP2)*P32+2.0*(G(3,3)*SP3-G(2,3)*CP3)	M	69
	1*P33)	M	70
C	N= 4	M	71
	IF (NMAX-4) 11,7,7	M	72
7	SP4=SP2*CP3+CP2*SP3	M	73
	CP4=CP2*CP3-SP2*SP3	M	74
	P41=P21*P31-0.266666666*P21	M	75
	DP41=P21*DP31+DP21*P31-0.266666666*DP21	M	76
	P42=P21*P32-0.200000000*P22	M	77
	DP42=P21*DP32+DP21*P32-0.200000000*DP22	M	78
	P43=P21*P33	M	79
	DP43=P21*DP33+DP21*P33	M	80
	P44=P22*P33	M	81
	DP44=3.0*P43	M	82
	AOR=AOR*AR	M	83
	C2=G(4,2)*CP2+G(1,4)*SP2	M	84
	C3=G(4,3)*CP3+G(2,4)*SP3	M	85
	C4=G(4,4)*CP4+G(3,4)*SP4	M	86
	BR=BR-4.0*AOR*(G(4,1)*P41+C2*P42+C3*P43+C4*P44)	M	87
	BT=BT+AOR*(G(4,1)*DP41+C2*DP42+C3*DP43+C4*DP44)	M	88
	BP=BP-AOR*((G(4,2)*SP2-G(1,4)*CP2)*P42+2.0*(G(4,3)*SP3-G(2,4)*CP3)	M	89
	1*P43+3.0*(G(4,4)*SP4-G(3,4)*CP4)*P44)	M	90
	IF (NMAX-5) 11,8,8	M	91
8	SP5=(SP3+SP3)*CP3	M	92
	CP5=(CP3+SP3)*(CP3-SP3)	M	93
	P51=P21*P41-0.25714285*P31	M	94
	DP51=P21*DP41+DP21*P41-0.25714285*DP31	M	95
	P52=P21*P42-0.22857142*P32	M	96
	DP52=P21*DP42+DP21*P42-0.22857142*DP32	M	97
	P53=P21*P43-0.14285714*P33	M	98
	DP53=P21*DP43+DP21*P43-0.14285714*DP33	M	99
	P54=P21*P44	M	100
	DP54=P21*DP44+DP21*P44	M	101
	P55=P22*P44	M	102
	DP55=4.0*P54	M	103
	AOR=AOR*AR	M	104
	C2=G(5,2)*CP2+G(1,5)*SP2	M	105
	C3=G(5,3)*CP3+G(2,5)*SP3	M	106
	C4=G(5,4)*CP4+G(3,5)*SP4	M	107
	C5=G(5,5)*CP5+G(4,5)*SP5	M	108
	BR=BR-5.0*AOR*(G(5,1)*P51+C2*P52+C3*P53+C4*P54+C5*P55)	M	109
	BT=BT+AOR*(G(5,1)*DP51+C2*DP52+C3*DP53+C4*DP54+C5*DP55)	M	110
	BP=BP-AOR*((G(5,2)*SP2-G(1,5)*CP2)*P52+2.0*(G(5,3)*SP3-G(2,5)*CP3)	M	111
	1*P53+3.0*(G(5,4)*SP4-G(3,5)*CP4)*P54+4.0*(G(5,5)*SP5-G(4,5)*CP5)*P	M	112
	255)	M	113
C	N= 6	M	114

9	IF (NMAX-6) 11,9,9	M 115
	SP6=SP2*CP5+CP2*SP5	M 116
	CP6=CP2*CP5-SP2*SP5	M 117
	P61=P21*P51-0.25396825*P41	M 118
	DP61=P21*DP51+DP21*P51-0.25396825*DP41	M 119
	P62=P21*P52-0.23809523*P42	M 120
	DP62=P21*DP52+DP21*P52-0.23809523*DP42	M 121
	P63=P21*P53-0.19047619*P43	M 122
	DP63=P21*DP53+DP21*P53-0.19047619*DP43	M 123
