NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
Bethesda, Maryland 20034

THE XYZ POTENTIAL FLOW PROGRAM

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COMPUTATION AND MATHEMATICS DEPARTMENT

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Report 3892

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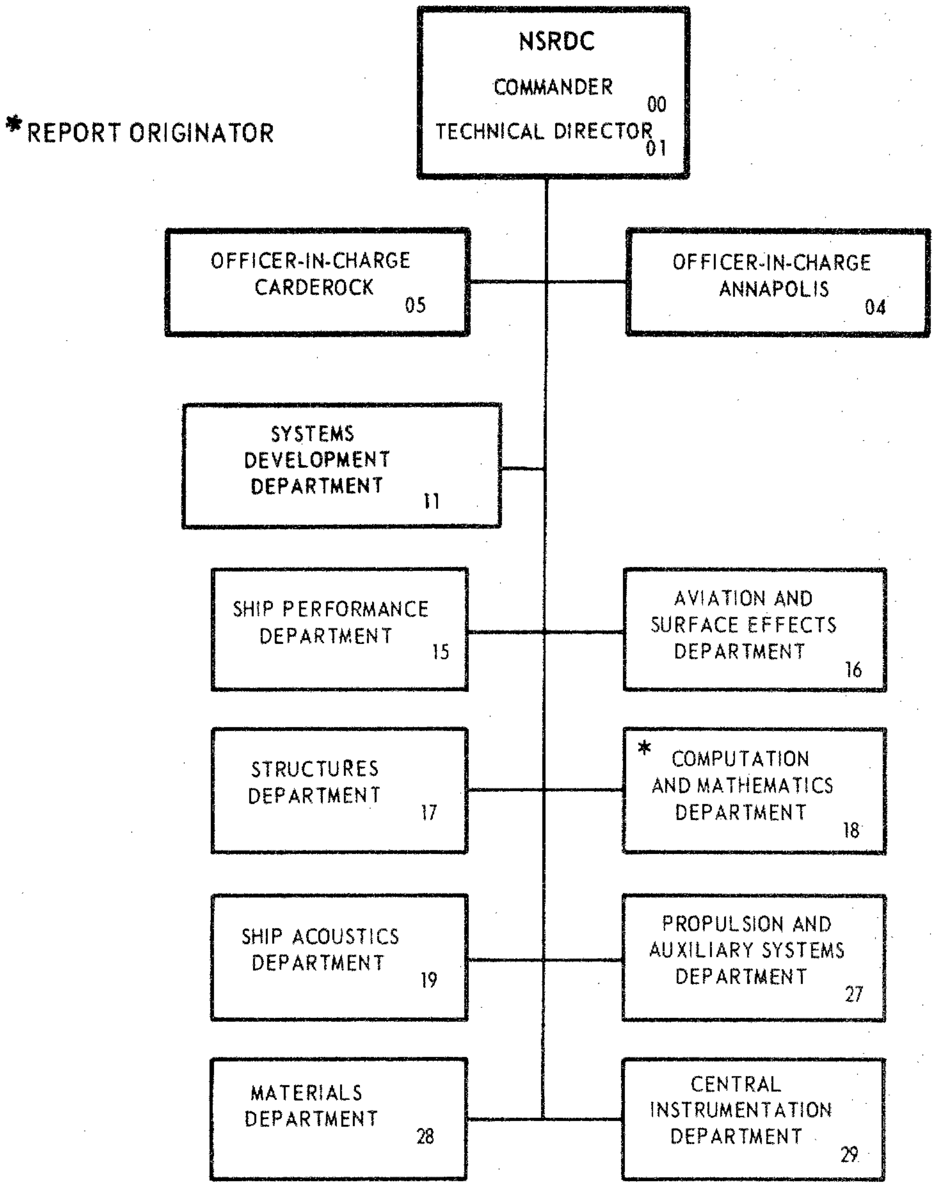

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ABSTRACT

The XYZ Potential Flow Program is a FORTRAN program which computes approximate solutions to problems of flow about three-dimensional bodies of arbitrary shape. The surface of the body is approximated by a set of plane quadrilaterals. The solution is constructed in terms of a source density on the surface of the body. The integral equation for the source density is approximated by a matrix equation on the assumption that the source density is constant in each quadrilateral. The matrix equation is solved by an iteration procedure. A problem with 500 quadrilaterals requires about 15 minutes of computer time when run with a CDC 6400 processor and costs about $50. A detailed discussion of the preparation of the input and a sample problem are included. Additional routines which compute streamlines on or off the body are described.

ADMINISTRATIVE INFORMATION

This work was sponsored by the Naval Ship Systems Command originally under Subproject SR 003 1001, Task 11572 and more recently under Subproject SF 14532 106, Task 15325.

I. INTRODUCTION

The XYZ Potential Flow Program is a computer program for the computation of irrotational, incompressible potential flow about three-dimensional bodies of arbitrary shape. This program, originally coded for the LARC computer, has been converted for use with the IBM 360-91 and the CDC 6700 computers. All the coding is in standard FORTRAN.

The method is essentially that used in the Douglas Aircraft Program[1,2]. The body surface is approximated by a set of plane quadrilaterals and the solution is constructed in terms of a source density on the surface of the body. The integral equation for the source density is approximated by a matrix equation on the assumption that the source density is constant in each quadrilateral. The source density in a quadrilateral is chosen so that the normal component of the velocity is zero at one point in the quadrilateral. The matrix equation is solved by a simultaneous displacement iteration scheme with a two-eigenvalue extrapolation procedure to speed up convergence. A problem with 500 quadrilaterals takes about 15 minutes of computer time when run with a CDC 6400 processor.

The input description was arranged to minimize the difficulty of preparing input for sequences of problems in which only part of the body is changed. Several checks are made on the input to reduce the chance that input errors will go undetected.

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[1] Hess, John L. and A.M.O. Smith, "Calculation of Non-Lifting Potential Flow About Arbitrary Three-Dimensional Bodies," Douglas Aircraft Company Report No. E.S. 40622, March 1962.

[2] Hess, John L. and A.M.O. Smith, "Calculation of Potential Flow About Arbitrary Bodies," Douglas Aircraft Company Engineering Paper 3327, published in The Pergamon Press Series "Progress in Aeronautical Science," volume 8, 1966.

There are two versions of the XYZ Potential Flow Program (XYZ PF). Version I is the standard version. Version II is a special program designed for problems with inlet pipes. Chapter IV deals with the special features of Version II. The remaining chapters have been written for Version I but generally apply to Version II as well.

II. BRIEF DESCRIPTION OF THE METHOD

The problem to be solved involves a stationary, three-dimensional body in a moving ideal fluid. The fluid is assumed to have a uniform velocity at infinity ($\vec{V}_\infty$). The velocity potential satisfies the following equations:

$$\nabla^2\varphi = 0 \qquad \text{in the fluid} \qquad (1)$$

$$\frac{\partial\varphi}{\partial n} = 0 \qquad \text{on the surface of the body} \qquad (2)$$

$$\varphi = -x \cdot V_{\infty_x} - y \cdot V_{\infty_y} - z \cdot V_{\infty_z} \qquad \text{at infinity} \qquad (3)$$

where n indicates the direction normal to the surface. A solution to these equations is constructed in the form of a source density (S) on the surface of the body,

$$\varphi(p) = \iint_{\text{Body Surface}} S(q) \frac{1}{r(p,q)} dA_q - x \cdot V_{\infty_x} - y \cdot V_{\infty_y} - z \cdot V_{\infty_z} \qquad (4)$$

where r(p, q) is the distance between the point p and the point q on the body. Note that Equations (1) and (3) are satisfied by φ as defined by Equation (4). The boundary condition on the body, Equation (2), can be applied to obtain an equation for the source density (S).

$$0 = \frac{\partial \varphi}{\partial n_p} = -2\pi S(p) + \iint_{\text{Body Surface}} S(q) \frac{\partial}{\partial n_p}\left(\frac{1}{r(p,q)}\right) dA_q$$

$$-n_{px} \cdot V_{\infty_x} - n_{py} \cdot V_{\infty_y} - n_{pz} \cdot V_{\infty_z} \tag{5}$$

Of course this equation is good only when the normal vector **n** is defined for every point on the surface. According to Hess and Smith[1], convex corners do not cause trouble in practice, but concave corners do. Thus, concave corners should be rounded. The problem of concave corners is discussed in the description of Version II in Chapter IV.

The surface of the body is approximated by a set of plane quadrilateral elements which are generated from the input. The source density is assumed to be constant in each of these elements and is computed by satisfying Equation (5) at one point in each of the quadrilaterals. The point chosen is the one at which the velocity induced by the quadrilateral itself is zero. This point is called the null point. (The centroid can also be used.) Thus, the integral Equation (5) is approximated by a matrix equation

$$S_i = \sum_j C_{ij} S_j + V_i \tag{6}$$

where $$C_{ij} = \frac{1}{2\pi} \iint_{\text{Quad. } j} \frac{\partial}{\partial n_i}\left(\frac{1}{r_{ij}}\right) dA$$

$$C_{ii} = 0 \text{, and}$$

$$V_i = -\frac{1}{2\pi}(n_x V_{\infty_x} + n_y V_{\infty_y} + n_z V_{\infty_z})$$

Equation (6) is solved for S_i by the iterative procedure described on page 6. Then the velocity components at each null point are computed from the following equations:

$$VX_i = \sum_j V1_{ij} S_j + V_{\infty_x} \tag{7}$$

$$VY_i = \sum_j V2_{ij} S_j + V_{\infty_y} \tag{8}$$

$$VZ_i = \sum_j V3_{ij} S_j + V_{\infty_z} \tag{9}$$

where

$$V1_{ij} = - \iint_{\text{Quad. } j} \frac{\partial}{\partial x} \left(\frac{1}{r_{ij}}\right) dA$$

$$V2_{ij} = - \iint_{\text{Quad. } j} \frac{\partial}{\partial y} \left(\frac{1}{r_{ij}}\right) dA, \text{ and}$$

$$V3_{ij} = - \iint_{\text{Quad. } j} \frac{\partial}{\partial z} \left(\frac{1}{r_{ij}}\right) dA$$

The pressure is then computed from the velocity.

An integral over a quadrilateral is evaluated by one of three methods, depending upon the ratio of the distance of the i^{th} point from the quadrilateral to the maximum dimension of the quadrilateral. If the ratio is greater than 4.0, the quadrilateral is approximated by a monopole (as if it were concentrated at one point). If the ratio is greater than 2.0 and less than or equal to 4.0, the quadrilateral is approximated by a quadrupole. If the ratio is less than or equal to 2.0, the integrals are evaluated exactly. The approximate methods are used because they require much less time than the exact method. The evaluation of the integrals is extensively discussed by Hess and Smith[1,2].

The velocity at points off the body is computed from the source terms (S) by equations similar to Equations (7), (8), and (9).

Points on an off-body streamline are computed by a Runge-Kutta integration with respect to time of the velocity. The velocities are computed in the same way as at other off-body points.

Points on an on-body streamline are computed by assuming that the velocity in a quadrilateral is constant and equal to that at the null point.

III. SPECIAL FEATURES AND DIFFERENCES FROM THE DOUGLAS PROGRAM

XYZ PF differs from the Douglas program in several respects. These differences and special features are:

(1) The input to XYZ PF is arranged to facilitate the preparation of input for a series of problems in which only one part of the body is changed. Also, a number of checks are made on the input to help detect errors. Details are given in the description of the input.

(2) An option was added for the recomputation of the source density and velocities for only part of the body when only small changes are made. This option also provides for the use of the solution of one problem as an initial guess for the solution of another problem.

(3) The matrix of influence coefficients is computed column by column instead of row by row. This column arrangement was used for the original LARC computer version because it required much less high-speed memory. The computation of the coefficients is also about 10% faster this way than with the row-by-row arrangement.

(4) A simultaneous displacement iterative scheme is used to solve the matrix equation for the source density. This scheme is slower than the successive displacement (Gauss-Seidel) scheme used in the Douglas program, but it can be carried out using the matrix column by column instead of row by row.

(5) When possible, an extrapolation procedure is used to reduce the number of iterations required for convergence. Assume that n iterations have been completed and let $S_i(P)$ be the source density at point P for iteration n-i. If there is only one dominant eigenvalue λ and n is sufficiently large, $S_i(P)$ may be approximated by

$$S_i(P) \approx S_f(P) + E(P)\lambda^{n-i} , \tag{10}$$

where $S_f(P)$ is the exact solution and E(P) is the eigenvector associated with λ. For $\lambda \neq 1$,

$$A\lambda + (1-A) = 0 \tag{11}$$

Now Equation (10), with i = 0, 1, 2, can be solved for a value of A at each point P.

$$A(P) = (S_1(P) - S_2(P))/D(P) \tag{12}$$

where $D(P) = S_0(P) - 2S_1(P) + S_2(P)$. Since, in general, A(P) will change from point to point, a weighted average $\overline{A}$ over all the points is used. For the weighting function the absolute value of D(P) is chosen, because D(P) may be very small or zero at points where the dominant eigenvector is very small or zero. The value of A(P) at these points may be greatly different from that at most other points. Thus, for $\overline{A}$

$$\overline{A} = \frac{\left[\sum_{P=1}^{\text{Max } P} (S_1(P) - S_2(P))(\text{Sign of } D(P))\right]}{\sum_{P=1}^{\text{Max } P} |D(P)|} \tag{13}$$

After every fifth iteration a new $\overline{A}$ is computed. If $\overline{A}$ has not changed by more than 0.02 from the last $\overline{A}$, the solution is extrapolated. The extrapolated solution $S_*(P)$ is

$$S_*(P) = \overline{A}\, S_0(P) + (1 - \overline{A})\, S_1(P) \tag{14}$$

The procedure is different when there are two dominant eigenvalues instead of only one. Then

$$S_i(P) \approx S_f(P) + E_1(P)\lambda_1^{(n-i)} + E_2(P)\lambda_2^{(n-i)} \tag{15}$$

For λ_1 and $\lambda_2 \neq 1$,

$$B_2\lambda^2 + B_1\lambda + (1 - B_1 - B_2) = 0 \tag{16}$$

which has roots λ_1 and λ_2.

