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Potential Flow Theory and Operation Guide for the Panel Code PMARC_14

Dale L. Ashby

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NOMENCLATURE

B_{JK}	Velocity potential influence coefficient at control point of panel J due to a uniform distribution of unit source on panel K
C_f	Local skin friction coefficient, $\dfrac{2\tau_w}{\rho U^2}$
C_{JK}	Velocity potential influence coefficient at control point of panel J due to a uniform distribution of unit doublet on panel K
C_P	Pressure coefficient
C_τ	Local shear stress integral coefficient, $\dfrac{2}{\rho U^2 \delta}\int_0^\delta \tau \, d\xi$
dS	Differential surface element on configuration
H	Boundary layer shape factor
N_s	Total number of surface panels
N_w	Total number of wake panels
$\bar{n}$	Unit normal vector to surface
P	An arbitrary point in space
$\bar{r}$	Vector between an arbitrary point P and a surface element dS
S	Surface of the configuration
S_∞	Imaginary surface at infinity
t	Time
U	Velocity at the outer edge of the boundary layer
u	Velocity in the boundary layer
u_τ	Friction velocity, $\sqrt{\dfrac{\tau_w}{\rho}}$
$\overline{V}$	Velocity vector
$\overline{V}_{\mu_{PK}}$	Velocity influence coefficient at point P due to a uniform distribution of unit doublet on panel K

$\overline{V}_{\sigma PK}$	Velocity influence coefficient at point P due to a uniform distribution of unit source on panel K
W	Wake surface
δ	Boundary layer thickness
δ^*	Displacement thickness
η	Generalized coordinate along streamline
θ	Momentum thickness
μ	Doublet singularity strength per unit area
ν	Kinematic viscosity
ξ	Generalized coordinate normal to surface along streamline
σ	Source singularity strength per unit area
τ_w	Shear stress at the wall
Φ	Total velocity potential
ϕ	Perturbation velocity potential
ϕ_∞	Free-stream velocity potential

subscripts:

i	Interior region
J	Refers to panel J or its control point
K	Refers to panel K or its control point
L	Lower surface
P	Refers to velocity scan point P
U	Upper surface
∞	Free-stream conditions

SUMMARY

The theoretical basis for PMARC, a low-order panel code for modeling complex three-dimensional bodies in potential flow, is outlined. PMARC can be run on a wide variety of computer platforms, including desktop machines, workstations, and supercomputers. Execution times for PMARC vary tremendously depending on the computer resources used, but typically range from several minutes for simple or moderately complex cases to several hours for very large complex cases. Several of the advanced features currently included in the code, such as internal flow modeling, boundary layer analysis, and time-dependent flow analysis, including problems involving relative motion, are discussed in some detail. The code is written in Fortran77, using adjustable-size arrays so that it can be easily redimensioned to match problem requirements and computer hardware constraints. An overview of the program input is presented. A detailed description of the input parameters is provided in the appendices. PMARC results for several test cases are presented along with analytic or experimental data, where available. The input files for these test cases are given in the appendices. PMARC currently supports plotfile output formats for several commercially available graphics packages. The supported graphics packages are Plot3D, Tecplot, and PmarcViewer.

INTRODUCTION

A potential flow panel code, called PMARC (Panel Method Ames Research Center), has been developed at NASA Ames Research Center to numerically predict flow fields around complex three-dimensional geometries[1,2]. The creation of PMARC was prompted by the need at Ames for a fast aerodynamic prediction code that is well documented and has an open architecture, which facilitates making modifications or adding new features. An open code allows users of PMARC to make additional contributions to the code. A second objective in the development of PMARC was to create an adjustable-size panel code. This allows PMARC to be tailored so an optimum match can be achieved between the computer hardware available to the user and the size of the problem being solved. Currently PMARC can be resized (i.e., the maximum number of panels can be changed) in a matter of minutes. PMARC can be run on computers ranging from a Power Macintosh workstation to a Cray C-90. At its present state of development, PMARC contains several features considered to be state of the art for panel methods including internal flow modeling for ducts and wind tunnel test sections and a time-stepping wake model which allows the study of time-dependent motions, including problems involving relative motion. PMARC is a research tool that is envisioned as being in a continual state of development. Existing routines will be improved or replaced by new routines, and new features and options will be added as they become available.

One of the decisions that had to be made in the development of PMARC was the type of panel method to be used. Panel methods can be subdivided into two groups: low order and high order. In a low-order panel method, singularities are distributed with constant strength over each panel. In a higher order method, singularity strengths are allowed to vary linearly or quadratically over each panel. Higher order panel methods claim a better accuracy in the modeling of the flow field, but this is at the expense of increased code complexity and computation time. Experience with panel methods such as PANAIR, MACAERO, VSAERO, and QUADPAN, developed under NASA contracts and/or industry internal research and development, has shown that low-order methods can provide nearly the same accuracy as higher order methods over a wide range of cases; however, the computation time for low-order panel methods is much shorter than for higher order panel methods[3]. Additionally, low-order panel methods do not require exact matching between panels as higher order methods do. For these reasons, and to reduce program cost and complexity, the low-order panel method was chosen for the basic methodology.

To avoid unnecessary duplication of previous work, existing software was utilized whenever possible to reduce development time of PMARC and cost to the government. Of the several low-order panel methods available, the 1000-panel version of VSAERO was felt to be the most robust, mature, and widely accepted by the engineering community. During its ten years of development by Analytical Methods Inc., which was supported largely by government and industry contracts, VSAERO has demonstrated that low-order panel methods are a viable means of predicting aerodynamic flows about complex shapes. Two versions of VSAERO were delivered to Ames Research Center, one in 1982 and the other in 1985 under contracts NAS2-11169 and NAS2-11944, respectively[4,5,6]. The basic potential flow computational methods and techniques used in PMARC were patterned after the most recent 1000-panel version of VSAERO, which is in the public domain.

THEORY

Potential Flow Model

In PMARC, the flow field around a three-dimensional body is assumed to be inviscid, irrotational, and incompressible. The body is modeled as a closed surface which divides space into two regions as shown in figure 1. One region contains the flow field of interest and the other contains a fictitious flow. Figure 1 shows the external region as the flow field of interest and the internal region as the fictitious flow. This is the typical arrangement for external flow problems such as a wing in a uniform stream. This arrangement is reversed for internal flow problems. The internal region contains the flow field of interest and the external flow field is fictitious. In either case it is assumed that the velocity potentials in both regions satisfy Laplace's equation:

$$\begin{aligned} \nabla^2\Phi &= 0 \\ \nabla^2\Phi_i &= 0 \end{aligned} \tag{1}$$

The potential at any point P in either region may be evaluated by applying Green's Theorem to both regions. This results in the following integral equation:

$$\Phi_P = \frac{1}{4\pi}\iint_{S+W+S_\infty} (\Phi - \Phi_i)\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ - \ \frac{1}{4\pi}\iint_{S+W+S_\infty} \left(\frac{1}{\bar{r}}\right)\ \bar{n}\cdot(\nabla\Phi - \nabla\Phi_i)\ dS \tag{2}$$

where $\bar{r}$ is the distance from the point P to the element dS on the surface and $\bar{n}$ is the unit normal vector to the surface pointing into the flow field of interest. In this equation the first integral represents the disturbance potential from a surface distribution of doublets with strength $(\Phi - \Phi_i)$ per unit area and the second integral represents the contribution from a surface distribution of sources with strength $-\bar{n}\cdot(\nabla\Phi - \nabla\Phi_i)$ per unit area. This equation may be simplified by noting that at the surface at infinity, the perturbation potential due to the configuration is essentially zero, leaving only the potential due to the uniform onset flow. It is assumed that the wake is thin and there is no entrainment so the source term for the wake disappears and the jump in normal velocity across the wake is zero. Hence the simplified equation becomes:

$$\begin{aligned} \Phi_P = {} & \frac{1}{4\pi}\iint_S (\Phi - \Phi_i)\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ - \ \frac{1}{4\pi}\iint_S \left(\frac{1}{\bar{r}}\right)\ \bar{n}\cdot(\nabla\Phi - \nabla\Phi_i)\ dS \\ & + \ \frac{1}{4\pi}\iint_W (\Phi_U - \Phi_L)\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ + \ \phi_{\infty_P} \end{aligned} \tag{3}$$

The point P must be excluded from the integration if it lies on the surface, since the integrals become singular in that case at point P. This is done by assuming a hemispherical deformation of the surface centered at P. If the integral is evaluated for this hemispherical deformation as its radius is allowed to go to zero, and point P (and hence the hemispherical deformation) is on the outside of the surface, the contribution at point P is $1/2(\Phi - \Phi_i)_P$. If point P lies on the inside of the surface, the contribution at point P is $-1/2(\Phi - \Phi_i)_P$. Hence for points P lying on the inside of the surface, equation 3 becomes:

$$\Phi_P = \frac{1}{4\pi}\iint_{S-P} (\Phi - \Phi_i)\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ - \ \frac{1}{4\pi}\iint_{S}\left(\frac{1}{\bar{r}}\right)\ \bar{n}\cdot(\nabla\Phi - \nabla\Phi_i)\ dS \qquad (4)$$
$$+\ \frac{1}{4\pi}\iint_{W}(\Phi_U - \Phi_L)\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ + \ \phi_{\infty_P} \ - \ \frac{1}{2}(\Phi - \Phi_i)_P$$

The boundary condition used to solve equation 4 is an internal Dirichlet boundary condition. The total potential Φ can be viewed as being made up of an onset potential ϕ_∞ and a perturbation potential $\phi = \Phi - \phi_\infty$. The potential of the fictitious flow is set equal to the onset potential, ϕ_∞. With this boundary condition, the singularities on the surface tend to be smaller than if the potential of the fictitious flow is set to zero because the singularities only have to provide the perturbation potential instead of the total potential. Using this boundary condition and looking at points P inside the surface, equation 4 can be rewritten as:

$$0 = \frac{1}{4\pi}\iint_{S-P} \phi\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ - \ \frac{1}{4\pi}\iint_{S}\left(\frac{1}{\bar{r}}\right)\ \bar{n}\cdot(\nabla\Phi - \nabla\phi_\infty)\ dS \qquad (5)$$
$$+\ \frac{1}{4\pi}\iint_{W}(\Phi_U - \Phi_L)\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \ - \ \frac{1}{2}\ \phi_P$$

Referring to the definitions made for equation 2, the following equations may be written for the doublet and source strengths:

$$4\pi\mu \ = \ \phi \ = \ (\Phi - \phi_\infty) \qquad (6)$$

$$4\pi\sigma \ = \ -\bar{n}\cdot(\nabla\Phi - \nabla\phi_\infty) \qquad (7)$$

Looking at equation 7, if it is assumed that the normal velocity at the surface is either zero or some known value, then the source strengths can be solved for immediately. The source strengths on the surface are given by the following equation:

$$\sigma \ = \ \frac{1}{4\pi}\ \left(V_{norm} - \bar{n}\cdot\bar{V}_\infty\right) \qquad (8)$$

The normal velocity, V_{norm}, on the surface is either zero (no flow through the surface) or a user-defined value (to simulate suction or blowing) and the onset velocity vector is known. Substituting equations 6 and 7 into equation 5 leaves the following integral equation with the unknown doublet strength over the surface to solve for:

$$0 = \left[\iint_{S-P} \mu\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS - 2\pi\mu_P\right] \ + \ \iint_{S}\left(\frac{\sigma}{\bar{r}}\right) dS \ + \ \iint_{W}\mu_W\ \bar{n}\cdot\nabla\left(\frac{1}{\bar{r}}\right) dS \qquad (9)$$

The general equation for the potential at any point P can be written as:

$$\Phi_P = \left[\iint_{S-P} \mu \ \bar{n} \cdot \nabla \left(\frac{1}{\bar{r}} \right) dS + \ K \mu_P \right] + \iint_S \left(\frac{\sigma}{\bar{r}} \right) dS + \iint_W \mu_W \ \bar{n} \cdot \nabla \left(\frac{1}{\bar{r}} \right) dS \ + \phi_{\infty_P} \quad (10)$$

where $K = 0$ if P is not on the surface, $K = 2\pi$ if P is on a smooth part of the outer surface, $K = -2\pi$ if P is on a smooth part of the inner surface and $K =$ the solid angle contained at the crease if P lies at a crease in the surface.

If the surface is broken up into panels, equation 9 can be written in discretized form, breaking the integrals up into surface integrals over each panel. PMARC assumes constant strength source and doublet distributions over each panel (thus making it a low-order panel method); therefore, the doublet and source strengths can be factored out of the integrals. Taking point P to be at the centroid on the inside surface of one of the panels, the surface integrals over each panel are summed for all panels. For the panel containing point P, the surface integral is zero and only the $-2\pi\mu_P$ term remains in the bracketed part of equation 9. For all other panels, the surface integral is used and the $-2\pi\mu_P$ term is zero since the point P is not on the surface of any of the other panels. The process is repeated for point P at the centroid of every panel to yield a set of linear simultaneous equations to be solved for the unknown doublet strength on each panel. The surface integrals represent the velocity potential influence coefficients per unit singularity strength for panel K acting on the control point of panel J. Hence equation 9 becomes:

$$\sum_{K=1}^{N_S} (\mu_K \, C_{JK}) + \sum_{K=1}^{N_S} (\sigma_K \, B_{JK}) + \sum_{L=1}^{N_W} (\mu_{W_L} \, C_{JL}) = 0 \Big|_{J=1,\ N_S} \quad (11)$$

where

$$B_{JK} = \iint_K \frac{1}{\bar{r}} \ dS \quad (12)$$

and

$$C_{JK} = \iint_K \bar{n} \cdot \nabla \left(\frac{1}{\bar{r}} \right) dS \quad (13)$$

$$C_{JJ} = -2\pi$$

The coefficients C_{JK} and B_{JK} represent the velocity potential influence coefficients per unit singularity strength for panel K acting on the control point of panel J. Equations 12 and 13 are functions of geometry only and thus can be solved for all panels to form the influence coefficient matrix. Solutions for equations 12 and 13 can be found in references 7 and 8. Since the source values are known, they may be transferred to the right hand side of the matrix equation. The wake doublet values can be determined as functions of the surface doublet values, as will be described in the section on time-stepping wakes, leaving only the surface doublet strengths as unknowns.

Coordinate Systems for Unsteady Flow Analysis

PMARC was written to allow both steady and unsteady aerodynamic analysis. The geometry of a configuration is input using a variety of construction coordinate systems (section, component, assembly), allowing multiple levels of scaling, translation, and rotation. All of the input geometry is transformed through the various construction coordinate systems into a fixed inertial coordinate system. The input geometry can be assigned to a single path coordinate system for the case where there is no relative motion between various parts of the input geometry or it can be subdivided into groups with each group assigned to a different path coordinate system for the case where there is relative motion between different parts of the input geometry. The path coordinate systems remain fixed relative to the geometry groups assigned to them. The origin and orientation of each path coordinate system is defined in the inertial reference frame at time $t = 0$. The motion of the bodies relative to the inertial reference frame at time $t > 0$ are then defined by describing the motion of the path coordinate systems in the inertial reference frame.

Currently in PMARC, the motion of the path coordinate systems can be described in two ways. Using the variables in the JOBCNTRL.INP input file, the motion of the path coordinate systems can be described in terms of a constant velocity vector, constant angular rotation rates about the three coordinate axes, sinusoidal translation oscillations in the three coordinate directions, and sinusoidal rotation oscillations about the three coordinate axes (see detailed input guide, appendix C). Alternatively, the velocity vector components and the angular rotation rates as a function of time can be read in for each path coordinate system from the file PATHDEF.DAT (see detailed input guide, appendix C). This allows very general motions for the path coordinate systems to be specified.

The path coordinate systems, and their associated geometry groups, are marched through the prescribed motion in a series of time steps. A PMARC solution is computed at each incremental time step to develop the time history of the flow. The surface source strengths for each geometry group (equation 8) must be updated at each time step to reflect the instantaneous velocity vector at the body surface resulting from the motion of the corresponding path coordinate system.

Time-Stepping Wake Model

In PMARC, wakes can be shed from user-defined separation lines on the surface geometry (trailing edges of wings, for example) to fix the rear stagnation point and the circulation around the body. The wakes in PMARC are time-stepping wakes[9]. The first row of wake panels is shed from the separation line at time $t = 0$. With each subsequent time step, a new row of wake panels is added to the wake at the separation line as the body moves away from its starting position at time $t = 0$. If a flexible wake has been specified (see detailed input guide, appendix C), then all the wake corner points are additionally perturbed by the local velocity induced by the presence of all bodies and wakes. Alternatively, an initial wake may be prescribed by the user to simulate a steady-state condition. The initial wake can then be time-stepped, if desired, to further develop the wake. This is equivalent to starting the time-stepping at some initial time $t > 0$.

The Kutta condition is used as a boundary condition to determine the strength of the doublets to be shed into the first row of a wake. The Kutta condition requires that the velocity at the rear stagnation point (i.e., wing trailing edge) must be finite. A panel (surface or wake) with a constant strength doublet distribution is equivalent to a vortex ring around the panel perimeter with strength equal to the doublet strength[10]. When two or more vortex lines coincide, the strength of the resulting vortex line is equal to the sum of the individual vortex lines. In PMARC, the wake separation line is defined as the common edge between two rows or columns of surface panels from which the wake is shed as shown in figure 2. The resultant strength of the vortex line along the separation line must therefore be zero to satisfy the Kutta condition at that point. The strength of the vortex line due to the two surface panels is the difference in their doublet strengths since the vortex lines from the individual panels go in opposite directions along their common edge (see fig. 2). The strength of the vortex ring on the wake panel that is attached to the separation line must be equal to the difference in doublet strengths of the two surface panels in order to cancel the vortex line along the separation line. Thus the doublet strengths on the first row of wake panels is set equal to the difference in doublet strengths of the two rows or columns of surface panels whose common edge forms the separation line.

When computing the first solution, two conditions can exist regarding the wakes. If no initial wake is specified, then no wake exists for the first solution, which corresponds to an impulsively started object. The only unknowns are the surface doublet strengths. If an initial wake is prescribed, the doublet strengths on each row of wake panels following the first row are set equal to the doublet strengths on the first row (steady-state flow condition). The strengths on the first row of wake panels are known in terms of the strengths of the doublets on the surface panels from which the wake separates, as described above. In this case, the second summation in equation 11 can be combined with the surface panel summation, again leaving only the surface doublet strengths as unknowns.

On subsequent time steps, a new row of wake panels is added to each wake at the wake separation line as the body moves away from its initial starting position. The doublet strengths on all the wake panels, except for the new first row of panels, are known from the previous time step and can therefore be transferred to the right hand side of equation 11. The doublet strengths on the new first row of wake panels are again defined in terms of the doublet strengths on the surface panels from which the wake separates. The terms from the second summation in equation 11 pertaining to the new first row of wake panels are then combined with the surface panel summation, yielding a new matrix equation to be solved at each time step.

Influence Coefficient Matrices

There are three large matrices generated by PMARC during the course of obtaining a solution. The first two are the source and doublet influence coefficient matrices. The third one is a modified doublet influence coefficient matrix containing the influence of all the wakes. This third matrix is the one used in the solver to obtain a solution for the unknown doublets. Because these matrices are large, $O(N_s^2)$, they are normally stored on disk and read into PMARC one line at a time to reduce memory requirements. The source and doublet influence coefficient matrices are accessed once each time step. The modified doublet influence coefficient matrix is accessed once every iteration of the solver, and the solver is called once each time step. Thus for a case involving 5 time steps, the source and doublet influence coefficient matrices are read in 5 times, while the modified doublet influence coefficient matrix is read in up to 100 or more times (assuming an average of 20 solver iterations per time step). Since disk access is much slower than memory (RAM) access, a considerable improvement in speed can be achieved if the modified doublet influence coefficient matrix is stored in memory rather than on disk. In PMARC, there is a parameter (INRAM in appendix A) that can be used to tell the code whether to store the modified doublet influence coefficient matrix on disk or in memory. The amount of memory required to store the modified doublet influence coefficient in memory can be evaluated using the information given in appendix B.

. The first step in the solution of equation 11 is the determination of the velocity potential influence coefficient matrix elements C_{JK} for the unknown doublet strengths and B_{JK} for the known source strengths. PMARC makes use of an approximation commonly employed in panel methods. For panels that are nearby, the influence coefficients are calculated exactly by treating the singularities as being distributed over the panel and integrating over the panel surface. For panels that are far away, however, the influence coefficients are calculated by treating the panel as though it were a point source or doublet. The distance at which this approximation starts being used is determined by the far-field radius. This distance is non-dimensionalized by a characteristic panel size to give a far-field factor. The characteristic panel size is the sum of the distance from the midpoint of one side to the centroid of the panel and the distance from the midpoint of an adjacent side to the centroid. The far-field factor is then defined as the far-field radius divided by the characteristic panel size. In PMARC the default value of 5.0 for the far-field factor produces sufficiently accurate results for most cases. The default value for far-field factor can be changed by the user if so desired. The main purpose in using this approximation is that it provides a considerable savings in time with little loss in accuracy for most configurations.

For problems which do not involve relative motion, the source and doublet influence coefficient matrices do not change from one time step to the next. Only the modified doublet influence coefficient matrix, which contains the influence of all the wakes, changes from one time step to the next. For problems involving relative motion, however, the source and doublet influence coefficient matrices must also be updated every time step. Only elements C_{JK} and B_{JK} which meet the criterion that panel J and panel K belong to different path coordinate systems need be updated at each time step. Elements of the matrices which do not meet this criterion do not change from one time step to the next and do not need to be updated. One special case that must handled is when the relative motion is between the geometry and a plane of symmetry or a ground plane. In this case, all doublet and source influence coefficients must be updated at each time step. PMARC stores the source and doublet influence coefficient matrices as direct access files so that the elements which need to be updated at each time step can be accessed quickly and efficiently.

Matrix Solver

Once the influence coefficients have been evaluated, equation 11 can be solved for the unknown doublet strengths. Because the matrix equation that must be solved can become very large (the influence coefficient matrix contains 1,000,000 elements for a 1000 panel case), a fast iterative matrix solver that solves line by line without requiring the whole matrix to be in memory at once is used. PMARC makes use of a matrix solver based on an iterative scheme for computing the eigenvalues of large matrices[11]. The solver can handle matrices of the order of $10^6 \times 10^6$. When the solver is configured in a minimum-memory mode, only two small matrices of order NSPDIM $\times$ IFOLDDIM and some scratch vectors of size NSPDIM are needed in memory during the iterative solution process. The variable NSPDIM is the number of surface panels the arrays in PMARC are dimensioned to handle. The variable IFOLDDIM represents the number of iterations performed by the solver, before the matrices containing the history of solution vector guesses and correction vectors are reset (see discussion below). In minimum-memory mode, the solver used in PMARC permits the solution of fairly complex problems (1000 to 4000 panels) on desktop computers without requiring large amounts of memory.

The limit on total number of solver iterations is set by the user in the input file. At each iteration, a correction vector is computed which is applied to the current solution vector guess to get the solution vector guess for the next iteration. As the solution iterations proceed, the solver stores all the solution vector guesses and the correction vectors from each iteration in the two small matrices of order NSPDIM × IFOLDDIM. The history of solution vector guesses and correction vectors from preceding iterations is used at each iteration to form the correction vector for the current iteration. After every IFOLDDIM iteration, the current set of small matrices is folded to one (i.e., reset so that it holds only the correction vector and solution guess vector from the previous iteration) to prevent memory requirements from becoming too large[11]. Increasing the value of IFOLDDIM will generally produce a corresponding increase in convergence rate, but at the expense of increased memory requirements.

The solver requires an initial solution vector to start the iterative process. For the first time step, the initial solution vector can either be generated by dividing the right-hand-side vector divided by the diagonal vector of the influence coefficient matrix or a predefined solution vector can be read in from a file to use as the initial solution vector. The latter option provides an accelerated restart capability for cases where flow conditions are changed from one run to the next or additional off-body velocity scans or streamlines need to be added to a case that has already been run. On subsequent time steps, the solver uses the doublet solution from the previous time step as its starting guess vector. This generally reduces the number of iterations required for a converged solution on all the time steps after the first one.

The convergence tolerance must also be passed to the solver. The convergence tolerance specified in PMARC is defined as the percent change in the solution vector elements between successive iterations. The element in the solution vector with the largest change is used to determine if the solution is converged or not. The cases run to date indicate that a convergence tolerance of 0.01 to 0.0005 is adequate for most problems, although smaller convergence tolerances may be necessary for certain cases. The solver will generally converge to a solution in 50 to 150 iterations, although complex geometries may require several hundred iterations to reach a converged solution.

On-body Analysis

Once the unknown doublet strengths have been determined, the singularities on all the panels are known; thus, the velocities at the control points of the panels can be evaluated. The velocities normal to the panels are either zero or the value specified by the user. The tangential velocities on the surface are evaluated in a local panel coordinate system by differentiating the doublet strengths in the appropriate direction for each tangential component of velocity. With the three components of velocity calculated in the panel coordinate system, the velocities can be transformed into the inertial coordinate system and a resultant velocity can be calculated. Using the resultant velocity at each panel control point, the pressure coefficient at each panel control point can be calculated using the following equation:

$$C_{P_K} = 1 - \frac{V_K^2}{V_\infty^2} + \left(\frac{2 * 4\pi}{V_\infty^2}\right)\left(\frac{\mu(t) - \mu(t-1)}{\Delta t}\right) \tag{14}$$

The last term in equation 14 is the unsteady term, $d\Phi/dt$.

With the pressure distribution over the body determined, the resultant forces and moments on the body can be evaluated. Forces and moments are summed up, panel by panel, for each patch, component, assembly, path coordinate system, and the entire geometry. Forces and moments are also summed up for each column of panels on all patches to give section forces and moments. The section forces and moments can be nondimensionalized either by using the projected area of the column of panels or by using the reference area SREF. The projected area of the column of panels is typically used for aerodynamic surfaces such as wings. The summed forces and moments, which are resolved into components in the inertial coordinate system, are put in coefficient form and are transformed to body and wind axes. Since the path coordinate systems remain fixed relative to the geometry assigned to them, transforming the force and moment coefficients from the inertial coordinate system to the path coordinate systems yields the body axes force and moment coefficients. The section coefficients are written to the solution file in wind and body axes, after each column of aerodynamic data for the patches on which they were computed. The patch, component, assembly, path coordinate system, and total force and moment coefficients are written to the solution file in wind and body axes, after the panel aerodynamic data for all the patches has been written. The patch wetted area, nondimensionalized by the reference area, is also written at this time. For the case where a plane of symmetry about y = 0.0 was used, the patch, component, assembly, and path coordinate system force and moment coefficients are for the paneled geometry only. The total coefficients include the contribution of the reflected image.

The section force and moment coefficients for each patch and a summary table of patch, component, assembly, path coordinate system, and total force and moment coefficients are also written to two other files in addition to the solution file. One file, named *wforcmom.out*, contains the wind axes force and moment coefficients, and the other file, named *bforcmom.out*, contains the body axes force and moment coefficients. These two files consolidate all the force and moment data for the entire model to facilitate plotting of load distributions on the model.

One problem with using surface pressure integration to obtain forces and moments is that on surfaces such as wings, which have large pressure peaks near the leading edge and are relatively thin, a large number of panels are required in the streamwise direction to resolve the induced drag accurately. In addition to computing induced drag using surface pressure integration, PMARC computes induced drag using a Trefftz plane analysis. Munk showed that induced drag of general lifting systems could be computed by evaluating the following integral along the intersection line between the wake and a plane normal to the free-stream velocity vector far downstream of the lifting surface (the Trefftz plane)[12].

$$D_i = \frac{\rho}{2}\int_{wake} \Gamma V_n dl \tag{15}$$

In equation 15, V_n is the normal component of the induced velocity at the wake in the Trefftz plane and Γ is the circulation on the lifting surface at the corresponding spanwise location.

In order for the forces computed using Trefftz plane analysis to be correct, the wakes intersecting the Trefftz plane must be force-free. This implies that the correct rolled up wake shape must be used in the Trefftz plane. However, to obtain only the correct induced drag from the Trefftz plane, the wakes intersecting the Trefftz plane need only be drag-free. Although the rolled up wake shape is (if done correctly) force-free and therefore drag-free, a simple wake sheet that extends from the wing trailing edge in the free-stream direction to the Trefftz plane is also drag-free. Either wake theoretically can be used to determine induced drag using Trefftz plane analysis. In cases where there are multiple nonplanar lifting surfaces, use of the correctly rolled up wake shape may be necessary to obtain the correct induced drag using Trefftz plane analysis. Thus PMARC allows the user the capability of using either a simple wake sheet extending in the free-stream direction or the correctly rolled up wake shape to compute induced drag.

In addition to the standard on-body analysis, on-body streamlines may also be requested. The panel on which the streamline is to start is specified by the user in the input file. The streamline is started at the centroid of that panel and traced upstream and downstream until a stagnation point or attachment line is encountered or until a panel neighbor cannot be found for the panel the streamline is currently over. The streamline is computed using the known velocity vector field on the surface to generate an integral curve passing through the specified starting point. The integral curve (streamline) will be unique as long as the starting point is not a critical point (i.e., a stagnation or separation point). To guarantee that the streamline remains on the body, the streamline calculation is performed in the panel local coordinate system of each panel the streamline crosses over.

Boundary Layer Analysis

A two-dimensional integral boundary layer method, applied along surface streamlines, has been incorporated into PMARC. The method comprises a laminar boundary layer analysis, a transition and separation analysis, and a turbulent boundary layer analysis. This approach was selected based on experience gained from earlier work done on incorporating boundary layer computations with panel methods[5,13]. The two-dimensional integral methods have been shown to be robust and faster than finite difference methods. The grids required for finite difference methods can be difficult and time consuming to implement over general three-dimensional configurations and the computations can take longer than the entire potential flow computation. Two-dimensional integral methods along surface streamlines, on the other hand, are easy to implement, are computationally very fast, and they can be applied to any general three-dimensional configuration. Most two-dimensional integral methods applied along surface streamlines are quite accurate as long as the flow is primarily two-dimensional (i.e., no significant crossflow exists). These methods can be expected to break down in regions of large crossflow such as flows near separation, where most methods have difficulty. The boundary layer method incorporated into PMARC is intended to give a preliminary estimate of boundary layer properties over a general configuration. The particular laminar, transition, and turbulent analysis methods selected were based on the work of references 5 and 13.

Laminar Boundary Layer Model – The laminar boundary layer analysis method used is a two-parameter extension of Thwaites method developed by Curle[14]. The two-dimensional momentum integral equation can be written as follows:

$$\frac{d\theta}{d\eta} + (2+H)*\frac{\theta}{U}\frac{dU}{d\eta} = \frac{1}{2}C_f \tag{16}$$

where η is the coordinate along the streamline, U is the velocity at the outer edge of the boundary layer (the potential flow velocity from PMARC), H is the shape factor, C_f is the local skin friction coefficient, and θ is the momentum thickness. Using the definition of C_f (see Nomenclature), equation 16 can be rewritten as

$$\frac{d}{d\eta}\left[\frac{\theta^2}{\nu}\right] = \frac{2}{U}\left\{\frac{\theta}{U}\left(\frac{\partial u}{\partial \xi}\right)_{\xi=0} - \frac{\theta^2}{\nu}\frac{dU}{d\eta}(H+2)\right\} \tag{17}$$

Equation 17 can be simplified by defining the following quantities:

$$K = \frac{\theta^2}{\nu}\frac{dU}{d\eta} \tag{18}$$

$$l = \frac{\theta}{U}\left(\frac{\partial u}{\partial \xi}\right)_{\xi=0} \tag{19}$$

$$L = 2\{l - K(H+2)\} \tag{20}$$

Using these definitions, equation 17 becomes

$$\frac{d}{d\eta}\left[\frac{K}{dU/d\eta}\right] = \frac{L}{U} \tag{21}$$

Based on exact solutions to a wide variety of laminar boundary layers, Thwaites found that L could be expressed as a function of a single parameter K with a fair degree of accuracy[15]. Thwaites used the following approximate relationship for L.

$$L(K) = 0.45 - 6K \tag{22}$$

However, Curle determined that the accuracy of L could be increased if it were expressed as a function of two parameters as follows:

$$L(K,\mu) = 0.45 - 6K + g(K,\mu) \tag{23}$$

where

$$\mu = \frac{\theta^4 U \, d^2U/d\eta^2}{\nu^2} \tag{24}$$

Equation 23 can be rewritten in terms of universal functions $F_0(K)$ and $G_0(K)$, which have been determined from a number of exact solutions to the laminar boundary layer equations, as shown in equation 25.

$$L(K,\mu) = F_0(K) - \mu G_0(K) \tag{25}$$

The functions $F_0(K)$ and $G_0(K)$ are tabulated in reference 12 and curve fits to the tabulated data were used in PMARC. Equating equations 25 and 23 yields an equation for the parameter $g(K,\mu)$.

$$g(K,\mu) = F_0(K) - \mu G_0(K) - 0.45 + 6K \tag{26}$$

If equations 23 and 18 are substituted into equation 21, the following differential equation is obtained.

$$U\frac{d}{d\eta}\left[\frac{\theta^2}{\nu}\right] = 0.45 - 6\frac{\theta^2}{\nu}\frac{dU}{d\eta} + g(K,\mu) \tag{27}$$

This is an exact differential equation which may be integrated to yield an equation for θ^2.

$$\theta(\eta)^2 = \frac{0.45\nu}{U(\eta)^6}\int_0^\eta (1 + 2.222g(K,\mu))\, U(\eta)^5 d\eta + \theta(0)^2\left(\frac{U(0)}{U(\eta)}\right)^6 \tag{28}$$

Equation 28 is solved iteratively by starting with $g(K,\mu) = 0.0$ and performing a numerical integration along the streamline. The value of $U(\eta)$ is known (from PMARC) along the streamline. The value of $\theta(0)$ can be computed using the equation

$$\theta(0) = \left[\frac{\nu\left(0.075 + {g(K,\mu)}/{6.0}\right)}{{dU}/{d\eta}\Big|_{\eta=0}} \right]^{0.5} \tag{29}$$

which, strictly speaking, is only valid at a stagnation point. However, the solution to equation 28 is fairly insensitive to the value of $\theta(0)$ provided the ratio $U(0)/U(\eta)$ is small in the vicinity of the starting point $\eta = 0$. Thus equation 29 can also be used for boundary layers starting at an attachment line, where $U(0)/U(\eta)$ generally decreases rapidly as η increases. Once a solution for $\theta(\eta)$ is obtained, values of K, $F_0(K)$, $G_0(K)$, and μ can be computed at each η point and the value of $g(K,\mu)$ can be updated at each η point using equation 26. The process is repeated until a converged solution for $\theta(\eta)$ is obtained.

With $\theta(\eta)$, $L(K,\mu)$, and K known along the streamline, the values of $H(\eta)$, $C_f(\eta)$, and $\delta^*(\eta)$ can be computed. Curle expressed the parameter l as a function of two parameters in a manner similar to that used to define $L(K,\mu)$. The functional relationship used by Curle is

$$l(K,\mu)^2 = F_1(K) - \mu G_1(K) \tag{30}$$

where $F_1(K)$ and $G_1(K)$ are universal functions derived from exact solutions of laminar flows and are tabulated in reference 14. With the value of $l(K,\mu)$ known at all points η, equation 20 can be used to compute $H(\eta)$ and equation 19 can be used to compute $C_f(\eta)$. The value of $\delta^*(\eta)$ is computed using the relationship

$$\delta^*(\eta) = H(\eta)*\theta(\eta) \tag{31}$$

The value of $\delta(\eta)$ can be approximated by using some relationships developed in the Karman-Pohlhausen integral method[16]. The following two relations are used in PMARC.

$$\frac{\delta^*(\eta)}{\delta(\eta)} = 0.3 - \frac{\Lambda(\eta)}{120} \tag{32}$$

$$\frac{\theta(\eta)}{\delta(\eta)} = \frac{1}{63}\left(\frac{37}{5} - \frac{\Lambda(\eta)}{15} - \frac{\Lambda(\eta)^2}{144}\right) \tag{33}$$

Equations 32 and 33 represent two equations in two unknowns, $\delta(\eta)$ and $\Lambda(\eta)$, which can be solved for $\delta(\eta)$.

Transition Model – A check is performed at each point as the laminar boundary layer is computed to determine if the laminar boundary layer continues to the next point, undergoes natural transition, separates and reattaches as a turbulent boundary layer, or separates with no reattachment. The transition/laminar separation analysis is based on empirical relationships developed from a wide variety of sources referenced in reference 13 and can be summarized as follows.