	P64=P21*P54-0.11111111*P44	M 124
	DP64=P21*DP54+DP21*P54-0.11111111*DP44	M 125
	P65=P21*P55	M 126
	DP65=P21*DP55+DP21*P55	M 127
	P66=P22*P55	M 128
	DP66=5.0*P65	M 129
	AOR=AOR*AR	M 130
	C2=G(6,2)*CP2+G(1,6)*SP2	M 131
	C3=G(6,3)*CP3+G(2,6)*SP3	M 132
	C4=G(6,4)*CP4+G(3,6)*SP4	M 133
	C5=G(6,5)*CP5+G(4,6)*SP5	M 134
	C6=G(6,6)*CP6+G(5,6)*SP6	M 135
	BR=BR-6.0*AOR*(G(6,1)*P61+C2*P62+C3*P63+C4*P64+C5*P65+C6*P66)	M 136
	BT=BT+AOR*(G(6,1)*DP61+C2*DP62+C3*DP63+C4*DP64+C5*DP65+C6*DP66)	M 137
	BP=BP-AOR*((G(6,2)*SP2-G(1,6)*CP2)*P62+2.0*(G(6,3)*SP3-G(2,6)*CP3)	M 138
	1*P63+3.0*(G(6,4)*SP4-G(3,6)*CP4)*P64+4.0*(G(6,5)*SP5-G(4,6)*CP5)*P	M 139
	265+5.0*(G(6,6)*SP6-G(5,6)*CP6)*P66)	M 140
10	IF (NMAX-7) 11,10,10	M 141
	SP7=(SP4+SP4)*CP4	M 142
	CP7=(CP4+SP4)*(CP4-SP4)	M 143
	P71=P21*P61-0.25252525*P51	M 144
	DP71=P21*DP61+DP21*P61-0.25252525*DP51	M 145
	P72=P21*P62-0.24242424*P52	M 146
	DP72=P21*DP62+DP21*P62-0.24242424*DP52	M 147
	P73=P21*P63-0.21212121*P53	M 148
	DP73=P21*DP63+DP21*P63-0.21212121*DP53	M 149
	P74=P21*P64-0.16161616*P54	M 150
	DP74=P21*DP64+DP21*P64-0.16161616*DP54	M 151
	P75=P21*P65-0.09090909*P55	M 152
	DP75=P21*DP65+DP21*P65-0.09090909*DP55	M 153
	P76=P21*P66	M 154
	DP76=P21*DP66+DP21*P66	M 155
	P77=P22*P66	M 156
	DP77=6.0*P76	M 157
	AOR=AOR*AR	M 158
	C2=G(7,2)*CP2+G(1,7)*SP2	M 159
	C3=G(7,3)*CP3+G(2,7)*SP3	M 160
	C4=G(7,4)*CP4+G(3,7)*SP4	M 161
	C5=G(7,5)*CP5+G(4,7)*SP5	M 162
	C6=G(7,6)*CP6+G(5,7)*SP6	M 163
	C7=G(7,7)*CP7+G(6,7)*SP7	M 164
	BR=BR-7.0*AOR*(G(7,1)*P71+C2*P72+C3*P73+C4*P74+C5*P75+C6*P76+C7*P7	M 165
	17)	M 166
	BT=BT+AOR*(G(7,1)*DP71+C2*DP72+C3*DP73+C4*DP74+C5*DP75+C6*DP76+C7*	M 167
	1DP77)	M 168
	BP=BP-AOR*((G(7,2)*SP2-G(1,7)*CP2)*P72+2.0*(G(7,3)*SP3-G(2,7)*CP3)	M 169
	1*P73+3.0*(G(7,4)*SP4-G(3,7)*CP4)*P74+4.0*(G(7,5)*SP5-G(4,7)*CP5)*P	M 170
	275+5.0*(G(7,6)*SP6-G(5,7)*CP6)*P76+6.0*(G(7,7)*SP7-G(6,7)*CP7)*P77	M 171
	3)	M 172
11	BP=BP/P22*1.E-5	M 173
