NASA Contractor Report 3279

An Improved Panel Method for the Solution of Three-Dimensional Leading-Edge Vortex Flows

Volume II - User's Guide and Programmer's Document

E. N. Tinoco, P. Lu, and F. T. Johnson

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1.0 SUMMARY

An improved panel method for the solution of three dimensional flow about wing and wing-body combinations with leading edge vortex separation is presented. The method employs a three-dimensional inviscid flow model in which the configuration, the rolled-up vortex sheets, and the wake are presented by quadratic doublet distributions. The strength of the singularity distribution, as well as shape and position of the vortex spirals, are computed in an iterative fashion starting with an assumed initial sheet geometry. The method calculates forces, moments, and detail surface pressure distributions. Improvements include the implementation of improved panel numerics for the purpose of eliminating the highly non-linear effects of ring vortices around doublet panel edges, and the development of a least squares procedure for damping vortex sheet geometry update instabilities.

The documentation is divided up into two parts:

Volume I	Theory Document
Volume II	User's Guide and Programmer's Document

Volume I contains a complete description of the method. A variety of cases generated by the computer program implementing the method are presented. These cases are of two types. The first type consists of numerical studies, which verify the underlying mathematical assumptions of the method and, moreover, show that the results are strongly invariant with respect to such user dependent input as wing panel layout, initial sheet shape, sheet rollup, etc. The second type consists of cases run for the purpose of comparing computed results with experimental data, and these comparisons verify the underlying physical assumptions made by the method.

Volume II contains instructions for the proper set up and input of a problem into the computer code. Program input formats and output are described. A description of the computer program and its overlay structure is also presented.

2.0 INTRODUCTION

A computer program has been developed for the solution of the subsonic, three-dimensional flow over wing-body configurations with leading-edge vortex separation. The program provides capabilities for calculating forces, moments, and detailed surface pressures on thin, sharp-edged wings of an arbitrary planform. The wing geometry is arbitrary in the sense that leading and trailing edges may be curved or kinked and the wing may have arbitrary camber and twist as long as in real flow it produces only a single well developed vortex system. The numerical methods employs an inviscid flow model in which the wing and the rolled-up vortex sheets are represented by continuous quadratic doublet sheet distribution. Furthermore, wing thickness may be represented by linear source distributions. The Kutta condition is imposed along all wing edges, and a zero force condition is imposed on the vortex core. An iterative scheme is applied to find the strengths of the doublet distributions as well as shape and position of the free vortex sheets spirals satisfying the nonlinear boundary conditions of the flow problem. The code includes two iterative solution procedures: (i) Quasi-Newton scheme and (ii) Least Squares Method. The least squares procedure for damping unstabilities was developed to alleviate convergence problems for certain cases using the standard Quasi-Newton iterative scheme.

The computer program is written in the CDC FORTRAN Extended (FTN4) language for the CDC Network Operating System (NOS). The program uses overlay structures and fourteen disk files which include the standard system files INPUT (TAPE5) for card reading and OUTPUT (TAPE6) for printing. The program has been checked out and run on NASA Langley Research Center's CDC CYBER series computers.

This method was originally developed by the Boeing Company under contracts NAS1-12185 and NAS1-13833. In order to upgrade the capability of the method and the code, a coordinated effort was launched involving contracts NAS1-15169 and NAS1-15275 from the Langley Research Center and work conducted for the Boeing Independent Research and Development Program. For purposes of completeness, the independent Boeing work is included in this documentation.

The documentation is divided into two parts:

Volume I - Theory Document
Volume II - User's Guide and Programmer's Document

The Theory Document (bound separately) contains a detailed description of the theoretical method. Also included are computed results which verify the underlying mathematical assumptions of the method and test theory comparisons which verify the underlying physical assumptions made by the method.

The remainder of this volume, the User's Guide and Programmer's Document, is organized as follows. In section 4 a brief description of the method is given for completeness. Section 5 provides instructions for the proper setup of analysis case. Network definitions and arrangements are discussed. The input formats are described followed by two example cases. Useful hints for practical use of these instructions are also included. Section 6 describes the output formats. Discussions and examples are provided. Section 7 describes the computer programs. This concludes with a description of the program structure, the overlay program, the file structure, common block definition and a linkage map of the programs and subroutines.