As the local Reynolds number based on momentum thickness gets larger, the laminar boundary layer becomes unstable and small disturbances in the boundary layer begin to amplify rather than damp out. The amplification of disturbances eventually leads to transition to a turbulent boundary layer. The local Reynolds number at which the laminar boundary layer becomes unstable can be correlated with the local pressure gradient parameter K (defined in equation 18) by means of the following empirical relationships.

$$\begin{aligned} K &= -0.4709 + 0.11066 * \ln(\mathrm{Re}_\theta) - 0.0058591 * \ln^2(\mathrm{Re}_\theta) \qquad (0 \le \mathrm{Re}_\theta \le 650) \\ K &= 0.69412 - 0.23992 * \ln(\mathrm{Re}_\theta) + 0.0205 * \ln^2(\mathrm{Re}_\theta) \qquad (650 < \mathrm{Re}_\theta \le 10000) \end{aligned} \tag{34}$$

At each point along the laminar boundary layer, the local Reynolds number is evaluated and K is computed by equation 34. If K, as computed by equation 34, is greater than K as computed by equation 18, then the laminar boundary layer has become unstable. In the unstable region, an average pressure gradient parameter $\overline{K}$ can be defined as

$$\overline{K} = \frac{\int_{\eta_{ins}}^{\eta} K d\eta}{\eta - \eta_{ins}} \tag{35}$$

where η_{ins} is the coordinate along the streamline at which the laminar boundary layer becomes unstable. The local Reynolds number at the transition point can be correlated with $\overline{K}$ by means of the following empirical relationships.

$$\begin{aligned} \overline{K} &= -0.0925 + 0.00007 * \mathrm{Re}_\theta \qquad (0 \le \mathrm{Re}_\theta \le 750) \\ \overline{K} &= -0.12571 + 0.000114286 * \mathrm{Re}_\theta \qquad (750 \le \mathrm{Re}_\theta \le 1100) \\ \overline{K} &= 1.59381 - 0.45543 * \ln(\mathrm{Re}_\theta) + 0.032534 * \ln^2(\mathrm{Re}_\theta) \qquad (1100 \le \mathrm{Re}_\theta \le 3000) \end{aligned} \tag{36}$$

When $\overline{K}$, as computed by equation 36, is greater than $\overline{K}$ as computed by equation 35 (where the integrand K is evaluated at each point using equation 18) transition is predicted. The transition from laminar to turbulent boundary layer is assumed to take place instantaneously at the transition point. The momentum thickness at the transition point is taken to be the initial momentum thickness for the turbulent boundary layer. The initial shape factor H for the turbulent boundary layer is determined from the following empirical relationship.

$$H = \frac{1.4754}{\log_{10}(\mathrm{Re}_\theta)} + 0.9698 \tag{37}$$

In some cases, the pressure gradient experienced by the laminar boundary layer is sufficient to cause it to separate prior to natural transition. The laminar boundary layer will either reattach as a turbulent boundary layer, allowing computations to proceed, or it will remain separated, in which case the boundary layer computation is terminated. In order to determine which, if either, of these cases occurs, the following empirical relationship between local Reynolds number and the pressure gradient parameter K is used[13].

$$\begin{aligned} K &= 0.0227 - 0.0007575 * \mathrm{Re}_\theta - 0.000001157 * \mathrm{Re}_\theta^2 \qquad (\mathrm{Re}_\theta \ge 125) \\ K &= -0.09 \qquad (\mathrm{Re}_\theta < 125) \end{aligned} \tag{38}$$

Note that the first term on the right hand side of equation 38 was erroneously reported as being 0.27 in reference 13 and the correct value given here (0.0227) was obtained from the actual computer code described in reference 5. Separation occurs whenever K as computed using equation 18 becomes less than –0.09. No reattachment occurs if the K computed using equation 18 is less than the K computed using equation 38. If reattachment is predicted, the turbulent boundary layer computation is started at the point of separation using the momentum thickness and shape factor (given by eq. 37) at that point as initial values. No attempt is made to model laminar separation bubbles. The laminar boundary layer is checked for separation at each point prior to performing the tests for transition.

Turbulent Boundary Layer Model – The turbulent boundary layer computation is based on the Nash-Hicks model[17]. This method has been shown to be robust and accurate for a wide variety of turbulent boundary layers[18]. If the continuity equation is used to eliminate the component of velocity normal to the surface from the momentum equation, and the resulting equation is multiplied by ξ^{α} and then integrated across the boundary layer, a family of integral equations of the following form can be developed.

$$\int_0^{\delta}[u\frac{\partial u}{\partial \eta}-\frac{\partial u}{\partial \xi}\int_0^{\xi}\frac{\partial u}{\partial \eta}d\xi]\xi^{\alpha}d\xi=\frac{\delta^{\alpha+1}}{\alpha+1}U\frac{dU}{d\eta}+\frac{1}{\rho}\int_0^{\delta}\xi^{\alpha}\frac{\partial \tau}{\partial \xi}d\xi \tag{39}$$

Setting $\alpha = 0$ in equation 39 yields the momentum integral equation, while setting $\alpha = 1$ yields the moment of momentum integral equation. The velocity distribution across the boundary layer is assumed to be given by Coles' velocity profile family,

$$u(\eta,\xi)=\frac{u_{\tau}}{K}\left\{\ln\left(\frac{u_{\tau}\xi}{\nu}\right)+C\right\}+\frac{u_{\beta}}{2}\left\{1-\cos\left(\frac{\pi\xi}{\delta}\right)\right\} \tag{40}$$

where the wake function is approximated by a cosine distribution, K = 0.41, and C = 2.05. Equation 40 can be substituted into equation 39 and the integration performed to yield two equations of the form

$$F_1\frac{1}{\delta}\frac{d\delta}{d\eta}+F_2\frac{du_{\beta}}{d\eta}+F_3\frac{du_{\tau}}{d\eta}=F_4\frac{dU}{d\eta}+\Phi \tag{41}$$

A third equation of this form can be obtained by substituting $\xi = \delta$ in equation 40 and differentiating the equation with respect to η, which corresponds to the case $\alpha = \infty$. The coefficients F_n and the function Φ are given as follows:

$\alpha = 0$ (momentum equation)

$$
\begin{aligned}
F_1 &= \left[\frac{3}{8}u_\beta^2 - \frac{1}{2}Uu_\beta + 2\frac{u_\tau^2}{K^2} + 1.58949u_\beta\frac{u_\tau}{K} - \frac{Uu_\tau}{K}\right] \\
F_2 &= \left[\frac{3}{4}u_\beta - \frac{1}{2}U + 1.58949\frac{u_\tau}{K}\right] \\
F_3 &= \frac{1}{K}\left[4\frac{u_\tau}{K} + 1.58949u_\beta - U\right] \\
F_4 &= \left[u_\beta + 2\frac{u_\tau}{K}\right] \\
\Phi &= -\frac{u_\tau^2}{\delta}
\end{aligned}
\tag{42}
$$

$\alpha = 1$ (moment of momentum equation)

$$
\begin{aligned}
F_1 &= \left[\frac{3}{4}\frac{u_\tau^2}{K^2} - \frac{1}{2}\frac{u_\tau U}{K} + \frac{u_\tau u_\beta}{K}\left(\frac{3}{4} + \frac{2}{\pi^2} - 0.16701\right) + u_\beta^2\left(\frac{5}{16} - \frac{1}{\pi^2}\right) - Uu_\beta\left(\frac{1}{2} - \frac{2}{\pi^2}\right)\right] \\
F_2 &= \left[\frac{u_\tau}{K}\left(\frac{3}{8} + \frac{2}{\pi^2} - \frac{0.16701}{2}\right) + u_\beta\left(\frac{1}{2} - \frac{2}{\pi^2}\right) - U\left(\frac{1}{4} - \frac{1}{\pi^2}\right)\right] \\
F_3 &= \frac{1}{K}\left[\frac{u_\tau}{K} - \frac{U}{4} + u_\beta\left(\frac{5}{8} + \frac{2}{\pi^2} - \frac{3*0.16701}{2}\right)\right] \\
F_4 &= \left[\frac{3}{4}\frac{u_\tau}{K} + u_\beta\left(\frac{3}{4} - \frac{3}{\pi^2}\right)\right] \\
\Phi &= -\frac{1}{\delta^2}\int_0^\delta \frac{\tau}{\rho}d\xi = -\frac{1}{2}C_\tau\frac{U^2}{\delta}
\end{aligned}
\tag{43}
$$

$\dot{\alpha} = \infty$ (differentiated skin friction law)

$$
\begin{aligned}
F_1 &= \frac{u_\tau}{K} \\
F_2 &= 1.0 \\
F_3 &= \frac{1}{K}\left[\ln\left(\frac{u_\tau \delta}{\nu}\right) + 1.0 + C\right] \\
F_4 &= 1.0 \\
\Phi &= 0.0
\end{aligned}
\tag{44}
$$

An additional relationship is needed in order to close the set of three equations represented by equation 41. In order to evaluate the Φ term in equation 43, the shear stress coefficient is assumed to satisfy the following equation

$$\frac{dC_\tau}{d\eta} = \frac{\lambda}{\delta}\left(\hat{C}_\tau - C_\tau\right) \tag{45}$$

where

$$C_\tau = \frac{1}{\frac{1}{2}\rho U^2 \delta}\int_0^\delta \tau \, d\xi \tag{46}$$

The parameters λ and $\hat{C}_\tau$ in equation 45 were determined experimentally and are given below.

$$
\begin{aligned}
\lambda &= 0.15 \\
\hat{C}_\tau &= 0.025\left(1.0 - \frac{1.0}{H}\right)^2
\end{aligned}
\tag{47}
$$

The turbulent boundary layer solution is marched downstream from the starting point using initial conditions given by the transition analysis. H from equation 37 is used to determine $\hat{C}_\tau$ and C_τ is taken to be equal to $\hat{C}_\tau$ at the starting point. The initial value of δ^* is determined from H and θ given by the transition analysis. Using the definition of u_τ and the value of C_f at the transition point, an initial guess for u_τ is made. Using the initial guess for u_τ, equation 40 evaluated at δ, and the following definitions of δ^* and θ (ref. 17)

$$
\begin{aligned}
\delta^* &= \delta\left[\frac{u_\tau}{KU} + \frac{u_\beta}{2U}\right] \\
\theta &= \delta^* - \delta\left[2\left(\frac{u_\tau}{KU}\right)^2 + \frac{3}{8}\left(\frac{u_\beta}{U}\right)^2 + 1.58949\frac{u_\tau u_\beta}{U^2}\right]
\end{aligned}
\tag{48}
$$

an iterative process can be used to determine the values of u_β, u_τ, and δ at the starting point.

As the solution is marched downstream, the derivatives at the current point are evaluated using equation 41 and equation 45. The values of δ, u_τ, u_β, and C_τ are then evaluated at the next point using a predictor-corrector scheme and the solution is advanced to the next point. At each point, the remaining boundary layer parameters can be computed using equation 48 and the definitions of H and C_f. The turbulent boundary layer analysis is terminated when turbulent separation is detected or when the end of the streamline is reached. Turbulent separation occurs when u_τ goes to zero.

Off-body Analysis

PMARC has the capability of computing the velocity at arbitrary points in the flow field. The velocities at points off the body are evaluated by taking the gradient of equation 10 with respect to the coordinates of point P. Thus equation 10 becomes

$$\overline{V}_P = -\iint_S \mu \nabla \left(\overline{n} \cdot \nabla\left(\frac{1}{\overline{r}}\right)\right) dS - \iint_S \sigma \nabla\left(\frac{1}{\overline{r}}\right) dS - \iint_W \mu_W \nabla\left(\overline{n} \cdot \nabla\left(\frac{1}{\overline{r}}\right)\right) dS + \overline{V}_\infty \tag{49}$$

Equation 49 can also be written in discretized form similar to the equation for the potential at point P. The resulting discretized equation is

$$\overline{V}_P = \overline{V}_\infty - \sum_{K=1}^{N_S}\left(\mu_K \ \overline{V}_{\mu PK}\right) - \sum_{L=1}^{N_W}\left(\mu_{W_L} \ \overline{V}_{\mu PL}\right) - \sum_{K=1}^{N_S}\left(\sigma_K \ \overline{V}_{\sigma PK}\right) \tag{50}$$

where

$$\overline{V}_{\sigma PK} = \iint_K \nabla\left(\frac{1}{\overline{r}}\right) dS \tag{51}$$

and

$$\overline{V}_{\mu PK} = \iint_K \nabla\left(\overline{n} \cdot \nabla\left(\frac{1}{\overline{r}}\right)\right) dS \tag{52}$$

The coefficients $\overline{V}_{\sigma PK}$ and $\overline{V}_{\mu PK}$ represent the velocity influence coefficients per unit singularity strength for panel K (surface or wake panel) acting on the point P. The velocity influence coefficients depend only on the geometry of the configuration and its wakes. The solution to equations 51 and 52 can be found in references 7 and 8. As with the velocity potential influence coefficients, the far-field approximation is employed in computing the velocity influence coefficients for the source distribution ($\overline{V}_{\sigma PK}$).

The doublet distribution on the surface, which is constant on each panel, can be replaced by a set of vortex rings around the perimeter of each panel with strength equal to the doublet strength on the panel. Therefore, the velocity induced at a point P by the doublet distribution can be computed using the vector form of the Biot-Savart Law for the velocity induced at a point by a vortex line element. For a linear vortex element, the velocity induced at point P is given by

$$\overline{V}_{P_i} = \frac{\overline{a} \times \overline{b} * (A + B)}{A * B * \left(A * B + \overline{a} \cdot \overline{b}\right)} * \mu_i \tag{53}$$

where $\bar{a}$ is the vector from the initial endpoint of panel edge i to point P, $\bar{b}$ is the vector from the terminal endpoint of panel edge i to point P, A and B are the lengths of vectors $\bar{a}$ and $\bar{b}$ respectively, and μ_i is the strength of the vortex line element, which in PMARC is simply the difference in the doublet strengths for the two panels which share the panel edge. The total velocity induced at point P by the doublet distribution on all surface and wake panels is then found by summing the contributions from all panel edges.

Equation 53 is singular if the point P lies on the vortex line element (i.e., the panel edge). This situation is avoided by establishing a vortex core radius. The vortex core radius for surface panels (RCORES) and wake panels (RCOREW) can be set by the user in the input file (see appendix C). If a vortex line element (panel edge) is located within a distance less than the core radius from point P, the contribution to the velocity vector at point P due to that vortex element is set to zero. The vortex core radius entered in the input file is expressed as a fraction of the reference chord (CBAR).

If the distance between point P and the surface of the body or wake is sufficiently large, the doublet distribution on the surface, which is constant on each panel and varies from panel to panel, appears as a continuous doublet distribution on the surface in terms of its influence on the velocity at point P. When point P is close to the surface of the body or wake, however, the individual panel edges have a strong influence on the velocity induced at point P. If point P is traversed at a constant height over the surface, the velocity at point P will oscillate in sawtooth fashion with peaks in velocity occurring as point P passes over each panel edge. This phenomenon is typical of low-order panel methods and becomes evident when the distance between point P and the surface of the body or wake is less than one panel width. The panel width is defined as twice the distance from the panel centroid to the midpoint of the panel edge whose influence on the velocity at point P is being computed.

A near-field velocity calculation routine is included in PMARC to improve the accuracy of velocity calculations for points P that are near the surface of the body or wake. The approach used for the near-field velocity calculation routine in PMARC is similar to that presented in reference 19. For points P that are identified as being in the near field of a vortex line element (panel edge), the vortex line element is replaced with a set of vortex line elements distributed uniformly over the two panels sharing the common panel edge. The strengths of the distributed set of vortex line elements on each panel are determined using the following fourth order polynomial curve

$$\Gamma_i = \left\{ \left[3 - 2\frac{(i-0.5)}{n} \right] + \left[\frac{4}{5} - \frac{28}{15}\frac{(i-0.5)}{n} + \left(\frac{(i-0.5)}{n} \right)^2 \right] C_1 \right\} \left(\frac{(i-0.5)}{n} \right)^2 \frac{\Gamma_0}{n} \tag{54}$$

where n is the total number vortex line elements used to represent the original single vortex line element, Γ_0 is the strength of the original vortex line element, i is an index which runs from 1 to n, Γ_i is the strength of the ith vortex line element, and C_1 is a numeric constant. The value of C_1 was determined using the analytical solution for the potential flow over a circular cylinder as a calibration. The near-field velocity calculation routine can be turned on or off by means of a variable (NF) in the input file. Equations 50 through 54 are used for computing velocities at scan points, computing off-body streamlines, and for convecting the time-stepping wake with the local perturbation velocity due to the presence of the bodies and wakes.

PMARC has an intersection subroutine that checks to see if a point (velocity scan point, off-body streamline point, or wake point) is inside the paneled surface or outside. If the point is a velocity scan point and the point is inside a paneled surface, the velocity at that point is set to zero. If the point is an off-body streamline point or a wake point, then the point is moved outside the body by moving it along a vector parallel to the surface normal vector of the surface panel closest to the point. The velocity is then computed at that point using the equations given above. The intersection routine can be turned on or off for individual wakes, off-body streamlines, and velocity scan volumes at the user's discretion. Since the intersection routine is computationally intensive, it should be turned off unless it is needed.

Internal Flow Model

PMARC currently supports modeling of internal flows[20, 21]. This is accomplished by modeling the internal flow geometry as a closed surface with the panel normal vectors pointing into the interior of the enclosing surface. For internal flows, the doublet influence coefficient matrix is singular in its conventional form[22]. This is because the potential function for internal flow geometries is known only to within an arbitrary constant, whereas for external flow geometries the arbitrary constant is determined by the potential at infinity (ϕ_∞). In order to circumvent this problem, the potential (or a doublet value) must be specified somewhere on the geometry as a boundary condition. Normally, the source values for all the panels are known on a geometry surface (eq. 8) and the doublet values are solved for as in equation 11. For internal flows, the matrix singularity can be eliminated by arbitrary specification of the tangential component of velocity somewhere on the surface. This is equivalent to specifying the doublet distribution somewhere on the surface. One place the tangential velocity distribution (and hence the doublet distribution) can be prescribed is on an inflow or outflow boundary. If an inflow or outflow boundary is attached to a section of duct with constant cross section, then the tangential velocity on that inflow or outflow boundary is by definition zero and thus the doublet gradient is also zero. The user specifies the normal velocity on either the inflow or outflow surface and specifies zero tangential velocity on the remaining surface. PMARC then computes the normal velocity on that surface which satisfies continuity. In the matrix equation, the known doublet values are substituted into equation 11 and the corresponding source values on the panels are treated as unknowns to be solved for. For example, assuming a known doublet value is specified on the first panel, equation 11 can be rewritten to yield

$$\begin{bmatrix} B_{11} & C_{12} & C_{13} & \cdots \\ B_{21} & C_{22} & C_{23} & \cdots \\ B_{31} & C_{32} & C_{33} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \mu_2 \\ \mu_3 \\ \vdots \end{bmatrix} = \begin{bmatrix} C_{11} & B_{12} & B_{13} & \cdots \\ C_{21} & B_{22} & B_{23} & \cdots \\ C_{31} & B_{32} & B_{33} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \begin{bmatrix} -\mu_1 \\ -\sigma_2 \\ -\sigma_3 \\ \vdots \end{bmatrix} \tag{55}$$

The solution of equation 53 yields the source value (σ_1) for the panel on which the doublet (μ_1) is prescribed.

The value of the free-stream velocity vector can have an effect on the solution for internal flow problems. For internal flow problems, the free-stream velocity merely sets the boundary condition for the problem. The entire internal flow geometry can be pictured as being embedded in a uniform velocity field with magnitude and direction set by the free-stream velocity vector. Source strengths on all the panels are determined by the free-stream velocity vector and any user-defined normal velocities using equation 8. The solution to equation 11 provides the doublet strengths on all panels required to perturb the uniform velocity field such that the flow within the internal flow geometry satisfies all imposed boundary conditions. If the free-stream velocity vector input by the user differs significantly from the value of normal velocity computed by PMARC on the inflow or outflow boundary where the zero tangential velocity boundary condition has been imposed, a large jump in doublet strength will result between the inflow or outflow boundary and the tunnel or duct walls adjacent to that boundary. The large jump in doublet strength results from the requirement that the uniform velocity field must be perturbed to match the velocity at the inflow or outflow boundary. The effect of a large jump in doublet strength between the inflow or outflow boundary and the tunnel or duct walls adjacent to that boundary is to distort the normal velocity distribution computed by PMARC on that boundary. While the integrated normal velocity on the inflow or outflow boundary will satisfy continuity for the internal flow geometry, the distribution of normal velocity may be grossly distorted. To avoid this situation, the free-stream velocity vector should be set to match the normal velocity which satisfies continuity on the inflow or outflow boundary where the zero tangential velocity boundary condition has been imposed. This value of normal velocity can be easily computed prior to running PMARC using the incompressible continuity equation.

When using a low-order potential flow method for internal flow problems, there is a certain amount of leakage in or out of the internal flow geometry. This leakage is due to the Neumann boundary condition for each panel being imposed only at panel control points[20]. The leakage from an internal flow geometry can be reduced to nearly zero by a combination of two methods. The first method has the largest effect on the leakage from an internal flow geometry. It is to turn off the far-field approximation, which is used to reduce computation time, so that all influence coefficients are evaluated using the exact integral equations rather than approximating panels that are far away as point sources and doublets. This provides the maximum accuracy for the computation of the influence coefficients. PMARC automatically turns off the far-field approximation when a geometry has been identified as an internal flow geometry, regardless of what has been entered for the RFF variable (see detailed input guide, appendix C) in the input file. The second method, which can be used as needed if leakage is a problem, is to increase panel density on the tunnel or duct walls. This is most effective in regions where the cross-sectional area is varying rapidly, such as a region where the duct is contracting or expanding.

Special care needs to be taken when including any kind of body, such as a wing, inside an internal flow geometry which does not have a constant cross section (i.e., the cross-sectional area or shape of the duct varies in the streamwise direction). The doublet strengths computed by PMARC for such an internal flow geometry are typically very large (2 or more orders of magnitude larger) compared to a normal external flow geometry. For example, the computed doublets on the panels of a wing in an external flow may have strengths of order 0.1 while the computed doublets on the panels of the same wing inside an internal flow geometry may have strengths of order 10 or more. This is because much larger doublet strengths are required to perturb the initial uniform velocity field to satisfy the imposed boundary conditions for the internal flow geometry. The principal consequence of the larger doublet strengths is that the solution is much more sensitive to imperfections in the paneling, such as gaps or overlaps, and to sudden changes in panel density. Any bodies included inside an internal flow geometry should be modeled carefully, avoiding any gaps or overlaps in paneling. All changes in panel density should be accomplished smoothly and not abruptly. All bodies should consist of completely closed surfaces (i.e., no open tips on wings). A sample input file for an internal flow geometry with a wing inside it is included in appendix E for reference.

The CZDUB parameter in the input file can be used to minimize the doublet strengths on a body inside an internal flow geometry, which will alleviate the sensitivity to imperfections in the paneling. This parameter is used to set the doublet strength on the inflow or outflow boundary which carries the zero tangential velocity boundary condition, and has the effect of shifting or offsetting the doublet solution for the entire problem. Thus it can be used to offset the doublet solution such that the doublets on the body enclosed in the internal flow geometry are relatively small.

DATA MANAGEMENT

One of the keys to the success or failure of any numerical method is how well data is managed within the code. In a panel code there are many large arrays and blocks of data that need to be manipulated within the code and written to output and plot files. If a good data management scheme is not implemented within the code, the code can quickly become too large, inefficient, and slow. A data management scheme has been devised for PMARC which seeks to maximize the number of panels the code can handle while minimizing the amount of memory and disk scratch space required to run the code. Specific aspects of the data management scheme include use of variable dimensioning for all major arrays within the code, provision of a reasonable balance between the amount of memory used and the amount of disk scratch space used, and elimination of redundancy of variables both within the code and in the plot file.

Code Sizing

PMARC was written using adjustable size arrays throughout the code. A set of parameter statements controls the dimensioning of all the arrays in PMARC (see appendix A). Integer limits for variables and loops within the code are also defined in terms of the parameter values. This eliminates the possibility of forgetting an array or limit in the redimensioning process. The parameter statements are all stored in a single file named PARAM.DAT, which is included in all necessary subroutines in PMARC through the use of INCLUDE statements. To change array dimensions in PMARC, the file PARAM.DAT must be edited and the appropriate parameter statements modified. For example, to change the number of surface panels PMARC can handle from 1000 to 4000, the parameter NSPDI = 1000 must be changed to NSPDIM = 4000. Once the changes have been made, the PMARC source code must be recompiled for the changes to become effective. Thus the size of the code (i.e., the number of panels it can handle) can be changed from several hundred to 10 or 20 thousand or more in a matter of minutes.

The main limitation on the number of panels the code can handle is the amount of memory and disk space available on the machine on which the code is being run. The parameter INRAM controls whether the doublet influence coefficient matrix used in the solver is stored on disk or in RAM. With INRAM = 1, the doublet influence coefficient matrix is stored on disk. The current version of PMARC dimensioned for 3000 panels and INRAM = 1 can be run with 5 Mb of memory and 125 Mb of disk space. If PMARC is dimensioned to handle 1000 panels with INRAM = 1, 3.5 Mb of memory and 16 Mb of disk space are required. Setting INRAM = NSPDIM stores the doublet influence coefficient matrix in RAM. PMARC dimensioned for 1000 panels with INRAM = NSPDIM requires 7.5 Mb of memory and 10 Mb of disk space. By selectively changing certain parameters, the user can increase the capacity of one particular part of the code, say the number of patches or wakes allowed, without having to increase the capacity of the entire code. This allows the users to customize the size of the code to fit their particular needs and hardware capacity.

The table in appendix B will give the user a feel for how changing the various parameter values in PMARC affect the amount of memory required for running the code. The information in appendix B relates to memory allocation for data storage only. A certain amount of memory is also required to store the code itself (the instruction set) and this will vary depending on the computer and the compiler used.

The amount of disk space required can be estimated using the following formulas:

INRAM = 1 disk space (bytes) = $NSPDIM^2 * 3 * RBYTES$

INRAM = NSPDIM disk space (bytes) = $NSPDIM^2 * 2 * RBYTES$

Additional disk space is required for storing the input, output, and plot files, but this is usually small compared to the amount required by the formulas above.

Plot File

The PMARC-native plot file is designed to contain as much information as possible regarding geometry and aerodynamic data in as compact a space as possible. The idea is to let PMARC do the computing and have a plotting package process and display the information. Computing should be kept to a minimum within the plotting package to keep its speed high. The general blocking of the data within the PMARC-native format plot file is shown in figure 3. The geometry data is written to the file first, including the initial position and orientation of all path coordinate systems. The initial geometry data is outside the wake time-step loop. The position and orientation of all path coordinate systems is written at each time step so that the initial geometry data can be transformed (by a post-processing package) into the correct position and orientation for each time step. By always transforming the initial geometry data to the current position and orientation using the path coordinate systems, cumulative errors are avoided. A block of wake and aerodynamic data is also written for each wake time step. The on-body streamline, off-body velocity scan, and off-body streamline data are appended to the wake and aerodynamic data block following the completion of the wake time-step loop.

The arrangement of the geometry data block is as follows. The first record contains the number 14 to identify this plotfile as a PMARC version 14 plotfile. The next record contains the length of the PMARC run, the number of time steps, the number of boundary layer iterations (currently set to zero as the boundary layer routines are currently only executed once after the on-body streamline routines), and the number of path coordinate systems. The next set of records contains the position and orientation of each path coordinate system in the inertial reference system. The next record contains the total number of patches in the geometry. This is followed by a set of pairs of records, one for each patch, containing the patch name on the first record and the number of columns and rows on the patch, the first and last panel number on the patch, and the path coordinate system to which this patch belongs on the second record. The next record after the patch data set contains the total number of panels in the geometry. Next, panel information is written, stepping through each patch, each column on each patch, and each row on each column (see figure 4 for patch nomenclature). Each record consists of the (x, y, z) coordinates of the first corner point of each panel, the coordinates of the panel centroid, and the panel normal vector at the panel centroid. At the end of each column of panels, an extra record must be included which contains the coordinates of the second corner point of the last panel in the column. After the data for the last column of panels has been written, an extra set of records is included to write the fourth corner point of the panels in the last column and the third corner point of the last panel in the last column. In this fashion all the corner points, centroids, and normal vectors are written to the plot file for each panel on each patch with no duplication within a patch. Following the corner point, centroid, and normal data is the panel neighbor data. Each record contains the neighbor panel number and the side of that neighbor panel adjacent to a given panel for each of the four sides of that panel.

Following the geometry data block is the initial wake data block. The initial wake data is written to the plot file in the same way as the geometry data. The only exceptions are that the path coordinate system to which each wake belongs is not written on the wake data record (since the wake coordinates are always in the inertial reference frame) and neighbor data is not written for wake panels. Thus the wake data includes wake panel corner points, centroids, and normal vectors.

The aerodynamic data block is written next. Aerodynamic data is written at the panel corner points and at the centroids using the same logic that is used to write the geometry and wake data. The aerodynamic quantities that are written to the plot file are doublet strength, the (x, y, z) components of velocity, the velocity magnitude, the pressure coefficient, and the local Mach number at each panel corner point and centroid. If the solution includes one or more time steps, the wake and aerodynamic data blocks, preceded by a set of records defining the current position and orientation of all path coordinate systems, are repeated for each time step.

The remainder of the data written to the plot file consists of optional data blocks. These include on-body streamline data, off-body velocity scan data, and off-body streamline data. The on-body and off-body streamline data sets include the number of lines, the number of points on each line, the (x, y, z) location of each point, the three velocity components and the velocity magnitude, the pressure coefficient, the local Mach number, and the arclength at each point on each streamline. The off-body velocity scan data consists of the number of rectangular volumes and the number of cylindrical volumes, and the number of points in the (**i, j, k**) directions within each volume. For each scan point the (x, y, z) location, the velocity components and magnitude, the pressure coefficient, and the local Mach number are written.

PMARC also supports plot file formats for other post-processing graphics packages. Currently, PMARC can output an ASCII plot file in the formats required for TecPlot version 7, which is a commercial graphics package developed by Amtec Engineering Inc., as well as for Plot3D, which is a graphics package developed by NASA. Both of these graphics packages are used extensively for post-processing computational fluid dynamics (CFD) data. The plot file in Plot3D format does not contain any of the optional data, such as on-body or off-body streamlines and off-body velocity scan data.

OVERVIEW OF PROGRAM INPUT

Geometry Modeling

PMARC has extensive built-in geometry modeling capabilities for handling complex, three-dimensional surfaces. As with all panel methods, the geometry is modeled by sets of panels. For convenience, the geometry is usually divided into several sets of panels called patches. Each patch is constructed from two or more sections. A section is a set of points defining a cross-sectional cut through the piece of geometry that the patch is modeling. Figure 4 shows the PMARC nomenclature and the conventions used for a patch. In general, each patch is four-sided; however, one or two sides of a patch may be of zero length (i.e., a point). A patch may also be folded over on itself so that opposing sides of the patch form a common line. For instance, wings are normally modeled with a folded patch with sides 2 and 4 meeting to form the trailing edge of the wing. The first section used to define a patch becomes side 1 of the patch. The direction of side 1 of the patch is the same as the direction of the first section definition. The direction of sides 2, 3, and 4 proceed counterclockwise around the patch when viewing the outer surface of the patch. The last section used to define a patch becomes side 3 of the patch. Columns of panels are established between sides 1 and 3 of the patch. Rows of panels are established between sides 2 and 4 of the patch. The sequence for panel numbering on a patch is as shown in figure 4.

One important factor to keep in mind when defining sections to create a patch is that the order of input determines whether or not the patch is "inside out" (i.e., the unit normal vector points into the interior of the model instead of out from the model). To determine whether or not a patch is inside out, a right hand rule can be used. If the fingers of the right hand are pointing in the direction of section definition, and the thumb of the right hand is pointing from the first section to the last section on the patch, the palm of the right hand will be resting on the outside surface of the patch. If a patch is inside out, it can be easily reversed using the patch reversal option on the PATCH1 namelist in the input file (see detailed input guide, appendix C).

Because PMARC is a low-order panel method, panels do not have to match exactly across patch boundaries. Small gaps and panel mismatches can be tolerated in PMARC; however, the panel mismatches should not be too severe or PMARC will have trouble computing the surface velocities near the patch boundaries. In general, it is best to provide smooth transitions in panel size and density between patches.

The hierarchy for modeling geometries in PMARC is shown in figure 5. There are several levels of geometry coordinate systems available in PMARC. The bottom level geometry coordinate system is the section coordinate system. The section coordinate system is used to define the sections that make up patches. The next level in the hierarchy is the component coordinate system. Above the component coordinate system is the assembly coordinate system. Finally at the top level of the hierarchy is the inertial reference coordinate system. Each coordinate system allows all the elements below it to be translated, rotated, and scaled. PMARC transfers all the panel corner points from the various coordinate systems into the inertial reference coordinate system for use within the code and for the output and plot files.

PMARC has the capability to automatically generate a closing tip patch on either side 1 or side 3 of a folded patch. Figure 6 illustrates a tip patch on a folded wing patch. The wing patch is folded such that side 2 and side 4 form a common trailing edge. The tip patch is then generated to close off side 3 of the wing. The input for generating a tip patch is given in the detailed input guide, appendix C. In order to form the tip patch, PMARC identifies the panel corner points on the side of the patch to be closed off. The total number of panel corner points is then divided in half. The first half of the corner points is used to form the first section of the tip patch and the second half of the corner points is used, in reverse order, to form the last section of the tip patch. In this way, the paneling on the tip patch matches exactly the paneling on the wing. The number of panels to be generated between the two sections of the tip patch is set by the user on the PATCH2 namelist (see detailed input guide, appendix C).

There are several other geometry generation options in PMARC including body of revolution, copying a previously defined patch with user-defined translation, rotation, and scaling, and generating symmetrical images of selected patches about the x-z plane of symmetry. The details on using these special options are given in the detailed input guide, appendix C.

PMARC can also read in corner point data for a set of patches which make up the geometry directly from an ASCII file written in Plot3D 3-D multi-grid whole format. In this case, the built-in geometry generation routines in PMARC are bypassed and the corner point arrays are loaded directly from the geometry definition file. This provides an easy path for importing geometries from other sources, such as CFD grids, CAD programs, or other panel codes, into PMARC. In addition, PMARC can output surface geometry corner points (and wake corner points) in either PMARC native format or Plot3D format. Thus imported geometry data can be written out in PMARC native format and the built-in geometry routines in PMARC can be used to further manipulate the data. PMARC geometry data can also be exported easily to other programs using the Plot3D file format. Thus many of the CFD grid-generation tools can be used to create or manipulate PMARC geometries.

Wake Modeling

As mentioned earlier, PMARC employs a time-stepping wake model. The wake is formed in the inertial coordinate system as the body from which the wake separates moves away from its initial position. A new row of wake panels is added to the wake at the wake separation line with each time step. The wake can be rigid, flexible, or a combination of the two. If the wake is flexible, it is deformed at each time step by the local velocity induced by the presence of all the bodies and wakes being modeled. The number of time steps and the step size are set by the user on the BINP5 namelist (see detailed input guide, appendix C). PMARC also allows an initial wake to be specified if desired. The time-stepping functions the same with or without an initial wake specified. The initial wake capability allows the user to look at steady-state problems without going through several time steps to reach the steady-state condition. A third option in PMARC is to have no wakes modeled. In this case a single WAKE1 namelist must be included in the input file to tell PMARC that there are no wakes.

Figure 7 shows the hierarchy for wake modeling in PMARC. If an initial wake is specified, section coordinate systems are used to define the wake sections. The wake section definitions are then transformed directly into the inertial reference coordinate system. If no initial wake is specified and the wake is time-stepped, then PMARC forms the wake directly in the inertial reference coordinate system as it goes through the time steps.

The first step in defining a wake (whether there is an initial wake specified or not) is to define the wake separation line. This is done on the WAKE2 namelist. The WAKE2 namelist identifies which patch a wake separates from. It also identifies the side (KWSIDE) of the patch which is parallel to the separation line and the row or column of panels within the patch that the wake separates from. The separation line can extend over the entire row or column of panels or can be limited to a subset of panels within the row or column. If the wake separates from more than one patch, a separate WAKE2 namelist must be included for each patch that the wake separates from (see detailed input guide, appendix C). The wake separation line will be in the same direction as the side KWSIDE. There will be one column of wake panels for each surface panel that the wake separates from. PMARC treats the wake separation line as the first section of the wake. Figure 8 shows the separation line for a wake separating from the trailing edge of a folded wing patch. In this case, the wake was defined to separate from side 2 of the patch. The wake could have been defined to separate from side 4 (since side 2 and side 4 form a common line) and the only difference would be that the direction of the separation line would be reversed.