The solution for B_1 and B_2 at each point P is obtained from

$$\begin{aligned}
B_1(P) = \{&[S_4(P)-S_3(P)]\,[S_4(P)-2S_2(P)+S_0(P)]-[S_4(P)-S_2(P)] \\
&[S_4(P)-S_3(P)-S_2(P)+S_1(P)]\,\}/D(P) \\
B_2(P) = \{&[S_4(P)-S_2(P)]\,[S_4(P)-2S_3(P)+S_2(P)]-[S_4(P)-S_3(P)] \\
&[S_4(P)-S_3(P)-S_2(P)+S_1(P)]\,\}/D(P) \\
D(P) = &[S_4(P)-2S_3(P)+S_2(P)+S_2(P)]\,[S_4(P)-2S_2(P)+S_0(P)] \\
&-[S_4(P)-S_3(P)-S_2(P)+S_1(P)]^2
\end{aligned} \tag{17}$$

As with A(P), a weighted average of $B_1(P)$ and $B_2(P)$ is obtained using the absolute value of D(P) for the weighting function. If the weighted averages $\overline{B}_1$ and $\overline{B}_2$ do not change from one set of five iterations to the next by more than $0.02\,(|\overline{B}_1| + |\overline{B}_2|)$, then the solution is extrapolated and

$$S_*(P) = \overline{B}_2 S_0(P) + \overline{B}_1 S_1(P) + (1-\overline{B}_1-\overline{B}_2) S_2(P) \qquad (18)$$

For many problems the dominant eigenvalues are complex and thus the solution can be extrapolated only by such a two-eigenvalue method. Extrapolation is very effective; the number of iterations is often reduced by a factor of 4.

IV. VERSION II, INLET PIPES AND CONCAVE REGIONS

Version II of XYZ PF was designed expecially for problems involving deep concave regions. For these problems Version I produces a solution with an excessive amount of leakage through the walls because the boundary condition is satisfied at only one point in each quadrilateral. Thus, if the normal component of the velocity changes with position in the quadrilateral, there may be a net flow through the quadrilateral. For most external flow problems there is not enough leakage to cause trouble. However, in problems with deep concave regions the effect is devastating. Even the external parts of the body leak as a result of the strong source on the concave part.

To eliminate this leakage, the net flow through the quadrilateral must be eliminated by setting the integral over the quadrilateral of the normal component of the velocity equal to zero. Since this integration cannot be performed analytically, a five-point quadrature formula is used. The five points are the centroid and the four surrounding points computed from weighted averages of the four corner points as shown in Equations (19).

XQ(1) = A1*XC(1) + A2*(XC(2)+XC(4)) + A3*XC(3)

XQ(2) = A1*XC(2) + A2*(XC(3)+XC(1)) + A3*XC(4)

$$XQ(3) = A1*XC(3) + A2*(XC(4)+XC(2)) + A3*XC(1)$$
$$XQ(4) = A1*XC(4) + A2*(XC(1)+XC(3)) + A3*XC(2) \quad (19)$$

where $XQ(I)$, $I = 1, 2, 3, 4$ are the quadrature points
$XC(I)$, $I = 1, 2, 3, 4$ are the corner points
$A1 = 0.736222$
$A2 = 0.105556$
$A3 = 0.052778$

The Y and Z coordinates of the quadrature points are found in a similar manner. The weights for the points are then found so that the quadrature formula will correctly compute the integrals of a constant, X, Y, X^2, and Y^2. Despite efforts to find a way of computing the quadrature points so that more functions would be correctly integrated, no method was found that would work for every quadrilateral. However, for a square this quadrature formula will correctly integrate XY, X^3, X^2Y, XY^2, Y^3, and $(X^2+Y^2)^2$.

Since the integration over the quadrilateral is not exact, there will still be some leakage, but it is usually much less than with Version I. However, unless care is used in the arrangement of the quadrilaterals, the errors may be very large. Although the choice of quadrilateral size and arrangement is still largely an art, the following rules are useful:

(1) The quadrilaterals must fit together tightly in the concave region without any gaps. Such a fit may require the use of "triangular quadrilaterals" in some places. A "triangular quadrilateral" is formed when two corner points coincide or when three corner points lie on a line.

(2) The angle formed by the normal vectors of two adjacent quadrilaterals in a concave region should not be greater than 30^o.

(3) The length of a quadrilateral in a cavity or pipe should not be greater than 1/6 of the diameter of the cavity or pipe.

V. ORGANIZATION OF THE PROGRAM

The XYZ PF program is divided into seven sections. Section 1 reads the input cards, computes the descriptive parameters for each quadrilateral, and checks for errors. Section 2 computes the matrix elements in the matrix equations for the source density and the velocity for points on the body. Section 3 solves the matrix equation for the source density. Section 4 computes and edits the velocity and pressure for points on the body. Section 5 computes the velocity and pressure at points off the body. Section 6 computes points on streamlines that do not touch the body surface. This section replaced an earlier one programmed by Jorgen Strom Tejsen. Section 7 computes points on streamlines on the body surface. Figures 1 through 7 show the flow charts for these sections. These sections are outlined on the following pages.

SECTION 1

A. Read, store, and edit the problem title and the control parameters.

B. Read the first point card and set the section indicator.

C. Store the coordinates of the point and a point indicator in four (40 by 70) arrays in the positions indicated by the M and N indices on the point card.

D. Read the next point card and check the section number against the section indicator. If they are the same, return to C. Otherwise, continue to E.

E. Set up DO loops to sweep point indicator array.

F. Have the four corner points (N, M; N, M+1; N+1, M+1; N+1, M) been specified? If not, skip to the end of the DO loops. If so, continue.

G. Fit a plane quadrilateral to the input points. Compute the normal vector, area, new corner points, second and third vectors of the quadrilateral system, centroid, and null point.

H. Store the normal vector, null point, and area in one array designated by T. Store the other quantities in a second array designated by B.

I. Test for errors in the input. One test is for large deviations of the four input points from a plane. The second is for normal vectors not pointing away from the origin. The third is for long thin quadrilaterals. If a test fails, a warning message is printed out. The solid angle subtended at the origin by the quadrilateral is computed and added to a partial sum for later testing. None of these tests will stop the program.

J. Edit and print the following information on the quadrilateral:

N and M for the first corner point

P - the number of the quadrilateral

X1, Y1, Z1 - the coordinates of the M, N input point

X2, Y2, Z2 - the coordinates of the M+1, N input point

X3, Y3, Z3 - the coordinates of the M+1, N+1 input point

X4, Y4, Z4 - the coordinates of the M, N+1 input point.

XP, YP, ZP - the coordinates of the null point.

XN, YN, ZN - the components of the normal vector.

D - the distance that the input points were moved to make a plane quadrilateral.

A - the area of the quadrilateral.

K. Test the B-array index to see if the B-array is full. If so, write out the B-array on file 4 and reset the B index. Also increment the index for the T-array.

L. End of the DO loops for sweeping the point indicator array.

M. Set the section indicator for the next section. Test for the end of the input. If there are no more sections, continue to N, otherwise return to C.

N. Test the number of quadrilaterals against the number of quadrilaterals indicated in the input. If they are different, print out an error message and stop. Test the solid angle subtended at the origin. If it is very different from both 4π and 0, print out a warning message.

O. Write the parameters and the T-array on file 3. Transfer to Section 2.

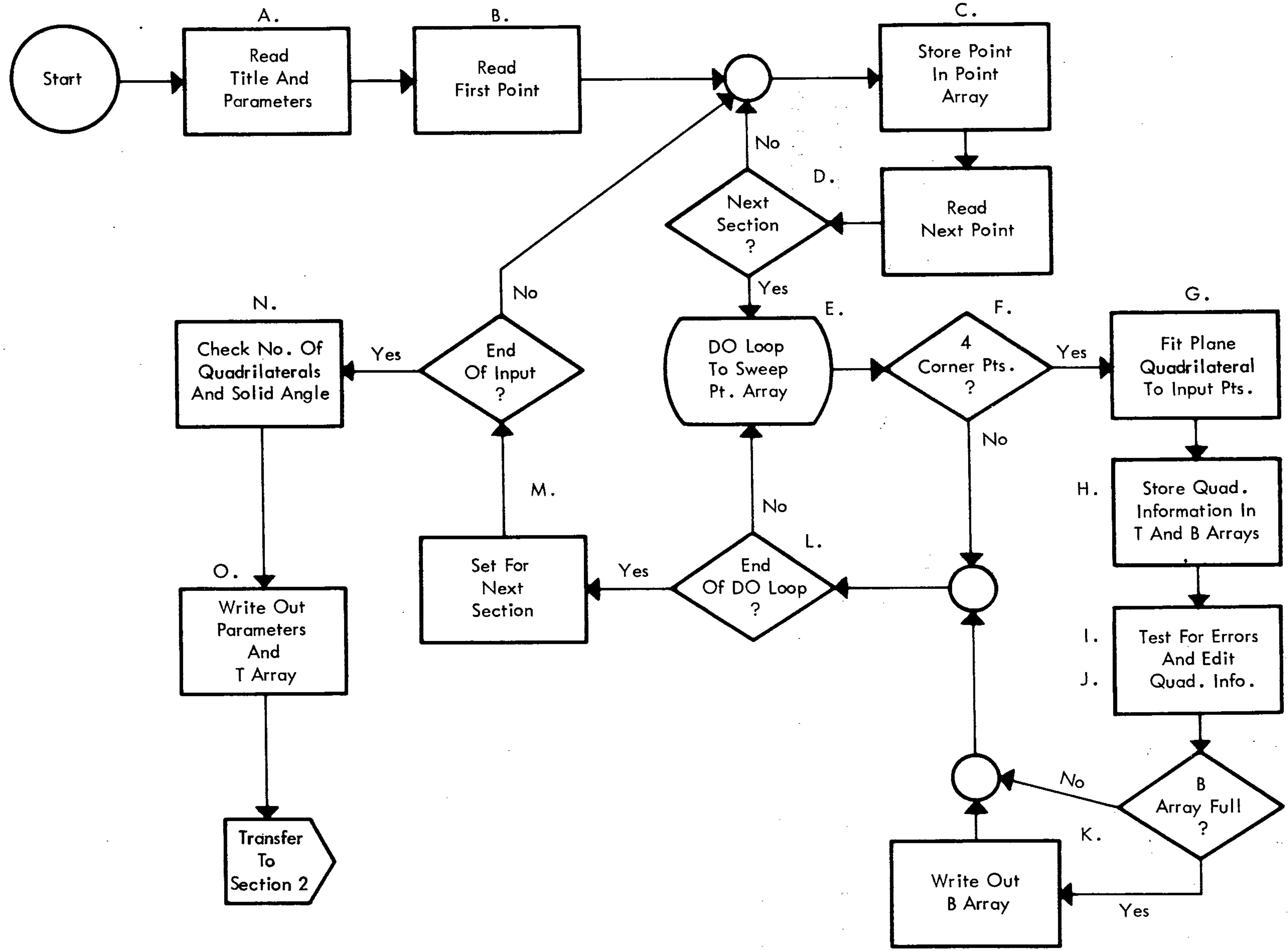


Figure 1 - Flow Chart Of Section 1

SECTION 2

A. Read the parameter block, the T-array, and the first block of the B-array.

B. Set up a loop to sweep the B- and T-arrays for all quadrilaterals.

C. Compute the lengths of the sides, the quadrupole moments, the maximum diameter of the quadrilateral, and other quantities needed for future use.

D. Set up a loop to sweep the T-array for all null points of the quadrilaterals.

E. Compute the distance between the quadrilateral selected by loop B and the null point selected by loop D. Test the ratio of this distance to the maximum diameter of the quadrilateral. If this ratio is greater than 4, transfer to H. If less than 4 and greater than 2, transfer to G; otherwise, continue.

F. Compute the matrix coefficients for the influence of the quadrilateral on the null point by the exact equations, and go to I.

G. Compute the matrix coefficients by the quadrupole equations and go to I.

H. Compute the matrix coefficients by the monopole equations.

I. If not all the reflections in planes of symmetry have been used, reflect the null point and return to step E. Otherwise, continue.

J. Add the contributions of the different reflections to obtain the composite influence coefficients.

K. Test the storage areas for the various velocity influence coefficients to see if they are full. If they are full, write out their contents.

L. Test for completion of the loop over the null points. If not completed, return to D. Otherwise, continue.

M. Read the next block of the B-array if it is needed.

N. Test for completion of the loop over the quadrilaterals. If not completed, go to B. Otherwise, continue.

O. Write out remaining coefficients.

P. Transfer to Section 3.

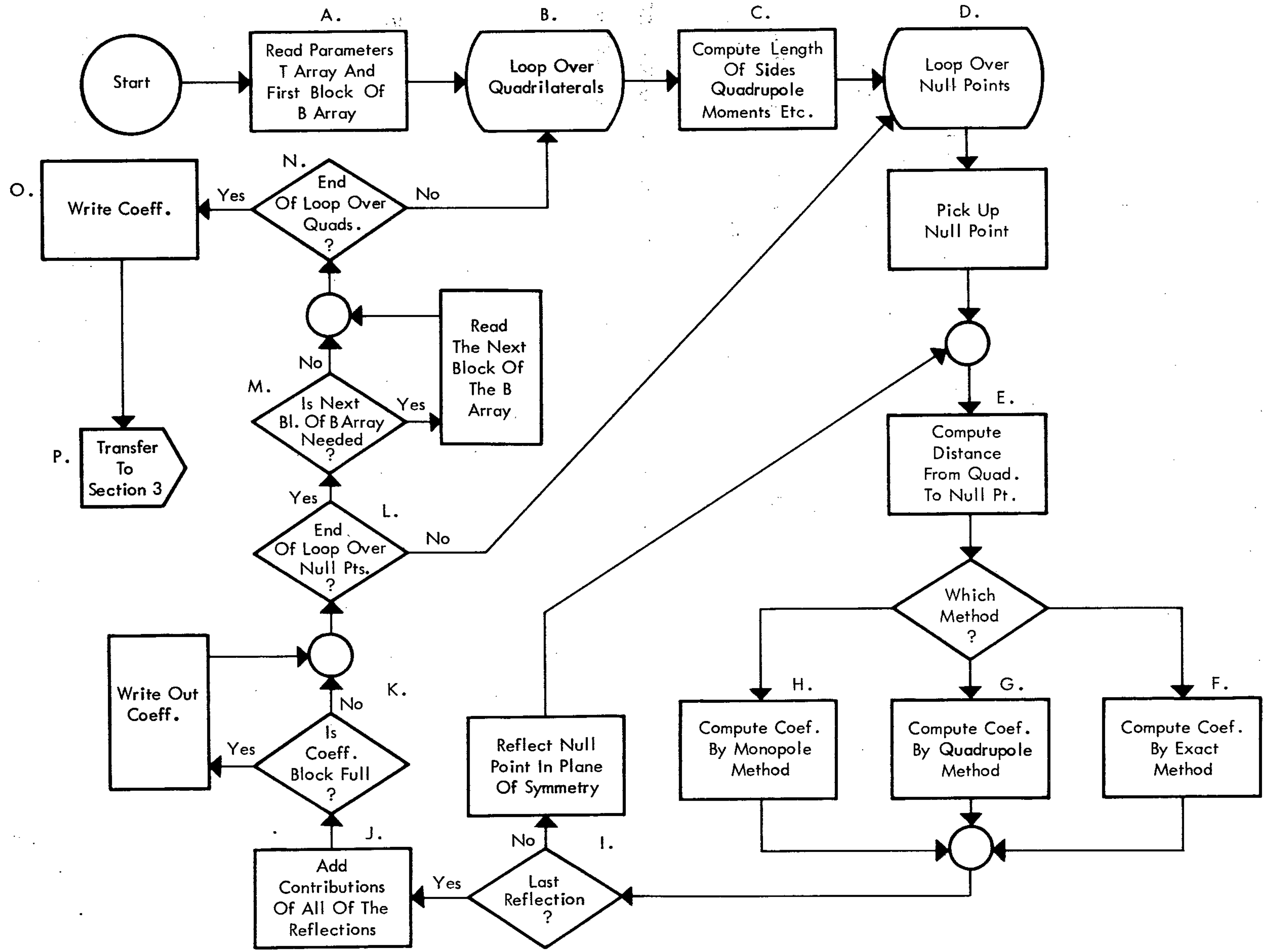


Figure 2 - Flow Chart Of Section 2

SECTION 3

A. Set the initial conditions for a flow at infinity of -1 in the x-direction.

B. Compute the initial approximation to the source density.

C. Set the partial sum vector of the induced normal velocity to zero.

D. Read the first two blocks of coefficients.

E. Set up a loop over the quadrilaterals.

F. Pick up the source for the quadrilateral.

G. Set up a loop over the null points to step five points at a time.

H. Compute new partial sums for next five null points.

I. Check for the end of the coefficient block. If the end has been reached, read the next block of coefficients.

J. Increment the index and test for the end of the loop over the null points. If the loop is completed, continue. Otherwise, return to step H.