3.0 NOMENCLATURE

a	free and fed sheet geometry parameter
AR	aspect ratio
b	local span
c	chord
C_N	normal force coefficient
C_p	pressure coefficient
F	equations determining singularity parameters
$\vec{F}$	force vector
G	equations determining vortex geometry parameters
K	equations penalizing panel twist
ℓ	panel width
$\hat{\ell}$	unit vector along vortex core or network junction
M	number of grid point rows on a network
M_∞	free stream Mach number
$\hat{n}$	surface unit normal vector
$\vec{n}$	normal vector at panel center
N	number of grid point columns on a network
p	circular arc parameter
p	pressure
p_i	isentropic pressure
p_2	second-order pressure
$\vec{P}$	field point
$\vec{Q}$	point on boundary B
$\vec{Q}_i$	nine canonical panel points
$\vec{Q}_o$	panel center

NOMENCLATURE (CONTINUED)

$\vec{Q}_s$, $\vec{Q}_t$, $\vec{Q}_{st}$	parametric coefficients defining H
s	local semispan used in Smith solution
(u,v,w)	perturbation velocity vector components
V_∞	free stream velocity magnitude
$\vec{w}$	perturbation mass flux vector
$\vec{W}$	total mass flux vector
$\vec{W}_A$	average surface value of total mass flux vector
$\hat{x}$	unit vector along x-axis
x,y,z	Cartesian coordinates
α	angle of attack
β	$\sqrt{1 - M_\infty{}^2}$
γ	delta wing semi apex angle
γ	ratio of specific heats
Δ	jump in quantity across singularity surface or line
Δ	change in quantity from one iteration to the next
δ	fraction of Newton step
$\bar{\zeta}$	surface vorticity vector
θ	vortex system orientation angles
Θ	all vortex systems geometry parameters
λ	vortex system scale factor
Λ	all singularity parameters
μ	doublet strength
$\hat{n}$	normal vector to panel edge
ν	fed sheet scale factor
ρ	Newton iteration step size limiter

NOMENCLATURE (CONCLUDED)

σ	source strength
ϕ	perturbation potential
(ϕ_x,ϕ_y,ϕ_z)	gradient of perturbation potential
$\bar{\nabla}$	gradient operator
$\otimes$	vector cross product

4.0 DESCRIPTION OF THE METHOD

For the sake of completeness, a brief description of the method is included in this document.

4.1 Theoretical Model

The flow model used in the Leading Edge Vortex (LEV) Program is illustrated in Figure 1. Flow about a highly swept wing at angle of attack separates at the leading edge and forms a spiral vortex. Studies (refs. 1,2) of the principal vortex indicate that its shape and strength are relatively independent of Reynolds number. This apparent lack of viscosity dependence suggests that the flow may be regarded as potential, with the free shear layer represented either as a vortex sheet or, equivalently, a doublet distribution supporting a discontinuity in tangential velocity. Since the position of the vortex sheet is not known a-priori, this results in a problem governed by the linear subsonic flow differential equation

$$\beta^2 \phi_{xx} + \phi_{yy} + \phi_{zz} = 0, \ \beta^2 = 1 - M_\infty^2 \tag{1}$$

where ϕ is the perturbation velocity potential and by non-linear boundary conditions.

The essential elements of the present flow model are the configuration surfaces, the trailing wake, the sheet emerging from the wing leading edge and the tip (we call this the free sheet), and the rolled-up core or spiral region fed by the leading edge and tip vortex sheets (we call this the fed sheet).

The following boundary conditions are imposed on these elements:

- The configuration surface must be impermeable.

  $$(\vec{W}_A \cdot \hat{n}) = 0 \tag{2}$$

  where W is the average surface value of the total mass flux vector and n is the surface unit normal vector.