If an initial wake is to be specified, at least one more section of the wake must be defined in addition to the separation line. Additional wake sections can be specified in the same manner as surface sections are (see detailed input guide, appendix C). There are two restrictions on wake section definitions. The first restriction is that the user-defined wake sections must all go in the same direction as the separation line, as shown in figure 8. The second restriction is that the total number of panels defined on each wake section must equal the total number of surface panels that the wake separates from. Aside from these restrictions, the wake sections can be defined to have any arbitrary shape and can be located anywhere in the inertial reference coordinate system the user chooses. PMARC forms the wake by fitting splines through corresponding panel corner points on all sections, starting from the first section (the wake separation line) and going to the last section. Thus an initial wake of arbitrary shape can be defined in much the same way a surface patch is defined.

As mentioned in the section on geometry modeling, PMARC can also import corner point data for wakes directly from a file written in Plot3D format. However, the wake separation line for each wake must also be defined in order to properly attach wakes to their corresponding surface patches. This is done by appending a set of WAKE2 namelists for each wake to the end of the Plot3D file. In addition, PMARC can output wake corner points in either PMARC native format or Plot3D format. Thus imported wake data can be written out in PMARC native format and the built-in wake generation routines in PMARC can be used to further manipulate the data. PMARC wake data can also be exported easily to other programs using the Plot3D file format.

On-body Streamlines

PMARC has the capability of computing streamlines on the body surface. The number of surface streamlines desired and a starting surface panel for each streamline must be specified. The streamlines are started from the centroid of the panel on which they begin. Care must be taken to ensure that surface streamlines are not started near a stagnation point on the surface as PMARC may have difficulty in starting the streamline calculation. The streamlines are then traced upstream and downstream until a stagnation point, an attachment line, or a wake separation line is encountered. Note that the streamline computation makes use of neighbor relationships between surface panels to trace the streamline upstream and downstream. If the neighbor relation has been cut for some reason between panels that the streamline needs to cross, the streamline computation in that direction will be terminated and a diagnostic message will be printed in the output file.

Off-body Velocity Scans

Once the doublet strengths have been determined and the on-body analysis has been completed, velocities can be computed at user-defined points in the flow field. Rectangular or cylindrical volumes of uniformly spaced scan points can be defined by the user. Either type of scan volume can be degenerated into planes, lines, or points. The velocity components, velocity magnitude, pressure coefficient, and Mach number are computed at every scan point.

The rectangular scan volume is specified in terms of three direction vectors (i, j, and k) all originating from a common point, as shown in figure 9. The length of each direction vector defines the corresponding length of that side of the scan volume. The number of points to be evenly distributed along each direction vector of the scan volume must be input. If zero is entered for the number of scan points along one direction vector, that side of the scan volume degenerates to zero length. For example, if zero were entered for the number of points in the k direction, the scan volume would degenerate into the plane of points defined by the i and j direction vectors. It is important to note that the specification of the i, j and k direction vectors is completely arbitrary. The i, j, and k direction vectors do not need to form an orthogonal set of vectors.

The cylindrical scan volume is specified in terms of a cylinder axis vector and a second vector used to define the plane from which angle of rotation is measured, as shown in figure 10. The cylinder axis vector and the second vector need not be orthogonal; PMARC uses the two vectors to construct a right-hand orthogonal coordinate system. The cylindrical scan volume can have any orientation desired in the inertial coordinate system. The beginning and ending radii and rotation angles are specified in the input file, while the length of the cylindrical scan volume is determined by the cylinder axis vector. The number of scan points to be distributed along the axial, radial, and angular directions must be specified in the input file. As with the rectangular scan volume, if zero is entered for the number of scan points along one direction, that side of the scan volume degenerates to zero length.

Off-body Streamlines

PMARC has the capability of computing streamlines in the flow field. A starting location for each streamline must be specified, as well as the distance upstream and downstream (measured along the streamline) the streamline calculation is to extend and the step size to be used. Streamlines that are started close to a stagnation streamline will tend to penetrate the body rather than go around the body unless the intersection routine is turned on. Since the intersection routine is computationally intensive, it should only be used for those streamlines that might penetrate a body.

TEST CASES

Test Case 1: Symmetric Wing/Body

A simple symmetric wing/body configuration was one of the test cases used to validate PMARC. The configuration selected was one for which extensive pressure data was available from wind tunnel tests and which was generic in nature[23]. The body has a circular cross section and a fineness ratio of 12 (the wind tunnel model was truncated at the trailing edge for mounting on a sting, yielding an effective fineness ratio of 10). The wing is mounted at the body centerline near the point of maximum thickness. The wing has a NACA 65A006 airfoil, an aspect ratio of 4.0, a taper ratio of 0.6, and is swept back 45° at the quarter chord.

The PMARC representation of the wing/body configuration is shown in figure 11. Only half of the configuration was modeled in PMARC. The other half of the configuration was simulated by reflecting the model across the plane of symmetry. The wing was represented with 300 panels: 15 panels in the chordwise direction on the upper and lower surface of the wing with denser spacing near the leading and trailing edges and 10 panels in the spanwise direction with denser spacing near the root and tip of the wing. The tip of the wing was closed off with a flat tip patch. The body was represented with 320 panels. The wing/body junction was modeled such that wing and body panels matched up exactly. An initial wake was attached to the trailing edge of the wing and to the aft fuselage and carried downstream 20 chord lengths. Ten time steps were specified to allow the wake to roll up. The input files for this test case can be found in appendix D.

A comparison of pressure coefficients from experimental data (ref. 23) and PMARC data at two spanwise stations on the wing is shown in figure 12. The model is at an angle of attack of 4°. Agreement between PMARC results and the experimental data is excellent. Figure 13 shows a comparison of pressure coefficients from experimental data and PMARC data along the centerline of the body. Again, the model is at an angle of attack of 4°. The PMARC results correlate well with the experimental data. There is some difference near the trailing edge of the body, but this can probably be attributed to the presence of the sting in the experimental results. The sting was not modeled in the PMARC analysis. Figure 13 also illustrates the importance of attaching a wake to the aft part of the body. Without a wake, the body carries no net lift. The experimental data shows that there is carryover lift from the wing to the body. By attaching a wake to the aft part of the body, the carryover lift is properly modeled.

Test Case 2: Cylinder/Near-Field Velocity

The test case used to validate the near-field velocity calculation routine was a circular cylinder. The longitudinal axis of the cylinder was perpendicular to the free-stream velocity vector. The cylinder had a radius of 1.0 and a length of 24.0. A plane of symmetry at $y = 0$ was used so that only half of the cylinder had to be modeled in PMARC. This test case was chosen because an analytical solution for the velocity distribution around a two-dimensional cylinder in a potential flow can be derived and used to validate the velocity distribution obtained from PMARC. The cylinder was modeled with 30 panels equally spaced around the circumference of the cylinder, 10 equally spaced divisions along the longitudinal axis of the cylinder between $y = 0.0$ and $y = 3.0$, and 10 divisions with full cosine spacing between $y = 3.0$ and $y = 12.0$. A semi-hemispherical cap is used to close off the end of the cylinder. The total number of panels used to represent the cylinder is 690. A cylindrical velocity scan plane was created at $y = 0.75$ (near the cylinder midpoint) where the flow is essentially two-dimensional. The cylindrical velocity scan plane starts at a radius of 1.01 from the center of the cylinder, extends to a radius of 1.21, and extends circumferentially from a theta of 180° to a theta of 360° (from forward to rear stagnation points over the upper half of the cylinder). The input files for this test case can be found in appendix E.

The x and z velocity component distributions over the cylinder at a radial distance of 1.01 as computed by PMARC with the near-field velocity routine turned off are shown in figures 14 and 15, respectively. The analytical solution is plotted for comparison. As can be seen, there are large oscillations in the velocity distribution computed by PMARC. This is typical of low-order panel methods. Because the constant doublet distribution on each panel is equivalent to a constant strength vortex ring around the perimeter of the panel, each panel edge becomes a vortex element. The singular nature of the vortex elements at the panel edges leads to the oscillatory velocity distributions observed in figures 14 and 15.

Figures 16 and 17 show, respectively, the x and z velocity component distributions over the cylinder at a radial distance of 1.01 as computed by PMARC with the near-field velocity routine turned on. Here it can be seen that the oscillations in the velocity component distributions computed by PMARC have been virtually eliminated and the PMARC solution agrees very closely with the analytic solution. Thus, the near-field velocity calculation routine allows accurate calculation of velocity at points that are very close to the surface of the body, eliminating one of the limitations of low-order panel methods.

Test Case 3: Looping Wings/Relative Motion Capability

The relative motion capabilities of PMARC were subjected to validation efforts during the development of the prototype code. References 24 and 25 describe some of the validation work that was done for the relative motion capability. To demonstrate the relative motion capabilities of PMARC, a test case involving two wings flying through side-by-side loops in opposite directions was run. Each wing had a rectangular planform with a chord of 1.0, a span of 5.0, and a NACA 4412 airfoil. Each wing was represented with 300 panels: 15 panels in the chordwise direction on the upper and lower surface of the wing with denser spacing near the leading and trailing edges and 10 panels in the spanwise direction with denser spacing near the tips of the wing. The tips of each wing were closed off with rounded tip patches. The initial condition for each wing was straight and level flight in opposite directions at an angle of attack of 0°. An initial wake with a length of 20 chords was attached to each wing. The two wings are initially side by side with a separation distance of one chord length between them. The wings are time-stepped through a loop of radius 10.0. The time steps were halted when the wings had flown through approximately 324° of the loop to prevent the wings from intersecting their own wake. The rotation rate was 180°/sec and the time step size was 0.1 sec. Figure 18 shows the two wings with their developed wakes after 18 time steps. The input files for this test case can be found in appendix F.

A plot of lift coefficient versus angular position in the loop for the two wings is plotted in figure 19. The lift coefficient for each wing is identical at all angular positions and exhibits a cosine variation as a function of angular position, as would be expected. The lift coefficient ranges from 0.68 at the initiation of the loop to –0.68 at the top of the loop.

Test Case 4: Wing in Ground Effect

To demonstrate the ground-plane modeling capability of PMARC, a test case involving a wing flying at one height above the ground plane and then moving to a new, lower height above the ground plane, was run. The wing is rectangular in planform with a chord of 1.0, a span of 5.0, and a NACA 4412 airfoil. A plane of symmetry at $y = 0$ was used so that only half of the wing had to be modeled. The wing was represented with 300 panels: 15 panels in the chordwise direction on the upper and lower surface of the wing with denser spacing near the leading and trailing edges and 10 panels in the spanwise direction with denser spacing near the tip of the wing. The initial condition for the wing was level steady flight at an angle of attack of 4°. An initial wake with a length of 20 chord lengths was attached to the wing.

The path for the wing was defined using the PATHDEF.DAT file. The input files for this test case are included in appendix G for reference. The wing flies straight and level for three seconds, then proceeds on an 8° downward glide path for 4 seconds, and finally returns to straight and level flight at a new, lower altitude. At the beginning and end of the 8° downward glide path, the wing is rotated to maintain a constant effective angle of attack of 4°. The wing is stepped through 30 time steps, with a time-step size of 0.5 second. A plot of the variation in lift coefficient and nondimensional height above the ground plane as a function of time is shown in figure 20. The height of the wing above the ground plane starts at $z/c = 0.75$ and is reduced to $z/c = 0.25$. As the wing moves closer to the ground plane, the lift coefficient increases from 0.35 to 0.45. Experimental data on the effect of ground proximity on the lift coefficient slope of rectangular wings presented in reference 26 indicates that for a rectangular wing with aspect ratio of 5.0 moving from $z/c = 0.75$ to $z/c = 0.5$, the increase in lift coefficient is 0.105. This agrees very well with the PMARC results shown in figure 20. The spikes in lift coefficient which appear at the beginning and end of the 8° downward glide path are the transients which result from the step change in path direction and geometric angle of attack of the wing.

Test Case 5: Boundary Layer on Swept Wing

The integral boundary layer routines used in PMARC are based on algorithms developed and validated in references 13–18. A test case involving the computation of boundary layer parameters over the upper surface of a swept wing was run to demonstrate the boundary layer routines in PMARC. The wing is swept 20° with a constant chord of 1.0, a semispan of 5.0, and a NACA 0012 airfoil. A plane of symmetry at $y = 0$ was used so that only half of the wing had to be modeled. The wing was represented with 1100 panels: 25 panels in the chordwise direction on the upper and lower surfaces of the wing with denser spacing near the leading and trailing edges and 20 panels in the spanwise direction with denser spacing near the tip of the wing. The wing was in level steady flight at an angle of attack of 4°. An initial wake with a length of 20 chord lengths was attached to the wing.

The variation of displacement thickness, momentum thickness, and skin friction coefficient with chordwise location on the airfoil is shown in figures 21, 22, and 23, respectively. The boundary layer parameters were computed along an upper surface streamline located at approximately $2y/b = 0.35$ at a Reynolds number of 2×10^6. Transition occurs at approximately $x/c = 0.063$, just after the peak pressure coefficient at the leading edge. The boundary layer remains attached all the way to the wing trailing edge.

CONCLUDING REMARKS

The theoretical basis for PMARC, a low-order potential-flow panel code for modeling complex three-dimensional geometries, has been outlined. Some of the advanced features currently included in the code, such as internal flow modeling and a time-stepping wake model which permits analysis of unsteady motions, including problems involving relative motion, have been discussed in some detail. The code was written using adjustable size arrays so that it can be easily redimensioned for the size problem being solved and the computer hardware being used. An overview of the program input was presented, with a detailed description of the input available in the appendices. Finally, PMARC results for a variety of test cases were presented and compared with experimental or analytical data where available. The input files for these test cases are given in the appendices.

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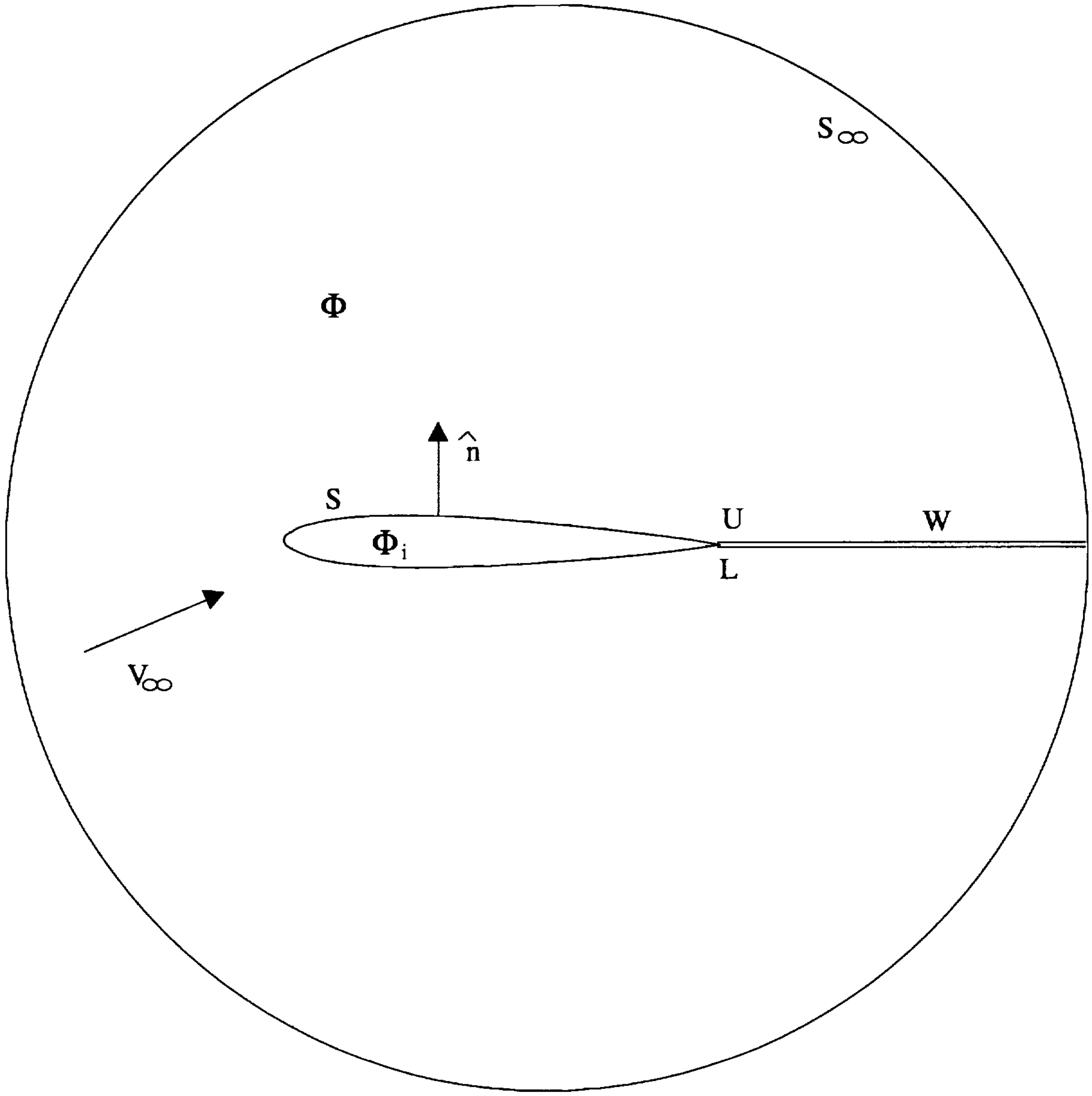


Figure 1.- Potential flow model for PMARC.

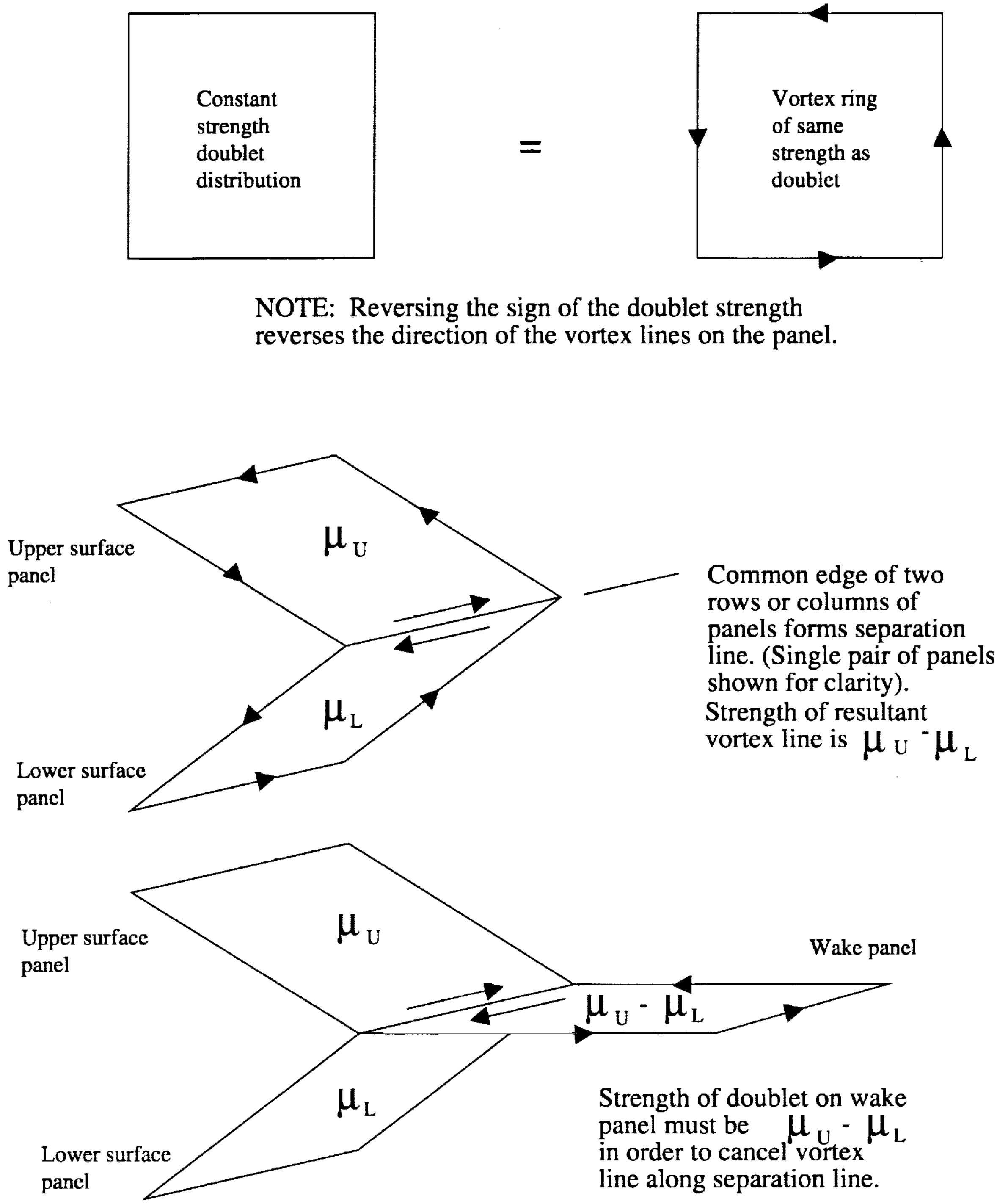


Figure 2.- Determination of doublet strength shed into wake.

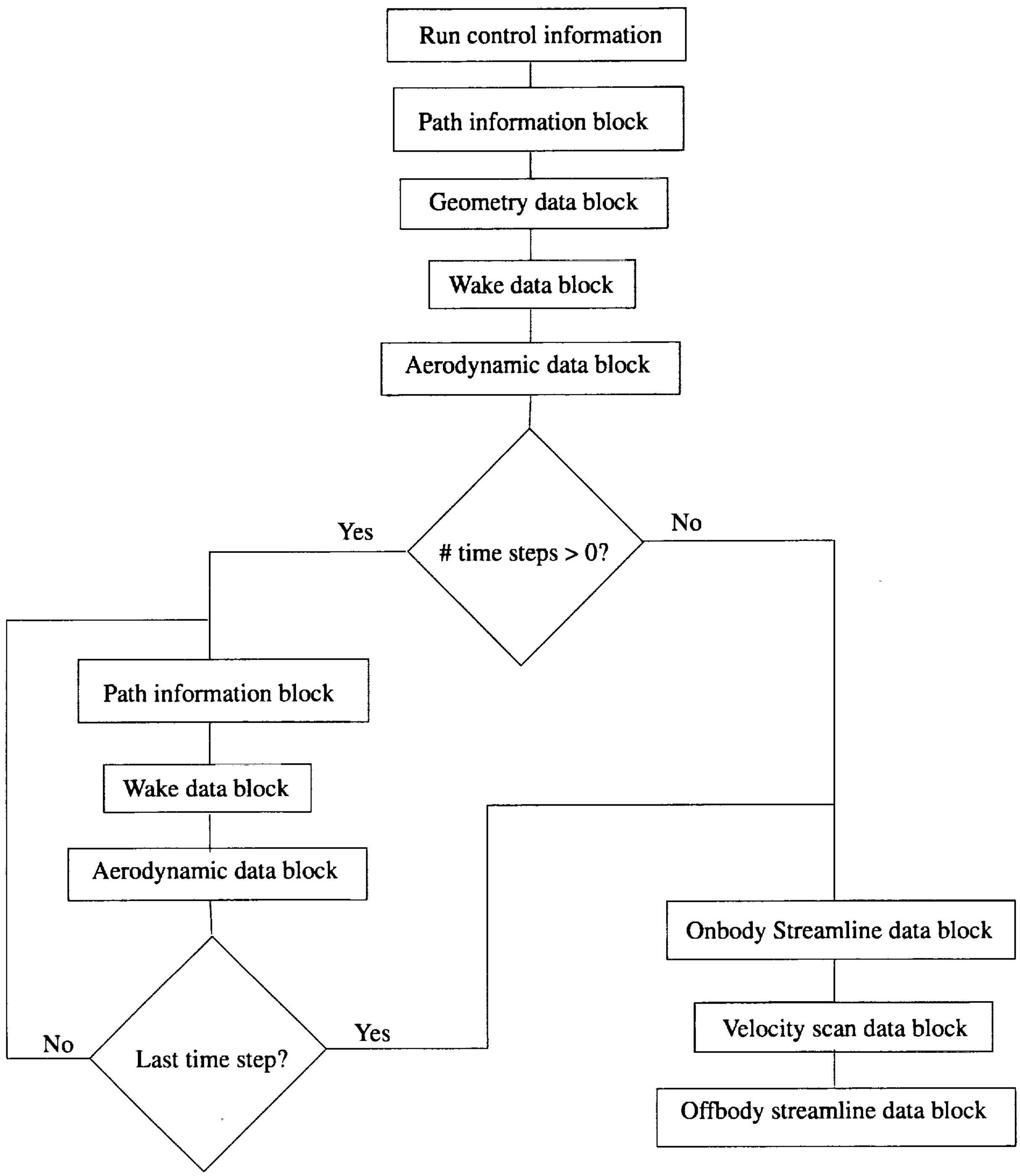
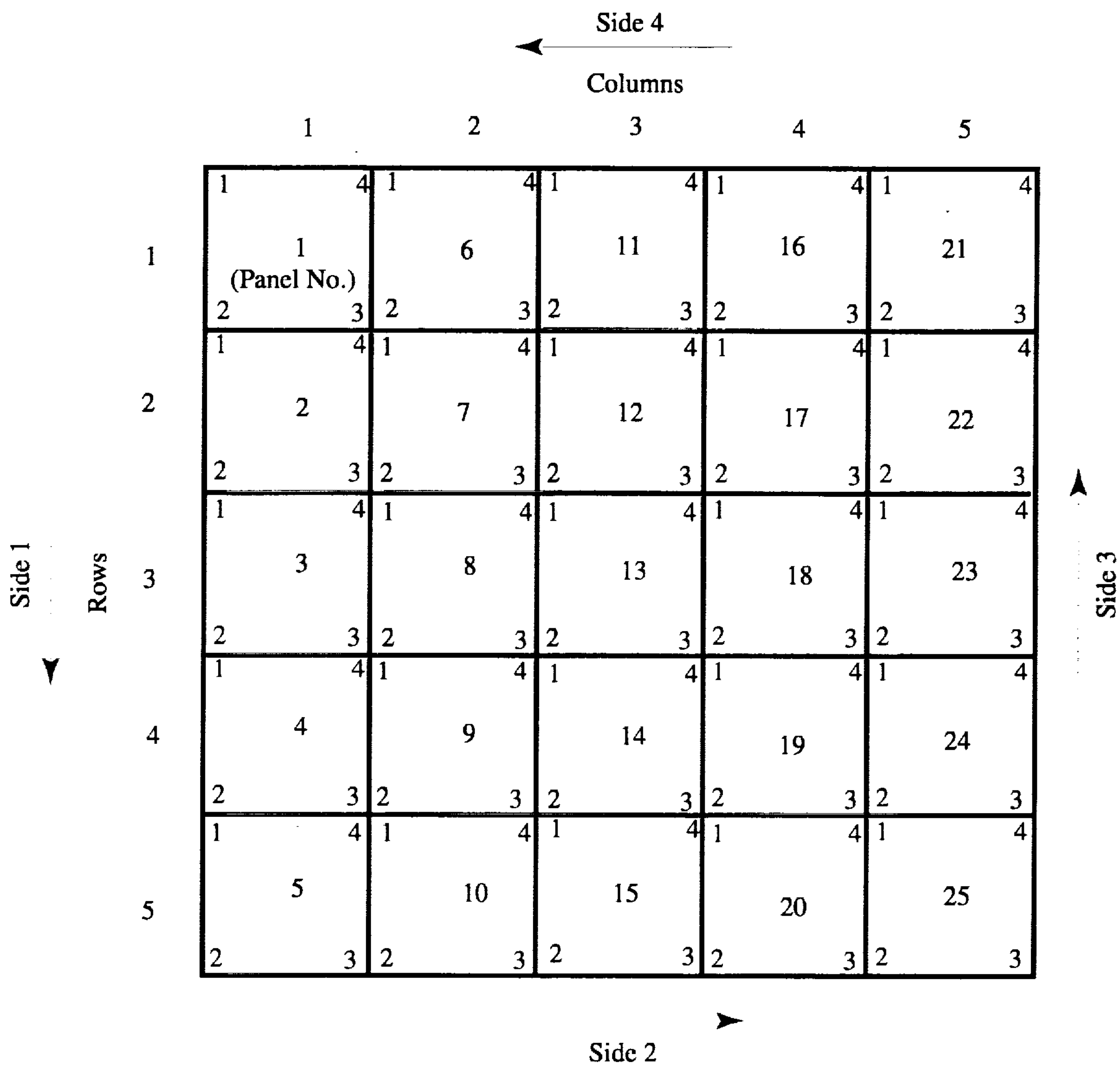


Figure 3.- Data arrangement within PMARC plot file.



Note: Sides of individual panels follow the same order and direction as the sides of the whole patch.

Figure 4. - PMARC surface patch nomenclature.

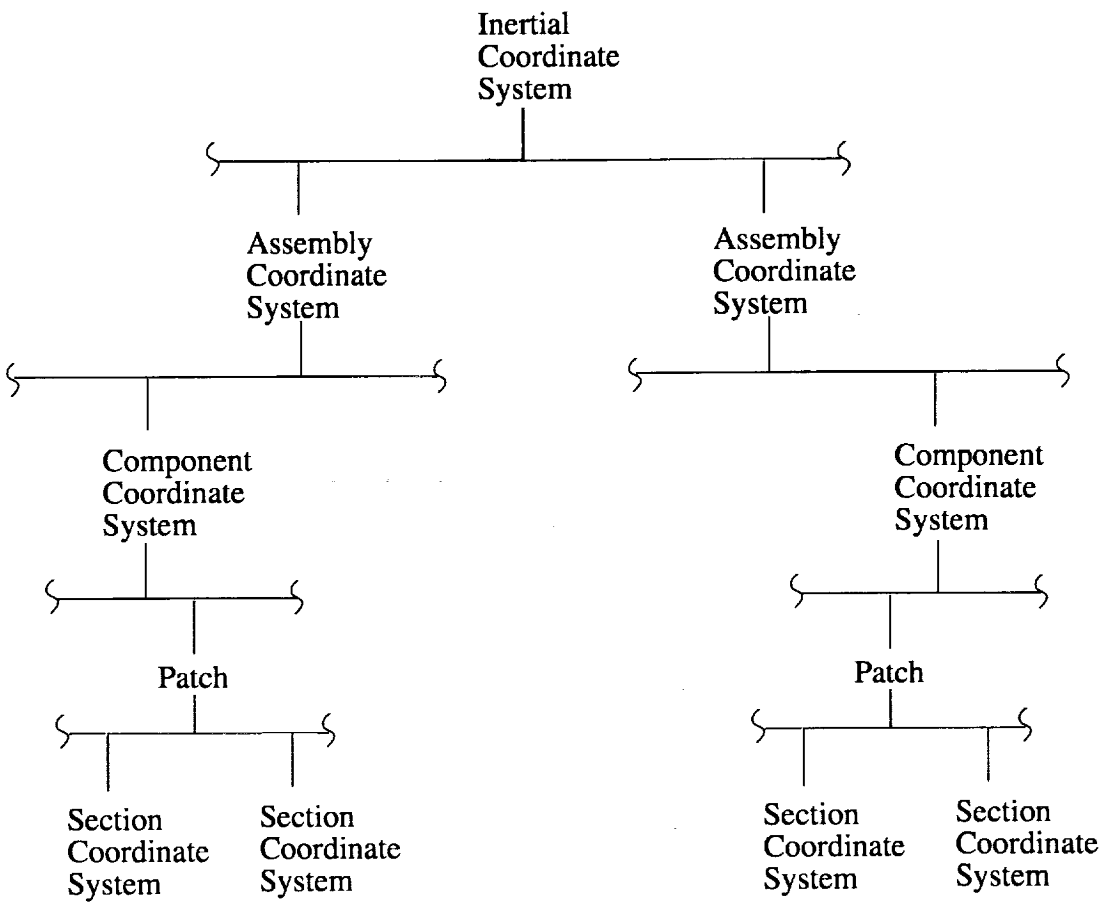
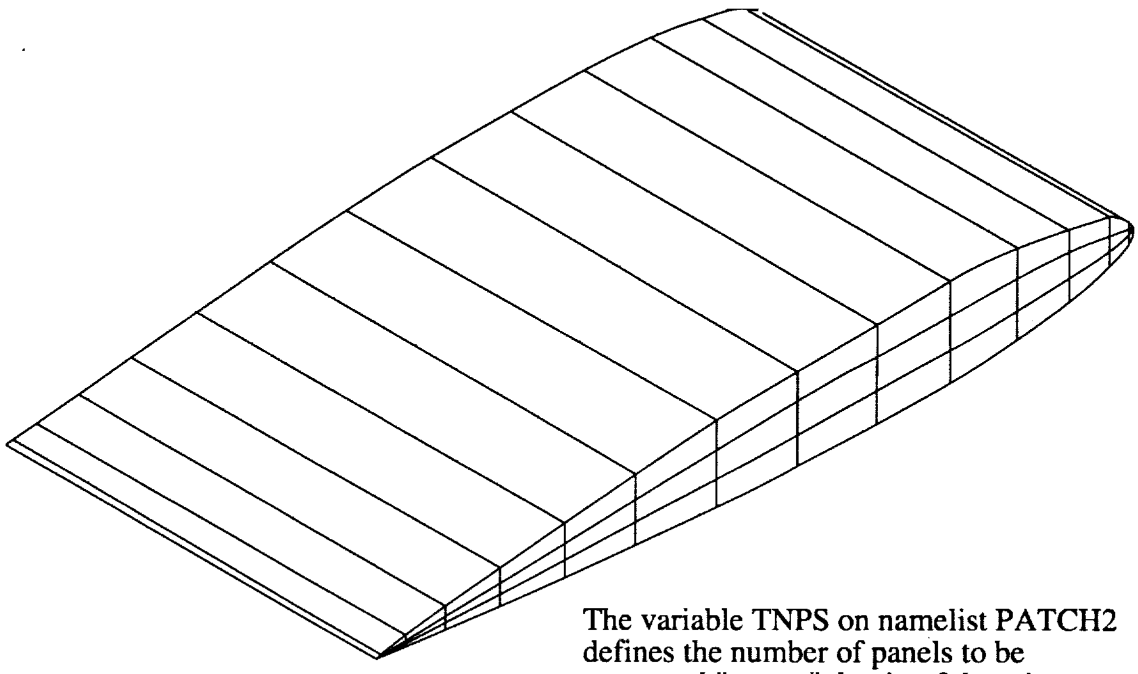
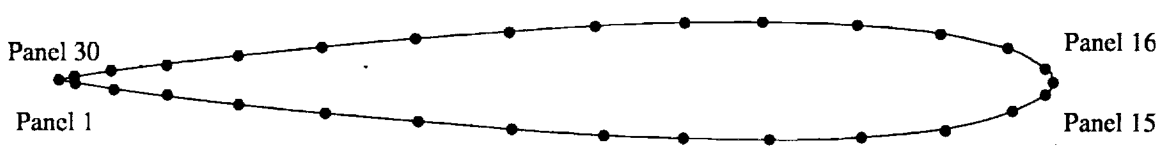


Figure 5.- PMARC surface geometry modeling hierarchy.



The variable TNPS on namelist PATCH2 defines the number of panels to be generated "across" the tip of the wing. (In this case, TNPS = 3).

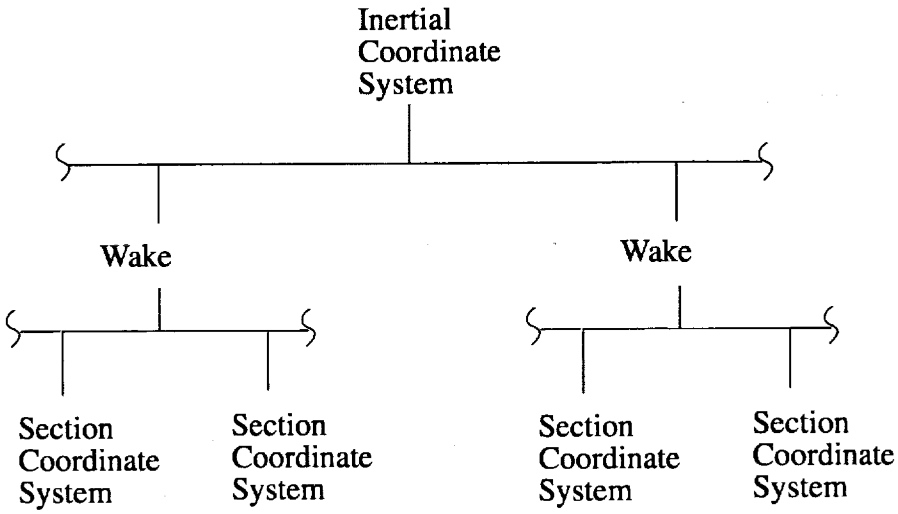
Side 3 of folded wing patch with 15 panels on both upper and lower surfaces.