K. Increment the indices and test for the end of the loop over the quadrilaterals. If the loop is completed, continue. Otherwise, return to step F.

L. Compute the new source density.

M. Test for convergence of the iteration scheme. If the iterations have converged, go to O. Otherwise, continue.

N. If a set of five iterations has been completed, compute $\bar{A}$, $\bar{B}_1$, $\bar{B}_2$. Otherwise, return to C.

If $\bar{A}$ has converged, perform an A extrapolation and return to C. Otherwise, continue.

If $\bar{B}_1$ and $\bar{B}_2$ have converged, perform a B extrapolation and return to C. Otherwise, just return to C.

O. Write out the source density.

P. Test for the last flow. If this was the last flow, transfer to Section 4. Otherwise, set conditions for the next flow and go to B.

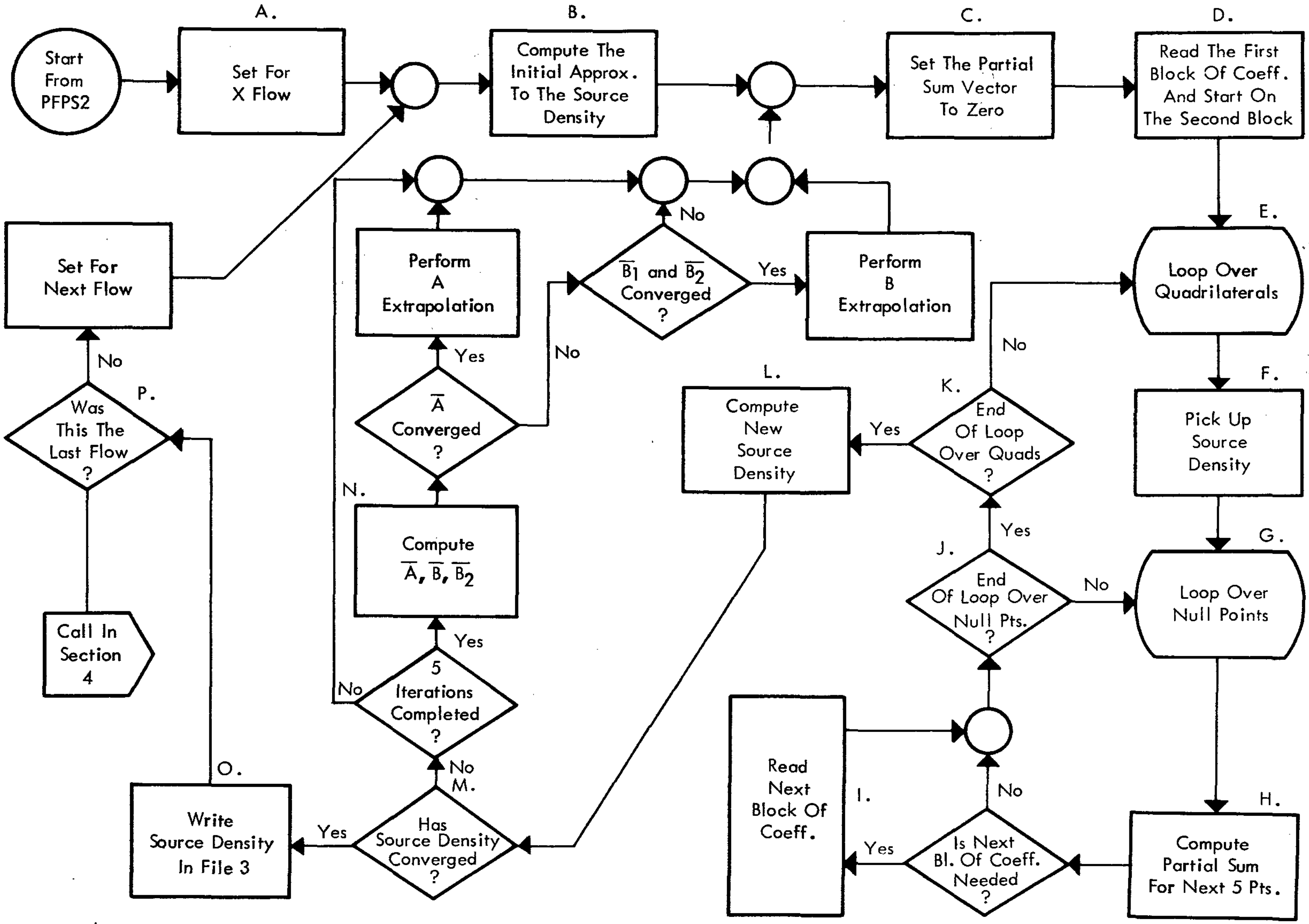


Figure 3 - Flow Chart Of Section 3

SECTION 4

A. Read the control parameters and source density from file 3.

B. Read the first block of velocity coefficients for each of the three onset flows and start reading the second block.

C. Set up a loop over the quadrilaterals.

D. Pick up the source densities for all three flows for the quadrilateral.

E. Set up a loop over the null points.

F. Compute the partial sums for the three velocity components for each flow.

G. Check to see if the next block of coefficients is needed. If it is needed, check for completion of the last tape read, and start reading the next block of coefficients.

H. Test for the end of the loop over the null points. If the loop is not finished, return to F. Otherwise, continue.

I. Test for the end of the loop over the quadrilaterals. If the loop is not finished, return to D. Otherwise, continue.

J. Compute the absolute values of the velocities and the pressures for the three flows.

K. Edit the velocities etc., and write them on the output tape.

L. Check to see if all flows have been edited; if so, stop. Otherwise, continue.

M. Compute velocity and pressure for the next flow.

N. Edit the velocity and pressure for the flow and write them on the output tape. Return to L.

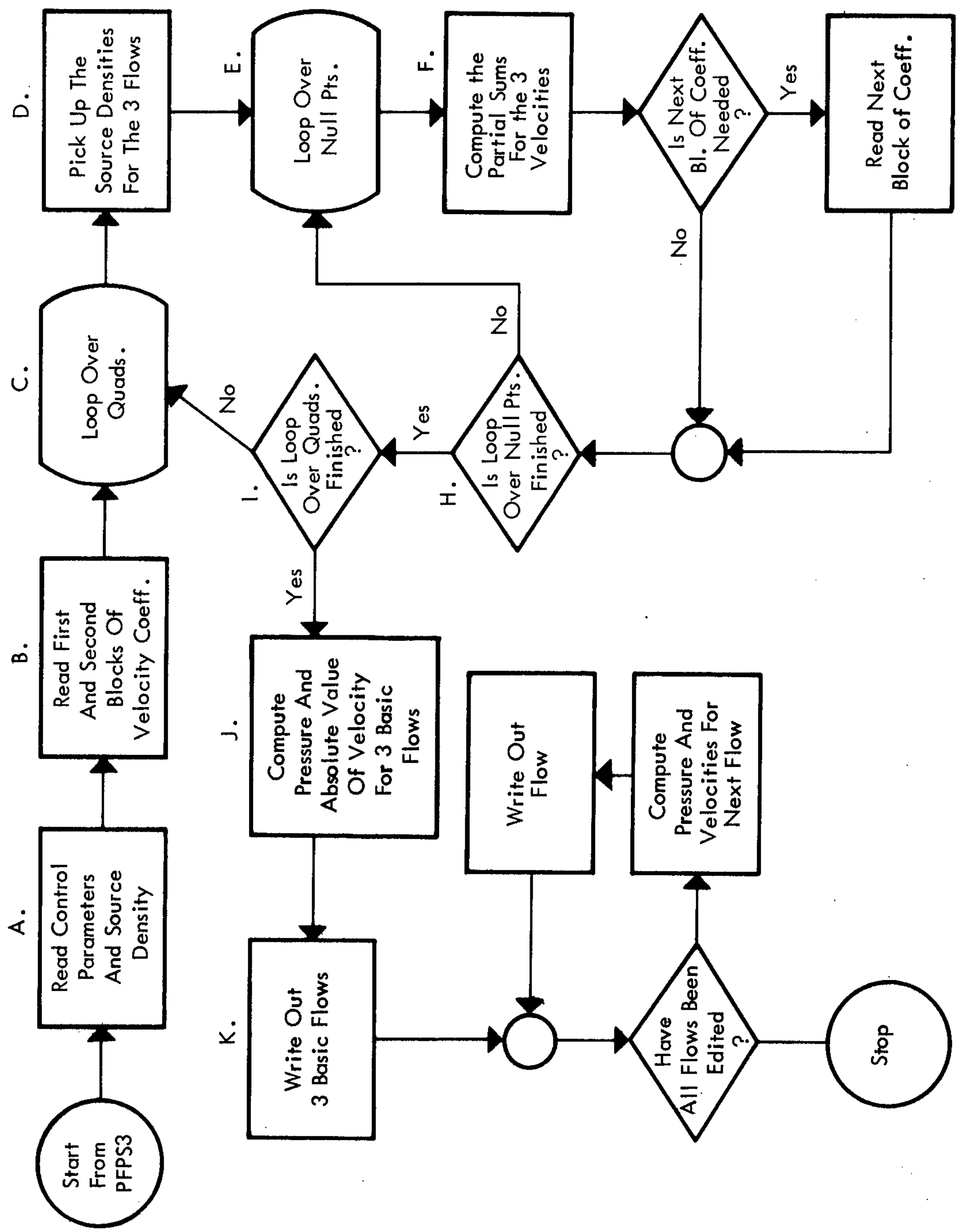


Figure 4 - Flow Chart Of Section 4

SECTION 5

A. Read the input giving the coordinates of the off-body points.

B. Read the problem identification, control parameters, null point, normal vector, area, and source densities of the quadrilaterals from file 3.

C. Read the first block of other quadrilateral information (corner points, quadrupole, moments, etc.) from file 4.

D. Set the velocity at the off-body points to the free-stream velocity.

E. Set up a loop over the quadrilaterals.

F. Pick up the three source densities and compute such coefficients as may be useful for computing the velocity induced at the off-body points by this quadrilateral.

G. Set up a loop over the off-body points.

H. Determine the method of computation to be used by computing the ratio of the radial distance between the quadrilateral and the off-body point to the length of the longer diagonal of the quadrilateral. If this ratio is greater than 4, go to K. If it is greater than 2.5 but less than 4, go to J. If it is less than 2.5, continue to I.

I. Compute the induced velocity by means of an equation derived from exact integration over a quadrilateral[1]. Then go to L.

J. Compute the induced velocity by means of an equation derived from a quadrupole expansion of the integral[1].

K. Compute the induced velocity by means of an equation derived from a monopole expansion of the integral[1].

L. Check for the last reflection in a plane of symmetry. If this was not the last reflection, reflect the point and return to H. Otherwise, continue.

M. Add the induced velocity to the velocity already computed for the point.

N. Test for completion of the loop over the off-body points. If it is not completed, return to H. Otherwise, continue.

O. If the next block of quadrilateral information (corner points, quadrupole moments, etc.) is needed, read it from file 4.

P. Test for the end of the loop over the quadrilaterals. If the loop has been completed, continue. Otherwise, return to F.

Q. Compute the pressure at each off-body point.

R. Edit and print the output.

S. Test for last flow. If the last flow has been edited, stop. Otherwise, continue.

T. Compute the velocity and pressure for this flow. Write out the edited output. Return to S.

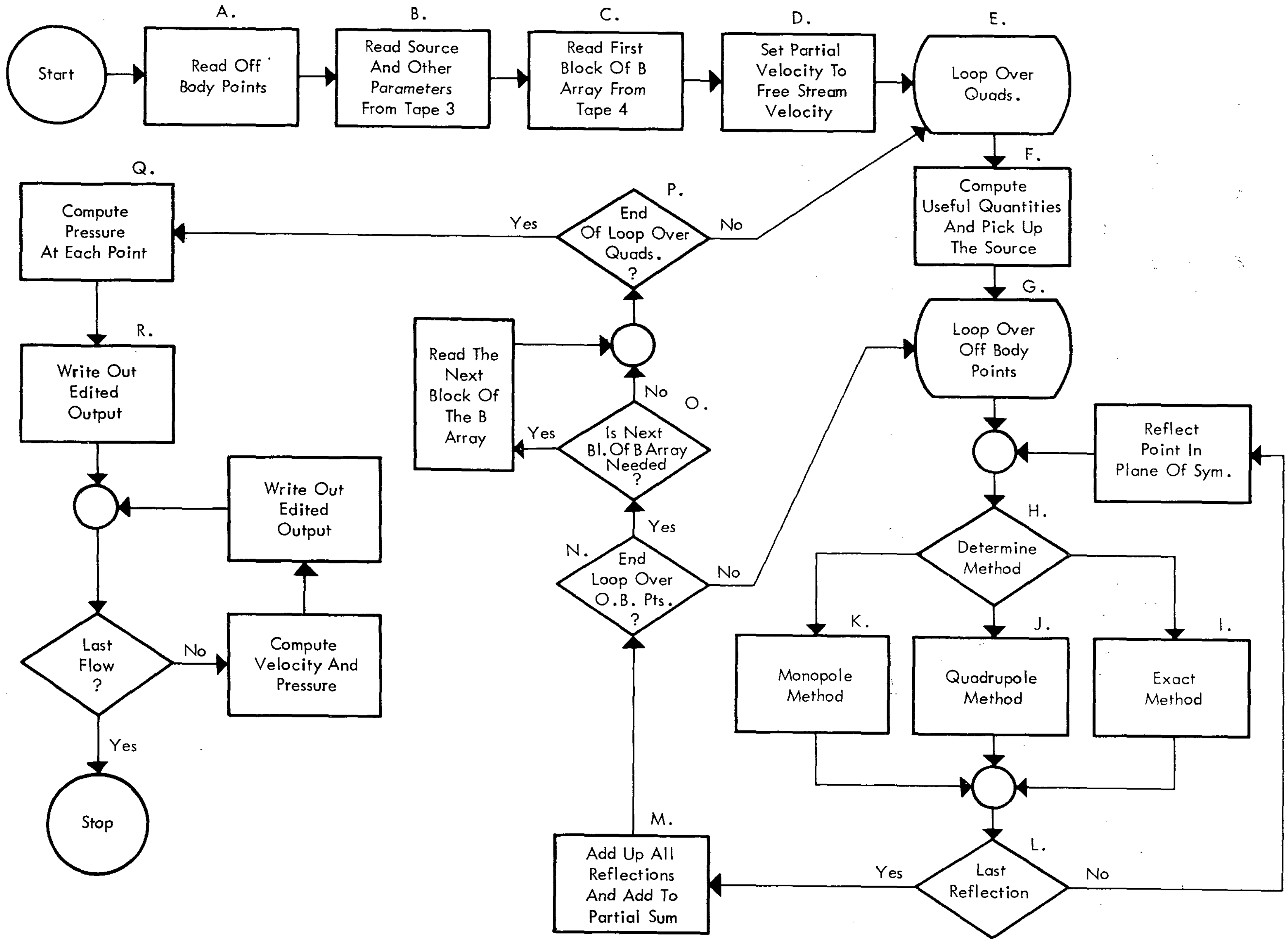


Figure 5 - Flow Chart Of Section 5

SECTION 6

A. Read the problem identification, control parameters, the T-array, and the B-array.

B. Read the input giving the number of streamlines in this group, the number of time steps to be taken along them, the length of the time step, the components of the free stream velocity, and the coordinates of the starting points.