- The free sheet and wake cannot support a pressure difference and must form a stream surface.

  $$\Delta C_{p_2} = 0 \tag{3}$$

  where ΔC_{p_2} is the jump in the second order pressure coefficient, see Section 6.2.2 for definition of C . Impermeable condition

  $$\hat{n} \cdot \vec{W}_A = 0 \tag{4}$$

- DIFFERENTIAL EQUATION

$$(1 - M_\infty^2)\,\phi_{xx} + \phi_{yy} + \phi_{zz} = 0$$

- BOUNDARY CONDITIONS
  - WING, BODY :
    IMPERMEABLE
  - WAKE, FREE SHEET:
    IMPERMEABLE
    ZERO PRESSURE JUMP
  - FED SHEET;
    ZERO TOTAL FORCE
  - KUTTA CONDITION

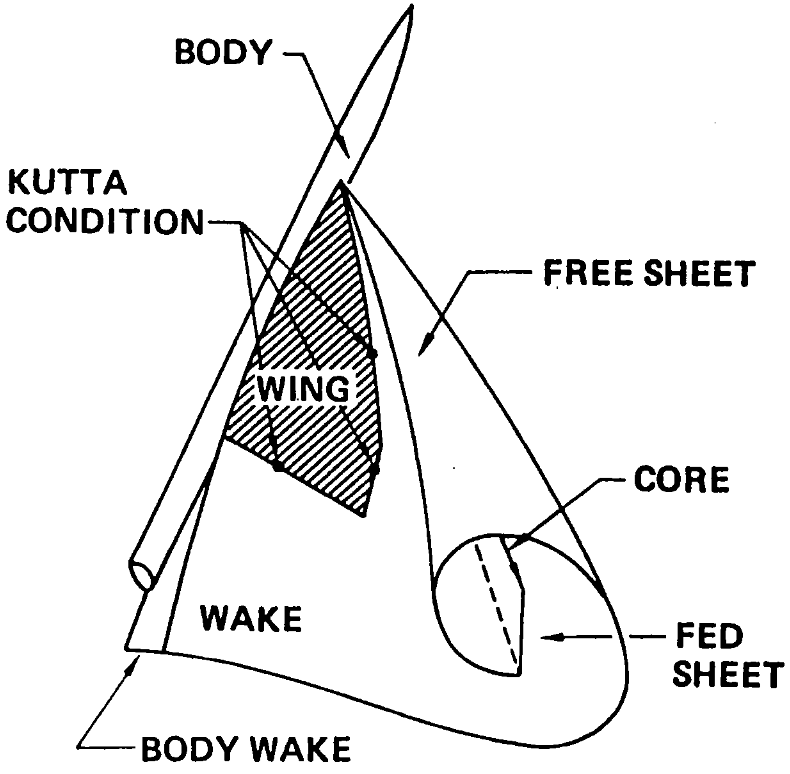


FIGURE 1 FLOW MODEL

o The fed sheet is an extension of the free sheet and feeds vorticity to the vortex core (modeled as a simple line vortex). The boundary condition governing fed sheet size and core orientation is that the total force induced on the fed sheet and core by the rest of the configuration be parallel to the core.

$$\hat{\ell} \otimes \Delta \vec{F} = 0 \tag{5}$$

where $\hat{\ell}$ is the unit vector along the vortex core and $\Delta \vec{F}$ is the force.

The size of the fed sheet is chosen initially by experience or from the conical flow results of Smith (ref. 3).

o Kutta conditions are imposed along the appropriate leading, side, and trailing edges of the wing in the presence of free sheets emanating from these edges. The Kutta condition is controlled by the appropriate edge matching condition.

$$\Delta \vec{\zeta} \cdot \hat{\ell} = 0$$

where $\vec{\zeta}$ is the surface vorticity vector and $\hat{\ell}$ is the unit vector along the junction.

The configuration impermeability condition, the free sheet pressure jump condition, and the Kutta edge conditions determine the solution of singularity strengths. The free sheet impermeability condition and the fed sheet zero force condition will determine the free and fed sheet positions.