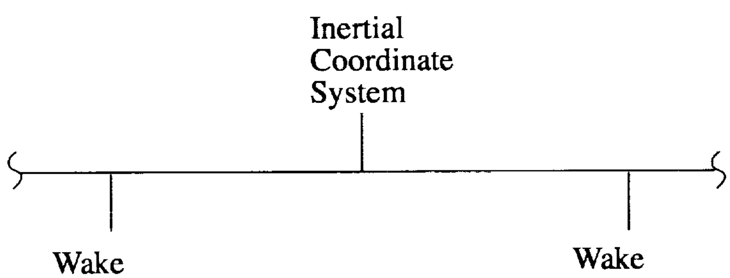
Corner points of panels 1 - 15 define first section of tip patch.

Corner points of panels 30 - 16 (note reverse order) define last section of tip patch.

Figure 6.- PMARC automatic tip patch option.



a) Initial wake defined



b) No initial wake defined (completely time-stepped wake)

Figure 7.- PMARC wake modeling hierarchy.

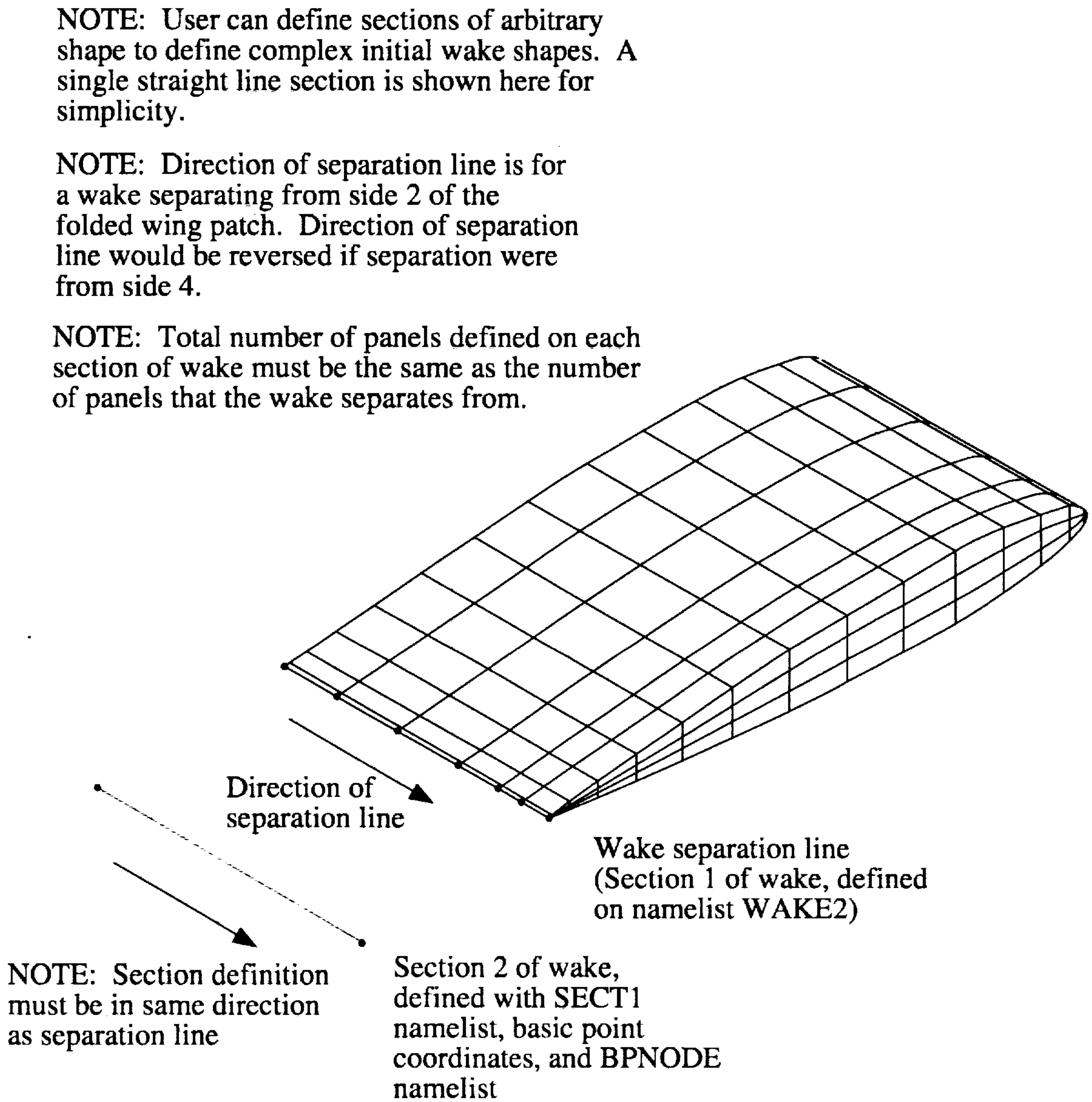


Figure 8.- PMARC wake modeling nomenclature.

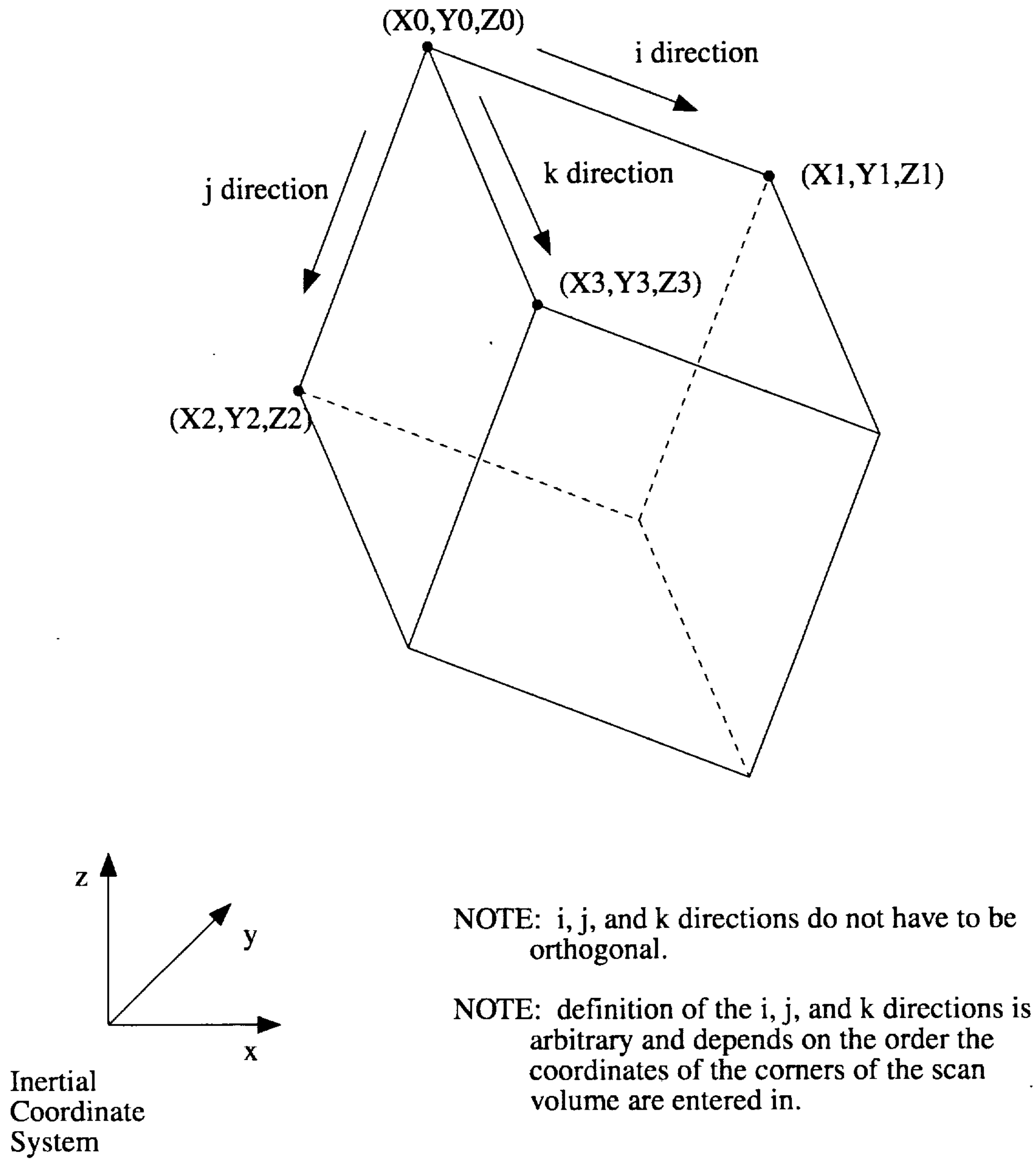
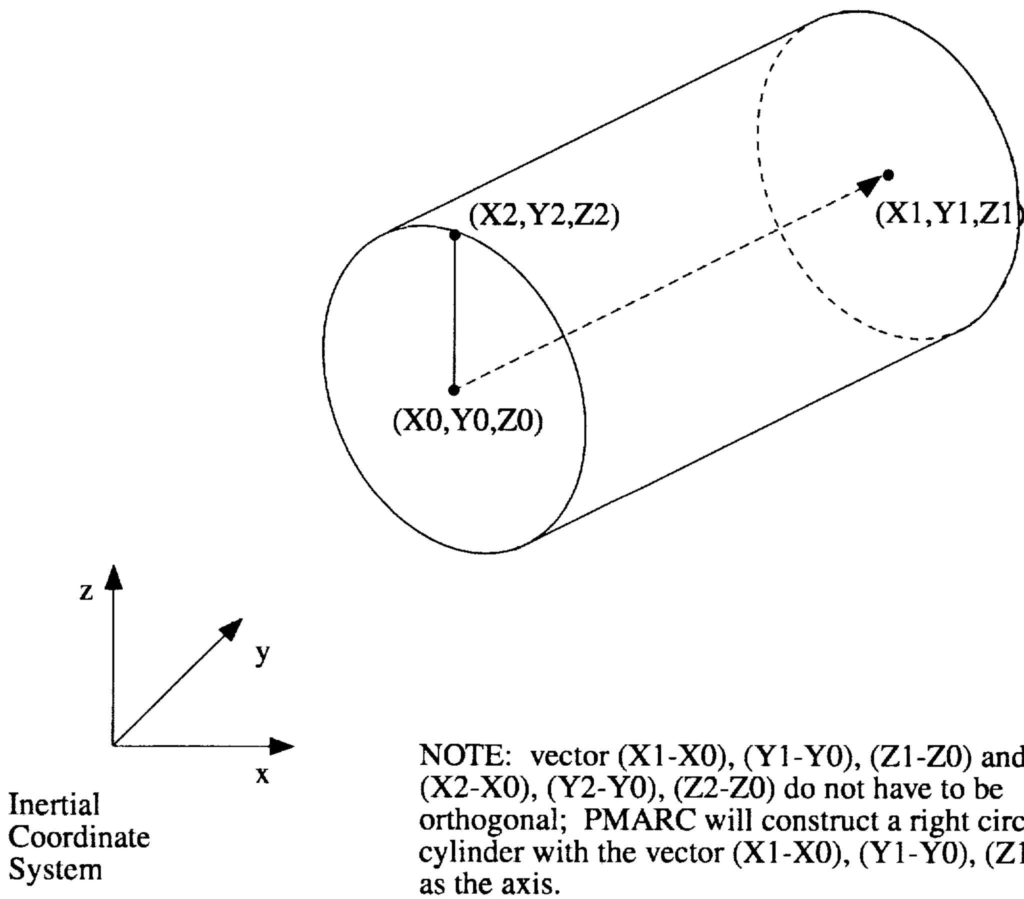


Figure 9.- Rectangular velocity scan volume nomenclature.



NOTE: vector (X1-X0), (Y1-Y0), (Z1-Z0) and vector (X2-X0), (Y2-Y0), (Z2-Z0) do not have to be orthogonal; PMARC will construct a right circular cylinder with the vector (X1-X0), (Y1-Y0), (Z1-Z0) as the axis.

NOTE: The angles PHI1 and PHI2 (from namelist VS8) are measured from the plane containing points 0, 1, and 2, with positive angles being defined by the Right Hand Rule about the cylinder axis.

Figure 10.- Cylindrical velocity scan volume nomenclature.

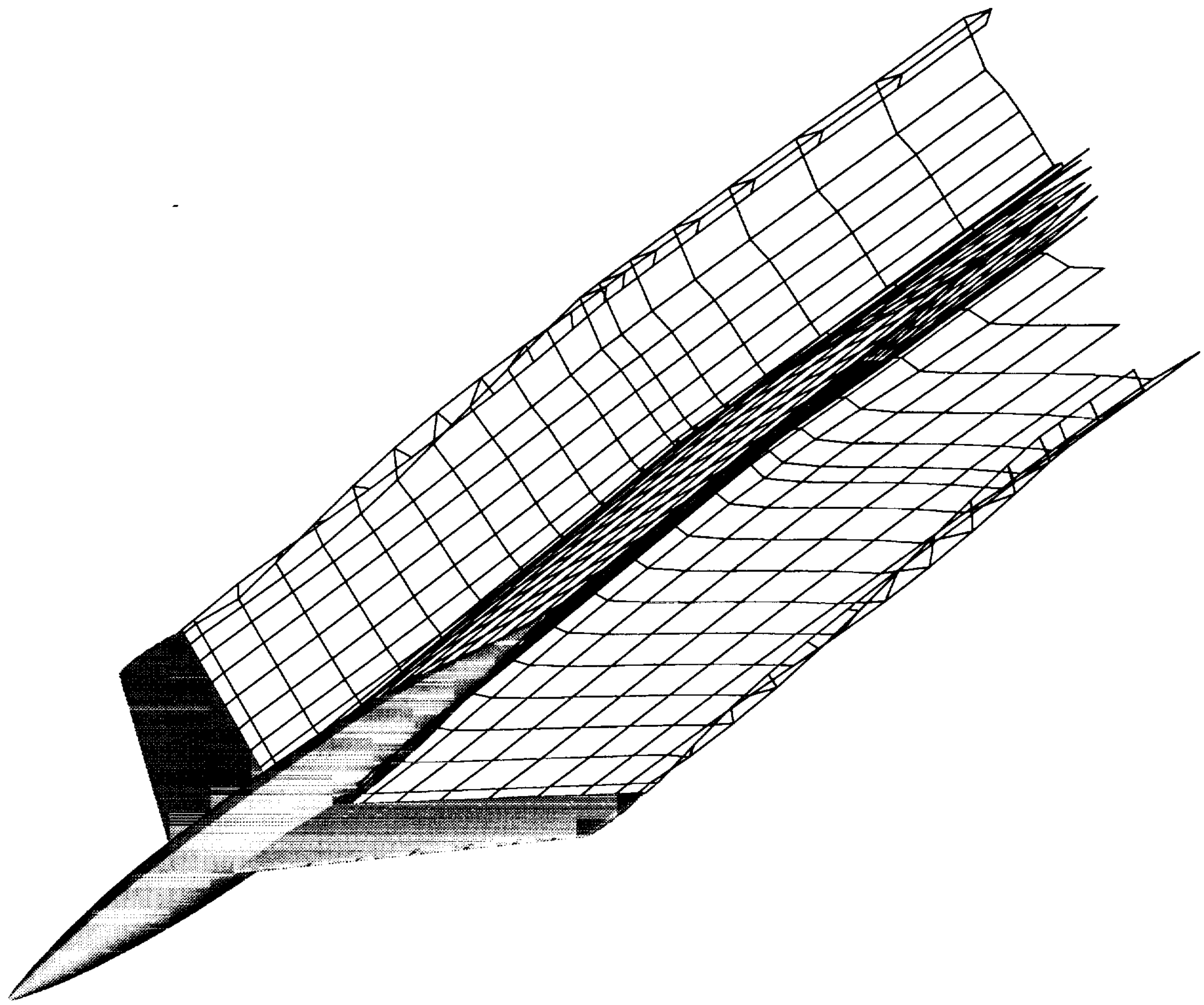
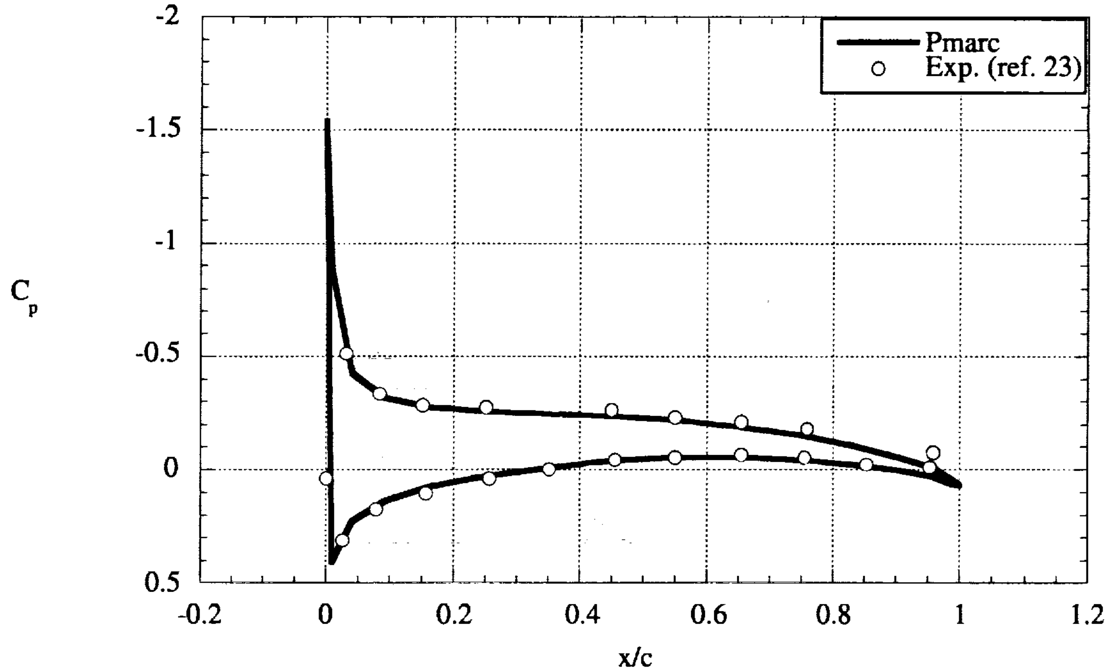
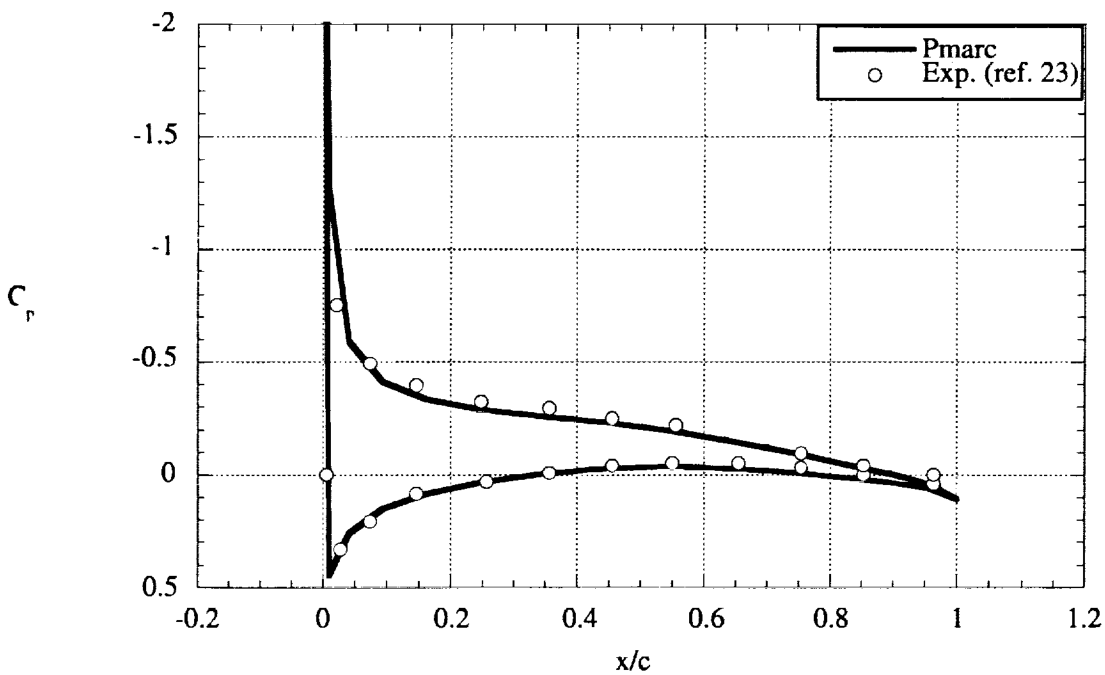


Figure 11.- PMARC representation of wing/body configuration.



a) 2y/b = 0.2



b) 2y/b = 0.6

Figure 12.- Comparison of experimental data and PMARC results for two spanwise stations on the wing of the wing/body configuration. Angle of attack is 4°.

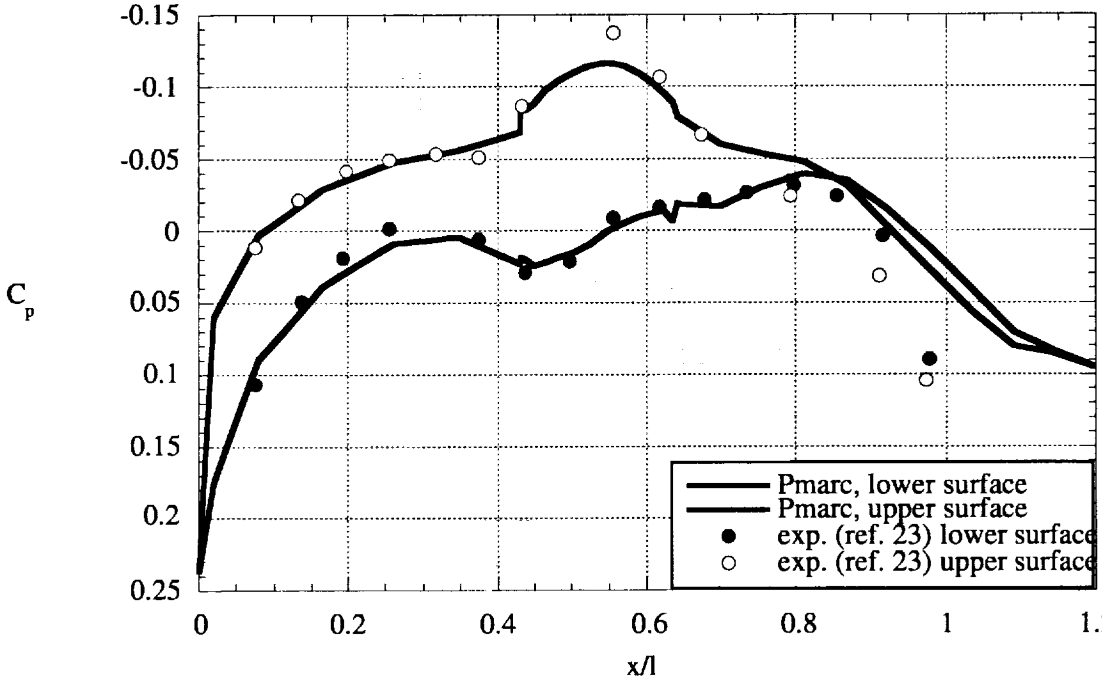


Figure 13.- Comparison of experimental data and PMARC results along fuselage centerline of the wing/body configuration. Angle of attack is 4°.

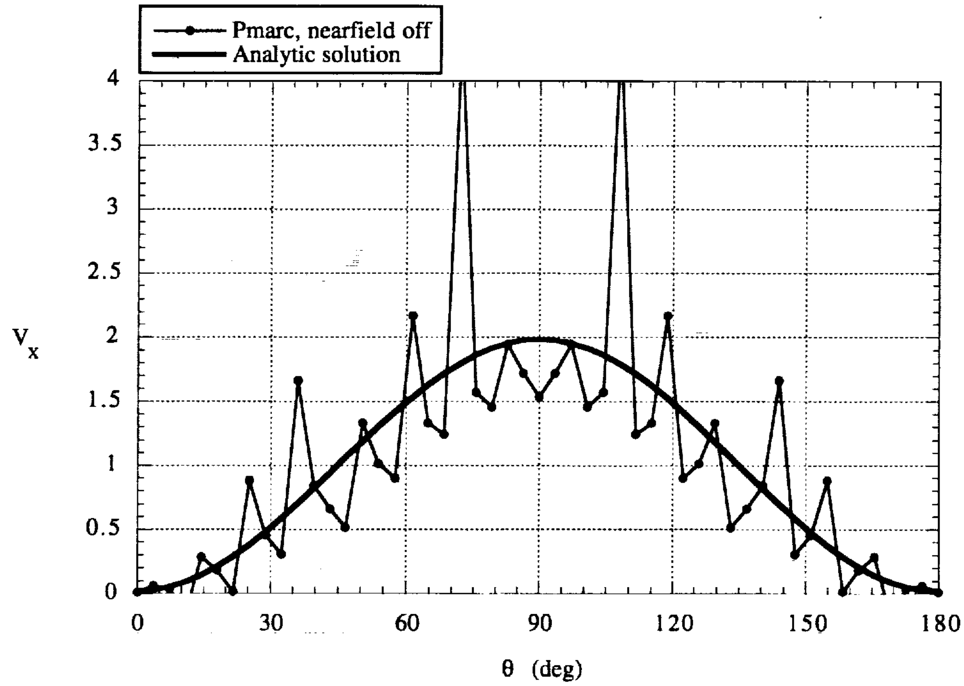


Figure 14.- Plot of X component of velocity computed by PMARC at a radius of R = 1.01 around a cylinder of radius r = 1.0 compared to the analytic solution. The near-field velocity calculation routine is disabled.

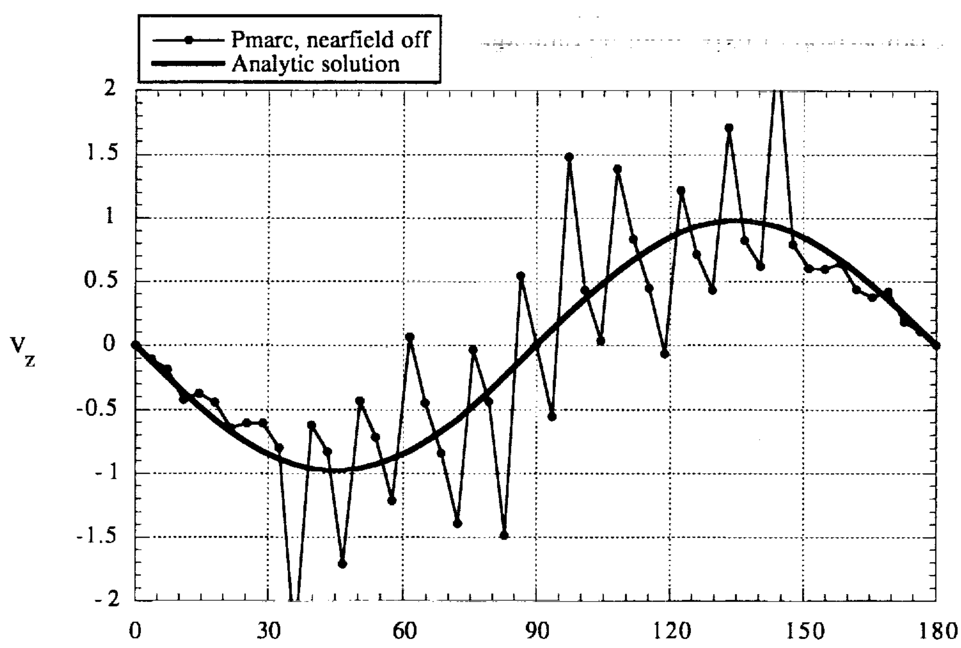


Figure 15.- Plot of Z component of velocity computed by PMARC at a radius of R = 1.01 around a cylinder of radius r = 1.0 compared to the analytic solution. The near-field velocity calculation routine is disabled.

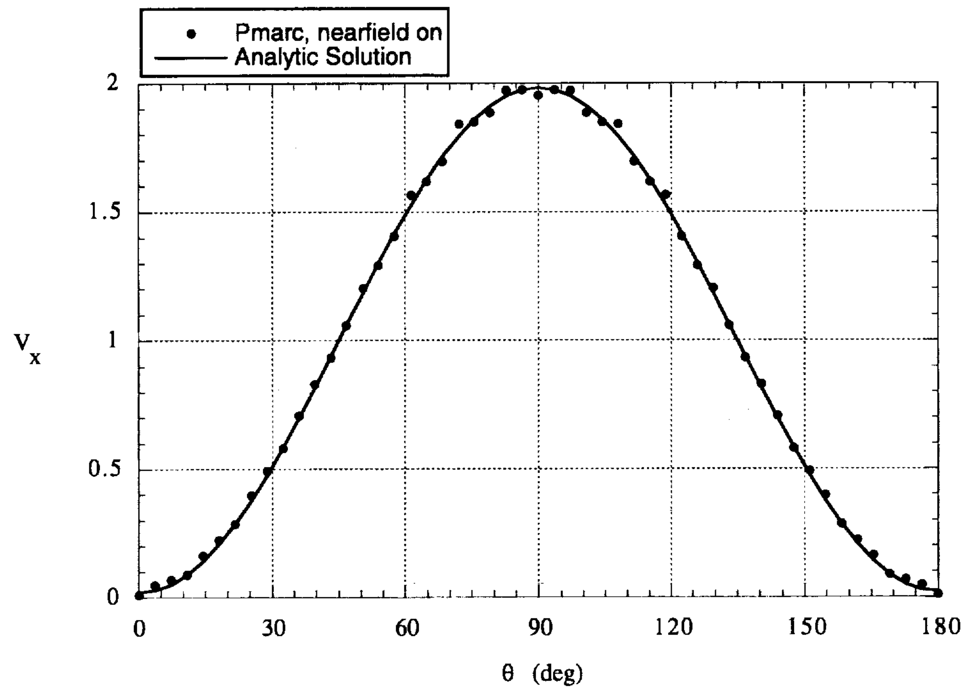


Figure 16.- Plot of X component of velocity computed by PMARC at a radius of R = 1.01 around a cylinder of radius r = 1.0 compared to the analytic solution. The near-field velocity calculation routine is enabled.

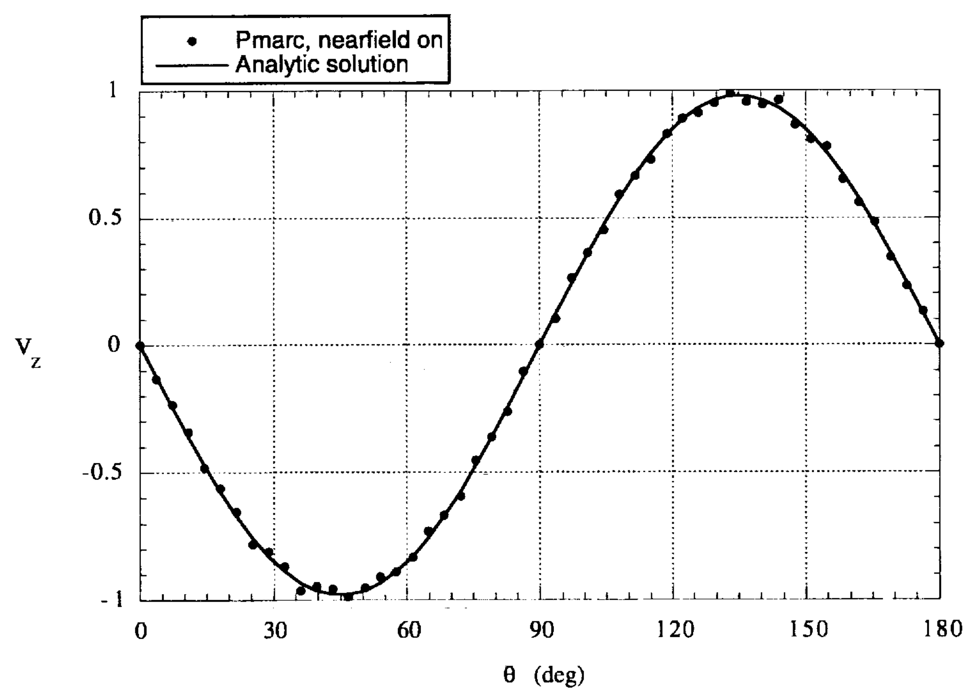


Figure 17.- Plot of Z component of velocity computed by PMARC at a radius of R = 1.01 around a cylinder of radius r = 1.0 compared to the analytic solution. The near-field velocity calculation routine is enabled.

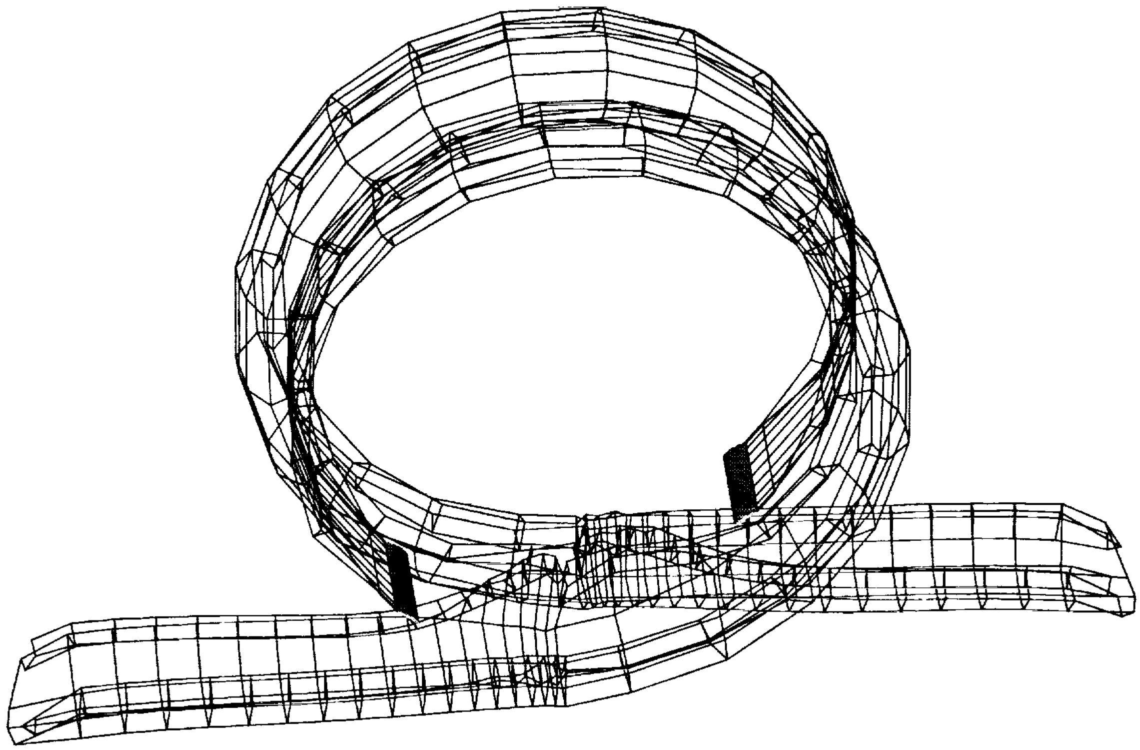


Figure 18.- Two wings flying through a loop in opposite directions.