C. Set indices for the first step of the Runge-Kutta integration of the first time step.

D. Compute the velocity at the current point of each streamline.

E. Check for the end of the Runge-Kutta integration step. If it is the end, skip to G. Otherwise, continue.

F. Compute the next point on each streamline. Return to D.

G. Edit and write out the current point and the velocity for each streamline.

H. Reset the indices for the next Runge-Kutta step.

I. Test for the last time step. If this was the last time step, continue. Otherwise, return to F.

J. Test for the last set of streamlines. If this was the last set, stop. Otherwise, return to B.

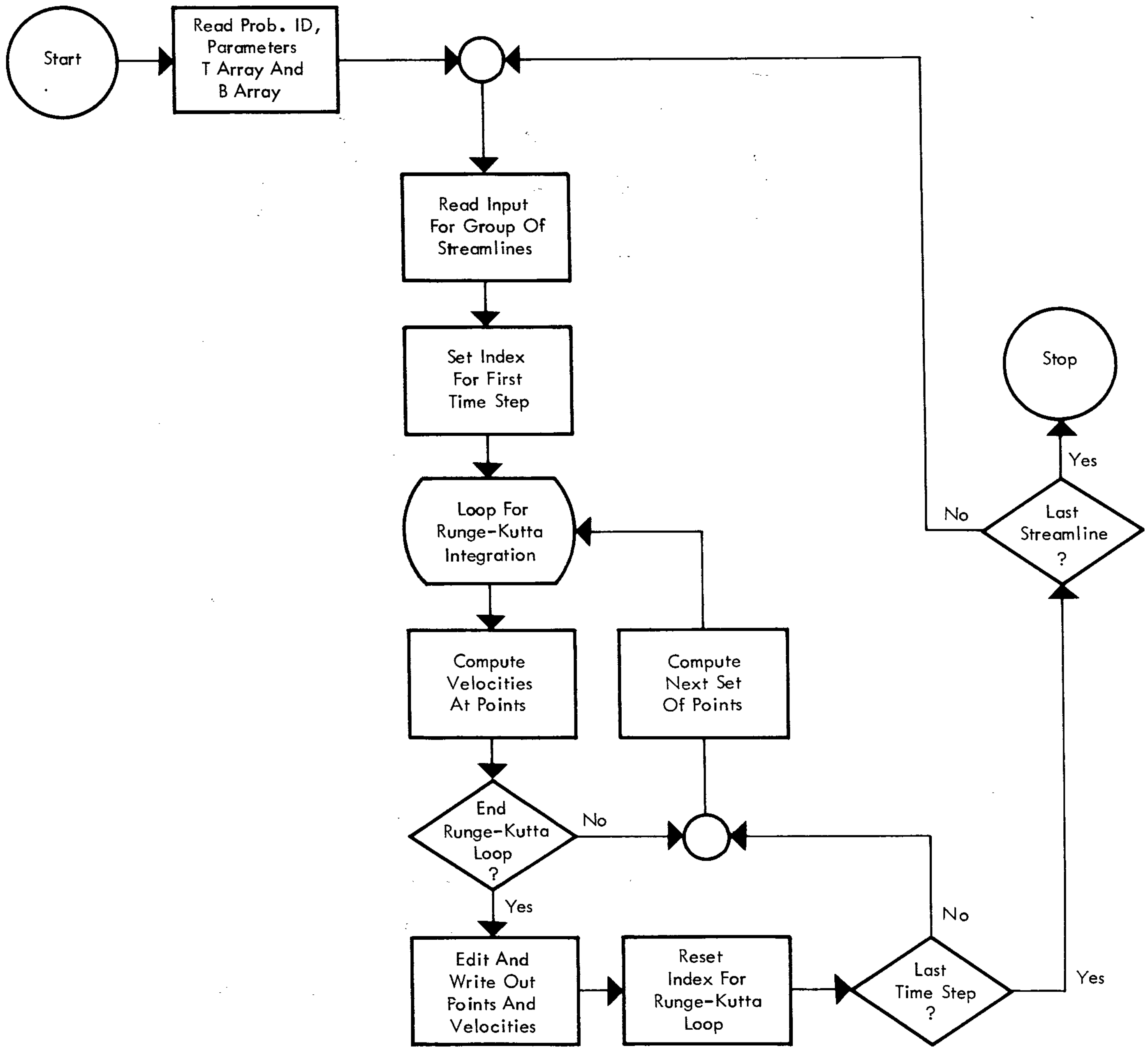


Figure 6 - Flow Chart of Section 6

SECTION 7

A. Read the quadrilateral parameters and the three basic velocity solutions from tapes 3 and 4.

B. For each quadrilateral compute the square of the radius of a circle about the centroid which encloses the quadrilateral with 10% to spare.

C. Read the number of streamlines, the numbers of the starting quadrilaterals, the coordinates of the starting points, and the velocity at infinity.

D. If the number of streamlines is zero, go to STOP. Otherwise, start the loop over the streamlines.

E. Set the direction indicator to +1 so that the streamline is traced in the direction of positive velocity.

F. Set the starting point to the projection of the specified starting point on the starting quadrilateral. Set the quadrilateral number to the starting quadrilateral number.

G. Compute the velocity at the quadrilateral. Compute values of a stream-function at each corner point. The stream-function is chosen so that it is zero at the last point of the streamline. (This can be done because the velocity is constant in the quadrilateral.)

H. For each side of the quadrilateral perform the following steps:

1. Test the side for a zero of the stream-function. If the stream-function is not zero on this side, skip to the next side.

2. Compute the coordinates of the point at which the stream-function is zero.

3. Check to see if the point is in the right direction in relation to the velocity.

4. Compute the square of the distance from the last point on the streamline to the point just computed.

If points on more than one side satisfy tests 1 and 3, take the point farthest from the last point on the streamline. If no points satisfy tests 1 and 3, skip to step M. Otherwise, continue.

I. Store the point just found as the last point on the streamline. Store the quadrilateral number as the last quadrilateral number. Set a quadrilateral index I equal to 1 and prepare to search for the next quadrilateral through which the streamline passes.

J. If I is equal to the last quadrilateral number, skip to step M. Otherwise, continue.

K. If the radial distance from the last point on the streamline to the centroid of the quadrilateral is greater than the radius of the circle enclosing the quadrilateral, skip to step M. Otherwise, continue.

L. Check to see if the last point of the streamline is close to one of the sides of the quadrilateral by comparing the sum of the distances between the last streamline point and two adjacent corner points with the length of the side. If the point is close to one of the sides, go to step G. Otherwise, continue.

M. Add one to the quadrilateral indicator I and, if I is less than or equal to the total number of quadrilaterals, return to step J. Otherwise, continue.

N. Write out the points on the streamline, and the velocity and the pressure coefficient between the points.

O. Change the sign of the direction indicator. If the sign is now positive, continue. Otherwise, return to step F.

P. End of the loop over the streamlines. If this was the last streamline, return to step C. Otherwise return to step E.

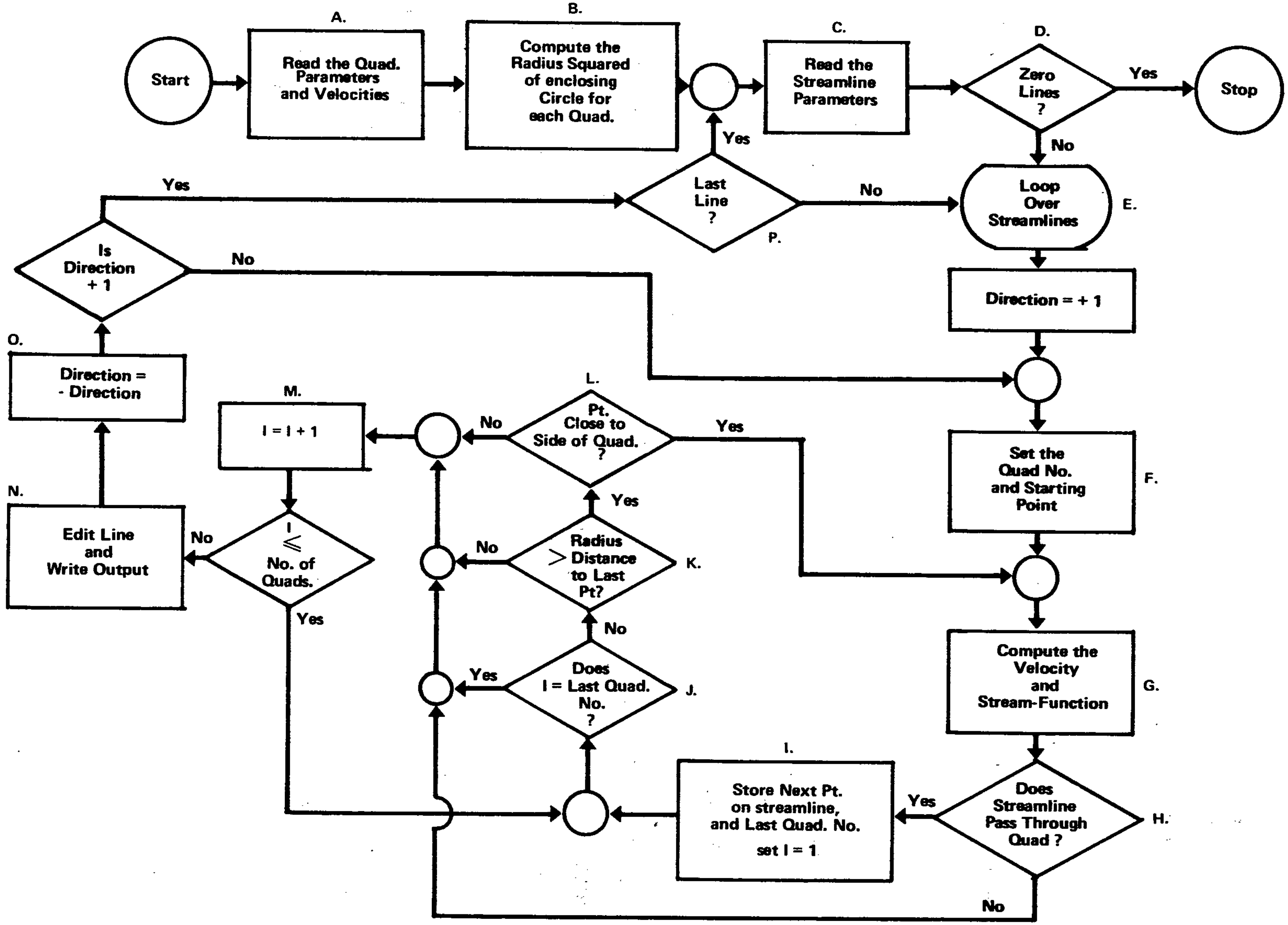


Figure 7 – Flow Chart of Section 7

VI. PREPARATION OF INPUT

DESCRIPTION OF THE BODY

The surface of the body is divided into sections. Each section is described separately from the other sections so that the description of one section can be changed without requiring changes in the descriptions of the other sections. Standard sections can thus be described and various combinations of these sections can be used in many problems with changes introduced as needed.

Each section is subdivided by two sets of lines, more or less at right angles to each other. The input consists of the X, Y, and Z coordinates of the points at the intersection of the lines and the indices N, M to indicate the lines. The indices for the lines should be chosen so that, when viewed from outside the body, N increases to the right when M increases toward the top. Any rotation of this arrangement is also permitted but a reflection will result in an inward-pointing normal vector. Of course, if a left-handed coordinate system is being used, N and M must be interchanged. See Figures 8, 9, 10 and also the sample problem sphere in Figure 11.

The plane quadrilaterals which make up the approximation to the surface are generated from the point data. A quadrilateral will be generated only when the four corner points N, M; N, M+1; N+1, M+1; and N+1, M are given. Thus, a section with a hole in it or a section with two parts can be specified. The advantage of this arrangement is that part of a body can be changed or more accurately represented without requiring that all the points be renumbered.