In subsonic flow, compressibility is accounted for by use of the Goethert rule which is used to transform the problem into the equivalent incompressible problem for solution.

4.2 Numerical Procedure

This problem can be represent by the proper distribution of logically independent paneling networks, which satisfy either Neumann (analysis) or Dirichlet (design) boundary conditions. Shown in Figure 2 is a typical paneling scheme for a wing-body configuration. Hyperboloidal (Hyperbolic-paraboloid) panels are used to ensure surface continuity. A continuous quadratic doublet distribution is used on the midplane to represent wing, wake, free and fed sheet networks. A linear surface source distribution can be used to represent the body and wing thickness if desired.

The main features of the numerical discretization and computational scheme are:

1) Geometry input for a network consists of a rectangular array of corner point coordinates. These corner points are fitted exactly by hyperbolic paraboloid patches (hyperboloidal panels). These exact

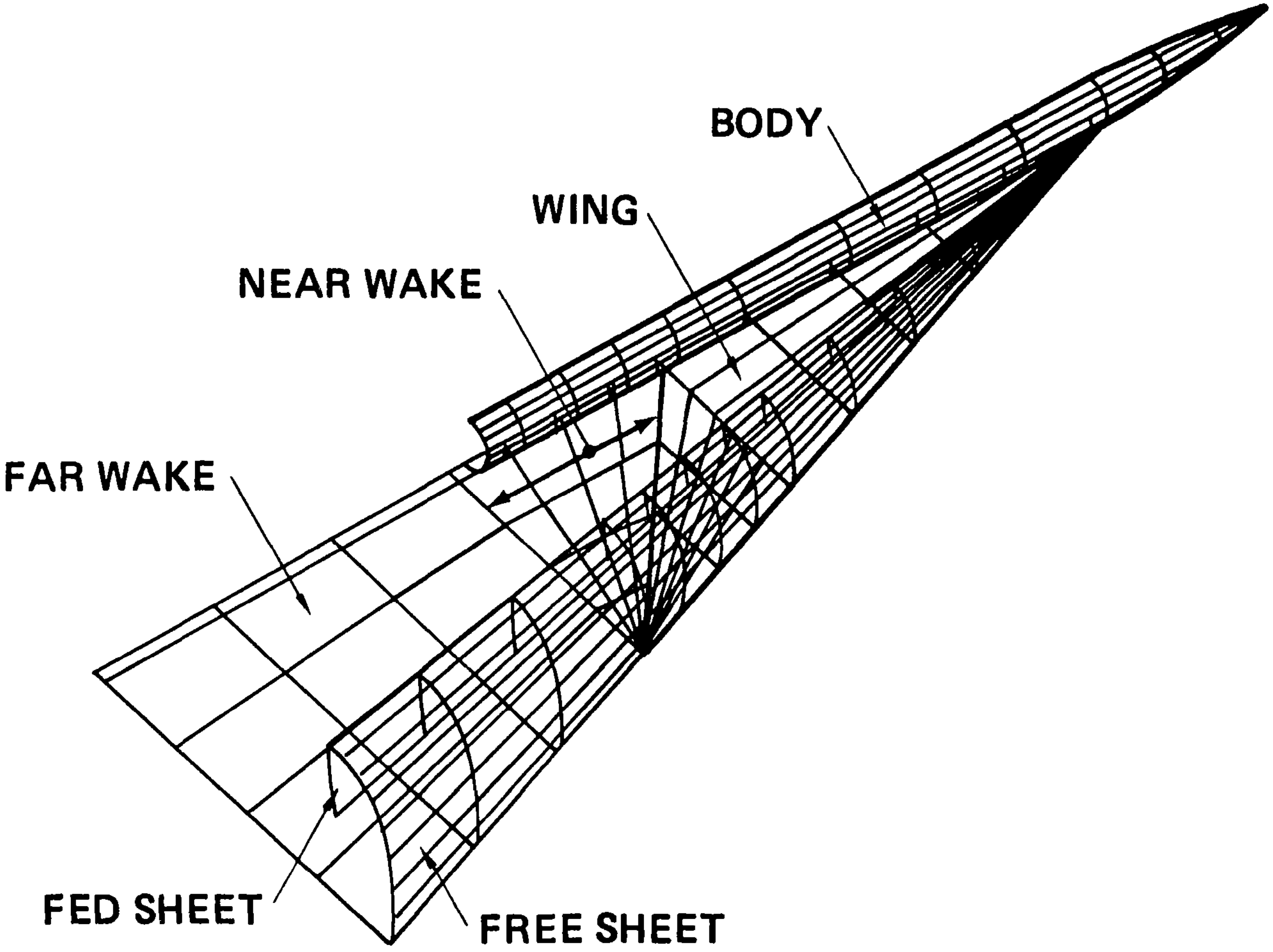


FIGURE 2 PANEL MODEL

fits ensure surface continuity.

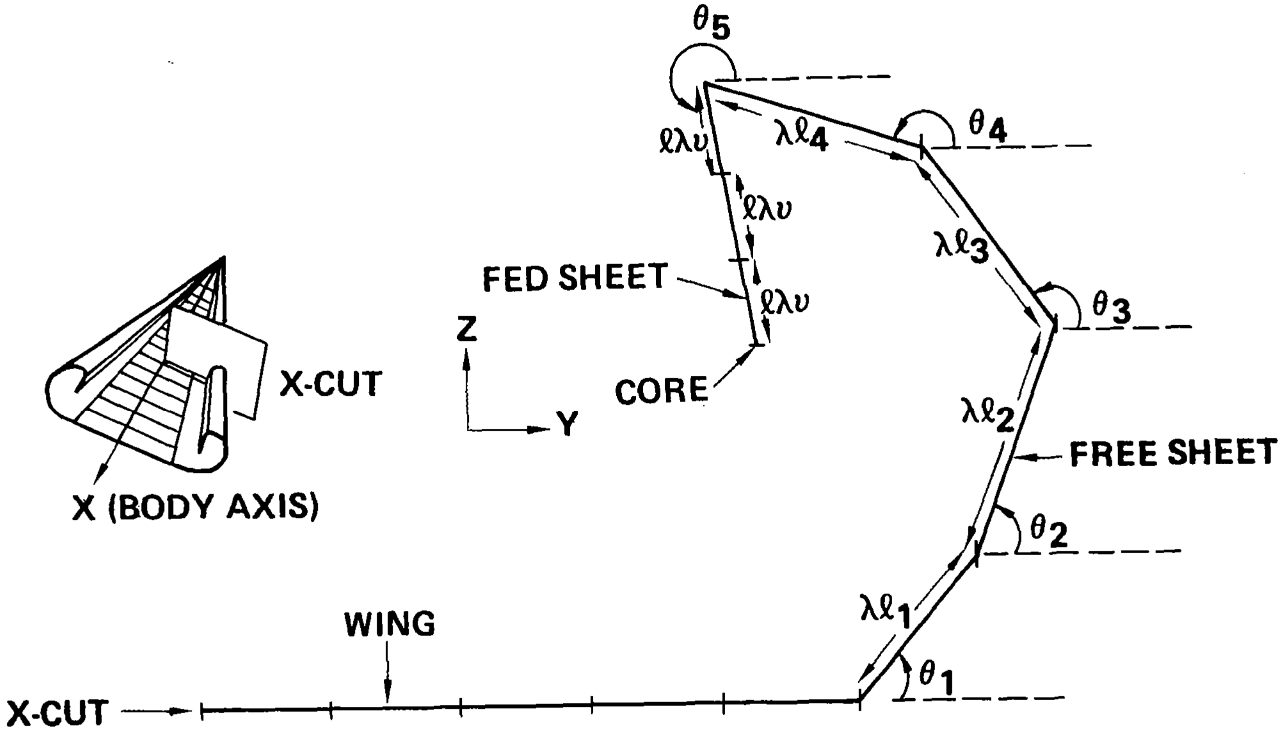
2) Discrete values of singularity strength are assigned to certain standard points on each network. A local distribution on surface singularity strength is obtained by fitting a linear source or quadratic doublet form to those discrete values in an immediate neighborhood by the method of least squares. An analysis type network is employed on the wing (geometry of the wing is specified), and a design type network of doublets simulates the free sheet (unknown free sheet geometry, zero pressure jump specified). In order to insure continuity of doublet strength between panels and networks, nine degree of freedom splines are used to describe the quadratic panel distributions.