	BT=BT*1.E-5	M 174
	BR=BR*1.E-5	M 175
	B=SQRT(BR*BR+BT*BT+BP*BP)	M 176
	RETURN	M 177
	END	M 178-

	SUBROUTINE SPLINE (X,Y,Y2DOT,M)	N	1
	DIMENSION X(400), Y(400), D(400), P(400), E(400), A(400,3), B(400)	N	2
	1, Y2DOT(400)	N	3
C		N	4
C	THIS SUBROUTINE GENERATES COEFFICIENTS NEEDED FOR A SPLINE	N	5
C	INTERPOLATION. GIVEN M VALUES OF X (INDEPENDENT VARIABLE)	N	6
C	AND THE CORRESPONDING Y VALUES (DEPENDENT VARIABLE), THE ROUTINE	N	7
C	CALCULATES THE VALUES OF THE 2ND DERIVATIVE (Y2DOT) AT EACH VALUE	N	8
C	X. M IS THE NUMBER OF DATA POINTS.	N	9
C		N	10
	DO 1 I=2,M	N	11
	IF (X(I).LE.X(I-1)) GO TO 2	N	12
1	CONTINUE	N	13
	GO TO 3	N	14
2	WRITE (6,8)	N	15
	WRITE (6,9) (I,X(I),Y(I),I=1,M)	N	16
3	CONTINUE	N	17
	IF (M.GT.400) WRITE (6,10)	N	18
	IF (M.GT.400) STOP	N	19
	IF (M.LT.4) WRITE (6,11)	N	20
	IF (M.LT.4) STOP	N	21
	MM=M-1	N	22
	DO 4 K=1,MM	N	23
	D(K)=X(K+1)-X(K)	N	24
	P(K)=D(K)/6.	N	25
4	E(K)=(Y(K+1)-Y(K))/D(K)	N	26
	DO 5 K=2,MM	N	27
5	B(K)=E(K)-E(K-1)	N	28
	A(1,2)=-1.-D(1)/D(2)	N	29
	A(1,3)=D(1)/D(2)	N	30
	A(2,3)=P(2)-P(1)*A(1,3)	N	31
	A(2,2)=2.*(P(1)+P(2))-P(1)*A(1,2)	N	32
	A(2,3)=A(2,3)/A(2,2)	N	33
	B(2)=B(2)/A(2,2)	N	34
	DO 6 K=3,MM	N	35
	A(K,2)=2.*(P(K-1)+P(K))-P(K-1)*A(K-1,3)	N	36
	B(K)=B(K)-P(K-1)*B(K-1)	N	37
	A(K,3)=P(K)/A(K,2)	N	38
6	B(K)=B(K)/A(K,2)	N	39
	Q=D(M-2)/D(M-1)	N	40
	A(M,1)=1.+Q+A(M-2,3)	N	41
	A(M,2)=-Q-A(M,1)*A(M-1,3)	N	42
	B(M)=B(M-2)-A(M,1)*B(M-1)	N	43
	Y2DOT(M)=B(M)/A(M,2)	N	44
	MN=M-2	N	45
	DO 7 I=1,MN	N	46
	K=M-I	N	47
7	Y2DOT(K)=B(K)-A(K,3)*Y2DOT(K+1)	N	48
	Y2DOT(1)=-A(1,2)*Y2DOT(2)-A(1,3)*Y2DOT(3)	N	49
	RETURN	N	50
C		N	51
8	FORMAT (33H X SHOULD BE INCREASING IN SPLINE.)	N	52
9	FORMAT (110,2E20,6)	N	53
10	FORMAT (73H INCREASE THE DIMENSION OF ALL DIMENSIONED VARIABLES IN	N	54
	1 SPLINE AND YSPLN.)	N	55
11	FORMAT (46H AT LEAST 4 POINTS ARE NEEDED IN THIS ROUTINE.)	N	56
	END	N	57-

	SUBROUTINE YSPLN (X,Y,NPTS,Y2DOT,UNKX,UNKY)	0	1
C		0	2