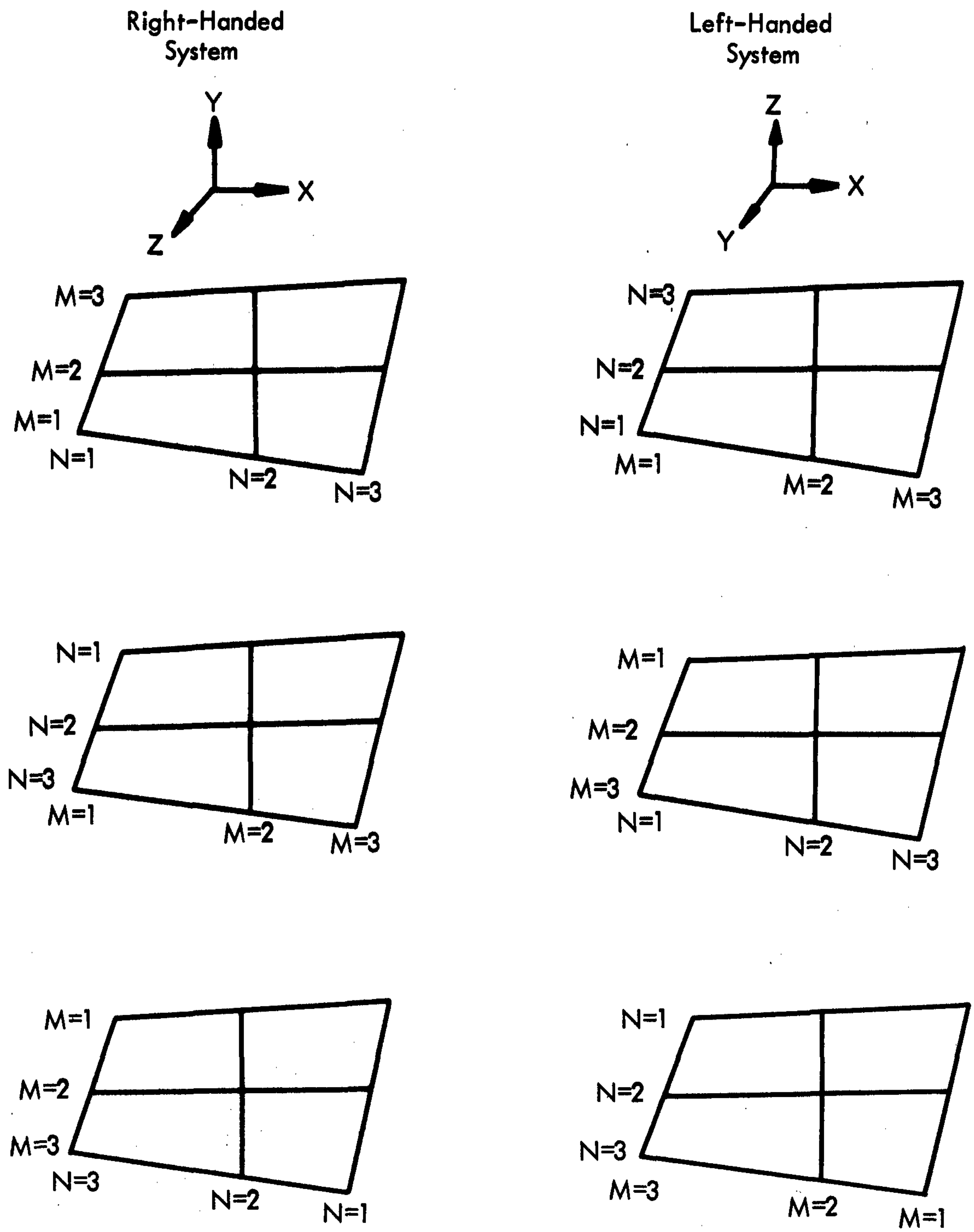
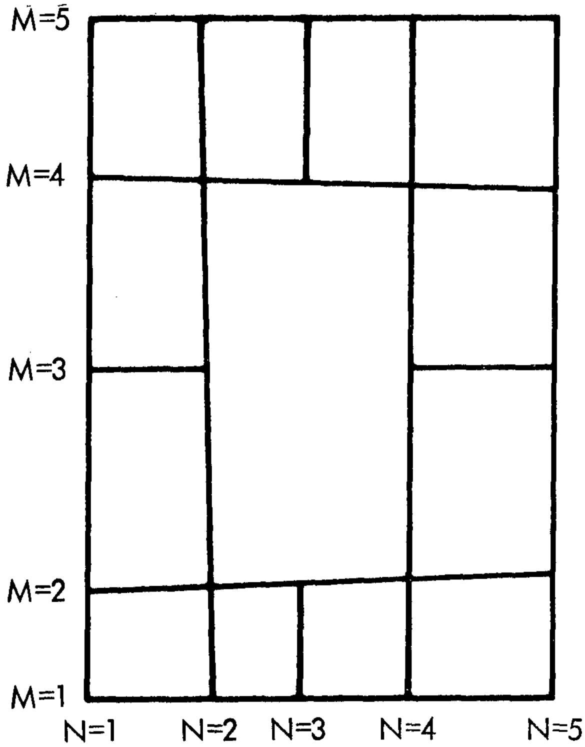
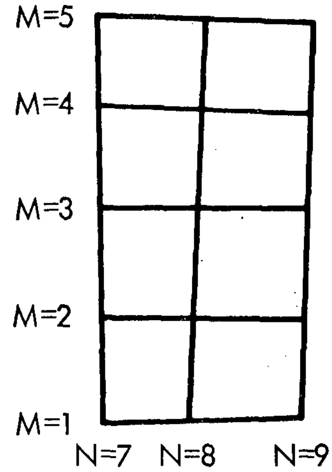


Figure 8 — Correct Indexing of Lines in Right and Left Handed Coordinate Systems



Part 1 with a hole



Part 2 to fill the hole

Figure 9 — Example of a Section in Two Parts with a Hole in One Part

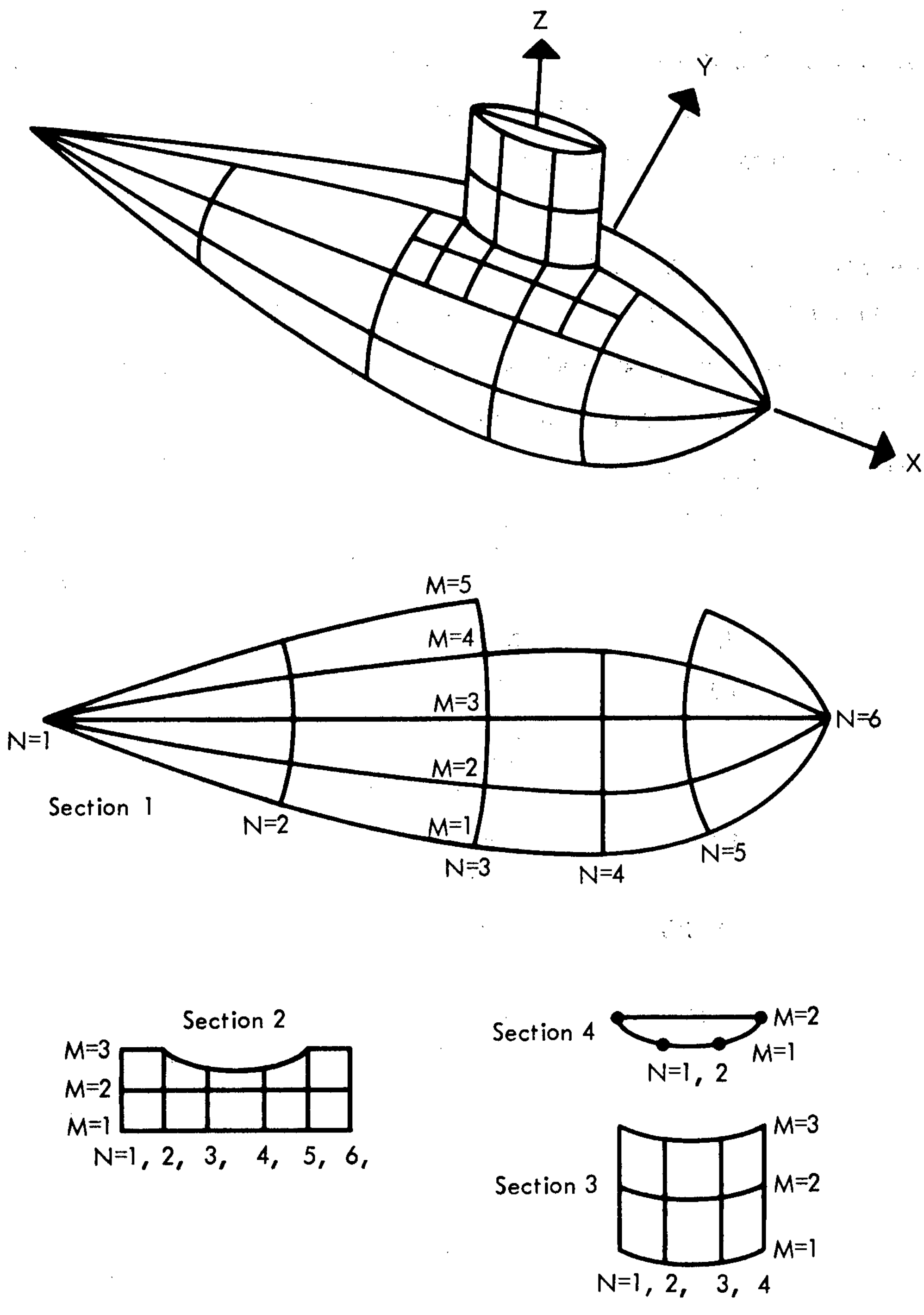


Figure 10 – Representation of a Submarine

ORGANIZATION OF THE DATA AND FORMATS OF THE CARDS

The input consists of an identification card, a parameter card, point cards, and cards for additional flows. The identification card, placed first, contains in columns 2 through 60 information to identify the problem.

The parameter card is second and contains the parameters listed below. The FORTRAN format for this card is (6I4, F8.4, 3I4). All integers must be right justified as blank columns are interpreted as zeros. Other numbers must include a decimal point.

Parameter	Column	Description
NQE	2-4	Number of quadrilateral elements to be specified by the point cards. The maximum value permitted for NQE is 650.
NSE	6-8	Number of sections used.
MIX	10-12	Maximum number of iterations to be performed for the X flow. A smaller number of iterations will be performed if the convergence test is passed.
MIY	14-16	Maximum number of iterations for the Y flow.
MIZ	18-20	Maximum number of iterations for the Z flow.
ISM	24	Number of planes of symmetry 0 indicates there are no planes of symmetry 1 indicates that Y=0 is a plane of symmetry 2 indicates that Y=0 and Z=0 are planes of symmetry 3 indicates that Y=0, Z=0 and X=0 are planes of symmetry
EPS	25-32	Convergence criteria used in testing the convergence of the iterations.

Parameter	Column	Description
IUCT	36	Centroid indicator. If IUCT > 0, the centroid is used in place of the null point. If IUCT is blank or zero the null point is used.
IPS IPF	38-40 42-44	Quadrilateral numbers used when small changes are being made in a previous problem. The values of IPS and IPF are obtained from the edit of the previous problem. New values of the source density are computed for the quadrilaterals IPS through IPF. The values of the source density from the previous problem are used for the values of the source density not computed and as an initial guess for the values of the source density being computed. The new problem may have a greater or lesser number of quadrilaterals than the previous problem only when the part being changed is at the end of the input. When there is no previous problem, IPS and IPF should be left blank.
ISP	47-48	Option indicator for SECTION 1. +1 stops the problem at the end of SECTION 1 so that any input errors can be found and corrected with a minimum use of computer time. 0 indicates a normal run. -1 blocks the writing of file 3. It is used for restarting a problem when file 4 must be regenerated but not file 3.

Each point card contains the following information for one point on the body surface. The FORTRAN format for this card is (3F12.5, 4I4, F12.5).

XI	1-12	X-coordinate of the point.
YI	13-24	Y-coordinate of the point.

Parameter	Column	Description
ZI	25-36	Z-coordinate of the point.
NI	39-40	N index of the point. NI < 71
MI	43-44	M index of the point. MI < 41
NS	45-48	Section identification number. Any positive integer from 1 to 9999 may be used. In general each section should have a unique section number. However, two sections can have the same number if they are separated by another section.
NE	52	Change indicator for the direction of the normal vector. When NE on the first card of a section is not blank or zero, NI and MI are interchanged for that section to change the direction of the normal vector. On other cards NE is ignored.
VN	53-64	Normal component of the velocity at the body surface. Usually blank or zero. For bodies with inlet pipes however, a nonzero VN is desirable on some sections. The value of VN from the first card in a section is used for the entire section.

All point cards for one section must be together, but within the section they may be in any order.

Cards for additional flows to be edited follow the last point card for the last section. A maximum of 18 flows may be edited. The FORTRAN format for these cards is (3F12.5). On each card are specified the three components of the free stream velocity for one flow as follows:

VXI	1-12	X-component
VYI	13-24	Y-component
VZI	25-36	Z-component

A blank card must follow the last flow card.

OFF-BODY POINTS

Computation of the velocity and pressure at points not on the body is carried out separately from that for the points on the body. This arrangement was convenient for the programming and also allows computation of the velocity and pressure at additional off-body points at any time, provided that files 3 and 4 from Sections 1 through 3 have been saved. File 4 may be easily regenerated by rerunning Section 1.

The first card of the input contains the number of off-body points in columns 2-4. (FORTRAN format (I4)).

Each of the remaining cards contains the X, Y, Z coordinates of one off-body point, the X-coordinate in columns 1-12, the Y-coordinate in columns 13-24, and the Z-coordinate in columns 25-36. (FORTRAN format (3F12.5)). A maximum of 500 off-body points may be specified.

STREAMLINES

Off-body streamlines are computed by SECTION 6. Files 3 and 4 from SECTIONS 1 through 3 are required just as they are for SECTION 5. The following input is required for each set of off-body streamlines:

The first card contains the following quantities in a FORTRAN format (3I4, 4F12.5).

NOBP	2-4	Number of streamlines in this set of streamlines. The maximum number is 100.
NST	5-8	Number of time steps to be taken. The slowness of the computation is the only limitation on NST.
IEND	12	Indicator to signal the last set of streamlines. When IEND is blank or zero, another set of streamlines will be expected. When IEND is 1, this set will be the last.

DT	13-24	Time step; may be positive or negative, depending on the direction in which the streamlines are to be traced.
VXI	25-36	X-component of the free stream velocity.
VYI	37-48	Y-component of the free stream velocity.
VZI	49-60	Z-component of the free stream velocity.

Each remaining card in the set contains the X, Y, Z coordinates of the starting point for one of the streamlines. The X-coordinate is in columns 1-12, the Y-coordinate in columns 13-24, and the Z-coordinate in columns 25-36. (FORTRAN format (3F12.5)).

On-body streamlines are computed by SECTION 7. File 3 from SECTIONS 1 through 4 is required. The following input is required for each set of streamlines. The FORTRAN format for each card of this input is (3F12.4, I4).

The first card for a set of streamlines contains the components of the free stream velocity (VXI in columns 1-12, VYI in columns 13-24, VZI in columns 25-36) and the number of streamlines in the set NLIN in columns 39 and 40.

The remaining cards in the set contain the coordinates of the starting point (X in columns 1-12, Y in columns 13-24, and Z in columns 25-36) and the quadrilateral number of the starting quadrilateral (NSP in columns 37-40). The quadrilateral number is the value of P in the output from SECTION 1. (See page 12.)

A blank card must follow the last set of streamlines.

CHECKS MADE ON THE INPUT

SECTION 1 of XYZ PF makes several checks on the input while it constructs the plane quadrilateral elements used to approximate the body. These checks are:

1. LARGE D. Since four points do not generally lie in a plane, it is necessary to move the corner points a distance D in constructing the plane quadrilateral. If D squared is more than .002 times the area of the quadrilateral, a warning message is printed out. This test helps in detecting keypunching errors in the point cards. However, a quadrilateral may sometimes fail this test when there is no error in the input, so the test does not stop the program.