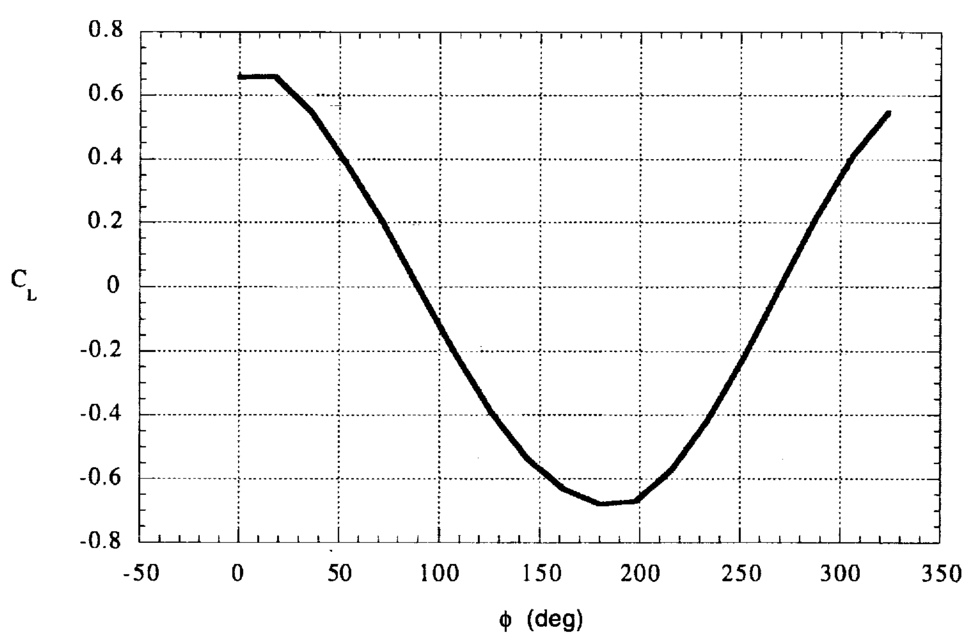


Figure 19.- Plot of C_L versus angular position in loop for two wings flying through a loop in opposite directions.

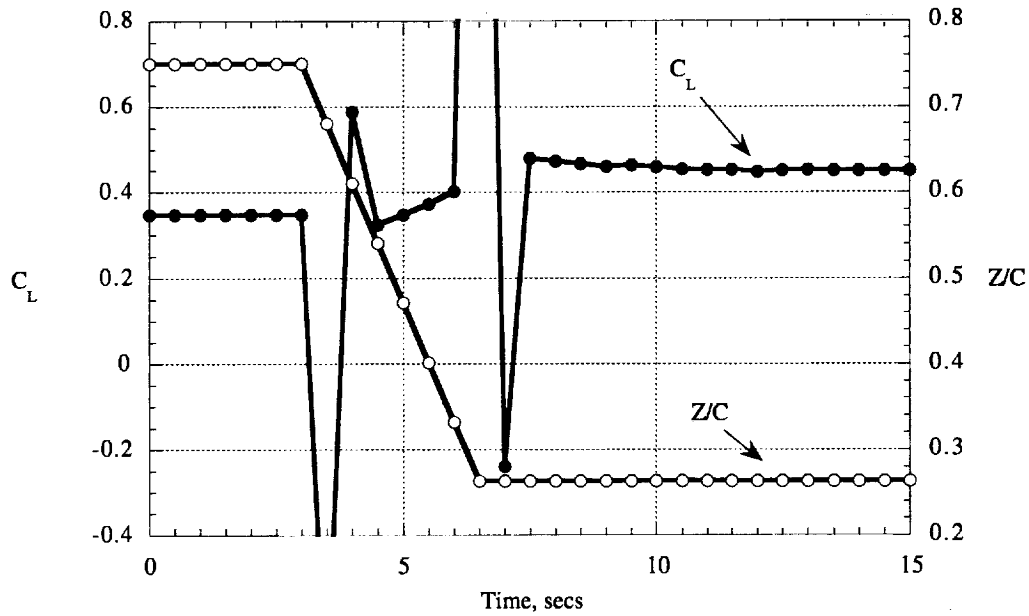


Figure 20.- Plot of C_L versus time for a wing in ground effect moving from a higher to a lower height above the ground.

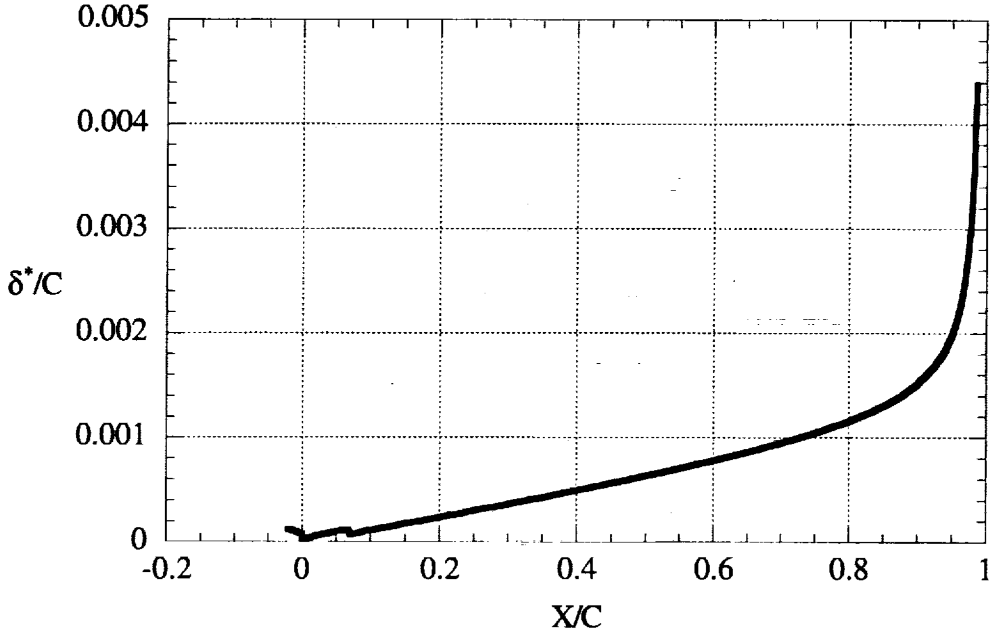


Figure 21. - Plot of displacement thickness versus chordwise location along the upper surface of a wing with a NACA 0012 airfoil. Angle of attack is 4°.

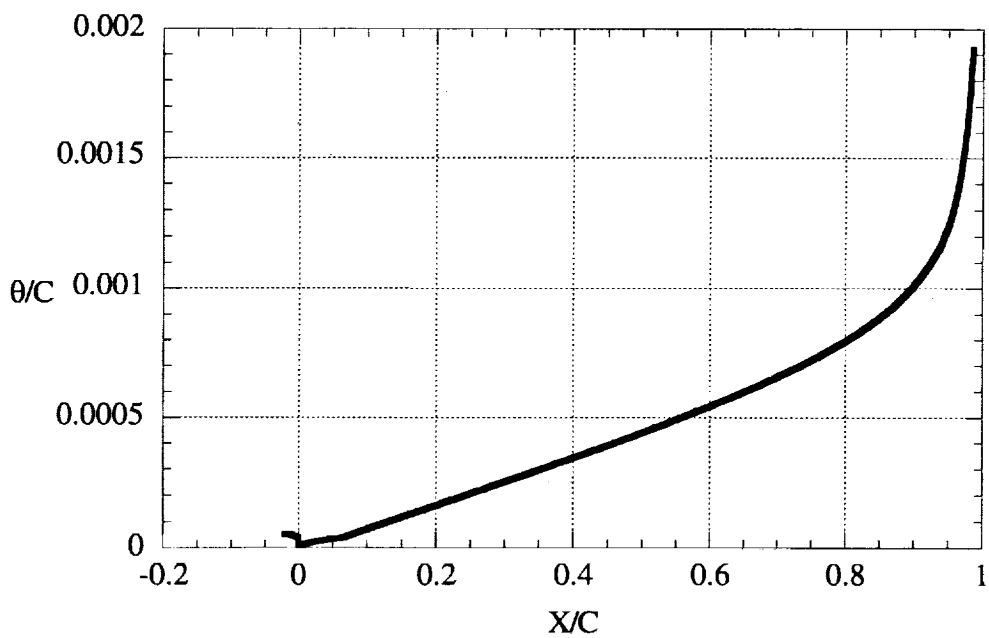


Figure 22. - Plot of momentum thickness versus chordwise location along the upper surface of a wing with a NACA 0012 airfoil. Angle of attack is 4°.

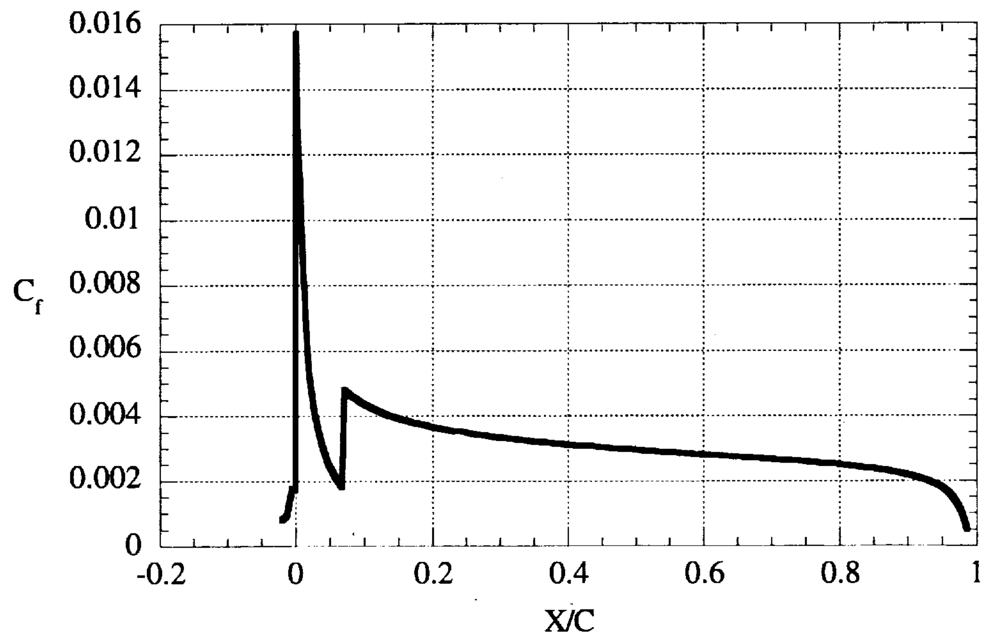


Figure 23. - Plot of skin friction coefficient versus chordwise location along the upper surface of a wing with a NACA 0012 airfoil. Angle of attack is 4°.

APPENDIX A

PMARC Parameter Statement Set

```
C
C  CODE DIMENSIONING PARAMETERS
C
C  NUMBER OF SURFACE PANELS ALLOWED
C
   PARAMETER (NSPDIM = 6000)
C
C  NUMBER OF NEUMANN PANELS ALLOWED
C
   PARAMETER (NNPDIM = 10)
C
C  NUMBER OF PATCHES ALLOWED
C
   PARAMETER (NPDIM = 20)
C
C  NUMBER OF BASIC POINTS ALLOWED FOR SECTION DEFINITION
C  (ALSO NUMBER OF SECTIONS ALLOWED PER PATCH)
C  (ALSO NUMBER OF ROWS OR COLUMNS + 1 ALLOWED ON A PATCH)
C  CAUTION:  DO NOT SET THIS PARAMETER TO LESS THAN 50!
C
   PARAMETER (NBPDIM = 100)
C
C  NUMBER OF WAKE PANELS ALLOWED
C
   PARAMETER (NWPDIM = 2500)
C
C  NUMBER OF WAKE COLUMNS OR ROWS ALLOWED ON EACH WAKE
C
   PARAMETER (NWCDIM = 100)
C
C  NUMBER OF WAKES ALLOWED
C
   PARAMETER (NWDIM = 10)
C
C  NUMBER OF SCAN VOLUMES OF EACH TYPE ALLOWED
C
   PARAMETER (NSVDIM = 10)
C
C  NUMBER OF POINTS PER OFF-BODY STREAMLINE ALLOWED
C
   PARAMETER (NSLPDIM = 2000)
C
C  NUMBER OF POINTS PER ON-BODY STREAMLINE ALLOWED
C
   PARAMETER (NONSLPDIM = 2000)
C
C  NUMBER OF GROUPS OF PANELS ON WHICH NONZERO NORMAL
C  VELOCITY IS PRESCRIBED
C
   PARAMETER (NVELDIM = 20)
```

```
C
C  NUMBER OF COMPONENT COORDINATE SYSTEMS ALLOWED
C
      PARAMETER (NCOMPDIM = 10)
C
C  NUMBER OF ASSEMBLY COORDINATE SYSTEMS ALLOWED
C
      PARAMETER (NASSEMDIM = 10)
C
C  NUMBER OF PATH COORDINATE SYSTEMS ALLOWED
C
      PARAMETER (NPATHDIM = 10)
C
C  NUMBER OF POINTS DEFINING A PATH ALLOWED
C
      PARAMETER (NPPTSDIM = 200)
C
C  NUMBER OF SUBVORTICES ALLOWED ON A PANEL FOR NEAR FIELD
C VELOCITY ROUTINE
C
      PARAMETER (NNFSVPP = 128)
      PARAMETER (NNFSVDIM = 2*NNFSVPP)
C
C  NUMBER OF WAKE SEPARATION POINTS ALLOWED
C
      PARAMETER (NWSPDIM = NWCDIM + NWDIM)
C
C  NUMBER OF WAKE CORNER POINTS ALLOWED
C
      PARAMETER (NWCPDIM=(NWPDIM + 1)*2)
C
C  NUMBER OF WAKE COLUMN EDGES ALLOWED ON EACH WAKE
C
      PARAMETER (NWCEDIM = NWCDIM + 1)
C
C  NUMBER OF SURFACE CORNER POINTS ALLOWED
C
      PARAMETER (NSCPDIM=(NSPDIM + 1)*2)
C
C  NUMBER OF EDGE PANELS ALLOWED ON A PATCH
C
      PARAMETER (NEPDIM = NBPDIM * 4)
C
C  PARAMETER CONTROLLING WHETHER THE DOUBLET INFL. COEFF.
C  MATRIX IS STORED ON DISK OR IN RAM.  IF INRAM IS SET TO 1, MATRIX C
IS STORED ON DISK.  IF INRAM IS SET TO NSPDIM, MATRIX IS STORED IN
C  RAM. NOTE THESE ARE THE ONLY TWO CHOICES!!!!  IF ANY OTHER
C  VALUE IS ENTERED, THE CODE WILL FAIL!!!
C
      PARAMETER (INRAM = NSPDIM)
C
C  NUMBER OF ITERATIONS PERFORMED BY THE ITERATIVE SOLVER
C BEFORE THE SOLUTION HISTORY IS FOLDED BACK TO ONE AND
C  RESTARTED.  THE  LARGER THIS PARAMETER, THE BETTER THE
```

```
C  CONVERGENCE OF THE SOLVER; HOWEVER LARGER VALUES ALSO
C  REQUIRE MORE MEMORY.  THE LOWER BOUND FOR THIS PARAMETER IS
C  20.  VALUES BETWEEN 50 AND 100 GIVE GOOD CONVERGENCE
C  PERFORMANCE WITHOUT REQUIRING TOO MUCH MEMORY.
C
      PARAMETER (IFOLDDIM = 100)
C
C  NUMBER OF BYTES USED TO REPRESENT REAL VARIABLES
C    0 = 8-BYTE REALS
C    1 = 4-BYTE REALS
C
      PARAMETER (NBYTR = 0)
```

APPENDIX B

Memory Requirements for Data Storage in PMARC

The data storage for PMARC can be divided into two types: common block storage and local storage. The memory requirements for both types of storage is presented below in terms of the parameter variables. Storage for local scalar variables and constants is not included in the information presented below. The value of RBYTE below is the number of bytes needed to represent a real number. RBYTE is 4 for most computers when single precision is used and 8 when double precision is used.

<u>Memory allocated for common blocks</u>

NSPDIM	* (55+INRAM) * RBYTE
NPDIM	* 11 * RBYTE
NNPDIM	* 3 * RBYTE
NWPDIM	* 23 * RBYTE
NWDIM	* (10+(15*NWCDIM)+NWDIM) * RBYTE
NVELDIM	* 6 * RBYTE
NONSLPDIM	* 12 * RBYTE
NPATHDIM	* (74+(7*NPPTSDIM))*RBYTE
Individual variables	* 61 * RBYTE

<u>Memory allocated locally in subroutines by dimension statements</u>

<u>Aerodat</u>

NPDIM	* 19 * RBYTE
NPATHDIM	* 12 * RBYTE
NCOMPDIM	* 12 * RBYTE
NASSEMDIM	* 12 * RBYTE

<u>Nabors</u>

NPDIM	* (1+(8*NBPDIM))* RBYTE
NSPDIM	* 2 * RBYTE

<u>Rhs</u>

NSPDIM	* 3 * RBYTE

<u>Solver : (Lineq)</u>

NSPDIM	* (3+2*IFOLDDIM)) * RBYTE
IFOLDDIM	* (2+2*IFOLDDIM)) * RBYTE

<u>Blcntrl</u>

NONSLPDIM	* 16 * RBYTE

<u>Solver: (Frmab)</u>

NSPDIM	* 2 * RBYTE

Strmlin

NSLPDIM	* 10 * RBYTE

Surfgen

NBPDIM	* (35+3*NBPDIM) * RBYTE
NCOMPDIM	* 11 * RBYTE
NASSEMDIM	* 11 * RBYTE

Surfinf

NSPDIM	* 11 * RBYTE

Surfinp

NPDIM	* 3 * RBYTE

Vcalc

NSPDIM	* 6 * RBYTE
NWPDIM	* 6 * RBYTE

Vscan

NSVDIM	* 35 * RBYTE

Wakinfl

NSPDIM	* 1 * RBYTE

Wakinp

NWCDIM	* 1 * RBYTE
NPDIM	* 3 * RBYTE

Wakgen

NWCDIM	* (40+3*NWCDIM) * RBYTE
NPDIM	* 3 * RBYTE

Wakstep

NWPDIM	* 7 * RBYTE
NWDIM	* 1 * RBYTE

Lamrbl

NONSLPDIM	* 8 * RBYTE

Onstrmln

NONSLPDIM	* 46 * RBYTE
NSPDIM	* 1 * RBYTE

Trefftz

NWDIM	* (2+7*NWCDIM) * RBYTE
NPATHDIM	* 4 * RBYTE

Filters

NSPDIM	* 26 * RBYTE
NWPDIM	* 3 * RBYTE
NSVDIM	* 6 * RBYTE
NSLPDIM	* 10 * RBYTE
NONSLPDIM	* 11 * RBYTE
NPDIM	* 2 * RBYTE
NWDIM	* 2 * RBYTE

Path

NPATHDIM	* 6 * RBYTE

APPENDIX C

PMARC Detailed Input Guide

JOBCNTRL.INP file

The JOBCNTRL.INP file for PMARC consists of a set of namelist definitions. The required format for the JOBCNTRL.INP file is shown below. All the namelists should always be included as shown below whether or not a particular namelist is needed for the job being run. If a namelist is not needed for a particular job, PMARC merely skips over that namelist. Each namelist must begin with an & in the second column and the namelist name (i.e. BINP2, BINP3, etc.) and end with &END. Blank spaces in a namelist are ignored, so the items in each namelist can be spaced in whatever fashion the user desires. A namelist can extend over as many lines as necessary. A description of each input variable and the valid input values follows the JOBCNTRL.INP file sample. Under the Value column in the input description, the letter I means an integer value and the letter R means a real value.

NOTE: Variables in the namelist definition which are arrays should have their elements listed out following the variable name. For example, if there were three values to be entered into the array NORPCH, the input would be as follows: NORPCH = N1,N2,N3. The rest of the elements in array NORPCH will automatically be left at zero.

TWO WING TEST CASE

```
 &BINP2   LSTINP=2,     LSTOUT=0,     LSTFRQ=1,     LENRUN=0,
          LPLTYP=1,                                                  &END
 &BINP3   LSTGEO=0,     LSTNAB=0,     LSTWAK=3,     LSTCPV=0,        &END
 &BINP4   MAXIT=200,    SOLRES=0.0005,   NRDDUB=0,  CPFLOOD=-10.0,   &END
 &BINP5   NTSTPS=20,    DTSTEP=0.1,                                  &END
 &BINP6   RSYM=0.0,     RGPR=0.0,     RFF=5.0,        NF=1,
          RCORES(1)=0.00001, RCOREW(1)=0.00001,
          RCORES(2)=0.00001, RCOREW(2)=0.00001,                      &END
 &BINP7   NPATH=     2, VSOUND=1116.0,  NRDPATH=0,  ICCOMP=0,        &END
 &BINP8   VTCX(1)=-1.0000,VTCY(1)= 0.0, VTCZ(1)=  0.00000,
          P(1)=  0.0,     Q(1)=  0.,    R(1)=  0.0,
          CX0(1)= 0.0,    CY0(1)= 0.0, CZ0(1)= 0.0,
          PHI(1)=  0.,    THE(1)=  0., PSI(1)=  0.,INCROT(1)=0,

          VTCX(2)= 1.0000,VTCY(2)= 0.0, VTCZ(2)=  0.00000,
          P(2)=  0.0,     Q(2)=  0.,    R(2)=  0.0,
          CX0(2)= 0.0,    CY0(2)= 0.0, CZ0(2)= 0.0,
          PHI(2)=  0.,    THE(2)=  0., PSI(2)=  0.,INCROT(2)=0,      &END

 &BINP8A  PHIMAX(1)= 0.0, THEMAX(1)=0.0, PSIMAX(1)=0.0,
          WRX(1)=0.0000,  WRY(1)=0.0000, WRZ(1)=0.0000,

          PHIMAX(2)= 0.0, THEMAX(2)=0.0, PSIMAX(2)=0.0,
          WRX(2)=0.0000,  WRY(2)=0.0000,  WRZ(2)=0.0000,             &END

 &BINP8B  DXMAX(1)=0.00,  DYMAX(1)=0.0,   DZMAX(1)=0.0,
          WTX(1)=0.0000,  WTY(1)=0.0000,  WTZ(1)=0.0000,

          DXMAX(2)=0.00,  DYMAX(2)=0.0,   DZMAX(2)=0.0,
          WTX(2)=0.0000,  WTY(2)=0.0000,  WTZ(2)=0.0000,             &END

 &BINP9   CBAR(1)=1.0000, SREF(1)=5.0000, SSPAN(1)=2.5,
          RMPX(1)=0.2500,   RMPY(1)=0.00,   RMPZ(1)=0.00,

          CBAR(2)=1.0000, SREF(2)=5.0000, SSPAN(2)=2.5,
          RMPX(2)=-0.2500,RMPY(2)=0.00,   RMPZ(2)=0.00,              &END

 &BINP10  NORSET=0,     NBCHGE=0,     NCZONE=0,
          NCZPCH=0,     CZDUB=0.0,    VREF=00.0,                     &END
 &BINP11  NORPCH=0,     NORF=0,       NORL=0,
          NOCF=0,       NOCL=0,       VNORM=0.0,                     &END
 &BINP12  KPAN=0,       KSIDE=0,      NEWNAB=0,     NEWSID=0,        &END
 &BINP13  NBLIT = 0,                                                 &END
 &BINP14  INSURF= 0,    INWAKE= 0,    OUTSURF= 0,   OUTWAKE= 0,      &END
testd_14.geom.pmarc
testd_14.wake.pmarc
testd_14.extras
```

RECORD 1: Job Title

Variable	Value	Description
TEXT		Alphanumeric text identifying the job. This record is not entered in namelist format, but merely typed in anywhere on the first line of the input file.

BINP2: Job Control

Variable	Value	Description
LSTINP		Input data print options
	0	Prints all input data except the geometry input.
	1	Prints all input data except the detailed coordinates of the geometry input.
	2	Prints all input data.
LSTOUT		Output print options
	0	Basic print of output.
	1	Allows any or all of the additional print options to be set manually on BINP3.
LSTFRQ		Controls frequency of printout in the time-stepping loop.
	0	Prints out detailed panel data only on last step. Force and moment data and solution iteration history printed at every step.
	1	Prints all data at every step.
	I	Prints out detailed panel data at every Ith step, including the first and last step. Force and moment data and solution iteration history printed at every step.

Variable	Value	Description
LENRUN	0	Complete run through code.
	2	Run through geometry only. Geometry is written to plot file.
	3	Run through geometry and wake initialization routines. Geometry and initial wake data are written to plot file.
	4	Run through geometry and wake routines. Step through all time steps, but don't do analysis. Geometry and wake data from all time steps written to plot file.
LPLTYP	0	Code outputs only an unformatted plot file
	1	Code outputs only a formatted ASCII plot file for the GVS post-processing program.
	2	Code outputs only a formatted ASCII plot file for the TecPlot post-processing program. Note that a separate file will be output for each time step.
	3	Code outputs only a formatted ASCII plot file for the Plot3D post-processing program. Note that two files will be output for each time step: an xy file containing corner point data and a q file containing corresponding aerodynamic data.

BINP3: Additional Print Options (must be included if LSTOUT=1)

Variable	Value	Description
LSTGEO		Panel geometry printout options.
	0	Print option off.
	1	Panel corner points for all panels are written to the solution.out file. Panel corner point data is also written in either PMARC native or Plot3D format to the file geom.pmarc or geom.p3d respectively. Format is determined by value of OUTSURF variable on BINP14 namelist. (see below)
	2	In addition to the panel corner point data, the unit normal vectors for all panels are written to the solution.out file.
	3	In addition to the panel corner point data, the unit normal vectors for all panels and panel sets with prescribed normal velocities are written to the solution.out file.
LSTNAB		Panel neighbor information printout options.
	0	Print option off
	1	Writes neighbor information for all panels to the solution.out file.

Variable	Value	Description
LSTWAK		Wake data printout options.
	0	Print option off.
	1	Writes wake-shedding information for each wake column to the solution.out file.
	2	Writes wake-shedding information for each wake column and wake line geometry to solution.out file. Wake corner point data is also written in either PMARC native or Plot3D format to the file wake.pmarc or wake.p3d respectively. Format is determined by value of OUTWAKE variable on BINP14 namelist. (see below)
	3	Writes wake-shedding information for each wake column, wake line geometry, and wake panel doublet values to solution.out file. Wake corner point data is also written in either PMARC native or Plot3D format to the file wake.pmarc or wake.p3d respectively. Format is determined by value of OUTWAKE variable on BINP14 namelist. (see below)
LSTCPV		Panel corner point analysis printout options.
	0	Print option off.
	1	Writes out panel corner point analysis results to the solution.out file according to the LSTFRQ value selected.

BINP4: Solver Parameters

Variable	Value	Description
MAXIT	I	Limit on number of solver iterations (150 is adequate for most cases)
SOLRES	R	Convergence criteria for the matrix solver. Recommended setting is 0.0005.
NRDDUB	I	Flag to read in a previous doublet solution for this job to use as a starting guess for the solver. Read from file doublet.dat.
	0	Do not read in doublet.dat file.
	1	Read in doublet.dat file.

Variable	Value	Description
CPFLOOD	R	Sets a minimum value for pressure coefficients computed by PMARC at surface panel centroids and corner points. Any value of Cp computed by PMARC that is less than CPFLOOD is set equal to CPFLOOD. Default value of 0.0 for CPFLOOD turns off this option (i.e. no limit is set on value of Cp).

BINP5: Time-Step Parameters

Variable	Value	Description
NTSTPS	I	Number of wake time-steps.
DTSTEP	R	Size of the time-step (seconds).

BINP6: Symmetry and Computation Parameters

Variable	Value	Description
RSYM	0.0	Symmetrical case (about Y=0). Code computes the influence of the mirror image of the paneled geometry. The paneled geometry must lie in the +Y side of the inertial coordinate system and abut the Y=0 plane.
	1.0	Asymmetrical case (about Y=0). The entire geometry must be paneled. The paneled geometry may lie in +Y or -Y (or both) side of the inertial coordinate system.
RGPR	0.0	No ground plane modeled at Z=0.
	1.0	Ground plane modeled at Z=0.
RFF	5.0	Far-field-factor. (multiplies panel reference length to determine far-field radius for each panel).
NF	I	Near field velocity calculation routine flag
	0	Near field turned off
	1	Near field turned on
RCORES(N)	0.0005	Surface panel core radius. Used when computing velocities near a doublet panel edge. This is a non-dimensional quantity expressed as a fraction of the variable CBAR(N) (BINP9). Value can be made smaller or larger to make velocity calculations more or less sensitive to surface panel edges.
RCOREW(N)	0.0005	Wake panel core radius. Used when computing velocities near a doublet panel edge. This is a non-dimensional quantity expressed as a fraction of the variable CBAR(N) (BINP9). Value can be made smaller or larger to make velocity calculations more or less sensitive to wake panel edges.

NOTE: N goes from 1 to NPATH

BINP7: Path coordinate system information

Variable	Value	Description
NPATH	I	Number of path coordinate systems to be used. Each path coordinate system will have its own translation, rotation, and oscillatory velocity components. The path coordinate system that each geometry patch belongs to is specified using the KPATH variable on the PATCH1 namelist.
VSOUND	R	Dimensional speed of sound. (A velocity of R length units/sec is used for computations involving speed of sound, where length unit is the global units used for the paneled geometry).
NRDPATH	I	Flag to read in a file containing tabulated translation and rotation velocity vector components as a function of time which describe the motion of each path coordinate system, rather than using the variables listed in namelist BINP8. Data read from file pathdef.dat (format of file given below).
	0	Do not read in the pathdef.dat file.
	1	Read in pathdef.dat file.
ICCOMP	I	Flag to control the computation of surface panel influence coefficients after each time step.
	0	Surface panel influence coefficients are only recomputed if there is more than one path coordinate system. Only the influence coefficients between panels that belong to different path coordinate systems are recomputed. Influence coefficients between panels that belong to the same path coordinate system are not recomputed.
	1	Forces all surface panel influence coefficients to be recomputed after each time step. This option is used when there are one or more path coordinate systems and a plane of symmetry or image plane and the distance between any part of the geometry and the plane of symmetry or image plane varies with time.

Format for Pathdef.dat file:

The Pathdef.dat file is an optional file used for defining the translation and rotation of all the path coordinate systems. This file is only required if the variable NRDPATH = 1 on namelist BINP7. When the Pathdef.dat file is used to define the motions of the path coordinate systems, the information on namelist BINP8 in the JOBCNTRL.INP file is ignored. The format for the Pathdef.dat file is as follows. The first entry is the PATHDEF namelist which defines the initial position and orientation of the path coordinate system in the inertial coordinate system. The variables included in the PATHDEF namelist are shown below and are equivalent to the corresponding BINP8 namelist variables. The PATHDEF namelist is followed by a text line defining the column headers as shown below. Note that all columns must be included in the order shown. The line of column headers is followed by N lines of data entered in free format defining the motion of the path coordinate system as a function of time. Note that PMARC uses linear interpolation to determine the values of the variables defining the motion of the path coordinate system at values of time lying between the tabulated values. As PMARC computes the solution for each time step, if the time, computed as the current time step number multiplied by the time step size, exceeds the largest value of time in the tabulated path definition, the last set of tabulated values are used for the rest of the time steps. The block of data shown below is repeated for each path coordinate system until all path coordinate systems have been defined. Note that the indices of the variables in the PATHDEF namelist must be incremented for each new path definition.

```
&PATHDEF CX0(1)= 0.0, CY0(1)= 0.0, CZ0(1)= 0.0,  PHI(1)=  0.,
         THE(1)=  0., PSI(1)=  0.,INCROT(1)=0,               &END
 T       VTCX       VTCY    VTCZ         P          Q          R
 0       -1.0        0.0    0.0          0.0        0.0        0.0
2.99     -1.0        0.0    0.0          0.0        0.0        0.0
3.01     -1.0        0.0    0.0          0.0        0.0        0.0
3.02     -0.9903     0.0    -0.1392      0.0      -16.0        0.0
3.51     -0.9903     0.0    -0.1392      0.0      -16.0        0.0
3.52     -0.9903     0.0    -0.1392      0.0        0.0        0.0
6.48     -0.9903     0.0    -0.1392      0.0        0.0        0.0
6.49     -0.9903     0.0    -0.1392      0.0       16.0        0.0
6.98     -0.9903     0.0    -0.1392      0.0       16.0        0.0
6.99     -1.0        0.0    0.0          0.0        0.0        0.0
7.01     -1.0        0.0    0.0          0.0        0.0        0.0
10.00    -1.0        0.0    0.0          0.0        0.0        0.0

&PATHDEF CX0(2)= 0.0, CY0(2)= 0.0, CZ0(2)= 0.0,  PHI(2)=  0.,
         THE(2)=  0., PSI(2)=  0.,INCROT(2)=0,               &END
 T       VTCX       VTCY    VTCZ         P          Q          R
 0       -1.0        0.0    0.0          0.0        0.0        0.0
100.     -1.0        0.0    0.0          0.0        0.0        0.0
```

BINP8: Path coordinate system location, orientation, and translation and rotation rates

Variable	Value	Description
VTCX(N)	R	Velocity of origin of path coordinate system N in the inertial coordinate system x direction.
VTCY(N)	R	Velocity of origin of path coordinate system N in the inertial coordinate system y direction.
VTCZ(N)	R	Velocity of origin of path coordinate system N in the inertial coordinate system z direction.
P(N)	R	Rotation rate of path coordinate system N about its x axis. (deg/sec)
Q(N)	R	Rotation rate of path coordinate system N about its y axis. (deg/sec)
R(N)	R	Rotation rate of path coordinate system N about its z axis. (deg/sec)
CX0(N) CY0(N) CZ0(N)	R	Coordinates of origin of path coordinate system N in the inertial coordinate system at time = 0.
PHI(N) THE(N) PSI(N)	R	Euler angles of path coordinate system N describing its orientation in the inertial coordinate system at time = 0.
INCROT(N)	I	Flag to determine whether or not rotational velocity is included in computing velocity magnitude used for CP calculation.
	0	Rotational velocity not included
	1	Rotational velocity included

NOTE: N goes from 1 to NPATH

BINP8A: Path coordinate system rotational oscillatory motion amplitudes and frequencies

Variable	Value	Description
PHIMAX(N)	R	Amplitude of oscillatory rotation about path X axis. (deg)
THEMAX(N)	R	Amplitude of oscillatory rotation about path Y axis. (deg)
PSIMAX(N)	R	Amplitude of oscillatory rotation about path Z axis. (deg)
WRX(N)	R	Frequency of oscillatory rotation about path X axis (rad/sec)
WRY(N)	R	Frequency of oscillatory rotation about path Y axis (rad/sec)
WRZ(N)	R	Frequency of oscillatory rotation about path Z axis (rad/sec)

NOTE: N goes from 1 to NPATH

BINP8B: Path coordinate system translational oscillatory motion amplitudes and frequencies

Variable	Value	Description
DXMAX(N)	R	Amplitude of oscillatory translation about path X axis. (deg)
DYMAX(N)	R	Amplitude of oscillatory translation about path Y axis. (deg)
DZMAX(N)	R	Amplitude of oscillatory translation about path Z axis. (deg)
WTX(N)	R	Frequency of oscillatory translation about path X axis (rad/sec)
WTY(N)	R	Frequency of oscillatory translation about path Y axis (rad/sec)
WTZ(N)	R	Frequency of oscillatory translation about path Z axis (rad/sec)

NOTE: N goes from 1 to NPATH

BINP9: Reference Dimensions for each path coordinate system

Variable	Value	Description
CBAR(N)	R	Reference chord used for normalizing pitching moment in path coordinate system N. (units must be consistent with units used to define geometry).
SREF(N)	R	Reference area for normalizing force and moment coefficients in path coordinate system N. If a plane of symmetry is used, the reference area for the paneled and reflected geometry should be used. (units must be consistent with units used to define geometry).
SSPAN(N)	R	Semispan used for normalizing rolling and yawing moments in path coordinate system N. (units must be consistent with units used to define geometry).
RMPX(N) RMPY(N) RMPZ(N)	R	Coordinates of the moment reference point in path coordinate system N.

NOTE: N goes from 1 to NPATH

BINP10: Special Options

Variable	Value	Description
NORSET	I	The number of groups of panels on which nonzero normal velocities are to be prescribed.
NBCHGE	I	The number of panel neighbor information changes that are to be made. Changing the neighbor information on one side of one panel constitutes one change.
NCZONE	0	Regular external flow problem.
	1	Internal flow problem
NCZPCH	I	Patch number of the patch on which the doublet value is specified for internal flow modeling. This patch will have constant doublet strength on all panels and thus zero tangential velocity. This must be an inflow or outflow patch. No normal velocity should be specified on this patch: PMARC will compute the normal flow through this patch.
CZDUB	R	The doublet value that is set on panel NCZPCH for internal flow modeling. A value of 0.0 is recommended unless convergence problems occur in the matrix solution.
VREF	R	The reference velocity for computing Cp in internal flow problems. If left at 0.0, then VINF will be used to compute Cp.

BINP11: Normal Velocity Specification

Variable	Value	Description
NORPCH(N)	I	Patch number of patch containing the group of panels to receive a prescribed normal velocity.
NORF(N) NORL(N)	I	Number of first and last row of panels in defined panel set. Using 0 defaults to all rows on this patch.
NOCF(N)	I	Number of first and last column of Using 0 defaults to all columns on this patch.
VNORM(N)	R	Specified normal velocity for the set of panels identified above. Positive direction is outwards from the surface.