3) Certain standard points on each network are assigned as control points, where boundary conditions are specified. These points include panel center points as well as edge abutment downwash points in the case of doublet networks. The latter serve to impose standard aerodynamic edge conditions automatically (e.g., the Kutta condition, zero potential jump at thin edges, continuity of singularity strength across abutting networks), in order to produce logical independence for each network. The number of boundary conditions on each network coincides with the number of assigned surface singularity parameters.

4) The induced potential and velocity integrals of the influence coefficient equations are all evaluated in closed form, although standard far field expansions are employed when the control point is sufficiently distant from the influencing panel.

Since the problem is non-linear, an iterative procedure must be used for solution. An initial guess must be made for the free and fed sheet position. Normally results from Smith's conical flow method are used for the initial guess, but the user can also input his own geometry. During the iterative solution the position and size of the free and fed sheet are updated until all the boundary conditions are satisfied. The standard free and fed sheet kinematics which allow this updating are shown in Figure 3. A cut normal to the longitudinal axis is shown. The wing panels, of course, remain fixed. The angle θ (theta) associated with the free sheet segments are free to change with the exception of the angle between the horizontal and fed sheets. The length of the free and fed sheet segments are controlled by the parameters λ (lambda) and the length of the fed sheet segments are further controlled by the parameters ν (nu). These parameters as well as the panel singularity strengths μ (mu) are all updated simultaneously using a Newton correction scheme.

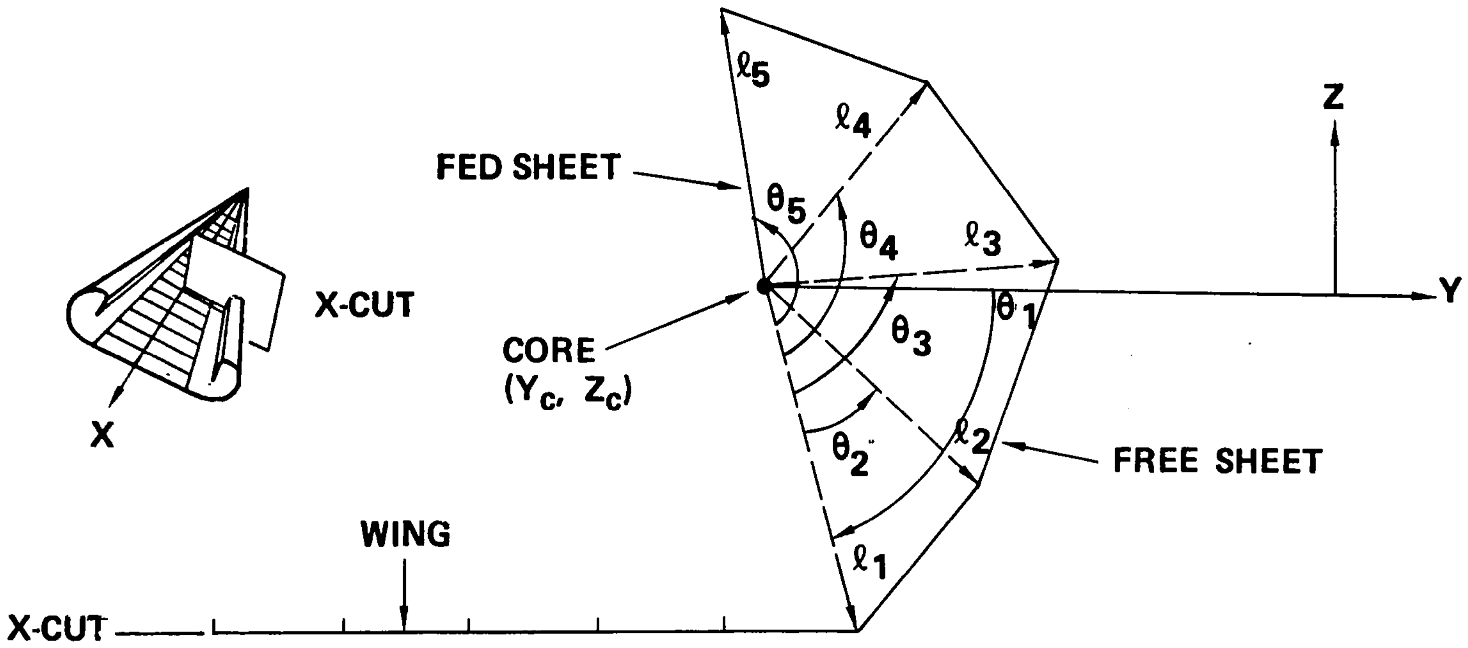
The above vortex system kinematics is, of course, only one of many possibilities. A good alternative is the kinematics of Smith (ref. 3) shown in Figure 4. Here, in contrast to the standard kinematics, angles θ are fixed and lengths ℓ and core location are chosen as the free parameters. Both kinematics schemes will lead to the same converged solution. Preliminary studies indicate that Smith's kinematics may results in faster convergence.