2. INWARD NORMAL. To obtain the proper solution, it is necessary to have the normal vectors pointing outward from the body. Most (but not all) outward pointing vectors will also point away from the origin. A check is made for normal vectors pointing toward the origin and a warning message is printed out if a normal vector points toward the origin. This test will not stop the program.

3. LONG THIN QUAD. Long thin quadrilaterals can result from a point that is out of position but is in the plane of the quadrilateral. To detect such points, a check is made of the ratio of the square of the circumference to the area of each quadrilateral. If this ratio is greater than 36 (as for a rectangle 7 units long and 1 unit wide), a warning message is printed out. This test will not stop the program.

4. CROSSED QUADRILATERAL. This message is printed when the diagonals of the quadrilateral do not cross. This test stops the program at the end of SECTION 1.

5. NUMBER OF QUADRILATERALS. A check is made of the number of quadrilaterals generated from the input against the number specified by NQE. If they are different, an error message is printed and the program stops.

6. SOLID ANGLE. The surface of any body that encloses the origin will subtend a solid angle of 4π. If the body does not enclose the origin, the solid angle will be 0. The solid angle is computed and, if it differs from 4π or 0 by more than .05, a warning message is printed out. The calculation of the solid angle is fairly crude so that a problem may fail this test even if there is no error in the input, especially if the body is crudely represented or if the surface passes close to the origin. This test will not stop the program.

EXAMPLE OF INPUT

The input for a sample problem of flow around a sphere is given here to clarify the description on the preceding pages. To save space very few quadrilaterals were used in this problem.

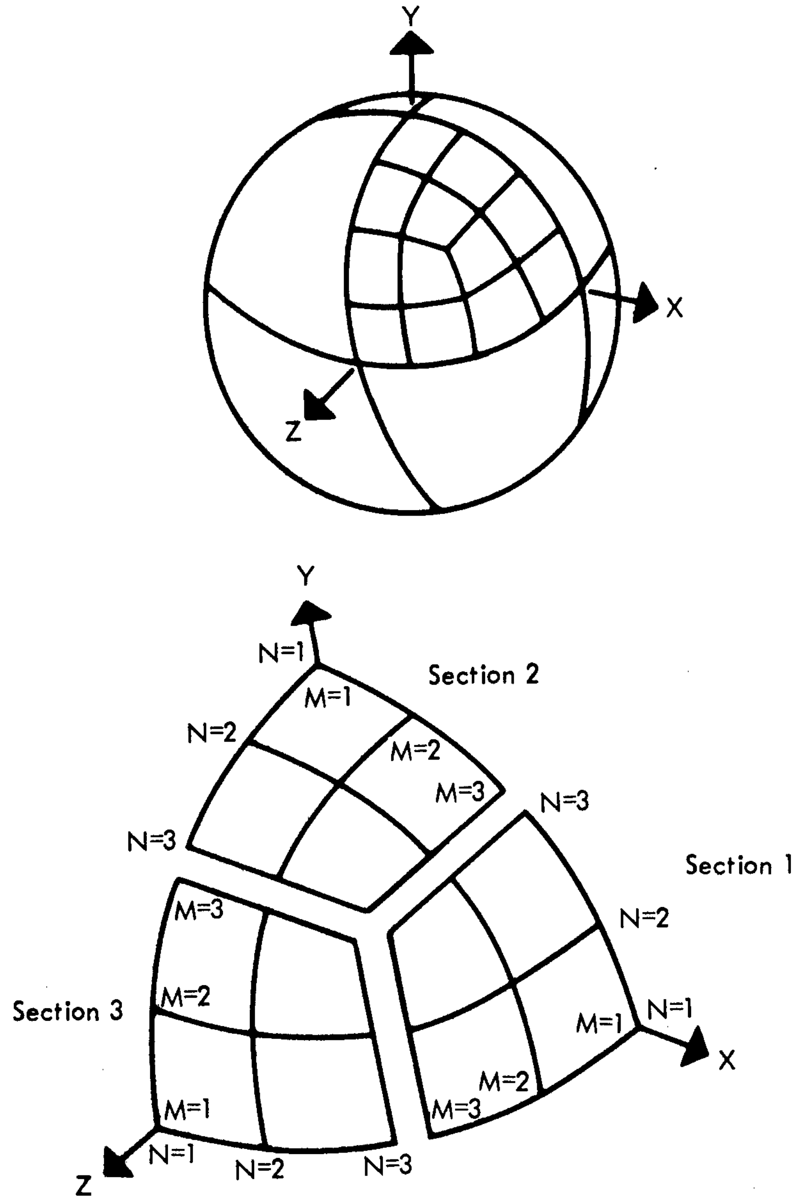


Figure 11 — Representation of a Sphere

TABLE 1

Table of Input for Sample Problem Sphere

Cols 1–12	Cols 13–24	Cols 25–36	Cols 37–40	Cols 41–44	Cols 45–48	Cols 49–64
SAMPLE	PROBLEM	SPHERE				
12 3 150	150 150 3	.0001				
1.0	.0	.0	1	1	1	
.92388	.0	.38268	1	2	1	
.70711	.0	.70711	1	3	1	
.92388	.38268	.0	2	1	1	
.88808	.32504	.32504	2	2	1	
.67383	.30320	.67383	2	3	1	
.70711	.70711	.0	3	1	1	
.67383	.67383	.30320	3	2	1	
.57735	.57735	.57735	3	3	1	
.0	1.0	.0	1	1	2	
.38268	.92388	.0	1	2	2	
.70711	.70711	.0	1	3	2	
.0	.92388	.38268	2	1	2	
.32504	.88808	.32504	2	2	2	
.67383	.67383	.30320	2	3	2	
.0	.70711	.70711	3	1	2	
.30320	.67383	.67383	3	2	2	
.57735	.57735	.57735	3	3	2	
.0	.0	1.0	1	1	3	
.0	.38268	.92388	1	2	3	
.0	.70711	.70711	1	3	3	
.38268	.0	.92388	2	1	3	
.32504	.32504	.88808	2	2	3	

TABLE 1 continued

.30320	.67383	.67383	2	3	3
.70711	.0	.70711	3	1	3
.67383	.30320	.67383	3	2	3
.57735	.57735	.57735	3	3	3
.57735	.57735	.57735			
.70711	.0	.70711			
					BLANK CARD
END OF RECORD					
4					
.999	.888	.777			OFF BODY PTS.
15.0	.0	-1.0			
-2.0	3.0	.0			
.0	.0	2.0			
END OF RECORD					
3 4 0	.15000	.70711	.0		.70711
.00	1.0	1.0			
1.0	1.0	.0			STREAMLINES
1.0	.0	1.0			
3 4 1	-.15	.70711	.0		.70711
.0	1.0	1.0			
1.0	1.0	.0			
1.0	.0	1.0			
END OF RECORD					
END OF FILE					

VII. OUTPUT

The edited output includes the following information: (See Appendix A for a sample of edited output.)

1. The problem identification and information from the parameter card.

2. Information on each of the quadrilaterals specified by the input. This includes

   a. Warning messages about possible errors.

   b. M, N - the indices for the first corner point.

   c. P - the quadrilateral number in the total array of quadrilaterals.

   d. X1, Y1, Z1 - the coordinates given for the first corner point. (Point M, N).

   e. X2, Y2, Z2 - the coordinates given for the second corner point. (Point M+1, N).

   f. X3, Y3, Z3 - the coordinates given for the third corner point. (Point M+1, N+1).

   g. X4, Y4, Z4 - the coordinates given for the fourth corner point. (Point M, N+1).

   h. XP, YP, ZP - the coordinates computed for the null point.

   i. XN, YN, ZN - the components of the normal vector.

   j. D - the distance the corner points must be moved to make them all lie in the same plane.

   k. A - the area of the quadrilateral.

3. Information about the convergence of the iterations for computing the source density. This information includes

a. The sum of the absolute values of the changes in the source density from the last iteration.

b. $\overline{A}$, $\overline{B}_1$, and $\overline{B}_2$ - the extrapolation coefficients computed from the last five iterations. (Once every five iterations.)

c. A message indicating extrapolation has been performed.

4. The edit of the final solution includes, for each of the three basic flows,

a. The point number - the same number as the P in Part 2.c of the output.

b. X, Y, Z - the coordinates of the null point.

c. VX, VY, VZ - the components of the velocity at the null point.

d. ABS · V - the absolute value of the velocity.

e. CP - the pressure coefficient, $CP = 1 - V^2/V_\infty^2$.

f. The source density.

g. The normal component of the velocity.

5. The edit of the solution for each additional flow includes the same items as for the three basic flows except that items f. and g. are omitted.

6. The edited output for the off-body points includes, for each basic flow and for each additional flow,

a. X, Y, Z - the coordinates of the point.

b. VX, VY, VZ - the components of the velocity.

c. ABS · V - the absolute value of the velocity.

d. CP - the pressure coefficient.

7. The edited output for each off-body streamline includes the coordinates of the points and the components of the velocities for the

streamline at each time step.

8. The edited output for each on-body streamline includes the coordinates of points on the streamline plus the components of the velocity and the pressure coefficients between these points.

VIII. OPERATING INSTRUCTIONS

COMPUTER REQUIREMENTS

The XYZ Potential Flow Program is designed to run on the CDC 6700 computer and uses about 50,000 words of computer memory and about 6,000,000 words of mass storage. The program should be compiled and stored on a permanent disc file. To prepare the control cards necessary to run the program the user must be familiar with the NSRDC CDC 6700 computer system.

STANDARD OPERATION

For a standard run the program is set up as shown in Figure 11 and Appendix A. Note that file 3 (TAPE03) and file 4 (TAPE04) are saved on permanent disc files for use in subsequent runs. These permanent files must be purged when they are no longer needed. File 01 uses a scratch tape rather than a disc to avoid exceeding the maximum allowable disc storage. For small problems (under 500 quadrilaterals) file 01 could be a scratch disc.

RERUNNING SECTIONS 5, 6 AND 7

SECTION 5 can be rerun at any time, provided that files 3 and 4 from SECTIONS 1 through 3 have been saved. If file 4 has not been saved, it can be easily generated by rerunning SECTION 1 with ISP set to -1 (see page 35). SECTION 6 or SECTION 7 can be rerun for

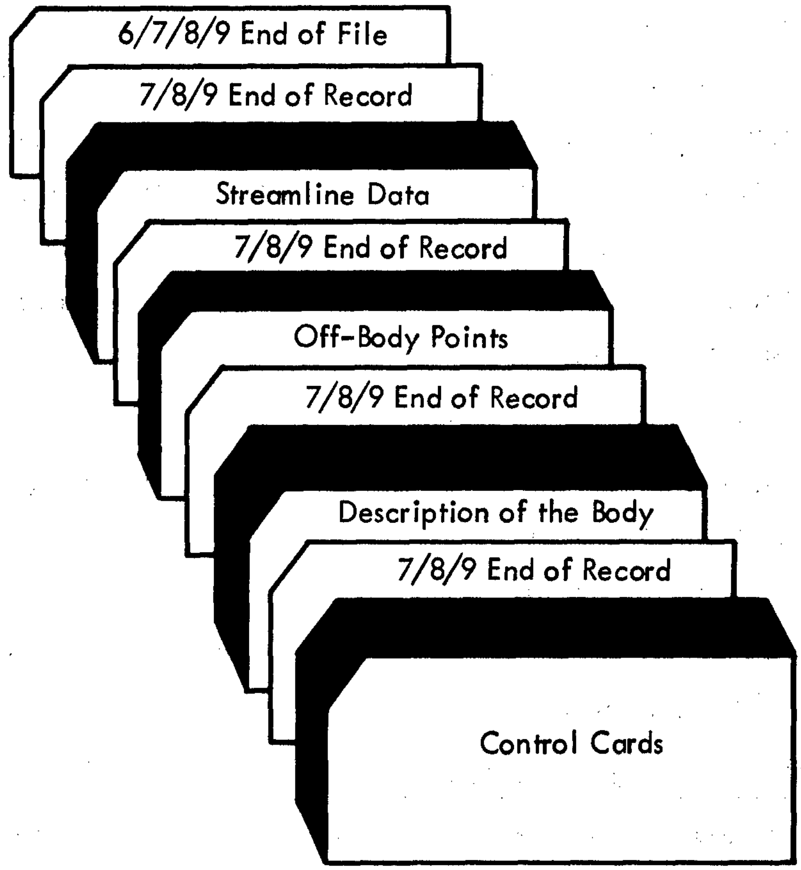


Figure 12 – Deck Setup for Standard Run

additional streamlines by using a similar deck setup. The deck setup for a rerun of SECTIONS 5, 6, and 7 is shown in Appendix C.

RERUNNING A PROBLEM WITH SMALL CHANGES

When a number of very similar problems are to be solved, it may be desirable to solve for the flow over the entire body only once and then to assume this solution for most of the body and obtain a new solution only in the region containing the part that was changed. (See page 35 for changes in the input.) The setup for such problems is the same as for a standard run except that file 3 (TAPE03) of the original problem is mounted as file 12 (TAPE12).

STOPPING AT THE END OF SECTION 1

For large problems where the probability of at least one error in the input is high, it is advisable to stop at the end of SECTION 1 and examine the edit of the quadrilaterals. A 1 in column 48 of the parameter card will cause the program to stop at this point. (See section on input, page 35.)

ESTIMATING COMPUTER TIME

The computer time required to solve a problem will depend on the number of quadrilaterals used to represent the body and to a lesser extent on the number of planes of symmetry and the shape of the body. An estimate of the computer time required for SECTIONS 1 through 4 as a function of the number of quadrilaterals is given by Figure 13. Most of this time is spent in SECTIONS 2 and 3.