NOTE: N goes from 1 to NORSET

BINP12: Panel Neighbor Information Change

Variable	Value	Description
KPAN(N) KSIDE(N)	I I	Panel number and the side of that panel requiring a modified neighbor.
NEWNAB(N) NEWSID(N)	I I	New neighbor and the side of that neighbor adjacent to KSIDE of KPAN. If NEWNAB is set to 0 for a particular panel, then NEWSID should be set to -KSIDE. This effectively cuts the neighbor relationship across side KSIDE.

NOTE: N goes from 1 to NBCHGE

BINP13: Boundary Layer Calculation Control

Variable	Value	Description
NBLIT	0	Boundary layer computations not performed
	1	Boundary layer computations performed on specified on-body streamlines. Requires namelist BLPARAM to follow the on-body streamline input.

BINP14: Input and Output File Format Control

Variable	Value	Description
INSURF	0	The geometry definition file to be read in by PMARC is in PMARC native format. Geometry will be generated using PMARC's internal geometry generation routines.
	1	The geometry definition file to be read in by PMARC is in Plot3D format. Panel corner points for each patch in the geometry will be read in from an ASCII file in Plot3D 3D multi-grid whole format. PMARC's internal geometry generation routines will be bypassed. See the geometry input section below for a description of this format.
INWAKE	0	The wake definition file to be read in by PMARC is in PMARC native format. Wakes will be generated using PMARC's internal wake generation routines.
	1	The wake definition file to be read in by PMARC is in Plot3D format. Panel corner points for each wake will be read in from an ASCII file in Plot3D 3D multi-grid whole format. PMARC's internal wake generation routines will be bypassed. See the wake input section below for a description of this format.
OUTSURF	0	The panel corner points for each patch will be written out to the file geom.pmarc in PMARC native format.
	1	The panel corner points for each patch will be written out to the file geom.p3d in Plot3D 3D multi-grid whole format.
OUTWAKE	0	The wake panel corner points for each wake will be written out to the file wakexx.pmarc in PMARC native format. The xx in the file name represents the time step number (01, 02, 03, ...).
	1	The wake panel corner points for each wake will be written out to the file wakexx.p3d in Plot3D 3D multi-grid whole format. The xx in the file name represents the time step number (01, 02, 03,...).

RECORD 2: Surface geometry definition file name

Variable	Value	Description
TEXT		File name for the geometry definition file to be read read in by PMARC. This record should follow immediately after the BINP14 namelist.

RECORD 3: Wake definition file name

Variable	Value	Description
TEXT		File name for the wake definition file to be read read in by PMARC. This record should follow immediately after the geometry definition file name.

RECORD 4: Additional options definition file name

Variable	Value	Description
TEXT		File name for the additional options definition file to be read in by PMARC. This record should follow immediately after the wake definition file name.

Surface Geometry Definition File in PMARC Native Format

The surface geometry definition file for PMARC can be in one of two formats: PMARC native format or Plot3D 3D multi-grid whole format. The PMARC native format consists of a set of namelist definitions. The required format for the PMARC native surface geometry definition file is shown below. Each namelist must begin with an & in the second column and the namelist name (i.e. PATCH1, SECT1, etc.) and end with &END. Blank spaces in a namelist are ignored, so the items in each namelist can be spaced in whatever fashion the user desires. A namelist can extend over as many lines as necessary. A description of each input variable and the valid input values follows. Under the Value column in the input description, the letter I means an integer value and the letter R means a real value.

The only geometry input data that does not use the namelist format is the basic point coordinate input. The basic point coordinate input is handled using a free format input. One set of three coordinates separated by at least one space must appear on each line. See the sample input below.

```
&ASEM1      ASEMX=0.00,       ASEMY=0.00,       ASEMZ=0.00,
            ASCAL=1.00,       ATHET=0.00,       NODEA=5,                     &END
&ASEM2      APXX=0.00,        APYY=0.00,        APZZ=0.00,
            AHXX=0.00,        AHYY=1.00,        AHZZ=0.00,                   &END


&COMP1      COMPX=    0.0000, COMPY=    0.0000, COMPZ=    0.0000,
            CSCAL=    1.0000, CTHET=    0.0000, NODEC= 5,                    &END
&COMP2      CPXX=    0.0000,  CPYY=    0.0000,  CPZZ=    0.0000,
            CHXX=    0.0000,  CHYY=    1.0000,  CHZZ=    0.0000,             &END


&PATCH1     IREV=  0,     IDPAT= 1,    MAKE=   0, KCOMP= 1,  KASS= 1,
            IPATSYM= 0,   IPATCOP= 0,  IPATH=  1,                            &END
PATCH NAME
&SECT1      STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
            ALF=    0.0,      THETA=   0.0,
            INMODE=  1,       TNODS= 3,       TNPS=  5,        TINTS= 3,     &END
            0.0    0.0    0.0
            1.0    0.0    0.0
            1.0    0.1    0.1
            1.1    0.2    0.3
            1.3    0.5    0.7
&BPNODE     TNODE= 3,     TNPC=  5,     TINTC=  0,                           &END
```

Description of Input Variables

ASEM1: Assembly Coordinate System Information

Variable	Value	Description
ASEMX ASEMY ASEMZ	R R R	Origin of assembly coordinate system in inertial coordinate system.
ASCAL	R	Assembly scale. If ASCAL < 0, then namelist ASEM2 must be included. ASCAL < 0 allows rotation of assembly about an arbitrarily defined axis (defined on ASEM2) instead of the default assembly coordinate system Y axis.
ATHET	R	Rotation angle of the assembly coordinate system about the rotation axis. The default rotation axis is the assembly coordinate system Y axis. An arbitrary axis may be specified on ASEM2 if ASCAL < 0 above. Positive rotation angle is determined by Right Hand Rule.
NODEA	0	Another assembly coordinate system to be defined after this one.
	5	This is the last assembly coordinate system to be defined.

NOTE: Up to NASSEMDIM (set in PARAM.DAT) assembly coordinate systems may be defined. One ASEM1 (and ASEM2 if required) must appear in the input file for each assembly to be defined. Each ASEM2 that is required must follow immediately after its corresponding ASEM1. The assembly coordinate systems are numbered in the order in which they are defined.

ASEM2: Assembly Coordinate System Rotation Axis Input

Variable	Value	Description
APXX APYY APZZ	R R R	Starting point for vector defining assembly coordinate system arbitrary rotation axis. (entered in assembly coordinates (i.e. prior to scaling by assembly scale factor)).
AHXX AHYY AHZZ	R R R	Ending point for vector defining assembly coordinate system arbitrary rotation axis. (entered in assembly coordinates (i.e. prior to scaling by assembly scale factor)).

COMP1: Component Coordinate System Information

Variable	Value	Description
COMPX COMPY COMPZ	R R R	Origin of component coordinate system in assembly coordinates.
CSCAL	R	Component scale. If CSCAL < 0, then namelist COMP2 must be included. CSCAL < 0 allows rotation of component about an arbitrarily defined axis (defined on COMP2) instead of the default component coordinate system Y axis.
CTHET	R	Rotation angle of the component coordinate system about the rotation axis. The default rotation axis is the component coordinate system Y axis. An arbitrary axis may be specified on COMP2 if CSCAL < 0 above. Positive rotation angle is determined by Right Hand Rule.
NODEC	0	Another component coordinate system to be defined after this one.
	5	This is the last component coordinate system to be defined.

NOTE: Up to NCOMPDIM (set in PARAM.DAT) assembly coordinate systems may be defined. One COMP1 (and COMP2 if required) must appear in the input file for each assembly to be defined. Each COMP2 that is required must follow immediately after its corresponding COMP1. The assembly coordinate systems are numbered in the order in which they are defined.

COMP2: Component Coordinate System Rotation Axis Input

Variable	Value	Description
CPXX CPYY CPZZ	R R R	Starting point for vector defining component coordinate system arbitrary rotation axis. (entered in component coordinates (i.e. prior to scaling by component scale factor)).
CHXX CHYY CHZZ	R R R	Ending point for vector defining component coordinate system arbitrary rotation axis. (entered in component coordinates (i.e. prior to scaling by component scale factor)).

PATCH1: Patch Information

Variable	Value	Description
IREV		Patch reversal flag (for inside out patches).
	0	Patch not reversed.
	-1	Patch reversed.
IDPAT		Patch type.
	1	Wing patch. Section force and moment data non-dimensionalized by projected area of the column of panels. Assumes the section definition for the patch starts at the trailing edge, proceeds to the leading edge, and then back to the trailing edge. Moments non-dimensionalized by CBAR for pitching moment and SSPAN for yawing and rolling moment.
	2	Normal patch. Section force and moment data non-dimensionalized by the reference area SREF. Moments non-dimensionalized by CBAR for pitching moment and SSPAN for yawing and rolling moment.
	3	Neumann patch. (Vortex lattice sheet).

Variable	Value	Description
MAKE	0	Normal patch input (namelist SECT1 must follow unless IPATCOP > 0).
	+I	Automatic tip patch generated for side 3 of patch I. (namelist PATCH2 must follow).
	-I	Automatic tip patch generated for side 1 of patch I. (namelist PATCH2 must follow).
KCOMP	I	Number of component coordinate system to which this patch belongs. Component coordinate systems are numbered sequentially as discussed in NOTE above on COMP1. If 0 is entered, KCOMP defaults to 1.
KASS	I	Number of assembly coordinate system to which this patch belongs. Assembly coordinate systems are numbered sequentially as discussed in NOTE above on ASEM1. If 0 is entered, KASS defaults to 1. Neighbor relationships are cut between patches on different assemblies.
IPATSYM	0	No symmetrical patch is generated
	1	A symmetrical copy of the current patch is generated automatically about the x-z plane of symmetry. Note that this will increment the number of patches by 1 for each patch that has a symmetrical copy. The symmetrical copy will be numbered sequentially following the patch it is copying. Care must be taken to count the symmetrical copies also when determining patch numbers that tip patches are assigned to or that wakes separate from.
IPATCOP	I	If I > 0, then this patch is created by copying a previously defined patch " I ". The xyz coordinates, in the inertial coordinate system, of the corner points of patch " I " are copied to generate this patch. This patch can then be scaled, rotated, and translated by the user-defined directives on namelist PATCH3, which must follow the patch name input.

Variable	Value	Description
IPATH	I	Number of path coordinate system to which this patch belongs. Path coordinate systems are numbered sequentially in the order input. If 0 is entered, IPATH defaults to 1.

RECORD to be inserted after PATCH1 namelist.

Variable	Value	Description
PNAME (A24)	Text	Patch name

PATCH2: Automatic Tip Patch Generation Information (needed only if MAKE $\neq$ 0 on PATCH1)

Variable	Value	Description
ITYP		Tip patch type
	1	Flat tip patch
	2	Circular arc tip patch
TNODS	3	More patches to follow this one.
	5	Last patch in the surface geometry input.
TNPS	I	Number of panels to be generated "across" the open tip. See figure 6.

NOTE: The tip patch paneling will match the edge paneling of the patch to which the tip patch is being fitted.

TINTS	0	Full cosine spacing of panels "across" the open tip, with smaller panels near outer perimeter of the tip patch.
	1	Half cosine spacing of panels with smaller panels near the first section of the tip patch. See figure 6.
	2	Half cosine spacing of panels with smaller panels near the last section of the tip patch. See figure 6.
	3	Equal spacing of panels "across" the open tip.

NOTE: This namelist completes the input required for this patch.

PATCH3: Transformation information for copied patches.

Variable	Value	Description
PATX PATY PATZ	R R R	Translation vector for this patch relative to the copied patch. Entered in inertial coordinates.
PSCAL	R	Scale factor for this patch relative to the copied patch.
PTHET	R	Rotation angle of this patch relative to the copied patch. Rotation is about the rotation vector defined below, with positive rotation angle determined by Right Hand Rule.
NODEP	0	Another patch to be defined after this one.
	5	This is the last patch to be defined.
PPXX PPYY PPZZ	R R R	Starting point for vector defining patch arbitrary rotation axis. (entered in inertial coordinates (i.e. prior to scaling by patch scale factor)).
PHXX PHYY PHZZ	R R R	Ending point for vector defining patch arbitrary rotation axis. (entered in inertial coordinates (i.e. prior to scaling by patch scale factor)).

SECT1: Section Coordinate System Information

Variable	Value	Description
STX STY STZ	R R R	Origin of section coordinate system in component coordinates.
SCALE	R	Section scale. If SCALE = 0.0, the defined section reduces to a single point at the origin of the section coordinate system.
ALF	R	Rotation angle of the section coordinate system about its Y axis. A positive rotation angle is defined by the Right Hand Rule. (degrees)
THETA	R	Rotation angle of the section coordinate system about its Z axis. A positive rotation angle is defined by the Right Hand Rule. (degrees)

Variable	Value	Description
INMODE	0	Copies section definition of previous section.
	1	Input Y, Z, DX coordinates to define section. The X coordinate is defaulted to 0.0, but local deviations can be entered in DX. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	2	Input X, Z, DY coordinates to define section. The Y coordinate is defaulted to 0.0, but local deviations can be entered in DY. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	3	Input X, Y, DZ coordinates to define section. The Z coordinate is defaulted to 0.0, but local deviations can be entered in DZ. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	4	Input X, Y, Z coordinates to define section. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	5	Generate a NACA 4 digit airfoil section. (SECT2 namelist must follow this namelist).
	7	Input R, θ, X coordinates to define section. R is measured perpendicular to the section X axis and θ is measured from the section +Y axis with the positive angular direction defined by the Right Hand Rule. (basic point coordinates and BPNODE namelists follow this namelist as needed).

NOTE: If a negative value of INMODE is entered from the above list, a body of revolution will be generated. The first section of this patch is entered by selecting the INMODE value desired and making it negative on the first SECT1 namelist. The value of TNODS on the SECT1 namelist must be either 3 or 5. The variables TNPS and TINTS should be set to the number of panel divisions and spacing desired in the angular direction on the body of revolution. Then a SECT3 namelist is input which gives the rotation vector and the rotation angle. The Right Hand Rule is used to determine positive rotation. Basic points defining the section are then entered along with appropriate BPNODE namelists.

Variable	Value	Description
TNODS	0	First or intermediate section of patch.
	1	Break point on patch with continuous slope into the next region of patch.
	2	Break point on patch with discontinuous slope into the next region of patch.
	3	Last section definition on this patch.
	5	Last section definition on last patch of surface geometry.
TNPS	I	Number of panels to be generated between this break point and the previous break point (or the first section of this patch if this is the first or only break point). If TNPS = 0 at a break point, the input sections between this break point and the previous one will be used to define the panel edges.
TINTS	0	Full cosine spacing of panels between this break point and the previous one, with smaller panels near the two break points.
	1	Half cosine spacing of panels between this break point and the previous one, with smaller panels near the previous break point.
	2	Half cosine spacing of panels between this break point and the previous one, with smaller panels near this break point.
	3	Equal spacing of panels between this break point and the previous break point.

SECT2: NACA 4 digit airfoil section generation information (needed only if INMODE = 5 on SECT1)

Variable	Value	Description
RTC	R	The thickness to chord ratio for the airfoil.
RMC	R	The maximum chamber to chord ratio for the airfoil.
RPC	R	The chordwise position of the maximum chamber (expressed as a ratio to chord).
IPLANE		The plane in the section coordinate system used to generate the airfoil coordinates.
	1	The YZ plane.
	2	The XZ plane.
	3	The XY plane.
TNPC	I	The number of panels to be distributed between the trailing edge and the leading edge of the airfoil. The same number of panels are distributed on the upper and lower surfaces.
TINTC		The type of panel spacing to be used on the upper and lower surfaces of the airfoil.
	0	Full cosine spacing with smaller panels near the leading and trailing edges.(This is the recommended spacing).
	1	Half cosine spacing with smaller panels near the trailing edge.
	2	Half cosine spacing with smaller panels near the leading edge.
	3	Equal spacing.

SECT3: Body of Revolution Information

Variable	Value	Description
GAMMA	R	Rotation angle for the body of revolution. Rotation is about the rotation vector defined below, with positive rotation angle determined by Right Hand Rule.
GPX GPY GPZ	R R R	Starting point for vector defining rotation axis for body of revolution. (entered in inertial coordinate system)
GHX GHY GHZ	R R R	Ending point for vector defining patch arbitrary rotation axis. (entered in inertial coordinate system)

RECORD : Section Basic Point Coordinate Input (This record is repeated for each basic point defining this section)

Variable	Value	Description
B1 B2 B3	R R R	Basic point coordinates for section definition The values that go in B1, B2, B3 depend on the value of INMODE on SECT1.

NOTE: The values of B1, B2, B3 are entered as triplets in free format, with at least one space separating each value. One triplet is entered per line.

BPNODE: Break Point Input (inserted between basic point coordinates on a section definition as needed. Must terminate basic point input for a section with a BPNODE namelist)

Variable	Value	Description
TNODE	0	First or intermediate point (i.e. not a break point. Values entered for TNPC and TINTC are ignored).
	1	Break point with continuous slope into the next region on this section.
	2	Break point with discontinuous slope into the next region on this section.
	3	Final break point. End of this section definition.
TNPC	I	Number of panels to be generated between this break point and the previous one (or the first point of the section definition if this is the first or only break point). If TNPC = 0 at a break point, the input points will be used as the panel corner points between this break point and the previous one.

NOTE: The total number of panels to be generated on each section of a given patch must be the same.

Variable	Value	Description
TINTC	0	Full cosine spacing of panels between this break point and the previous one, with smaller panels near the two break points.
	1	Half cosine spacing of panels between this break point and the previous one, with smaller panels near the previous break point.
	2	Half cosine spacing of panels between this break point and the previous one, with smaller panels near this break point.
	3	Equal spacing of panels between this break point and the previous break point.

Surface Geometry Definition File in Plot3D 3D Multi-Grid Whole Format

The geometry definition file written in Plot3D format consists of an input defining the total number of patches (or grids in CFD terminology), followed by inputs defining the number of rows and columns of corner points in each patch (or grid). This is followed by a free-format list of all the x coordinates, then all the y coordinates, and finally all the z coordinates of the panel corner points for each patch (or grid). If the input data is a 3D structured volume grid of I x J x K points where I x J x 1 defines the surface grid and K > 1, PMARC reads the entire grid and discards all points except the surface grid points. The following segment of Fortran code illustrates the format in which PMARC expects to see the data in the geometry definition file.

```
READ(IUNIT,*) NGRID
READ(IUNIT,*) (IDIM(IGRID), JDIM(IGRID), KDIM(IGRID), IGRID=1,NGRID)
DO 10 IGRID=1,NGRID
   READ(IUNIT,*)
c       (((X(I,J,K),I=1,IDIM(IGRID)),J=1,JDIM(IGRID)),K=1,KDIM(IGRID)),
c       (((Y(I,J,K),I=1,IDIM(IGRID)),J=1,JDIM(IGRID)),K=1,KDIM(IGRID)),
c       (((Z(I,J,K),I=1,IDIM(IGRID)),J=1,JDIM(IGRID)),K=1,KDIM(IGRID))
10  CONTINUE
```

Wake Definition File in PMARC Native Format

The wake definition file for PMARC can be in one of two formats: PMARC native format or Plot3D 3D multi-grid whole format. The PMARC native format consists of a set of namelist definitions. The required format for the PMARC native wake definition file is shown below. Each namelist must begin with an & in the second column and the namelist name (i.e. WAKE1, SECT1, etc.) and end with &END. Blank spaces in a namelist are ignored, so the items in each namelist can be spaced in whatever fashion the user desires. A namelist can extend over as many lines as necessary. A description of each input variable and the valid input values follows. Under the Value column in the input description, the letter I means an integer value and the letter R means a real value.

The only wake input data that does not use the namelist format is the basic point coordinate input. The basic point coordinate input is handled using a free format input. One set of three coordinates separated by at least one space must appear on each line. See the sample input below.

```
&WAKE1     IDWAK=1,        IFLXW=2,         ITRFTZ=1,        INTRW=1,     &END
 TYPE WAKE NAME HERE
&WAKE2     KWPACH=1,        KWSIDE=2,       KWLINE=0,         KWPAN1=0,
           KWPAN2=0,        NODEW=5,        INITIAL=1,                    &END
&WAKE3     NFLEXWC(4)=0,
           NFLEXWC(5)=0,
           NFLEXWC(6)=0,                                                  &END
&SECT1     STX=     0.0000, STY=     0.0000, STZ=      0.0000, SCALE= 1.0000,
           ALF=   0.0,      THETA=    0.0,
           INMODE= 4,       TNODS= 3,       TNPS=   10,       TINTS= 3,   &END
           0.0    0.0    0.0
           0.0    1.0    0.0
           0.0    2.0    0.0
           0.0    5.0    0.0
&BPNODE    TNODE= 3,    TNPC=   10,    TINTC=  3,                         &END
```

Description of input variables

WAKE1: Wake Identification

Variable	Value	Description
IDWAK		Wake type
	0	No wakes
	1	Regular wake
IFLXW	0	Rigid wake. Wake will be time-stepped with the free-stream velocity only.
	1	Flexible wake. Wake will be time-stepped with the local velocity (includes influence of all surface and wake panels).
	2	Flexible wake with some wake columns treated as rigid. Requires WAKE3 namelist to follow the last WAKE2 namelist for this wake. WAKE3 namelist identifies which wake columns are treated as rigid.
ITRFTZ	0 or 1	Wake separation line used for Trefftz plane computation of induced drag for this wake. No wake roll-up effects are included.
	I	Wake row "I" used for Trefftz plane computation of induced drag for this wake. Wake roll-up effects will be included if wake is time-stepped and IFLXW = 0. If "I" exceeds the number of rows in this wake, then ITRFTZ is defaulted back to 1.
INTRW	0	Intersection routine turned off. Wake points are NOT checked to see if they have penetrated a paneled surface before velocity calculations are made for flexible wakes.
	1	Intersection routine turned on. Wake points are checked to see if they have penetrated a paneled surface before velocity calculations are made for flexible wakes.

RECORD: Wake Name (record to be inserted immediately following WAKE1 namelist).

Variable	Value	Description
WNAME (A24)		Text identifying the wake

WAKE2: Wake Separation Line Information

Variable	Value	Description
KWPACH	I	Surface geometry patch number that this wake separates from. If this wake separates from more than one patch, then additional WAKE2 namelists must be included for each patch this wake separates from.
KWSIDE	I	Side of the patch which is parallel to separation line. Separation line will be in same "direction" as the patch side specified (see figure 8).
KWLINE	I	Row or column number within patch from which the wake separates. The side of the panels on row or column KWLINE from which the wake separates will be the same as KWSIDE. If KWLINE=0, separation is from patch edge (see figure 4 for patch nomenclature).
KWPAN1	I	Number of first panel on row or column from which wake separates (numbered locally on row or column, i.e. the first panel on the row or column is 1, the second is 2, etc.). KWPAN1=0 defaults to the first panel on the row or column.
KWPAN2	I	Number of last panel on row or column from which wake separates (numbered locally on row or column). KWPAN2=0 defaults to the last panel on the row or column.

Variable	Value	Description
NODEW	0	Indicates that another WAKE2 namelist will follow to continue the wake separation line definition for this wake.
	3	Indicates this wake separation line definition is complete and there are more wakes to be defined after this wake.
	5	Indicates this wake separation line definition is complete and this is the last wake to be defined.
INITIAL	0	No initial wake geometry to be specified.
	1	Initial wake geometry to be specified. (SECT1 namelist must follow this namelist).

NOTE: When specifying a wake which separates from more than one patch, the order in which the separation patches (KWPACH) are input must be such that a single continuous separation line is defined.

WAKE3: Rigid wake column identification information

Variable	Value	Description
NFLEXWC(N)	0	Wake column N to be treated as rigid
	1	Wake column N to be treated as flexible

SECT1: Section Coordinate System Information

Variable	Value	Description
STX STY STZ	R R R	Origin of section coordinate system in inertial coordinate system.
SCALE	R	Section scale. If SCALE=0.0, the section reduces to a point at the section coordinate system origin.
ALF	R	Rotation angle of the section coordinate system about its Y axis. A positive rotation angle is defined by the Right Hand Rule.

THETA	R	Rotation angle of the section coordinate system about its Z axis. A positive rotation angle is defined by the Right Hand Rule.
INMODE	-1	Copies the basic point coordinates of previous section and the values entered for STX, STY, and STZ on this section are displacement distances from the origin of the previous section.
	0	Copies the basic point coordinates of previous section.
	1	Input Y, Z, DX coordinates to define section. The X coordinate is defaulted to 0.0, but local deviations can be entered in DX. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	2	Input X, Z, DY coordinates to define section. The Y coordinate is defaulted to 0.0, but local deviations can be entered in DY. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	3	Input X, Y, DZ coordinates to define section. The Z coordinate is defaulted to 0.0, but local deviations can be entered in DZ. (basic point coordinates and BPNODE namelists follow this namelist as needed).
	4	Input X, Y, Z coordinates to define section. (basic point coordinates and BPNODE namelists follow this namelist as needed).

Variable	Value	Description
TNODS	0	First or intermediate section of wake.
	1	Break point on wake with continuous slope into the next region of wake.
	2	Break point on wake with discontinuous slope into the next region of wake.
	3	Last section definition on this wake.
TNPS	I	Number of panels to be generated between this break point and the previous break point (or the first section of this wake if this is the first or only break point). If TNPS = 0 at a break point, the input sections between this break point and the previous one will be used to define the panel edges.
TINTS	0	Full cosine spacing of panels between this break point and the previous one, with smaller panels near the two break points.
	1	Half cosine spacing of panels between this break point and the previous one, with smaller panels near the previous break point.
	2	Half cosine spacing of panels between this break point and the previous one, with smaller panels near this break point.
	3	Equal spacing of panels between this break point and the previous break point.

RECORD : Section Basic Point Coordinate Input (This record is repeated for each basic point defining this section)

Variable	Value	Description
B1 B2 B3	R R R	Basic point coordinates for section definition. The values that go in B1, B2, B3 depend on the value of INMODE on SECT1.

NOTE: The values of B1, B2, B3 are entered as triplets in free format, with at least one space separating each value. One triplet is entered per line.

BPNODE: Break Point Input (inserted between basic point coordinates on a section definition as needed. Must terminate basic point input for a section with a BPNODE namelist)

Variable	Value	Description
TNODE	0	First or intermediate point (i.e. not a break point. Values entered for TNPC and TINTC are ignored).
	1	Break point with continuous slope into the next region on this section.
	2	Break point with discontinuous slope into the next region on this section.
	3	Final break point. End of this section definition.
TNPC	I	Number of panels to be generated between this break point and the previous one (or the first point of the section definition if this is the first or only break point). If TNPC = 0 at a break point, the input points will be used as the panel corner points between this break point and the previous one.

NOTE: The total number of panels to be generated on each section of this wake must be the same as the total number of surface geometry panels that this wake separates from.

Variable	Value	Description
TINTC	0	Full cosine spacing of panels between this break point and the previous one, with smaller panels near the two break points.
	1	Half cosine spacing of panels between this break point and the previous one, with smaller panels near the previous break point.
	2	Half cosine spacing of panels between this break point and the previous one, with smaller panels near this break point.
	3	Equal spacing of panels between this break point and the previous break point.

Wake Definition File in Plot3D 3D Multi-Grid Whole Format

The wake definition file written in Plot3D format consists of an input defining the total number of wakes (or grids in CFD terminology), followed by inputs defining the number of rows and columns of corner points in each wake (or grid). This is followed by a free-format list of all the x coordinates, then all the y coordinates, and finally all the z coordinates of the panel corner points for each wake (or grid). If the input data is a 3D structured volume grid of I x J x K points where I x J x 1 defines the wake surface grid and K > 1, PMARC reads the entire grid and discards all points except the surface grid points. Following the corner point data for all the wakes in Plot3D format, the WAKE2 namelist must be used to specify the wake separation line information which identifies which set of surface patches each wake separates from. The format for the WAKE2 namelist has already been described in the preceding section. One set of WAKE2 namelists must be entered for each wake in the wake definition file and all WAKE 2 namelists are appended to the end of the file. The following segment of Fortran code illustrates the format in which PMARC expects to see the data in the wake definition file.

```
READ(IUNIT,*) NGRID
READ(IUNIT,*) (IDIM(IGRID), JDIM(IGRID), KDIM(IGRID), IGRID=1,NGRID)
DO 10 IGRID=1,NGRID
   READ(IUNIT,*)
c       (((X(I,J,K),I=1,IDIM(IGRID)),J=1,JDIM(IGRID)),K=1,KDIM(IGRID)),
c       (((Y(I,J,K),I=1,IDIM(IGRID)),J=1,JDIM(IGRID)),K=1,KDIM(IGRID)),
c       (((Z(I,J,K),I=1,IDIM(IGRID)),J=1,JDIM(IGRID)),K=1,KDIM(IGRID))
10 CONTINUE
```

```
 &WAKE2     KWPACH=1,     KWSIDE=2,     KWLINE=0,     KWPAN1=0,
            KWPAN2=0,     NODEW=5,      INITIAL=1,                   &END
```

Additional Options Definition File

On-body streamline input section

The on-body streamline input section of PMARC consists of a single namelist definition. The required format for the on-body streamline input section is shown below. The namelist for the on-body streamline input must always be included, even if there are no on-body streamlines. This namelist tells PMARC whether or not there are on-body streamlines and if so, how many and what panels they start on. The namelist must begin with an & in the second column and the namelist name (i.e. ONSTRM) and end with &END. Blank spaces in a namelist are ignored, so items in each namelist can be spaced in whatever fashion the user desires. A namelist can extend over as many lines as necessary. A description of each input variable and the valid input values follows. Under the Value column in the input description, the letter I means an integer value and the letter R means a real value.

NOTE: Variables in the namelist definition which are arrays should have their elements listed out following the variable name. For example, if there were three values to be entered into the array KPSL, the input would be as follows: KPSL = I1, I2, I3. The rest of the elements in array KPSL will automatically be left at zero.

```
 &ONSTRM     NONSL= 5,        KPSL= 20,50,80,110,140,                          &END
```

ONSTRM:

Variable	Value	Description
NONSL	I	Number of on-body streamlines
KPSL(N)	I	Surface panel number on which each streamline starts. Streamline will start at panel centroid and trace upstream and downstream until a stagnation point or attachment line is encountered or a separation point is encountered.

NOTE: N goes from 1 to NONSL

BLPARAM: Namelist for boundary layer parameters (needed only if NBLIT = 1 on &BINP13)

Variable	Value	Description
RN	R	Reynolds number based on CBAR, VISC, and Free-stream velocity. Note that the dimensional Free-stream velocity is computed from RN, CBAR, and VISC.
VISC	R	Dimensional kinematic viscosity to be used in boundary layer calculations. Units must agree with global geometry units ((length units)^2/sec)
NSLBL(N)	I	Streamline number(s) of streamline(s) on which boundary layer calculations are to be performed. Streamlines are numbered locally from 1 to NONSL.

NOTE: N goes from 1 to NONSL

Off-body velocity scan input section

The off-body velocity scan input data follows immediately after the on- body streamline input section. The off-body velocity scan input section of PMARC consists of a set of namelist definitions. The required format for the velocity scan input section is shown below. The best way to handle the velocity scan input section is to create a template file which can then be included into any PMARC file and the values modified appropriately. All the namelists should always be included as shown below whether or not a particular namelist is needed for the job being run. If a namelist is not needed for a particular job, PMARC merely skips over that namelist. Each namelist must begin with an & in the second column and the namelist name (i.e. VS1, VS2, etc.) and end with &END. Blank spaces in a namelist are ignored, so items in each namelist can be spaced in whatever fashion the user desires. A namelist can extend over as many lines as necessary. A description of each input variable and the valid input values follows. Under the Value column in the input description, the letter I means an integer value and the letter R means a real value.

NOTE: Variables in the namelist definition which are arrays should have their elements listed out following the variable name. For example, if there were three values to be entered into the array X0, the input would be as follows: X0 = R1,R2,R3. The rest of the elements in array X0 will automatically be left at zero.

```
&VS1    NVOLR= 1,         NVOLC= 1,                                          &END
&VS2    X0=    -2.0000,  Y0=      0.0000,  Z0=     -2.0000,  INTVSR=1,       &END
&VS3    X1=     2.0000,  Y1=      0.0000,  Z1=     -2.0000,  NPT1= 20,       &END
&VS4    X2=    -2.0000,  Y2=      0.0000,  Z2=     -2.0000,  NPT2=  0,       &END
&VS5    X3=    -2.0000,  Y3=      0.0000,  Z3=      2.0000,  NPT3= 40,       &END

&VS6    XR0=    0.0000,  YR0=     0.0000,  ZR0=     0.0000,  INTVSC=1,       &END
&VS7    XR1=    0.0000,  YR1=    10.0000,  ZR1=     0.0000,
        XR2=    0.0000,  YR2=     0.0000,  ZR2=     1.0000,                  &END
&VS8    R1=     0.5000,  R2=      5.0000,  PHI1=   0.0,      PHI2=330.0,     &END
&VS9    NRAD=  10,        NPHI=   12,       NLEN=   5,                        &END
```

VS1:

Variable	Value	Description
NVOLR	I	Number of rectangular scan volumes
NVOLC	I	Number of cylindrical scan volumes

VS2:

Variable	Value	Description
X0(N) Y0(N) Z0(N)	R R R	Coordinates of origin of rectangular scan volume N. See figure 9.
INTVSR(N)	0	Intersection routine turned off. Scan points are NOT checked to see if they are inside a paneled surface before velocity calculations are made.
	1	Intersection routine turned on. Scan points are checked to see if they are inside a paneled surface before velocity calculations are made.

VS3:

Variable	Value	Description
X1(N) Y1(N) Z1(N)	R R R	Coordinates of corner in **i** direction for rectangular scan volume N. See figure 9.
NPT1(N)	I	Number of scan points to be distributed along side **i** of scan volume N.

VS4:

Variable	Value	Description
X2(N) Y2(N) Z2(N)	R R R	Coordinates of corner in **j** direction for rectangular scan volume N. See figure 9.
NPT2(N)	I	Number of scan points to be distributed along side **j** of scan volume N.

VS5:

Variable	Value	Description
X3(N) Y3(N) Z3(N)	R R R	Coordinates of corner in **k** direction for rectangular scan volume N. See figure 9.
NPT3(N)	I	Number of scan points to be distributed along side **k** of scan volume N.

NOTE: N goes from 1 to NVOLR
NOTE: If NPT1, NPT2, or NPT3 is zero, the corresponding side of the rectangular scan volume collapses to a point. Thus a rectangular scan volume can be reduced to a plane, a line, or a point.

VS6:

Variable	Value	Description
XR0(N) YR0(N) ZR0(N)	R R R	Coordinates of origin of cylindrical scan volume N. See figure 10.
INTVSC(N)	0	Intersection routine turned off. Scan points are NOT checked to see if they are inside a paneled surface before velocity calculations are made.
	1	Intersection routine turned on. Scan points are checked to see if they are inside a paneled surface before velocity calculations are made.

VS7:

Variable	Value	Description
XR1(N) YR1(N) ZR1(N)	R R R	Coordinates of point defining axis (from XR0, YR0, ZR0) of cylindrical scan volume N. (Cannot be XR0, YR0, ZR0). See figure 10.
XR2(N) YR2(N) ZR2(N)	R R R	Coordinates of point defining vector (from XR0, YR0, ZR0) from which PHI is measured for scan volume N. See figure 10.

VS8:

Variable	Value	Description
R1(N)	R	Inner radius of cylindrical scan volume N.
R2(N)	R	Outer radius of cylindrical scan volume N.
PHI1(N)	R	Starting angle (measured from the vector (XR2-XR0),(YR2-YR0), (ZR2-ZR0)) for cylindrical scan volume N. Positive angle is determined by the Right Hand Rule.
PHI2(N)	R	Ending angle (measured from the vector (XR2-XR0),(YR2-YR0), (ZR2-ZR0)) for cylindrical scan volume N. Positive angle is determined by the Right Hand Rule.

VS9:

Variable	Value	Description
NRAD(N)	I	Number of points to be distributed in the radial direction for cylindrical scan volume N.
NPHI(N)	I	Number of points to be distributed in the ϕ direction for cylindrical scan volume N.
NLEN(N)	I	Number of points to be distributed in the axial direction for cylindrical scan volume N.

NOTE: N goes from 1 to NVOLC
NOTE: The cylindrical scan volume can be reduced to a plane, a line, or a point by setting NLEN, NPHI, or NRAD equal to zero.