C	SPLINE INTERPOLATION ROUTINE USING Y2DOT VALUES CALCULATED IN	0	3
C	SUBROUTINE SPLINE.	0	4
C		0	5
C	GIVEN NPTS VALUES OF X (INDEPENDENT VARIABLE) AND THEIR CORRESPON-	0	6
C	DING Y VALUES (DEPENDENT VARIABLE) AND VALUES OF THE 2ND DERIV-	0	7
C	ATIVE (Y2DOT) AT EACH POINT, ROUTINE INTERPOLATES FOR Y (UNKY)	0	8
C	AT X=UNKX.	0	9
C		0	10
	DIMENSION X(400), Y(400), Y2DOT(400)	0	11
C		0	12
C	INTERPOLATION INTERVAL SEARCH	0	13
C		0	14
	NBG=1	0	15
	NND=NPTS	0	16
	MDL=NPTS/2+1	0	17
	IF (NPTS-2) 1,2,2	0	18
1	WRITE (6,18)	0	19
	STOP	0	20
2	IF (UNKX-X(MDL)) 3,6,8	0	21
3	IF (MDL-NBG-1) 4,4,7	0	22
4	IF (UNKX-X(NBG)) 5,5,6	0	23
5	NK=NBG-1	0	24
	GO TO 13	0	25
6	NK=MDL-1	0	26
	GO TO 13	0	27
7	NND=MDL	0	28
	MDL=NBG+(NND-NBG)/2	0	29
	GO TO 2	0	30
8	IF (NND-MDL-1) 9,9,12	0	31
9	IF (UNKX-X(NND)) 10,11,11	0	32
10	NK=MDL	0	33
	GO TO 13	0	34
11	NK=NND	0	35
	GO TO 13	0	36
12	NBG=MDL	0	37
	MDL=NBG+(NND-MDL)/2	0	38
	GO TO 2	0	39
13	IF (NK) 15,14,15	0	40
14	NK=1	0	41
	GO TO 17	0	42
15	IF (NK-NPTS) 17,16,17	0	43
16	NK=NPTS-1	0	44
C		0	45
C	INTERPOLATION FOR UNKY	0	46
C		0	47
17	VRX1=X(NK+1)-UNKX	0	48
	VRX2=UNKX-X(NK)	0	49
	VRY1=Y(NK)	0	50
	VRY2=Y(NK+1)	0	51
	DNK=X(NK+1)-X(NK)	0	52
	TRM1=Y2DOT(NK)*VRX1**3	0	53
	TRM2=Y2DOT(NK+1)*VRX2**3	0	54
	TRM3=(TRM1+TRM2)/(6.0*DNK)	0	55
	UNKY=TRM3	0	56
	TRM1=VRY1/DNK	0	57

	TRM2=Y2DOT(NK)*DNK/6.0	0	58
	TRM3=VRX1*(TRM1-TRM2)	0	59
	UNKY=UNKY+TRM3	0	60
	TRM1=VRY2/DNK	0	61
	TRM2=Y2DOT(NK+1)*DNK/6.0	0	62
	TRM3=VRX2*(TRM1-TRM2)	0	63
	UNKY=UNKY+TRM3	0	64
C		0	65
C	THE COMPLETE EXPRESSION FOR UNKY IS GIVEN BY	0	66
C	UNKY=(Y2DOT(NK)*VRX1**3+Y2DOT(NK+1)*VRX2**3)/(6.0*DNK)+VRX1*(VRY1/	0	67
C	1DNK-Y2DOT(NK)*DNK/6.0)+VRX2*(VRY2/DNK-Y2DOT(NK+1)*DNK/6.0)	0	68
C		0	69
	RETURN	0	70
C		0	71
18	FORMAT (79H1PROGRAM HALT IN SUBROUTINE YSPLN----SEARCH LIST CONTAI	0	72
	NS LESS THAN TWO POINTS.)	0	73
	END	0	74-
1511			

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