The CDC 6700 computer at the Naval Ship Research and Development Center has a 6400 Processor and a 6600 Processor. The 6600 Processor is about three times faster than the 6400 Processor. To simplify the bookkeeping, all times are given in equivalent 6400

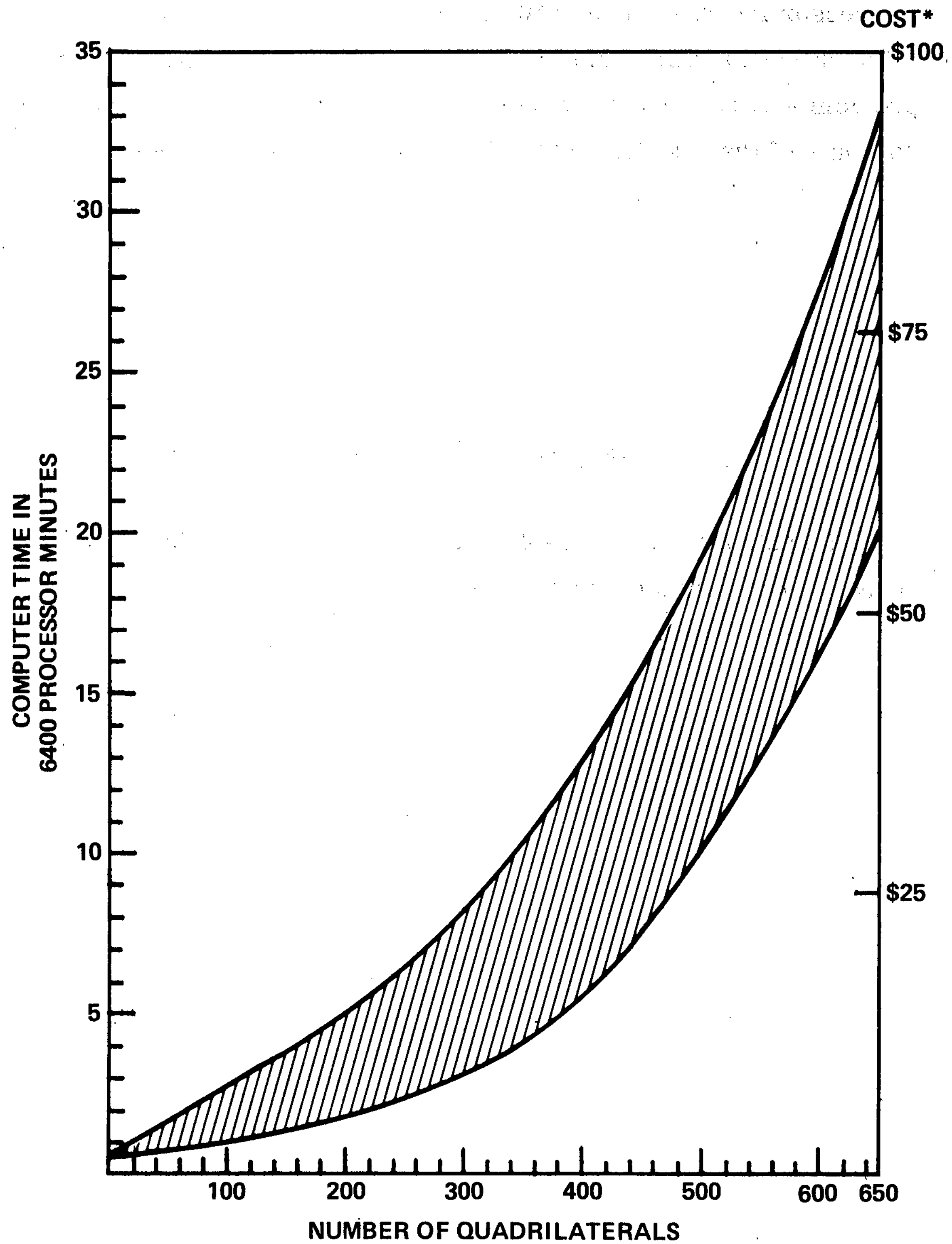


Figure 13 – Estimate of Computer Time and Cost for Version I

*Based on the low priority rates for the CDC 6700 at NSRDC as of March 1972.

Processor minutes. (One 6600 Processor minute equals three 6400 Processor minutes.) The cost algorithm was designed so that a problem will cost about the same amount with either Processor. An estimate of the cost for SECTIONS 1 through 4 is also given in Figure 13.

ACKNOWLEDGMENT

The authors wish to thank Mr. Curtis Ash for his help with the numerical experiments that led to Version II.

APPENDIX A

DECK SETUP FOR A STANDARD RUN OF SAMPLE PROBLEM SPHERE

```
JOBNAME,CM130000,T400,P2.                      * USERS JOB CARD *
CHARGE,CXXX,PPPPPPPPP,CC,B.                    * USERS CHARGE CARD *
REQUEST,TAPE03,*PF.
REQUEST,TAPE04,*PF.
ATTACH(PF1,CXXXPF101)     * CXXX IS USERS ID *
ATTACH(PF2,CXXXPF201)
ATTACH(PF3,CXXXPF301)
ATTACH(PF4,CXXXPF401)
ATTACH(PF5,CXXXPF501)     * PPPPPPPPP IS USERS JOB NUMBER *
ATTACH(PF6,CXXXPF601)
ATTACH(PF7,CXXXPF701)
RFL,65000.
SETCORE(INDEF,ADDR)
PF1.     VERSION 1
RFL,75000.
SETCORE(INDEF,ADDR)
PF2.     VERSION 1
RFL,55000.
SETCORE(INDEF,ADDR)
PF3.     VERSION 1
RFL,65000.
SETCORE(INDEF,ADDR)
PF4.     VERSION 1
CATALOG(TAPE03,CXXXT03,ID=PPPPPPPPP)
CATALOG(TAPE04,CXXXT04,ID=PPPPPPPPP)
RFL,65000.
SETCORE(INDEF,ADDR)
PF5.     VERSION 1
RFL,75000.
SETCORE(INDEF,ADDR)
PF6.     VERSION 1
RFL,130000.
SETCORE(INDEF,ADDR)
PF7.     VERSION 1
EXIT.
DMP,130000.
CATALOG(TAPE03,CXXXT03,ID=PPPPPPPPP)
CATALOG(TAPE04,CXXXT04,ID=PPPPPPPPP)
'          7/8/9     END OF RECORD
       SAMPLE PROBLEM    SPHERE
  12    3 150 150 150    3   .0001
  1.0            .0              .0              1    1    1
   .92388        .0              .38268          1    2    1
  .70711         .0              .70711          1    3    1
   .92388        .38268          .0              2    1    1
   .88808        .32504          .32504          2    2    1
   .67383        .30320          .67383          2    3    1
```

```
  .70711      .70711      .0          3   1   1
  .67383      .67383      .30320      3   2   1
  .57735      .57735      .57735      3   3   1
  .0         1.0          .0          1   1   2
  .38268      .92388      .0          1   2   2
  .70711      .70711      .0          1   3   2
  .0          .92388      .38268      2   1   2
  .32504      .88808      .32504      2   2   2
  .67383      .67383      .30320      2   3   2
  .0          .70711      .70711      3   1   2
  .30320      .67383      .67383      3   2   2
  .57735      .57735      .57735      3   3   2
  .0          .0         1.0          1   1   3
  .0          .38268      .92388      1   2   3
  .0          .70711      .70711      1   3   3
  .38268      .0          .92388      2   1   3
  .32504      .32504      .88808      2   2   3
  .30320      .67383      .67383      2   3   3
  .70711      .0          .70711      3   1   3
  .67383      .30320      .67383      3   2   3
  .57735      .57735      .57735      3   3   3
  .57735      .57735      .57735
        7/8/9     END OF RECORD
  4
  .999        .888        .777
 15.0         .0        -1.0
  2.0        3.0          .0
  .0          .0         2.0
        7/8/9     END OF RECORD
  3    4    0 .15000      .70711       .0             .70711
  .0         1.0         1.0
 1.0         1.0          .0
 1.0          .0         1.0
  3    4    1 -.15        .70711       .0             .70711
  .0         1.0         1.0
 1.0         1.0          .0
 1.0          .0         1.0
        7/8/9     END OF RECORD
 1.0          .0         1.0          2
  .71         .45         .45         4
  .17         .17         .95         9
        7/8/9     END OF RECORD
      6/7/8/9     END OF FILE
```

APPENDIX B

Output for Sample Problem Sphere

```
POTENTIAL FLOW PROGRAM  SECTION 1

     SAMPLE PROBLEM   SPHERE

NO. OF QUADS.  =  12
NO. OF SECTIONS=   3
MAX. NO. OF ITERATIONS X FLOW 150  Y FLOW 150  Z FLOW 150
3 PLANES OF SYMMETRY

CONVERGENCE CRITERIA ,  .00010
```

SECTION 1

M	X1	X2	X3	X4	XP	XN	D
N	Y1	Y2	Y3	Y4	YP	YN	
P	Z1	Z2	Z3	Z4	ZP	ZN	A
1	.10000E+01	.92388E+00	.88808E+00	.92388E+00	.93552E+00	.97162E+00	-.49730E-02
1	0.	0.	.32504E+00	.38268E+00	.17239E+00	.16728E+00	
1	0.	.38268E+00	.32504E+00	0.	.17239E+00	.16728E+00	.12802E+00
2	.92388E+00	.70711E+00	.67383E+00	.88808E+00	.79947E+00	.82765E+00	-.28618E-02
1	0.	0.	.30320E+00	.32504E+00	.15753E+00	.16848E+00	
2	.38268E+00	.70711E+00	.67383E+00	.32504E+00	.52009E+00	.53536E+00	.12715E+00
1	.92388E+00	.88808E+00	.67383E+00	.70711E+00	.79947E+00	.82765E+00	-.28618E-02
2	.38268E+00	.32504E+00	.67383E+00	.70711E+00	.52009E+00	.53536E+00	
3	0.	.32504E+00	.30320E+00	0.	.15753E+00	.16848E+00	.12715E+00
2	.88808E+00	.67383E+00	.57735E+00	.67383E+00	.71071E+00	.75413E+00	-.48732E-02
2	.32504E+00	.30320E+00	.57735E+00	.67383E+00	.46381E+00	.46437E+00	
4	.32504E+00	.67383E+00	.57735E+00	.30320E+00	.46381E+00	.46437E+00	.12400E+00

SECTION 2

M N P	X1 Y1 Z1	X2 Y2 Z2	X3 Y3 Z3	X4 Y4 Z4	XP YP ZP	XN YN ZN	D A
1	0.	.38268E+00	.32504E+00	0.	.17239E+00	.16728E+00	-.49730E-02
1	.10000E+01	.92388E+00	.88808E+00	.92388E+00	.93552E+00	.97162E+00	
5	0.	0.	.32504E+00	.38268E+00	.17239E+00	.16728E+00	.12802E+00
2	.38268E+00	.70711E+00	.67383E+00	.32504E+00	.52009E+00	.53536E+00	-.28618E-02
1	.92388E+00	.70711E+00	.67383E+00	.88808E+00	.79947E+00	.82765E+00	
6	0.	0.	.30320E+00	.32504E+00	.15753E+00	.16848E+00	.12715E+00
1	0.	.32504E+00	.30320E+00	0.	.15753E+00	.16848E+00	-.28618E-02
2	.92388E+00	.88808E+00	.67383E+00	.70711E+00	.79947E+00	.82765E+00	
7	.38268E+00	.32504E+00	.67383E+00	.70711E+00	.52009E+00	.53536E+00	.12715E+00
2	.32504E+00	.67383E+00	.57735E+00	.30320E+00	.46381E+00	.46437E+00	-.48732E-02
2	.88808E+00	.67383E+00	.57735E+00	.67383E+00	.71071E+00	.75413E+00	
8	.32504E+00	.30320E+00	.57735E+00	.67383E+00	.46381E+00	.46437E+00	.12400E+00

SECTION 3

M N P	X1 Y1 Z1	X2 Y2 Z2	X3 Y3 Z3	X4 Y4 Z4	XP YP ZP	XN YN ZN	D A
1	0.	0.	.32504E+00	.38268E+00	.17239E+00	.16728E+00	-.49730E-02
1	0.	.38268E+00	.32504E+00	0.	.17239E+00	.16728E+00	
9	.10000E+01	.92388E+00	.88808E+00	.92388E+00	.93552E+00	.97152E+00	.12802E+00
2	0.	0.	.30320E+00	.32504E+00	.15753E+00	.16848E+00	-.28618E-02
1	.38268E+00	.70711E+00	.67383E+00	.32504E+00	.52009E+00	.53536E+00	
10	.92388E+00	.70711E+00	.67383E+00	.88808E+00	.79947E+00	.82765E+00	.12715E+00
1	.38268E+00	.32504E+00	.67383E+00	.70711E+00	.52009E+00	.53536E+00	-.28618E-02
2	0.	.32504E+00	.30320E+00	0.	.15753E+00	.16848E+00	
11	.92388E+00	.88808E+00	.67383E+00	.70711E+00	.79947E+00	.82765E+00	.12715E+00
2	.32504E+00	.30320E+00	.57735E+00	.67383E+00	.46381E+00	.46437E+00	-.48732E-02
2	.32504E+00	.67383E+00	.57735E+00	.30320E+00	.46381E+00	.46437E+00	
12	.88808E+00	.67383E+00	.57735E+00	.67383E+00	.71071E+00	.75413E+00	.12400E+00

PROBABLE ERROR IN INPUT - SOLID ANGLE =13.00

X VELOCITY= 0.0   Y VELOCITY= 0.0   Z VELOCITY=-1.0

ITERATION	SUM OF CHANGES	A	B1	B2
1	.10067E+00			
2	.19881E-01			
3	.38136E-02			
4	.72987E-03			
5	.13969E-03			

X VELOCITY= 0.0   Y VELOCITY=-1.0   Z VELOCITY= 0.0

ITERATION	SUM OF CHANGES	A	B1	B2
1	.10067E+00			
2	.19881E-01			
3	.38136E-02			
4	.72987E-03			
5	.13969E-03			

X VELOCITY=-1.0   Y VELOCITY= 0.0   Z VELOCITY= 0.0

ITERATION	SUM OF CHANGES	A	B1	B2
1	.10067E+00			
2	.19881E-01			
3	.38136E-02			
4	.72987E-03			
5	.13969E-03			

SAMPLE PROBLEM SPHERE PAGE = 1

X FLOW

PT.	X	Y	Z	VX	VY	VZ	ABS.V	CP	SOURCE	V NORMAL
1	.93552	.17239	.17239	-.08694	.25258	.25258	.36763	.86485	.13017	.26E-04
2	.79947	.15753	.52009	-.47240	.20620	.66547	.84175	.29146	.11072	.22E-04
3	.79947	.52009	.15753	-.47240	.66547	.20620	.84175	.29146	.11072	.22E-04
4	.71071	.46381	.46381	-.65932	.53538	.53538	1.00397	-.00796	.10270	.19E-04
5	.17239	.93552	.17239	-1.45345	.24368	.03806	1.47423	-1.17336	.02119	.57E-05
6	.52009	.79947	.15753	-1.06558	.66201	.13394	1.26161	-.59166	.07136	.15E-04
7	.15753	.79947	.52009	-1.46413	.21138	.13400	1.48536	-1.20630	.02315	.41E-05
8	.46381	.71071	.46381	-1.17206	.52127	.32556	1.32342	-.75144	.06033	.14E-04
9	.17239	.17239	.93552	-1.45345	.03806	.24368	1.47423	-1.17336	.02119	.57E-05
10	.15753	.52009	.79947	-1.46413	.13400	.21138	1.48536	-1.20630	.02315	.41E-05
11	.52009	.15753	.79947	-1.06558	.13394	.66201	1.26161	-.59166	.07136	.15E-04
12	.46381	.46381	.71071	-1.17206	.32556	.52127	1.32342	-.75144	.06033	.14E-04