Off-body streamline input section

The off-body streamline input data must follow immediately after the off-body velocity scan data. The off-body streamline input section of PMARC consists of a namelist which defines the number of streamlines there will be for the job and a namelist definition which is repeated for each separate streamline. The required format for the off-body streamline input section is shown below. The best way to handle the off-body streamline input section is to create a template file with a single streamline which can then be included into any PMARC file and the values modified appropriately. Both of the namelists shown below should always be included in the input file, whether or not there will be any off-body streamlines. If a namelist is not needed for a particular job, PMARC merely skips over that namelist. Each namelist must begin with an & in the second column and the namelist name (i.e. SLIN1, SLIN2, etc.) and end with &END. Blank spaces in a namelist are ignored, so the items in each namelist can be spaced in whatever fashion the user desires. A namelist can extend over as many lines as necessary. A description of each input variable and the valid input values follows. Under the Value column in the input description, the letter I means an integer value and the letter R means a real value.

```
&SLIN1     NSTLIN=1,                                                  &END
&SLIN2     SX0=    -3.0000,  SY0=     0.0000,  SZ0=     0.0500,
           SU=      0.0000,  SD=      6.5000,  DS=      0.0250,  INTSL=1,   &END
```

SLIN1:

Variable	Value	Description
NSTLIN	I	Number of streamlines to be defined.

SLIN2:

Variable	Value	Description
SX0 SY0 SZ0	R R R	Coordinates for starting point of streamline in the inertial coordinate system
SU	R	Distance streamline to be traced in upstream direction (same units of length as geometry).
SD	R	Distance streamline to be traced in downstream direction (same units of length as geometry).
DS	R	Step size to be used in tracing streamline (D distance)
INTSL	0	Intersection routine turned off. Streamline points are NOT checked to see if they have penetrated a paneled surface before velocity calculations are made for the current point.
	1	Intersection routine turned on. Streamline points are checked to see if they have penetrated a paneled surface before velocity calculations are made for the current point.

NOTE: Record SLIN2 must be repeated NSTLIN times (one for each streamline).

APPENDIX D

Symmetric Wing/Body Test Case Input File

JOBCNTRL.INP File

```
WING BODY COMBINATION TEST CASE

 &BINP2   LSTINP=2,    LSTOUT=1,    LSTFRQ=1,    LENRUN=0,    LPLTYP=1,     &END
 &BINP3   LSTGEO=1,    LSTNAB=0,    LSTWAK=3,    LSTCPV=0,                  &END
 &BINP4   MAXIT=200,   SOLRES=0.0005,            NRDDUB=0,    CPFLOOD=0,    &END
 &BINP5   NTSTPS= 10,   DTSTEP=3.00,                                        &END
 &BINP6   RSYM=0.0,    RGPR=0.0,    RFF=5.0,     NF= 0,
          RCORES(1)=0.00001, RCOREW(1)=0.00010,                             &END
 &BINP7   NPATH=    1, VSOUND=1116.0, NRDPATH=0, ICCOMP=0,                  &END
 &BINP8   VTCX(1)=-0.9976,VTCY(1)= 0.0, VTCZ(1)= -0.0698,
          P(1)=  0.0,    Q(1)=  0.,    R(1)=  0.0,
          CX0(1)= 0.0,   CY0(1)= 0.0, CZ0(1)= 0.0,
          PHI(1)=  0.,   THE(1)=  0., PSI(1)=  0.,INCROT(1)=0,              &END
 &BINP8A  PHIMAX(1)= 0.0, THEMAX(1)=0.0, PSIMAX(1)=0.0,
          WRX(1)=0.0000,  WRY(1)=0.0000, WRZ(1)=0.0000,                     &END
 &BINP8B  DXMAX(1)=0.00,  DYMAX(1)=0.0,   DZMAX(1)=0.0,
          WTX(1)=0.0000,  WTY(1)=0.0000,  WTZ(1)=0.0000,                    &END
 &BINP9   CBAR(1)=6.1250, SREF(1)=147.00, SSPAN(1)=12.0,
          RMPX(1)=9.0000,   RMPY(1)=0.00,    RMPZ(1)=0.00,                  &END
 &BINP10  NORSET=0,    NBCHGE=0,    NCZONE=0,
          NCZPCH=0,    CZDUB=0.0,   VREF=00.0,                              &END
 &BINP11  NORPCH=0,    NORF=0,      NORL=0,
          NOCF=0,      NOCL=0,      VNORM=0.0,                              &END
 &BINP12  KPAN=0,      KSIDE=0,     NEWNAB=0,    NEWSID=0,                  &END
 &BINP13  NBLIT = 1,                                                        &END
 &BINP14  INSURF= 0,   INWAKE= 0,   OUTSURF= 0,  OUTWAKE= 0,                &END
wingbody_14.geom.pmarc
wingbody_14.wake.pmarc
wingbody_14.extras
```

Geometry Definition File (PMARC native format, wingbody_14.geom.pmarc)

```
 &ASEM1   ASEMX=     0.0000, ASEMY=     0.0000, ASEMZ=     0.0000,
          ASCAL=     1.0000, ATHET=    0.0,     NODEA=    0,                &END
 &ASEM2   APXX=0.00,         APYY=0.00,         APZZ=0.00,
          AHXX=0.00,         AHYY=1.00,         AHZZ=0.00,                  &END


 &ASEM1   ASEMX=     0.0000, ASEMY=     0.0000, ASEMZ=     0.0000,
          ASCAL=     1.0000, ATHET=    0.0,     NODEA=    5,                &END
 &ASEM2   APXX=0.00,         APYY=0.00,         APZZ=0.00,
          AHXX=0.00,         AHYY=1.00,         AHZZ=0.00,                  &END


 &COMP1   COMPX=     0.0000, COMPY=     0.0000, COMPZ=     0.0000,
          CSCAL=     1.0000, CTHET=    0.0,     NODEC=    5,                &END
 &COMP2   CPXX= 0.0000,      CPYY= 0.0000,      CPZZ= 0.0000,
          CHXX= 0.0000,      CHYY=  1.000    ,  CHZZ= 0.0000,               &END
```

```
&PATCH1  IREV=  0, IDPAT= 1, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
         IPATCOP=0,          IPATH=  1,                                &END
WING
&SECT1   STX=    0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=       0.0, THETA=     0.0,
         INMODE=      4, TNODS=       0, TNPS=         0, TINTS=         0, &END
  21.4641     1.6481    0.0000
  21.3866     1.6482   -0.0059
  21.1575     1.6484   -0.0228
  20.7868     1.6488   -0.0493
  20.2908     1.6495   -0.0847
  19.6855     1.6440   -0.1260
  18.9955     1.6313   -0.1662
  18.2571     1.6195   -0.1979
  17.5037     1.6103   -0.2125
  16.7691     1.6043   -0.2083
  16.0776     1.5933   -0.1902
  15.4628     1.5811   -0.1616
  14.9568     1.5731   -0.1252
  14.5818     1.5692   -0.0855
  14.3560     1.5698   -0.0434
  14.2985     1.5751    0.0000
  14.3560     1.5698    0.0434
  14.5818     1.5692    0.0855
  14.9568     1.5731    0.1252
  15.4628     1.5811    0.1616
  16.0776     1.5933    0.1902
  16.7691     1.6043    0.2083
  17.5037     1.6103    0.2125
  18.2571     1.6195    0.1979
  18.9955     1.6313    0.1662
  19.6855     1.6440    0.1260
  20.2908     1.6495    0.0847
  20.7868     1.6488    0.0493
  21.1575     1.6484    0.0228
  21.3866     1.6482    0.0059
  21.4641     1.6481    0.0000
&BPNODE  TNODE=       3, TNPC=        0, TINTC=       0,               &END
&SECT1   STX=   25.3750, STY=   12.0000, STZ=    0.0000, SCALE=    4.5000,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  2,  TNODS= 3,    TNPS= 10,     TINTS= 0,            &END
   1.0000   0.00000        0.0
   0.9500  -0.00370        0.0
   0.9000  -0.00727        0.0
   0.8500  -0.01083        0.0
   0.8000  -0.01437        0.0
   0.7500  -0.01775        0.0
   0.7000  -0.02087        0.0
   0.6500  -0.02364        0.0
   0.6000  -0.02602        0.0
   0.5500  -0.02793        0.0
   0.5000  -0.02925        0.0
   0.4500  -0.02992        0.0
   0.4000  -0.02996        0.0
   0.3500  -0.02945        0.0
   0.3000  -0.02842        0.0
   0.2500  -0.02687        0.0
   0.2000  -0.02474        0.0
```

```
   0.1500  -0.02194       0.0
   0.1000  -0.01824       0.0
   0.0750  -0.01591       0.0
   0.0500  -0.01313       0.0
   0.0250  -0.00981       0.0
   0.0125  -0.00718       0.0
   0.0075  -0.00563       0.0
    0.005  -0.00464       0.0
      0.0       0.0       0.0
&BPNODE  TNODE= 2,    TNPC= 15,     TINTC=  0,                          &END
      0.0       0.0       0.0
    0.005   0.00464       0.0
   0.0075   0.00563       0.0
   0.0125   0.00718       0.0
   0.0250   0.00981       0.0
   0.0500   0.01313       0.0
   0.0750   0.01591       0.0
   0.1000   0.01824       0.0
   0.1500   0.02194       0.0
   0.2000   0.02474       0.0
   0.2500   0.02687       0.0
   0.3000   0.02842       0.0
   0.3500   0.02945       0.0
   0.4000   0.02996       0.0
   0.4500   0.02992       0.0
   0.5000   0.02925       0.0
   0.5500   0.02793       0.0
   0.6000   0.02602       0.0
   0.6500   0.02364       0.0
   0.7000   0.02087       0.0
   0.7500   0.01775       0.0
   0.8000   0.01437       0.0
   0.8500   0.01083       0.0
   0.9000   0.00727       0.0
   0.9500   0.00370       0.0
   1.0000   0.00000       0.0
&BPNODE  TNODE= 3,    TNPC= 15,     TINTC=  0,                          &END

&PATCH1  IREV=  0, IDPAT= 2, MAKE=   1, KCOMP= 1, KASS= 2, IPATSYM=0,
         IPATCOP=0,          IPATH=  1,                                 &END
WING_TIP
&PATCH2  ITYP=  2,    TNODS= 3,    TNPS=   4,    TINTS= 3,              &END

&PATCH1  IREV=  0, IDPAT= 2, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
         IPATCOP=0,          IPATH=  1,                                 &END
FORWARD_FUSELAGE
&SECT1   STX=    0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    0.0000,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  1,  TNODS= 0,    TNPS=  0,    TINTS= 0,               &END
   0.0000   -1.0000    0.0000
   0.1735   -0.9845    0.0000
   0.3420   -0.9395    0.0000
   0.5000   -0.8660    0.0000
   0.6425   -0.7660    0.0000
   0.7660   -0.6425    0.0000
   0.8660   -0.5000    0.0000
```

```
    0.9395   -0.3420    0.0000
    0.9845   -0.1735    0.0000
    1.0000    0.0000    0.0000
    0.9845    0.1735    0.0000
    0.9395    0.3420    0.0000
    0.8660    0.5000    0.0000
    0.7660    0.6425    0.0000
    0.6425    0.7660    0.0000
    0.5000    0.8660    0.0000
    0.3420    0.9395    0.0000
    0.1735    0.9845    0.0000
    0.0000    1.0000    0.0000
&BPNODE  TNODE= 3,    TNPC= 10,     TINTC=  3,                                    &END
&SECT1   STX=     0.2000, STY=     0.0000, STZ=     0.0000, SCALE=     0.0924,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=     0.5000, STY=     0.0000, STZ=     0.0000, SCALE=     0.1712,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=     1.0000, STY=     0.0000, STZ=     0.0000, SCALE=     0.2889,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=     2.0000, STY=     0.0000, STZ=     0.0000, SCALE=     0.4820,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=     4.0000, STY=     0.0000, STZ=     0.0000, SCALE=     0.7884,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=     8.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.2360,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=    12.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.4964,
         ALF=    0.0,  THETA=    0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,     TINTS= 0,                        &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=       0.0,
         INMODE=       4, TNODS=         3, TNPS=         7, TINTS=          0, &END
   14.2983    0.0000   -1.5829
   14.2983    0.4893   -1.5050
   14.2983    0.9307   -1.2802
   14.2983    1.2808   -0.9297
   14.2983    1.5053   -0.4881
   14.2985    1.5751    0.0000
   14.2983    1.5048    0.4900
   14.2983    1.2800    0.9309
   14.2983    0.9299    1.2807
   14.2983    0.4888    1.5051
   14.2983    0.0000    1.5829
&BPNODE  TNODE=        3, TNPC=         0, TINTC=        0,                       &END

&PATCH1  IREV=  0, IDPAT= 2, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
         IPATCOP=0,           IPATH=  1,                                          &END
LOWER_MID_FUSELAGE
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=       0.0,
         INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   14.2983    0.0000   -1.5829
```

```
  14.2983     0.4893    -1.5050
  14.2983     0.9307    -1.2802
  14.2983     1.2808    -0.9297
  14.2983     1.5053    -0.4881
  14.2985     1.5751     0.0000
&BPNODE  TNODE=        3, TNPC=        0, TINTC=        0,                  &END
&SECT1   STX=     0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=       0, TNPS=         0, TINTS=         0, &END
  14.3558     0.0000    -1.5846
  14.3558     0.4811    -1.5091
  14.3558     0.9169    -1.2919
  14.3558     1.2664    -0.9527
  14.3558     1.4962    -0.5234
  14.3560     1.5698    -0.0434
&BPNODE  TNODE=        3, TNPC=        0, TINTC=        0,                  &END
&SECT1   STX=     0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=       0, TNPS=         0, TINTS=         0, &END
  14.5815     0.0000    -1.5912
  14.5815     0.4751    -1.5176
  14.5815     0.9070    -1.3067
  14.5815     1.2565    -0.9767
  14.5815     1.4913    -0.5575
  14.5818     1.5692    -0.0855
&BPNODE  TNODE=        3, TNPC=        0, TINTC=        0,                  &END
&SECT1   STX=     0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=       0, TNPS=         0, TINTS=         0, &END
  14.9565     0.0000    -1.6014
  14.9565     0.4707    -1.5295
  14.9565     0.8999    -1.3239
  14.9565     1.2500    -1.0016
  14.9565     1.4896    -0.5908
  14.9568     1.5731    -0.1252
&BPNODE  TNODE=        3, TNPC=        0, TINTC=        0,                  &END
&SECT1   STX=     0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=       0, TNPS=         0, TINTS=         0, &END
  15.4626     0.0000    -1.6139
  15.4626     0.4676    -1.5432
  15.4626     0.8952    -1.3420
  15.4626     1.2463    -1.0260
  15.4626     1.4904    -0.6219
  15.4628     1.5811    -0.1616
&BPNODE  TNODE=        3, TNPC=        0, TINTC=        0,                  &END
&SECT1   STX=     0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=       0, TNPS=         0, TINTS=         0, &END
  16.0776     0.0000    -1.6271
  16.0776     0.4664    -1.5573
  16.0776     0.8935    -1.3589
  16.0776     1.2461    -1.0470
  16.0776     1.4940    -0.6472
  16.0776     1.5933    -0.1902
&BPNODE  TNODE=        3, TNPC=        0, TINTC=        0,                  &END
&SECT1   STX=     0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=        0.0, THETA=     0.0,
```

```
          INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   16.7691     0.0000    -1.6396
   16.7691     0.4668    -1.5701
   16.7691     0.8948    -1.3730
   16.7691     1.2492    -1.0627
   16.7691     1.5000    -0.6645
   16.7691     1.6043    -0.2083
&BPNODE   TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1    STX=     0.0000, STY=      0.0000, STZ=     0.0000, SCALE=     1.0000,
          ALF=        0.0, THETA=       0.0,
          INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   17.5036     0.0000    -1.6507
   17.5036     0.4693    -1.5808
   17.5036     0.8997    -1.3830
   17.5036     1.2563    -1.0715
   17.5036     1.5089    -0.6716
   17.5037     1.6103    -0.2125
&BPNODE   TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1    STX=     0.0000, STY=      0.0000, STZ=     0.0000, SCALE=     1.0000,
          ALF=        0.0, THETA=       0.0,
          INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   18.2570     0.0000    -1.6594
   18.2570     0.4747    -1.5884
   18.2570     0.9097    -1.3869
   18.2570     1.2691    -1.0699
   18.2570     1.5221    -0.6635
   18.2571     1.6195    -0.1979
&BPNODE   TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1    STX=     0.0000, STY=      0.0000, STZ=     0.0000, SCALE=     1.0000,
          ALF=        0.0, THETA=       0.0,
          INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   18.9955     0.0000    -1.6650
   18.9955     0.4825    -1.5920
   18.9955     0.9236    -1.3844
   18.9955     1.2860    -1.0582
   18.9955     1.5377    -0.6413
   18.9955     1.6313    -0.1662
&BPNODE   TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1    STX=     0.0000, STY=      0.0000, STZ=     0.0000, SCALE=     1.0000,
          ALF=        0.0, THETA=       0.0,
          INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   19.6855     0.0000    -1.6670
   19.6855     0.4910    -1.5918
   19.6855     0.9385    -1.3769
   19.6855     1.3032    -1.0401
   19.6855     1.5522    -0.6110
   19.6855     1.6440    -0.1260
&BPNODE   TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1    STX=     0.0000, STY=      0.0000, STZ=     0.0000, SCALE=     1.0000,
          ALF=        0.0, THETA=       0.0,
          INMODE=       4, TNODS=         0, TNPS=         0, TINTS=          0, &END
   20.2908     0.0000    -1.6660
   20.2908     0.4985    -1.5887
   20.2908     0.9515    -1.3669
   20.2908     1.3177    -1.0199
   20.2908     1.5630    -0.5794
   20.2908     1.6495    -0.0847
&BPNODE   TNODE=        3, TNPC=          0, TINTC=        0,                     &END
```

```
&SECT1    STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=        0.0, THETA=      0.0,
          INMODE=       4, TNODS=        0, TNPS=         0, TINTS=         0, &END
  20.7869    0.0000   -1.6635
  20.7869    0.5044   -1.5844
  20.7869    0.9614   -1.3570
  20.7869    1.3281   -1.0018
  20.7869    1.5697   -0.5522
  20.7868    1.6488   -0.0493
&BPNODE   TNODE=        3, TNPC=         , TINTC=      0,                    &END
&SECT1    STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=        0.0, THETA=      0.0,
          INMODE=       4, TNODS=        0, TNPS=         0, TINTS=         0, &END
  21.1576    0.0000   -1.6605
  21.1576    0.5085   -1.5802
  21.1576    0.9682   -1.3487
  21.1576    1.3349   -0.9875
  21.1576    1.5733   -0.5313
  21.1575    1.6484   -0.0228
&BPNODE   TNODE=        3, TNPC=        0, TINTC=      0,                    &END
&SECT1    STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=        0.0, THETA=      0.0,
          INMODE=       4, TNODS=        0, TNPS=         0, TINTS=         0, &END
  21.3867    0.0000   -1.6583
  21.3867    0.5110   -1.5771
  21.3867    0.9722   -1.3431
  21.3867    1.3389   -0.9781
  21.3867    1.5751   -0.5179
  21.3866    1.6482   -0.0059
&BPNODE   TNODE=        3, TNPC=        0, TINTC=      0,                    &END
&SECT1    STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=        0.0, THETA=      0.0,
          INMODE=       4, TNODS=        3, TNPS=         0, TINTS=         0, &END
  21.4642    0.0000   -1.6574
  21.4642    0.5124   -1.5759
  21.4642    0.9745   -1.3404
  21.4642    1.3412   -0.9734
  21.4642    1.5762   -0.5110
  21.4641    1.6481    0.0000
&BPNODE   TNODE=        3, TNPC=        0, TINTC=      0,                    &END


&PATCH1   IREV= 0, IDPAT= 2, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
          IPATCOP=0,          IPATH=  1,                                     &END
UPPER_MID_FUSELAGE
&SECT1    STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=        0.0, THETA=      0.0,
          INMODE=       4, TNODS=        0, TNPS=         0, TINTS=         0, &END
  14.2985    1.5751    0.0000
  14.2983    1.5048    0.4900
  14.2983    1.2800    0.9309
  14.2983    0.9299    1.2807
  14.2983    0.4888    1.5051
  14.2983    0.0000    1.5829
&BPNODE   TNODE=        3, TNPC=        0, TINTC=      0,                    &END
&SECT1    STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=        0.0, THETA=      0.0,
          INMODE=       4, TNODS=        0, TNPS=         0, TINTS=         0, &END
```

```
  14.3560    1.5698    0.0434
  14.3558    1.4962    0.5234
  14.3558    1.2664    0.9527
  14.3558    0.9169    1.2919
  14.3558    0.4811    1.5091
  14.3558    0.0000    1.5846
&BPNODE  TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=         0, TNPS=         0, TINTS=           0, &END
  14.5818    1.5692    0.0855
  14.5815    1.4913    0.5575
  14.5815    1.2565    0.9767
  14.5815    0.9070    1.3067
  14.5815    0.4751    1.5176
  14.5815    0.0000    1.5912
&BPNODE  TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=         0, TNPS=         0, TINTS=           0, &END
  14.9568    1.5731    0.1252
  14.9565    1.4896    0.5908
  14.9565    1.2500    1.0016
  14.9565    0.8999    1.3239
  14.9565    0.4707    1.5295
  14.9565    0.0000    1.6014
&BPNODE  TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=         0, TNPS=         0, TINTS=           0, &END
  15.4628    1.5811    0.1616
  15.4626    1.4904    0.6219
  15.4626    1.2463    1.0260
  15.4626    0.8952    1.3420
  15.4626    0.4676    1.5432
  15.4626    0.0000    1.6139
&BPNODE  TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=         0, TNPS=         0, TINTS=           0, &END
  16.0776    1.5933    0.1902
  16.0776    1.4940    0.6472
  16.0776    1.2461    1.0470
  16.0776    0.8935    1.3589
  16.0776    0.4664    1.5573
  16.0776    0.0000    1.6271
&BPNODE  TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=        0.0, THETA=     0.0,
         INMODE=       4, TNODS=         0, TNPS=         0, TINTS=           0, &END
  16.7691    1.6043    0.2083
  16.7691    1.5000    0.6645
  16.7691    1.2492    1.0627
  16.7691    0.8948    1.3730
  16.7691    0.4668    1.5701
  16.7691    0.0000    1.6396
&BPNODE  TNODE=        3, TNPC=          0, TINTC=        0,                     &END
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
```

```
          ALF=          0.0, THETA=      0.0,
          INMODE=         4, TNODS=        0, TNPS=           0, TINTS=           0, &END
   17.5037     1.6103     0.2125
   17.5036     1.5089     0.6716
   17.5036     1.2563     1.0715
   17.5036     0.8997     1.3830
   17.5036     0.4693     1.5808
   17.5036     0.0000     1.6507
&BPNODE   TNODE=          3, TNPC=         0, TINTC=        0,                        &END
&SECT1    STX=       0.0000, STY=     0.0000, STZ=     0.0000, SCALE=      1.0000,
          ALF=          0.0, THETA=      0.0,
          INMODE=         4, TNODS=        0, TNPS=           0, TINTS=           0, &END
   18.2571     1.6195     0.1979
   18.2570     1.5221     0.6635
   18.2570     1.2691     1.0699
   18.2570     0.9097     1.3869
   18.2570     0.4747     1.5884
   18.2570     0.0000     1.6594
&BPNODE   TNODE=          3, TNPC=         0, TINTC=        0,                        &END
&SECT1    STX=       0.0000, STY=     0.0000, STZ=     0.0000, SCALE=      1.0000,
          ALF=          0.0, THETA=      0.0,
          INMODE=         4, TNODS=        0, TNPS=           0, TINTS=           0, &END
   18.9955     1.6313     0.1662
   18.9955     1.5377     0.6413
   18.9955     1.2860     1.0582
   18.9955     0.9236     1.3844
   18.9955     0.4825     1.5920
   18.9955     0.0000     1.6650
&BPNODE   TNODE=          3, TNPC=         0, TINTC=        0,                        &END
&SECT1    STX=       0.0000, STY=     0.0000, STZ=     0.0000, SCALE=      1.0000,
          ALF=          0.0, THETA=      0.0,
          INMODE=         4, TNODS=        0, TNPS=           0, TINTS=           0, &END
   19.6855     1.6440     0.1260
   19.6855     1.5522     0.6110
   19.6855     1.3032     1.0401
   19.6855     0.9385     1.3769
   19.6855     0.4910     1.5918
   19.6855     0.0000     1.6670
&BPNODE   TNODE=          3, TNPC=         0, TINTC=        0,                        &END
&SECT1    STX=       0.0000, STY=     0.0000, STZ=     0.0000, SCALE=      1.0000,
          ALF=          0.0, THETA=      0.0,
          INMODE=         4, TNODS=        0, TNPS=           0, TINTS=           0, &END
   20.2908     1.6495     0.0847
   20.2908     1.5630     0.5794
   20.2908     1.3177     1.0199
   20.2908     0.9515     1.3669
   20.2908     0.4985     1.5887
   20.2908     0.0000     1.6660
&BPNODE   TNODE=          3, TNPC=         0, TINTC=        0,                        &END
&SECT1    STX=       0.0000, STY=     0.0000, STZ=     0.0000, SCALE=      1.0000,
          ALF=          0.0, THETA=      0.0,
          INMODE=         4, TNODS=        0, TNPS=           0, TINTS=           0, &END
   20.7868     1.6488     0.0493
   20.7868     1.5697     0.5522
   20.7868     1.3281     1.0018
   20.7868     0.9614     1.3570
   20.7868     0.5044     1.5844
   20.7868     0.0000     1.6635
```

```
&BPNODE  TNODE=         3, TNPC=         0, TINTC=        0,                    &END
&SECT1   STX=    0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=       0.0, THETA=     0.0,
         INMODE=       4, TNODS=        0, TNPS=          0, TINTS=          0, &END
  21.1575    1.6484    0.0228
  21.1576    1.5733    0.5313
  21.1576    1.3349    0.9875
  21.1576    0.9682    1.3487
  21.1576    0.5085    1.5802
  21.1576    0.0000    1.6605
&BPNODE  TNODE=         3, TNPC=         0, TINTC=        0,                    &END
&SECT1   STX=    0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=       0.0, THETA=     0.0,
         INMODE=       4, TNODS=        0, TNPS=          0, TINTS=          0, &END
  21.3866    1.6482    0.0059
  21.3867    1.5751    0.5179
  21.3867    1.3389    0.9781
  21.3867    0.9722    1.3431
  21.3867    0.5110    1.5771
  21.3867    0.0000    1.6583
&BPNODE  TNODE=         3, TNPC=         0, TINTC=        0,                    &END
&SECT1   STX=    0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=       0.0, THETA=     0.0,
         INMODE=       4, TNODS=        3, TNPS=          0, TINTS=          0, &END
  21.4641    1.6481    0.0000
  21.4642    1.5756    0.5132
  21.4642    1.3402    0.9748
  21.4642    0.9736    1.3411
  21.4642    0.5118    1.5760
  21.4642    0.0000    1.6574
&BPNODE  TNODE=         3, TNPC=         0, TINTC=        0,                    &END


&PATCH1  IREV=  0, IDPAT= 2, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
         IPATCOP=0,           IPATH=  1,                                        &END
AFT_FUSELAGE
&SECT1   STX=    0.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.0000,
         ALF=       0.0, THETA=     0.0,
         INMODE=       4, TNODS=        0, TNPS=          0, TINTS=          0, &END
  21.4642    0.0000   -1.6574
  21.4642    0.5124   -1.5759
  21.4642    0.9745   -1.3404
  21.4642    1.3412   -0.9734
  21.4642    1.5762   -0.5110
  21.4641    1.6481    0.0000
  21.4642    1.5756    0.5132
  21.4642    1.3402    0.9748
  21.4642    0.9736    1.3411
  21.4642    0.5118    1.5760
  21.4642    0.0000    1.6574
&BPNODE  TNODE=         3, TNPC=         0, TINTC=        0,                    &END
&SECT1   STX=   24.0000, STY=    0.0000, STZ=    0.0000, SCALE=    1.6096,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  1,  TNODS= 0,    TNPS=  0,    TINTS= 0,                       &END
   0.0000   -1.0000    0.0000
   0.1735   -0.9845    0.0000
   0.3420   -0.9395    0.0000
   0.5000   -0.8660    0.0000
```

```
    0.6425   -0.7660    0.0000
    0.7660   -0.6425    0.0000
    0.8660   -0.5000    0.0000
    0.9395   -0.3420    0.0000
    0.9845   -0.1735    0.0000
    1.0000    0.0000    0.0000
    0.9845    0.1735    0.0000
    0.9395    0.3420    0.0000
    0.8660    0.5000    0.0000
    0.7660    0.6425    0.0000
    0.6425    0.7660    0.0000
    0.5000    0.8660    0.0000
    0.3420    0.9395    0.0000
    0.1735    0.9845    0.0000
    0.0000    1.0000    0.0000
 &BPNODE TNODE= 3,    TNPC= 10,     TINTC=  3,                             &END
 &SECT1  STX=   28.0000, STY=    0.0000, STZ=    0.0000, SCALE=   1.4248,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,    TINTS= 0,                  &END
 &SECT1  STX=   32.0000, STY=    0.0000, STZ=    0.0000, SCALE=   1.0104,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,    TINTS= 0,                  &END
 &SECT1  STX=   33.3330, STY=    0.0000, STZ=    0.0000, SCALE=   0.8332,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,    TINTS= 0,                  &END
 &SECT1  STX=   36.0000, STY=    0.0000, STZ=    0.0000, SCALE=   0.4500,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,    TINTS= 0,                  &END
 &SECT1  STX=   38.0000, STY=    0.0000, STZ=    0.0000, SCALE=   0.1756,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 0,    TNPS=  0,    TINTS= 0,                  &END
 &SECT1  STX=   40.0000, STY=    0.0000, STZ=    0.0000, SCALE=   0.0000,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 5,    TNPS= 10,    TINTS= 3,                  &END
```

Wake Definition File (PMARC native format, wingbody_14.wake.pmarc)

```
&WAKE1   IDWAK=1,        IFLXW=2,        ITRFTZ=1,       INTRW=0,         &END
  WING/BODY_WAKE
 &WAKE2  KWPACH=6,       KWSIDE=4,       KWLINE=6,       KWPAN1=0,
         KWPAN2=0,       NODEW=0,        INITIAL=1,                       &END
 &WAKE2  KWPACH=1,       KWSIDE=2,       KWLINE=0,       KWPAN1=0,
         KWPAN2=0,       NODEW=5,        INITIAL=1,                       &END
 &WAKE3  NFLEXWC(1)  = 0,
         NFLEXWC(2)  = 0, NFLEXWC(3)  = 0,
         NFLEXWC(4)  = 0, NFLEXWC(5)  = 0,
         NFLEXWC(6)  = 0, NFLEXWC(7)  = 0,
         NFLEXWC(8)  = 0, NFLEXWC(9)  = 0,
         NFLEXWC(10)  = 0,  NFLEXWC(11)  = 0,
         NFLEXWC(12)  = 0,                                                &END
 &SECT1  STX=  150.0000, STY=    0.0000, STZ=     0.0000, SCALE=   1.0000,
         ALF=   0.0,  THETA=   0.0,
         INMODE=-1,   TNODS= 3,    TNPS= 20,    TINTS= 1,                 &END
```

Additional Options Definition File (wingbody_14.extras)

```
&ONSTRM   NONSL =4, KPSL = 110,140,170,200,                                         &END


&BLPARAM RN =8000000,      VISC = 0.00016, NSLBL = 1,2,3,4,                         &END


&VS1      NVOLR= 1,        NVOLC= 0,                                                &END
&VS2      X0=     12.0000, Y0=      1.7500, Z0=     -1.0000, IDPATHR= 1, INTVSR=1,  &END
&VS3      X1=     12.0000, Y1=      1.7500, Z1=      1.0000, NPT1=  9,              &END
&VS4      X2=     24.0000, Y2=     12.0000, Z2=     -1.0000, NPT2= 13,              &END
&VS5      X3=     24.0000, Y3=      1.7500, Z3=     -1.0000, NPT3= 25,              &END
&VS6      XR0=     0.0000, YR0=     0.0000, ZR0=     0.0000, IDPATHC= 1, INTVSC=1,  &END
&VS7      XR1=     0.0000, YR1=    10.0000, ZR1=     0.0000,
          XR2=     0.0000, YR2=     0.0000, ZR2=     1.0000,                        &END
&VS8      R1=      0.5000, R2=      5.0000, PHI1=   0.0,     PHI2=360.0,            &END
&VS9      NRAD=   10,      NPHI=   12,      NLEN=   6,                              &END


&SLIN1    NSTLIN=1,                                                                 &END
&SLIN2    SX0=    18.0000, SY0=    10.0000, SZ0=     0.0800,
          SU=      0.0000, SD=     12.0000, DS=      0.2500, IDPATH= 1,  INTSL=1,   &END
```

APPENDIX E

Cylinder Test Case Input File

JOBCNTRL.INP File

```
Cylinder

 &BINP2   LSTINP=2,    LSTOUT=1,    LSTFRQ=1,    LENRUN=0,    LPLTYP=1,      &END
 &BINP3   LSTGEO=1,    LSTNAB=0,    LSTWAK=3,    LSTCPV=0,                   &END
 &BINP4   MAXIT=100,   SOLRES=0.0005,            NRDDUB=0,    CPFLOOD=0,     &END
 &BINP5   NTSTPS= 0,   DTSTEP=0.5,                                           &END
 &BINP6   RSYM=0.0,    RGPR=0.0,    RFF=10.0,    NF= 1,
          RCORES(1)=0.001, RCOREW(1)=0.001,                                  &END
 &BINP7   NPATH=    1, VSOUND=1116.0, NRDPATH=0, ICCOMP=0,                   &END
 &BINP8   VTCX(1)=-1.0000,VTCY(1)= 0.0, VTCZ(1)=  0.00000,
          P(1)=  0.0,    Q(1)=  0.,    R(1)=  0.0,
          CX0(1)= 0.0,   CY0(1)= 0.0, CZ0(1)= 0.0,
          PHI(1)=  0.,   THE(1)=  0., PSI(1)=  0.,INCROT(1)=0,               &END
 &BINP8A  PHIMAX(1)= 0.0, THEMAX(1)=0.0, PSIMAX(1)=0.0,
          WRX(1)=0.0000,  WRY(1)=0.0000, WRZ(1)=0.0000,                      &END
 &BINP8B  DXMAX(1)=0.00,  DYMAX(1)=0.0,   DZMAX(1)=0.0,
          WTX(1)=0.0000,  WTY(1)=0.0000,  WTZ(1)=0.0000,                     &END
 &BINP9   CBAR(1)=1.0000, SREF(1)=6.0000, SSPAN(1)=3.0,
          RMPX(1)=0.2500,   RMPY(1)=0.00,    RMPZ(1)=0.00,                   &END
 &BINP10  NORSET=0,    NBCHGE=0,    NCZONE=0,
          NCZPCH=0,    CZDUB=0.0,   VREF=0.0,                                &END
 &BINP11  NORPCH=0,    NORF=0,      NORL=0,
          NOCF=0,      NOCL=0,      VNORM= 0.00000,                          &END
 &BINP12  KPAN=0,      KSIDE=0,     NEWNAB=0,    NEWSID=0,                   &END
 &BINP13  NBLIT=0,                                                           &END
 &BINP14  INSURF= 0,   INWAKE= 0,   OUTSURF= 0,  OUTWAKE= 0,                 &END
testc_14.geom.pmarc
testc_14.wake.pmarc
testc_14.extras
```