SAMPLE PROBLEM SPHERE PAGE = 2

Y FLOW

PT.	X	Y	Z	VX	VY	VZ	ABS.V	CP	SOURCE	V NORMAL
1	.93552	.17239	.17239	.24368	-1.45345	.03806	1.47423	-1.17336	.02119	.57E-05
2	.79947	.15753	.52009	.21138	-1.46413	.13400	1.48536	-1.20630	.02315	.41E-05
3	.79947	.52009	.15753	.66201	-1.06558	.13394	1.26161	-.59166	.07136	.15E-04
4	.71071	.46381	.46381	.52127	-1.17206	.32556	1.32342	-.75144	.06033	.14E-04
5	.17239	.93552	.17239	.25258	-.08694	.25258	.36763	.86485	.13017	.26E-04
6	.52009	.79947	.15753	.66547	-.47240	.20620	.84175	.29146	.11072	.22E-04
7	.15753	.79947	.52009	.20620	-.47240	.66547	.84175	.29146	.11072	.22E-04
8	.46381	.71071	.46381	.53538	-.65932	.53538	1.00397	-.00796	.10270	.19E-04
9	.17239	.17239	.93552	.03806	-1.45345	.24368	1.47423	-1.17336	.02119	.57E-05
10	.15753	.52009	.79947	.13394	-1.06558	.66201	1.26161	-.59166	.07136	.15E-04
11	.52009	.15753	.79947	.13400	-1.46413	.21138	1.48536	-1.20630	.02315	.41E-05
12	.46381	.46381	.71071	.32556	-1.17206	.52127	1.32342	-.75144	.06033	.14E-04

SAMPLE PROBLEM SPHERE PAGE = 3

Z FLOW

PT.	X	Y	Z	VX	VY	VZ	ABS.V	CP	SOURCE	V NORMAL
1	.93552	.17239	.17239	.24368	.03806	-1.45345	1.47423	-1.17336	.02119	.57E-05
2	.79947	.15753	.52009	.66201	.13394	-1.06558	1.26161	-.59166	.07136	.15E-04
3	.79947	.52009	.15753	.21138	.13400	-1.46413	1.48536	-1.20630	.02315	.41E-05
4	.71071	.46381	.46381	.52127	.32556	-1.17206	1.32342	-.75144	.06033	.14E-04
5	.17239	.93552	.17239	.03806	.24368	-1.45345	1.47423	-1.17336	.02119	.57E-05
6	.52009	.79947	.15753	.13400	.21138	-1.46413	1.48536	-1.20630	.02315	.41E-05
7	.15753	.79947	.52009	.13394	.66201	-1.06558	1.26161	-.59166	.07136	.15E-04
8	.46381	.71071	.46381	.32556	.52127	-1.17206	1.32342	-.75144	.06033	.14E-04
9	.17239	.17239	.93552	.25258	.25258	-.08694	.36763	.86485	.13017	.26E-04
10	.15753	.52009	.79947	.20620	.66547	-.47240	.84175	.29146	.11072	.22E-04
11	.52009	.15753	.79947	.66547	.20620	-.47240	.84175	.29146	.11072	.22E-04
12	.46381	.46381	.71071	.53538	.53538	-.65932	1.00397	-.00796	.10270	.19E-04

SAMPLE PROBLEM SPHERE PAGE = 4

ONSET FLOW, VXI= .577 VYI= .577 VZI= .577

PT.	X	Y	Z	VX	VY	VZ	ABS.V	CP
1	.93552	.17239	.17239	-.23119	.67135	.67135	.97717	.04513
2	.79947	.15753	.52009	-.23151	.64893	.15364	.70592	.50168
3	.79947	.52009	.15753	-.23151	.15364	.64893	.70592	.50168
4	.71071	.46381	.46381	-.22126	.17963	.17963	.33688	.88651
5	.17239	.93552	.17239	.67135	-.23119	.67135	.97717	.04513
6	.52009	.79947	.15753	.15364	-.23151	.64893	.70592	.50168
7	.15753	.79947	.52009	.64893	-.23151	.15364	.70592	.50168
8	.46381	.71071	.46381	.17963	-.22126	.17963	.33688	.88651
9	.17239	.17239	.93552	.67135	.67135	-.23119	.97717	.04513
10	.15753	.52009	.79947	.64893	.15364	-.23151	.70592	.50168
11	.52009	.15753	.79947	.15364	.64893	-.23151	.70592	.50168
12	.46381	.46381	.71071	.17963	.17963	-.22126	.33688	.88651

SAMPLE PROBLEM SPHERE PAGE = 5

ONSET FLOW, VXI= .707 VYI= 0.000 VZI= .707

PT.	X	Y	Z	VX	VY	VZ	ABS.V	CP
1	.93552	.17239	.17239	-.11083	-.20552	.84915	.88067	.22443
2	.79947	.15753	.52009	-.13407	-.24052	.28292	.39480	.84413
3	.79947	.52009	.15753	.18457	-.56531	.88949	1.06997	-.14483
4	.71071	.46381	.46381	.09761	-.60878	.45020	.76343	.41719
5	.17239	.93552	.17239	1.00084	-.34462	1.00084	1.45675	-1.12209
6	.52009	.79947	.15753	.65873	-.61759	.94059	1.30386	-.70003
7	.15753	.79947	.52009	.94059	-.61759	.65873	1.30386	-.70003
8	.46381	.71071	.46381	.59857	-.73719	.59857	1.12251	-.26002
9	.17239	.17239	.93552	.84915	-.20552	-.11083	.88067	.22443
10	.15753	.52009	.79947	.88949	-.56531	.18457	1.06997	-.14483
11	.52009	.15753	.79947	.28292	-.24052	-.13407	.39480	.84413
12	.46381	.46381	.71071	.45020	-.60878	.09761	.76343	.41719

POTENTIAL FLOW PROGRAM SECTION 5

SAMPLE PROBLEM SPHERE

OFF BODY POINTS

X FLOW

PT.	X	Y	Z	VX	VY	VZ	CP
1	.99900	.88800	.77700	-.96460	.15771	.13792	.02565
2	15.00000	0.00000	-1.00000	-.99969	.00000	-.00003	.00061
3	-2.00000	3.00000	0.00000	-1.00085	-.01545	-.00000	-.00197
4	0.00000	0.00000	2.00000	-1.06515	.00000	.00000	-.13454

PAGE 2

Y FLOW

PT.	X	Y	Z	VX	VY	VZ	CP
1	.99900	.88800	.77700	.15759	-1.00185	.12239	-.04351
2	15.00000	0.00000	-1.00000	-.00000	-1.00015	.00000	-.00031
3	-2.00000	3.00000	0.00000	-.01546	-.98798	.00000	.02365
4	0.00000	0.00000	2.00000	.00000	-1.06515	-.00000	-.13454

PAGE 3

Z FLOW

PT.	X	Y	Z	VX	VY	VZ	CP
1	.99900	.88800	.77700	.13775	.12233	-1.03453	-.10419
2	15.00000	0.00000	-1.00000	-.00003	.00000	-1.00015	-.00030
3	-2.00000	3.00000	0.00000	.00000	-.00000	-1.01116	-.02244
4	0.00000	0.00000	2.00000	-.00000	.00000	-.86918	.24452

PAGE 4

ONSET FLOW VX = .577
VY = .577
VZ = .577

PT.	X	Y	Z	VX	VY	VZ	CP
1	.99900	.88800	.77700	.38640	.41674	.44699	.47722
2	15.00000	0.00000	-1.00000	.57719	.57744	.57746	-.00004
3	-2.00000	3.00000	0.00000	.58677	.57933	.58379	-.02074
4	0.00000	0.00000	2.00000	.51496	.61496	.50182	-.00818

PAGE 5

ONSET FLOW VX = .707
VY = 0.000
VZ = .707

PT.	X	Y	Z	VX	VY	VZ	CP
1	.99900	.88800	.77700	.58467	-.19802	.63400	.21700
2	15.00000	0.00000	-1.00000	.70692	-.00000	.70724	.00009
3	-2.00000	3.00000	0.00000	.70772	.01093	.71500	-.01220
4	0.00000	0.00000	2.00000	.75318	-.00000	.61461	.05499

3 STREAMLINES TO BE COMPUTED AT 4 STEPS OF .1500 T FOR AN ONSET VELOCITY OF .7071 0.0000 .7071

STARTING POINTS

PT	X	Y	Z
1	0.00000	1.00000	1.00000
2	1.00000	1.00000	0.00000
3	1.00000	0.00000	1.00000

STEP 0

LINE	X	Y	Z	VX	VY	VZ
1	0.00000	1.00000	1.00000	.83793	-.19663	.64231
2	1.00000	1.00000	0.00000	.64231	-.19663	.83793
3	1.00000	0.00000	1.00000	.44568	-.00000	.44568

STEP 1

LINE	X	Y	Z	VX	VY	VZ
1	.12282	.97057	1.09352	.79971	-.19299	.60747
2	1.09352	.97057	.12282	.60747	-.19299	.79971
3	1.07060	-.00000	1.07060	.49425	-.00000	.49425

STEP 2

LINE	X	Y	Z	VX	VY	VZ
1	.24009	.94273	1.18304	.76490	-.17679	.58865
2	1.18304	.94273	.24009	.58865	-.17679	.76490
3	1.14785	-.00000	1.14785	.53443	-.00000	.53443

STEP 3

LINE	X	Y	Z	VX	VY	VZ
1	.35262	.91784	1.27076	.73681	-.15444	.58274
2	1.27076	.91784	.35262	.58274	-.15444	.73681
3	1.23054	-.00000	1.23054	.56698	.00000	.56698

STEP 4

LINE	X	Y	Z	VX	VY	VZ
1	.46150	.89646	1.35831	.71612	-.13064	.58574
2	1.35831	.89646	.46150	.58574	-.13064	.71612
3	1.31761	-.00000	1.31761	.59296	-.00000	.59296

```
  3 STREAMLINES TO BE COMPUTED AT    4 STEPS OF   -.1500 T FOR AN ONSET VELOCITY OF    .7071  0.0000   .7071
STARTING POINTS
 PT      X            Y            Z
  1    0.00000      1.00000      1.00000
  2    1.00000      1.00000      0.00000
  3    1.00000      0.00000      1.00000

 STEP   0

 LINE     X            Y            Z                        VX          VY          VZ
  1    0.00000      1.00000      1.00000                  .83793     -.19663      .64231
  2    1.00000      1.00000      0.00000                  .64231     -.19663      .33793
  3    1.00000      0.00000      1.00000                  .44568     -.00000      .44568

 STEP   1

 LINE     X            Y            Z                        VX          VY          VZ
  1    -.12839      1.02858       .90002                  .87259     -.18065      .69319
  2     .90002      1.02858     -.12839                   .69319     -.18065      .87259
  3     .93729       .00000       .93729                  .38915      .00000      .38915

 STEP   2

 LINE     X            Y            Z                        VX          VY          VZ
  1    -.26113      1.05301       .79153                  .89438     -.14118      .75423
  2     .79153      1.05301     -.26113                   .75423     -.14118      .89438
  3     .88358       .00000       .88358                  .32635     -.00000      .32635

 STEP   3

 LINE     X            Y            Z                        VX          VY          VZ
  1    -.39565      1.06985       .67375                  .89529     -.08018      .81527
  2     .67375      1.06985     -.39565                   .81527     -.08018      .89529
  3     .83955       .00000       .83955                  .26052     -.00000      .26052

 STEP   4

 LINE     X            Y            Z                        VX          VY          VZ
  1    -.52843      1.07638       .54751                  .87078     -.00566      .86510
  2     .54751      1.07638     -.52843                   .86510     -.00566      .87078
  3     .80537       .00000       .80537                  .19589     -.00000      .19589
```

APPENDIX C

DECK SETUP FOR RERUNNING SECTIONS 5, 6, AND 7

```
JOBNAME,CM130000,T400,P2.                          * USERS JOB CARD *
CHARGE,CXXX,PPPPPPPPP,CC,B.                        * USERS CHARGE CARD *
ATTACH(TAPE03,CXXXT03)
ATTACH(PF1,CXXXPF101)      * CXXX IS USERS ID *
ATTACH(PF5,CXXXPF501)      * PPPPPPPPP IS USERS JOB NUMBER *
ATTACH(PF6,CXXXPF601)
ATTACH(PF7,CXXXPF701)
RFL,65000.
SETCORE(INDEF,ADDR)
PF1.     VERSION 1
RFL,65000.
SETCORE(INDEF,ADDR)
PF5.     VERSION 1
RFL,75000.
SETCORE(INDEF,ADDR)
PF6.     VERSION 1
RFL,130000.
SETCORE(INDEF,ADDR)
PF7.     VERSION 1
EXIT.
DMP,130000.
'          7/8/9     END OF RECORD
       SAMPLE PROBLEM     SPHERE
  12    3 150 150 150    3   .0001                       -1
  1.0             .0              .0          1    1    1
   .92388         .0              .38268      1    2    1
  .70711          .0              .70711      1    3    1
   .92388         .38268          .0          2    1    1
   .88808         .32504          .32504      2    2    1
   .67383         .30320          .67383      2    3    1
   .70711         .70711          .0          3    1    1
   .67383         .67383          .30320      3    2    1
   .57735         .57735          .57735      3    3    1
   .0            1.0              .0          1    1    2
   .38268         .92388          .0          1    2    2
   .70711         .70711          .0          1    3    2
   .0             .92388          .38268      2    1    2
   .32504         .88808          .32504      2    2    2
   .67383         .67383          .30320      2    3    2
   .0             .70711          .70711      3    1    2
   .30320         .67383          .67383      3    2    2
   .57735         .57735          .57735      3    3    2
   .0             .0             1.0          1    1    3
   .0             .38268          .92388      1    2    3
   .0             .70711          .70711      1    3    3
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 .38268        .0           .92388      2    1    3
 .32504        .32504       .88808      2    2    3
 .30320        .67383       .67383      2    3    3
 .70711        .0           .70711      3    1    3
 .67383        .30320       .67383      3    2    3
 .57735        .57735       .57735      3    3    3
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          7/8/9     END OF RECORD
 4
 .999          .888         .777
15.0           .0         -1.0
 2.0          3.0           .0
  .0           .0          2.0
          7/8/9     END OF RECORD
 3    4    0 .15000         .70711      .0             .70711
  .0          1.0          1.0
 1.0          1.0           .0
 1.0           .0          1.0
 3    4    1 -.15           .70711      .0             .70711
  .0          1.0          1.0
 1.0          1.0           .0
 1.0           .0          1.0
          7/8/9     END OF RECORD
 1.0           .0          1.0          2
  .71          .45          .45         4
  .17          .17          .95         9
          7/8/9     END OF RECORD
        6/7/8/9     END OF FILE
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13. ABSTRACT

The XYZ Potential Flow Program is a FORTRAN program which computes approximate solutions to problems of flow about three-dimensional bodies of arbitrary shape. The surface of the body is approximated by a set of plane quadrilaterals. The solution is constructed in terms of a source density on the surface of the body. The integral equation for the source density is approximated by a matrix equation on the assumption that the source density is constant in each quadrilateral. The matrix equation is solved by an iteration procedure. A problem with 500 quadrilaterals requires about 15 minutes of computer time when run with a CDC 6400 processor and costs about $50. A detailed discussion of the preparation of the input and a sample problem are included. Additional routines which compute streamlines on or off the body are described.

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