Geometry Definition File (PMARC native format, testc_14.geom.pmarc)

```
&ASEM1   ASEMX=0.00,       ASEMY=0.00,       ASEMZ=0.00,
          ASCAL=1.00,       ATHET=0.00,       NODEA=5,                       &END
 &ASEM2   APXX=0.00,        APYY=0.00,        APZZ=0.00,
          AHXX=0.00,        AHYY=1.00,        AHZZ=0.00,                     &END


 &COMP1   COMPX=     0.0000, COMPY=     0.0000, COMPZ=     0.0000,
          CSCAL=     1.0000, CTHET=    0.0,      NODEC=    5,                &END
 &COMP2   CPXX=      0.0000, CPYY=     0.0000,   CPZZ=     0.0000,
          CHXX=      0.0000, CHYY=     1.0000,   CHZZ=     0.0000,           &END


 &PATCH1  IREV=  0, IDPAT= 1, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
          IPATCOP=0,    IPATH=1,                                             &END
           CYLINDER
 &SECT1   STX=    0.0000, STY= 0.0000,    STZ= 0.0000,    SCALE=  1.00000 ,
          ALF=   0.0,   THETA=   0.0,
          INMODE=  2,   TNODS= 0,    TNPS=  0,    TINTS= 0,                  &END
```

```
    1.0000    0.0000    0.0000
    0.9845   -0.1735    0.0000
    0.9395   -0.3420    0.0000
    0.8660   -0.5000    0.0000
    0.7660   -0.6425    0.0000
    0.6425   -0.7660    0.0000
    0.5000   -0.8660    0.0000
    0.3420   -0.9395    0.0000
    0.1735   -0.9845    0.0000
    0.0000   -1.0000    0.0000
   -0.1735   -0.9845    0.0000
   -0.3420   -0.9395    0.0000
   -0.5000   -0.8660    0.0000
   -0.6425   -0.7660    0.0000
   -0.7660   -0.6425    0.0000
   -0.8660   -0.5000    0.0000
   -0.9395   -0.3420    0.0000
   -0.9845   -0.1735    0.0000
   -1.0000    0.0000    0.0000
 &BPNODE  TNODE= 1,    TNPC= 15,     TINTC=  3,                          &END
   -0.9845    0.1735    0.0000
   -0.9395    0.3420    0.0000
   -0.8660    0.5000    0.0000
   -0.7660    0.6425    0.0000
   -0.6425    0.7660    0.0000
   -0.5000    0.8660    0.0000
   -0.3420    0.9395    0.0000
   -0.1735    0.9845    0.0000
    0.0000    1.0000    0.0000
    0.1735    0.9845    0.0000
    0.3420    0.9395    0.0000
    0.5000    0.8660    0.0000
    0.6425    0.7660    0.0000
    0.7660    0.6425    0.0000
    0.8660    0.5000    0.0000
    0.9395    0.3420    0.0000
    0.9845    0.1735    0.0000
    1.0000    0.0000    0.0000
 &BPNODE  TNODE= 3,    TNPC= 15,     TINTC=  3,                          &END
 &SECT1   STX=    0.0000, STY= 3.0000,    STZ= 0.0000,    SCALE=  1.00000 ,
          ALF=   0.0,  THETA=   0.0,
          INMODE=  0,  TNODS= 1,    TNPS= 10,    TINTS= 3,               &END
 &SECT1   STX=    0.0000, STY=12.0000,    STZ= 0.0000,    SCALE=  1.00000 ,
          ALF=   0.0,  THETA=   0.0,
          INMODE=  0,  TNODS= 3,    TNPS= 10,    TINTS= 0,               &END


 &PATCH1  IREV=  0, IDPAT= 1, MAKE=   1, KCOMP= 1, KASS= 1, IPATSYM=0,
          IPATCOP=0,          IPATH = 1,                                 &END
 CYL TIP
 &PATCH2  ITYP=  2,    TNODS= 5,    TNPS=   6,    TINTS= 3,              &END
```

Wake Definition File (PMARC native format, testc_14.wake.pmarc)

```
&WAKE1   IDWAK=0,          IFLXW=0,          ITRFTZ= 0,       INTRW= 0,         &END
 WAKE
 &WAKE2   KWPACH=1,         KWSIDE=2,         KWLINE=0,        KWPAN1=0,
          KWPAN2=0,         NODEW=5,          INITIAL=0,                         &END
```

Additional Options Definition File (testc_14.extras)

```
&ONSTRM   NONSL =0,  KPSL = 50,                                                &END


 &BLPARAM RN =3700000,     VISC = 0.00016, NSLBL = 1, 2,                       &END


 &VS1      NVOLR= 0,         NVOLC= 1,                                         &END
 &VS2      X0=      1.0100,  Y0=      0.0000, Z0=     -0.1500,
           IDPATHR=1,        INTVSR= 0,                                        &END
 &VS3      X1=      1.0100,  Y1=      0.0000, Z1=     -0.1500, NPT1=  0,       &END
 &VS4      X2=      1.0100,  Y2=      0.0000, Z2=      0.1500, NPT2= 13,       &END
 &VS5      X3=      1.0100,  Y3=      3.5000, Z3=     -0.1500, NPT3= 15,       &END

 &VS6      XR0=     0.0000,  YR0=     0.7500, ZR0=     0.0000,
           IDPATHC=1,        INTVSC= 0,                                        &END
 &VS7      XR1=     0.0000,  YR1=     2.0000, ZR1=     0.0000,
           XR2=     2.0000,  YR2=     0.7500, ZR2=     0.0000,                 &END
 &VS8      R1=      1.0100,  R2=      1.2100, PHI1=180.0,     PHI2=360.0,      &END
 &VS9      NRAD=  21,        NPHI=  51,       NLEN=  0,                        &END


 &SLIN1    NSTLIN= 8,                                                          &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.00500,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.0100,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.01500,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.02000,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.02500,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.03000,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.03500,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
 &SLIN2    SX0=    -0.0000,  SY0=     0.7500, SZ0=     1.04000,
           SU=      3.0000,  SD=      3.0000, DS=      0.0500, IDPATH= 1,
           INTSL= 0,                                                           &END
```

APPENDIX F

Looping Wings Test Case Input File

JOBCNTRL.INP File

```
LOOPING WINGS TEST CASE

 &BINP2   LSTINP=2,    LSTOUT=0,    LSTFRQ=1,    LENRUN=0,    LPLTYP=1,     &END
 &BINP3   LSTGEO=1,    LSTNAB=0,    LSTWAK=3,    LSTCPV=0,                  &END
 &BINP4   MAXIT=200,   SOLRES=0.0005,            NRDDUB=0,    CPFLOOD=0,    &END
 &BINP5   NTSTPS=18,   DTSTEP=0.1,                                          &END
 &BINP6   RSYM=1.0,    RGPR=0.0,    RFF=5.0,     NF=0,
          RCORES(1)=0.00001, RCOREW(1)=0.00500,
          RCORES(2)=0.00001, RCOREW(2)=0.00500,                             &END
 &BINP7   NPATH=    2, VSOUND=1116.0,    NRDPATH=0, ICCOMP=0,               &END

 &BINP8   VTCX(1)= 0.0,  VTCY(1)= 0.0,      VTCZ(1)= 0.0,
          P(1)=    0.0,  Q(1)= 180.0000,   R(1)=    0.0,
          CX0(1)= 0.0,   CY0(1)= 0.0,       CZ0(1)= 0.0,
          PHI(1)= 0.0,   THE(1)= 0.0,       PSI(1)= 0.0,INCROT(1)=1,

          VTCX(2)= 0.0,  VTCY(2)= 0.0,      VTCZ(2)= 0.0,
          P(2)=    0.0,  Q(2)=-180.0000,   R(2)=    0.0,
          CX0(2)= 0.0,   CY0(2)= 0.0,       CZ0(2)= 0.0,
          PHI(2)= 0.0,   THE(2)= 0.0,       PSI(2)= 0.0, INCROT(2)=1,       &END

 &BINP8A  PHIMAX(1)=0.0,  THEMAX(1)=0.0, PSIMAX(1)=0.0,
          WRX(1)=    0.0, WRY(1)=    0.0, WRZ(1)=    0.0,

          PHIMAX(2)= 0.0, THEMAX(2)=0.0, PSIMAX(2)=0.0,
          WRX(2)=0.0,     WRY(2)=0.0,     WRZ(2)=0.0,                       &END

 &BINP8B  DXMAX(1)=0.0,   DYMAX(1)=0.0,   DZMAX(1)=0.0,
          WTX(1)=0.0,     WTY(1)=0.0,     WTZ(1)=0.0,

          DXMAX(2)=0.0,   DYMAX(2)=0.0,   DZMAX(2)=0.0,
          WTX(2)=0.0,     WTY(2)=0.0,     WTZ(2)=0.0,                       &END

 &BINP9   CBAR(1)=1.0,    SREF(1)=5.0,    SSPAN(1)=2.5,
          RMPX(1)=0.25,   RMPY(1)=0.00,   RMPZ(1)=0.00,

          CBAR(2)=1.0,    SREF(2)=5.0,    SSPAN(2)=2.5,
          RMPX(2)=0.25,   RMPY(2)=0.00,   RMPZ(2)=0.00,                     &END

 &BINP10  NORSET=0,    NBCHGE=0,    NCZONE=0,
          NCZPCH=0,    CZDUB=0.0,   VREF=0.0,                               &END
 &BINP11  NORPCH=0,    NORF=0,      NORL=0,
          NOCF=0,      NOCL=0,      VNORM=0.0,                              &END
 &BINP12  KPAN=0,      KSIDE=0,     NEWNAB=0,    NEWSID=0,                  &END
 &BINP13  NBLIT = 0,                                                        &END
 &BINP14  INSURF= 0,   INWAKE= 0,   OUTSURF= 0,  OUTWAKE= 0,                &END
loop_14.geom.pmarc
loop_14.wake.pmarc
loop_14.extras
```

Geometry Definition File (PMARC native format, loop 14.geom.pmarc)

```
&ASEM1   ASEMX=0.00,      ASEMY=0.00,      ASEMZ=0.00,
          ASCAL=1.00,      ATHET=0.00,      NODEA=0,                      &END
 &ASEM2   APXX=0.00,       APYY=0.00,       APZZ=0.00,
          AHXX=0.00,       AHYY=1.00,       AHZZ=0.00,                    &END


 &ASEM1   ASEMX=0.00,      ASEMY=0.00,      ASEMZ=0.00,
          ASCAL=1.00,      ATHET=0.00,      NODEA=5,                      &END
 &ASEM2   APXX=0.00,       APYY=0.00,       APZZ=0.00,
          AHXX=0.00,       AHYY=1.00,       AHZZ=0.00,                    &END


 &COMP1   COMPX=     0.0000, COMPY=   0.500,  COMPZ=  -10.0000,
          CSCAL=     1.0000, CTHET=   0.0,     NODEC=   0,                &END
 &COMP2   CPXX=      0.0000, CPYY=    0.0000,  CPZZ=    0.0000,
          CHXX=      0.0000, CHYY=    1.0000,  CHZZ=    0.0000,           &END

 &COMP1   COMPX=     0.0000, COMPY=  -0.500,  COMPZ=  -10.000,
          CSCAL=    -1.0000, CTHET= 180.0000,  NODEC=   5,                &END
 &COMP2   CPXX=      0.0000, CPYY=    0.0000,  CPZZ=    0.0000,
          CHXX=      0.0000, CHYY=    0.0000,  CHZZ=    1.0000,           &END


 &PATCH1  IREV=  0, IDPAT= 1, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
          IPATCOP=0,          IPATH=  1,                                  &END
 WING 1
 &SECT1   STX=    0.0000, STY= 0.0000,    STZ= 0.0000,    SCALE=  1.000   ,
          ALF=   0.0,  THETA=   0.0,
          INMODE=  5,  TNODS= 0,    TNPS=  0,     TINTS= 0,               &END
 &SECT2   RTC=    0.1200, RMC= 0.0400,    RPC= 0.4000,
          IPLANE=  2,  TNPC= 15,    TINTC= 0,                             &END
 &SECT1   STX=    0.0000, STY= 5.0000,    STZ= 0.0000,    SCALE=  1.000   ,
          ALF=   0.0,  THETA=   0.0,
          INMODE=  0,  TNODS= 3,    TNPS= 10,     TINTS= 0,               &END


 &PATCH1  IREV=  0, IDPAT= 1, MAKE=   1, KCOMP= 1, KASS= 1, IPATSYM=0,
          IPATCOP=0,          IPATH = 1,                                  &END
 WING TIP 1 R
 &PATCH2  ITYP=  2,    TNODS= 3,    TNPS=   4,    TINTS= 3,               &END


 &PATCH1  IREV=  0, IDPAT= 1, MAKE=  -1, KCOMP= 1, KASS= 1, IPATSYM=0,
          IPATCOP=0,          IPATH = 1,                                  &END
 WING TIP 1 L
 &PATCH2  ITYP=  2,    TNODS= 3,    TNPS=   4,    TINTS= 3,               &END


 &PATCH1  IREV=  0, IDPAT= 1, MAKE=   0, KCOMP= 2, KASS= 1, IPATSYM=0,
          IPATCOP=0,          IPATH=  2,                                  &END
 WING 2
 &SECT1   STX=    0.0000, STY= 0.0000,    STZ= 0.0000,    SCALE=  1.000   ,
          ALF=   0.0,  THETA=   0.0,
          INMODE=  5,  TNODS= 0,    TNPS=  0,     TINTS= 0,               &END
 &SECT2   RTC=    0.1200, RMC= 0.0400,    RPC= 0.4000,
```

```
         IPLANE=  2,  TNPC= 15,    TINTC= 0,                             &END
&SECT1   STX=    0.0000, STY= 5.0000,    STZ= 0.0000,    SCALE=  1.000   ,
         ALF=   0.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 3,    TNPS= 10,    TINTS= 0,               &END

&PATCH1  IREV=  0, IDPAT= 1, MAKE=   4, KCOMP= 2, KASS= 1, IPATSYM=0,
         IPATCOP=0,          IPATH = 2,                                  &END
WING TIP 2 R
&PATCH2  ITYP=  2,    TNODS= 3,    TNPS=   4,    TINTS= 3,               &END

&PATCH1  IREV=  0, IDPAT= 1, MAKE=  -4, KCOMP= 2, KASS= 1, IPATSYM=0,
         IPATCOP=0,          IPATH = 2,                                  &END
WING TIP 2 L
&PATCH2  ITYP=  2,    TNODS= 5,    TNPS=   4,    TINTS= 3,               &END
```

Wake Definition File (PMARC native format, loop_14.wake.pmarc)

```
&WAKE1   IDWAK=1,        IFLXW=1,        ITRFTZ=1,       INTRW=1,        &END
WAKE 1
&WAKE2   KWPACH=1,       KWSIDE=2,       KWLINE=0,       KWPAN1=0,
         KWPAN2=0,       NODEW=3,        INITIAL=1,                      &END
&SECT1   STX=   20.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
         ALF=   0.0,  THETA=   0.0,
         INMODE=-1,   TNODS= 3,    TNPS= 20,    TINTS= 1,               &END

&WAKE1   IDWAK=1,        IFLXW=1,        ITRFTZ=1,       INTRW=1,        &END
WAKE 2
&WAKE2   KWPACH=4,       KWSIDE=2,       KWLINE=0,       KWPAN1=0,
         KWPAN2=0,       NODEW=5,        INITIAL=1,                      &END
&SECT1   STX=  -20.0000, STY=     0.0000, STZ=     0.0000, SCALE=    1.0000,
         ALF=   0.0,  THETA=   0.0,
         INMODE=-1,   TNODS= 3,    TNPS= 20,    TINTS= 1,               &END
```

Additional Options Definition File (loop_14.extras)

```
&ONSTRM NONSL = 0, KPSL = 0,                                                  &END

&BLPARAM  RN= 2000000,     VISC=0.00016,     NSLBL=0,                        &END

&VS1     NVOLR= 0,       NVOLC= 0,                                            &END
&VS2     X0=     0.5000, Y0=      0.0000, Z0=     -2.0000, IDPATHR= 0,   INTVSR=1,&END
&VS3     X1=     0.5000, Y1=      0.7500, Z1=     -2.0000, NPT1= 20,          &END
&VS4     X2=    -2.0000, Y2=      0.0000, Z2=     -2.0000, NPT2=  0,          &END
&VS5     X3=     0.5000, Y3=      0.0000, Z3=      2.0000, NPT3= 40,          &END

&VS6     XR0=     0.0000, YR0=     0.0000, ZR0=     0.0000, IDPATHC= 1,  INTVSC=1,&END
&VS7     XR1=     0.0000, YR1=    10.0000, ZR1=     0.0000,
         XR2=     0.0000, YR2=     0.0000, ZR2=     1.0000,                   &END
&VS8     R1=      0.5000, R2=      5.0000, PHI1=  0.0,     PHI2=330.0,        &END
&VS9     NRAD=  10,      NPHI=  12,      NLEN=  5,                            &END


&SLIN1   NSTLIN=0,                                                            &END
&SLIN2   SX0=    -3.0000, SY0=     0.0000, SZ0=     0.0500,
         SU=      0.0000, SD=      6.5000, DS=      0.0250, IDPATH= 1,   INTSL=1, &END
```

APPENDIX G

Wing in Ground Effect Test Case Input File

JOBCNTRL.INP File

```
Wing in Ground Effect

 &BINP2    LSTINP=2,     LSTOUT=0,     LSTFRQ=1,     LENRUN=0,     LPLTYP=1,     &END
 &BINP3    LSTGEO=0,     LSTNAB=0,     LSTWAK=3,     LSTCPV=0,                   &END
 &BINP4    MAXIT=200,    SOLRES=0.0005,              NRDDUB=0,     CPFLOOD=0,    &END
 &BINP5    NTSTPS=30,    DTSTEP=0.5,                                             &END
 &BINP6    RSYM=0.0,     RGPR=1.0,     RFF=5.0,      NF=0,
           RCORES(1)=0.00001, RCOREW(1)=0.00500,                                 &END
 &BINP7    NPATH=    1, VSOUND=1116.0, NRDPATH=1, ICCOMP=1,                      &END
 &BINP8    VTCX(1)= 0.0000,VTCY(1)= 0.0, VTCZ(1)=  0.00000,
           P(1)=  0.0,    Q(1)=  0.,    R(1)=  0.0,
           CX0(1)= 0.0,   CY0(1)= 0.0, CZ0(1)= 0.0,
           PHI(1)=  0.,   THE(1)=  0., PSI(1)=  0.,INCROT(1)=0,                  &END

 &BINP8A   PHIMAX(1)= 0.0, THEMAX(1)=0.0, PSIMAX(1)=0.0,
           WRX(1)=0.0000,  WRY(1)=0.0000, WRZ(1)=0.0000,                         &END

 &BINP8B   DXMAX(1)=0.00,  DYMAX(1)=0.0,   DZMAX(1)=0.0,
           WTX(1)=0.0000,  WTY(1)=0.0000,  WTZ(1)=0.0000,                        &END

 &BINP9    CBAR(1)=1.0000, SREF(1)=5.0000, SSPAN(1)=2.5,
           RMPX(1)=0.2500,    RMPY(1)=0.00,    RMPZ(1)=0.00,                     &END

 &BINP10   NORSET=0,     NBCHGE=0,     NCZONE=0,
           NCZPCH=0,     CZDUB=0.0,    VREF=00.0,                                &END
 &BINP11   NORPCH=0,     NORF=0,       NORL=0,
           NOCF=0,       NOCL=0,       VNORM=0.0,                                &END
 &BINP12   KPAN=0,       KSIDE=0,      NEWNAB=0,     NEWSID=0,                   &END
 &BINP13   NBLIT = 0,                                                            &END
 &BINP14   INSURF= 0,    INWAKE= 0,    OUTSURF= 0,   OUTWAKE= 0,                 &END
testd_14.geom.pmarc
testd_14.wake.pmarc
testd_14.extras
```

PATHDEF.DAT File

&PATHDEF CX0(1)= 0.0, CY0(1)= 0.0, CZ0(1)= 0.0,
PHI(1)= 0., THE(1)= 0., PSI(1)= 0.,INCROT(1)=0, &END

T	VTCX	VTCY	VTCZ	P	Q	R
0	-1.0	0.0	0.0	0.0	0.0	0.0
2.99	-1.0	0.0	0.0	0.0	0.0	0.0
3.01	-1.0	0.0	0.0	0.0	0.0	0.0
3.02	-0.9903	0.0	-0.1392	0.0	-16.0	0.0
3.51	-0.9903	0.0	-0.1392	0.0	-16.0	0.0
3.52	-0.9903	0.0	-0.1392	0.0	0.0	0.0
6.48	-0.9903	0.0	-0.1392	0.0	0.0	0.0
6.49	-0.9903	0.0	-0.1392	0.0	16.0	0.0
6.98	-0.9903	0.0	-0.1392	0.0	16.0	0.0
6.99	-1.0	0.0	0.0	0.0	0.0	0.0
7.01	-1.0	0.0	0.0	0.0	0.0	0.0
10.00	-1.0	0.0	0.0	0.0	0.0	0.0

Geometry Definition File (PMARC native format, testd 14.geom.pmarc)

```
&ASEM1   ASEMX=     0.0000, ASEMY=     0.0000, ASEMZ=     0.0000,
         ASCAL=     1.0000, ATHET=    0.0,     NODEA=    0,                  &END
&ASEM2   APXX=0.00,         APYY=0.00,         APZZ=0.00,
         AHXX=0.00,         AHYY=1.00,         AHZZ=0.00,                     &END


&ASEM1   ASEMX=     0.0000, ASEMY=     0.0000, ASEMZ=     0.0000,
         ASCAL=     1.0000, ATHET=    0.0,     NODEA=    5,                  &END
&ASEM2   APXX=0.00,         APYY=0.00,         APZZ=0.00,
         AHXX=0.00,         AHYY=1.00,         AHZZ=0.00,                     &END


&COMP1   COMPX=     0.0000, COMPY=     0.0000, COMPZ=     0.7500,
         CSCAL=     1.0000, CTHET=    0.0,     NODEC=    5,                  &END
&COMP2   CPXX= 0.0000,      CPYY= 0.0000,      CPZZ= 0.0000,
         CHXX= 0.0000,      CHYY=  1.000    ,  CHZZ= 0.0000,                 &END


&PATCH1  IREV=  0, IDPAT= 1, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
         IPATCOP=0,           IPATH=  1,                                      &END
WING
&SECT1   STX=     0.0000, STY=     0.0000, STZ=     0.0000, SCALE=     1.0000,
         ALF=    4.0,  THETA=   0.0,
         INMODE=  2,  TNODS= 0,     TNPS=  0,     TINTS= 0,                   &END
   1.0000   0.00000       0.0
   0.9500  -0.00370       0.0
   0.9000  -0.00727       0.0
   0.8500  -0.01083       0.0
   0.8000  -0.01437       0.0
   0.7500  -0.01775       0.0
   0.7000  -0.02087       0.0
   0.6500  -0.02364       0.0
   0.6000  -0.02602       0.0
   0.5500  -0.02793       0.0
   0.5000  -0.02925       0.0
   0.4500  -0.02992       0.0
   0.4000  -0.02996       0.0
   0.3500  -0.02945       0.0
   0.3000  -0.02842       0.0
   0.2500  -0.02687       0.0
   0.2000  -0.02474       0.0
   0.1500  -0.02194       0.0
   0.1000  -0.01824       0.0
   0.0750  -0.01591       0.0
   0.0500  -0.01313       0.0
   0.0250  -0.00981       0.0
   0.0125  -0.00718       0.0
   0.0075  -0.00563       0.0
    0.005  -0.00464       0.0
      0.0       0.0       0.0
&BPNODE  TNODE= 2,    TNPC= 15,      TINTC=  0,                               &END
    0.005   0.00464       0.0
   0.0075   0.00563       0.0
   0.0125   0.00718       0.0
   0.0250   0.00981       0.0
   0.0500   0.01313       0.0
```

```
   0.0750   0.01591        0.0
   0.1000   0.01824        0.0
   0.1500   0.02194        0.0
   0.2000   0.02474        0.0
   0.2500   0.02687        0.0
   0.3000   0.02842        0.0
   0.3500   0.02945        0.0
   0.4000   0.02996        0.0
   0.4500   0.02992        0.0
   0.5000   0.02925        0.0
   0.5500   0.02793        0.0
   0.6000   0.02602        0.0
   0.6500   0.02364        0.0
   0.7000   0.02087        0.0
   0.7500   0.01775        0.0
   0.8000   0.01437        0.0
   0.8500   0.01083        0.0
   0.9000   0.00727        0.0
   0.9500   0.00370        0.0
   1.0000   0.00000        0.0
&BPNODE  TNODE= 3,    TNPC= 15,     TINTC=  0,                          &END
&SECT1   STX=    0.0000, STY=    2.5000, STZ=    0.0000, SCALE=    1.0000,
         ALF=   4.0,  THETA=   0.0,
         INMODE=  0,  TNODS= 3,    TNPS= 10,    TINTS= 2,               &END


&PATCH1  IREV=  0, IDPAT= 2, MAKE=   1, KCOMP= 1, KASS= 2, IPATSYM=0,
         IPATCOP=0,         IPATH=  1,                                  &END
WING_TIP 1
&PATCH2  ITYP=  2,    TNODS= 5,    TNPS=   4,   TINTS= 3,               &END
```

Wake Definition File (PMARC native format, testd_14.wake.pmarc)

```
&WAKE1   IDWAK=1,         IFLXW=1,         ITRFTZ=1,        INTRW=1,        &END
 WING 1 WAKE
 &WAKE2   KWPACH=1,        KWSIDE=2,        KWLINE=0,        KWPAN1=0,
          KWPAN2=0,        NODEW=5,         INITIAL=1,                      &END
 &SECT1   STX=  15.0000,  STY=    0.0000, STZ=     0.0000, SCALE=    1.0000,
          ALF=   0.0,  THETA=   0.0,
          INMODE=-1,   TNODS= 3,    TNPS= 15,    TINTS= 1,                  &END
```

Additional Options Definition File (testd_14.extras)

```
&ONSTRM NONSL = 0, KPSL = 0,                                                   &END

&BLPARAM  RN= 2000000,     VISC=0.00016,     NSLBL=0,                          &END

&VS1      NVOLR= 0,        NVOLC= 0,                                           &END
&VS2      X0=     0.5000, Y0=     0.0000, Z0=    -2.0000, IDPATHR= 0,  INTVSR=1,&END
&VS3      X1=     0.5000, Y1=     0.7500, Z1=    -2.0000, NPT1= 20,            &END
&VS4      X2=    -2.0000, Y2=     0.0000, Z2=    -2.0000, NPT2=  0,            &END
&VS5      X3=     0.5000, Y3=     0.0000, Z3=     2.0000, NPT3= 40,            &END

&VS6      XR0=    0.0000, YR0=    0.0000, ZR0=    0.0000, IDPATHC= 1,  INTVSC=1,&END
&VS7      XR1=    0.0000, YR1=   10.0000, ZR1=    0.0000,
          XR2=    0.0000, YR2=    0.0000, ZR2=    1.0000,                      &END
&VS8      R1=     0.5000, R2=     5.0000, PHI1=  0.0,     PHI2=330.0,          &END
&VS9      NRAD=  10,      NPHI=  12,      NLEN=  5,                            &END
```

```
&SLIN1   NSTLIN=0,                                                            &END
&SLIN2   SX0=    -3.0000, SY0=    0.0000, SZ0=    0.0500,
         SU=      0.0000, SD=     6.5000, DS=     0.0250, IDPATH= 1,   INTSL=1, &END
```

APPENDIX H

Boundary Layer on Swept Wing Test Case Input File

JOBCNTRL.INP File

```
 NACA 0012 WING BOUNDARY LAYER TEST CASE

 &BINP2   LSTINP=2,     LSTOUT=0,     LSTFRQ=0,     LENRUN=0,     LPLTYP=1,     &END
 &BINP3   LSTGEO=1,     LSTNAB=0,     LSTWAK=3,     LSTCPV=0,                   &END
 &BINP4   MAXIT=200,    SOLRES=0.0005,              NRDDUB=0,     CPFLOOD=0,    &END
 &BINP5   NTSTPS= 0,    DTSTEP=0.1,                                             &END
 &BINP6   RSYM=0.0,     RGPR=0.0,     RFF=5.0,      NF=0,
          RCORES(1)=0.00001, RCOREW(1)=0.00500,                                 &END
 &BINP7   NPATH=    1, VSOUND=1116.0,     NRDPATH=0, ICCOMP=0,                  &END

 &BINP8   VTCX(1)=-0.9976,  VTCY(1)= 0.0,     VTCZ(1)=-0.0698,
          P(1)=    0.0,     Q(1)=    0.0000,  R(1)=    0.0,
          CX0(1)= 0.0,      CY0(1)= 0.0,      CZ0(1)= 0.0,
          PHI(1)= 0.0,      THE(1)= 0.0,      PSI(1)= 0.0,INCROT(1)=0,          &END

 &BINP8A  PHIMAX(1)=0.0,   THEMAX(1)=0.0, PSIMAX(1)=0.0,
          WRX(1)=    0.0,  WRY(1)=    0.0, WRZ(1)=    0.0,                      &END

 &BINP8B  DXMAX(1)=0.0,    DYMAX(1)=0.0,    DZMAX(1)=0.0,
          WTX(1)=0.0,      WTY(1)=0.0,      WTZ(1)=0.0,                         &END

 &BINP9   CBAR(1)=1.00,    SREF(1)=10.00,   SSPAN(1)=5.00,
          RMPX(1)=0.2500, RMPY(1)=0.00,    RMPZ(1)=0.00,                        &END

 &BINP10  NORSET=0,     NBCHGE=0,     NCZONE=0,
          NCZPCH=0,     CZDUB=0.0,    VREF=0.0,                                 &END
 &BINP11  NORPCH=0,     NORF=0,       NORL=0,
          NOCF=0,       NOCL=0,       VNORM=0.0,                                &END
 &BINP12  KPAN=0,       KSIDE=0,      NEWNAB=0,     NEWSID=0,                   &END
 &BINP13  NBLIT = 1,                                                            &END
 &BINP14  INSURF= 0,    INWAKE= 0,    OUTSURF= 0,   OUTWAKE= 0,                 &END
wingBL_14.geom.pmarc
wingBL_14.wake.pmarc
wingBL_14.extras
```

Geometry Definition File (PMARC native format, wingBL_14.geom.pmarc)

```
 &ASEM1   ASEMX=0.00,        ASEMY=0.00,        ASEMZ=0.00,
          ASCAL=1.00,        ATHET=0.00,        NODEA=0,                        &END
 &ASEM2   APXX=0.00,         APYY=0.00,         APZZ=0.00,
          AHXX=0.00,         AHYY=1.00,         AHZZ=0.00,                      &END


 &ASEM1   ASEMX=0.00,        ASEMY=0.00,        ASEMZ=0.00,
          ASCAL=1.00,        ATHET=0.00,        NODEA=5,                        &END
 &ASEM2   APXX=0.00,         APYY=0.00,         APZZ=0.00,
          AHXX=0.00,         AHYY=1.00,         AHZZ=0.00,                      &END


 &COMP1   COMPX=     0.0000, COMPY=    0.000,  COMPZ=     0.0000,
          CSCAL=     1.0000, CTHET=    0.0,     NODEC=    5,                    &END
 &COMP2   CPXX=      0.0000, CPYY=     0.0000,  CPZZ=     0.0000,
```

```
         CHXX=     0.0000, CHYY=    1.0000,  CHZZ=    0.0000,             &END

&PATCH1  IREV=  0, IDPAT= 1, MAKE=   0, KCOMP= 1, KASS= 1, IPATSYM=0,
         IPATCOP=0,         IPATH=  1,                                    &END
WING
&SECT1   STX=    0.0000, STY= 0.0000,    STZ= 0.0000,    SCALE=  1.000   ,
         ALF=   0.0,   THETA=   0.0,
         INMODE=  5,   TNODS= 0,     TNPS=  0,     TINTS= 0,              &END
&SECT2   RTC=    0.1200, RMC= 0.0000,    RPC= 0.0000,
         IPLANE=  2,   TNPC= 25,     TINTC= 0,                            &END
&SECT1   STX=    1.8199, STY= 5.0000,    STZ= 0.0000,    SCALE=  1.000   ,
         ALF=   0.0,   THETA=   0.0,
         INMODE=  0,   TNODS= 3,     TNPS= 20,     TINTS= 2,              &END

&PATCH1  IREV=  0, IDPAT= 1, MAKE=   1, KCOMP= 1, KASS= 2, IPATSYM=0,
         IPATCOP=0,         IPATH = 1,                                    &END
WING TIP
&PATCH2  ITYP=  2,     TNODS= 5,     TNPS=   4,    TINTS= 3,              &END
```

Wake Definition File (PMARC native format, wingBL_14.wake.pmarc)

```
&WAKE1   IDWAK=1,         IFLXW=1,         ITRFTZ=0,        INTRW=0,      &END
WING WAKE
&WAKE2   KWPACH=1,        KWSIDE=2,        KWLINE=0,        KWPAN1=0,
         KWPAN2=0,        NODEW=5,         INITIAL=1,                     &END
&SECT1   STX=   20.0000, STY=     0.0000, STZ=      0.0000, SCALE=    1.0000,
         ALF=   0.0,   THETA=   0.0,
         INMODE=-1,    TNODS= 3,     TNPS= 20,     TINTS= 1,              &END
```

Additional Options Definition File (wingBL_14.extras)

```
&ONSTRM NONSL = 1, KPSL = 235,                                             &END

&BLPARAM  RN= 2000000,     VISC=0.00016,     NSLBL=1,                      &END

&VS1     NVOLR= 0,        NVOLC= 0,                                        &END
&VS2     X0= 0.5000, Y0=  0.0000, Z0=  -2.0000,  IDPATHR= 0,   INTVSR=1,   &END
&VS3     X1= 0.5000, Y1=  0.7500, Z1=  -2.0000, NPT1= 20,                  &END
&VS4     X2=-2.0000, Y2=  0.0000, Z2=  -2.0000, NPT2=  0,                  &END
&VS5     X3= 0.5000, Y3=  0.0000, Z3=   2.0000, NPT3= 40,                  &END

&VS6     XR0= 0.0000, YR0= 0.0000, ZR0= 0.0000, IDPATHC= 1,  INTVSC=1,     &END
&VS7     XR1= 0.0000, YR1=10.0000, ZR1= 0.0000,
         XR2= 0.0000, YR2= 0.0000, ZR2= 1.0000,                            &END
&VS8     R1=  0.5000, R2=  5.0000, PHI1=0.0,    PHI2=330.0,                &END
&VS9     NRAD=  10,   NPHI=  12,   NLEN=  5,                               &END

&SLIN1   NSTLIN=0,                                                         &END
&SLIN2   SX0=-3.0000, SY0= 0.0000, SZ0=    0.0500,
         SU=  0.0000, SD=  6.5000, DS=     0.0250, IDPATH= 1,   INTSL=1,   &END
```

APPENDIX J

PMARC Installation Guide

Computer Platforms Supported:

PMARC version 14 can be run on any computer platform for which a Fortran77 compiler with NAMELIST extension and direct access files is available and which has sufficient disk space and memory. PMARC has been successfully run on Macintosh PowerPC and Intel Pentium desktop machines, SGI and Sun workstations, VAX minicomputers, and Cray supercomputers. There may be limitations on certain computer platforms which will limit the size (number of panels) of the jobs that can be run. Some VAX computers, for instance, running under the VMS operating system have a limitation on the number of records that can be stored in a direct access file, which limits the number of panels that can be run.

Minimum Hardware Configuration:

The dimensioning of the arrays in PMARC version 14 can be tailored to match the computer hardware capabilities. The amount of memory required can be estimated using the information given in Appendix B. The amount of disk space required can be estimated by using the following formula:

$$NSPDIM^2 * RBYTE * INCOR$$

where NSPDIM is the number of surface panels that PMARC is dimensioned to handle, RBYTE is the number of bytes used to represent a REAL variable (RBYTE=4 for single precision, RBYTE=8 for double precision), and INCOR = 2 if the influence coefficient matrix used in the solver is stored in memory and INCOR = 3 if it is stored on disk.

Minimum Operating System Version Required:

It is recommended that the latest version of the operating system for a given platform be utilized on systems to be used for running PMARC version 14.

Additional Software Required:

None

Installation Procedure:

The source code for PMARC version 14 (Pmarc.f, COMMON.F, PARAM.DAT) should be copied from the distribution media to the hard drive of the computer and placed in the desired directory. Edit the PARAM.DAT file to dimension the arrays in PMARC to the desired size. Compile PMARC using a Fortran 77 (or Fortran 90) compiler to create an executable file.

Execution Procedure:

The input files for the job to be run should be located in the same directory as the PMARC executable. Launch the PMARC executable to initiate the job. PMARC can be run in batch mode by utilizing the appropriate scripting language for the platform being used.

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13. ABSTRACT *(Maximum 200 words)*

The theoretical basis for PMARC, a low-order panel code for modeling complex three-dimensional bodies in potential flow, is outlined. PMARC can be run on a wide variety of computer platforms, including desktop machines, workstations, and supercomputers. Execution times for PMARC vary tremendously depending on the computer resources used, but typically range from several minutes for simple or moderately complex cases to several hours for very large complex cases. Several of the advanced features currently included in the code, such as internal flow modeling, boundary layer analysis, and time-dependent flow analysis, including problems involving relative motion, are discussed in some detail. The code is written in Fortran77, using adjustable-size arrays so that it can be easily redimensioned to match problem requirements and computer hardware constraints. An overview of the program input is presented. A detailed description of the input parameters is provided in the appendices. PMARC results for several test cases are presented along with analytic or experimental data, where available. The input files for these test cases are given in the appendices. PMARC currently supports plotfile output formats for several commercially available graphics packages. The supported graphics packages are Plot3D, Tecplot, and PmarcViewer.

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