FREE PARAMETERS: $\theta_1, \theta_2, \theta_3, \theta_4, \lambda, \upsilon$

FIXED PARAMETERS: $\ell_1, \ell_2, \ell_3, \ell_4, \theta_5, \ell$

FIGURE 3 FREE/FED SHEET KINEMATICS



FREE PARAMETERS: $\ell_2, \ell_3, \ell_4, \ell_5, Y_c, Z_c$

FIXED PARAMETERS: $\theta_2. \theta_3, \theta_4, \theta_5$

FIGURE 4 SMITH'S FREE/FED SHEET KINEMATICS

4.3 Solution Procedure

The boundary value problem of wings with leading edge vortex separation is nonlinear due to the fact that the shape of the free vortex sheet as well as its strength are unknown. The solution procedure must therefore be iterative. Two solution procedures are available in the LEV code, ITFLOW and LSFLOW.

4.3.1 Quasi-Newton Scheme, ITFLOW

The standard procedure ITFLOW uses a Quasi-Newton scheme for the iterative solution of the flow problem. The incompressible boundary conditions as derived from the compressible formulation by application of the Goethert rule, can be written symbolically in terms of the following equations

$$F(\Lambda, \Theta) = \left\{ \begin{array}{ll} (\vec{W}_A \cdot \hat{n}) = 0 & \text{Wing-body} \\ \Delta C_{p_2} = 0 & \text{Free sheet and wake} \\ \Delta \vec{\zeta} \cdot \hat{\ell} = 0 & \text{Kutta condition} \end{array} \right. \qquad (6)$$

$$G(\Lambda, \Theta) = \left\{ \begin{array}{ll} (\vec{W}_A \cdot \hat{n}) = 0 & \text{Free sheet} \\ \hat{\ell} \otimes \Delta \vec{F} = 0 & \text{Fed sheet} \end{array} \right. \qquad (7)$$

where Λ denotes all the singularity parameters and Θ denotes all the geometric degrees of freedom. The function F symbolizes the impermeable boundary condition of the wing and body, equation (2), zero pressure jump across the free sheet and wake, equation (3), and the Kutta condition. The function G represents the stream surface boundary condition of the free sheet, equation (4), and the global boundary condition of zero net force acting on the fed sheet and the line vortex, equation (5).

Starting with an assumed initial geometry (i.e., a given set of parameters Θ), the initial singularity strength parameters Λ are obtained using the set of equations (6) in which ΔC_{p_2} has been replaced by the linear form of the pressure equation (see section 6.2.2).

To obtain a solution, two phases of iterative procedure are performed alternatively. The first phase, which is called subiteration, merely produces convergence to the nonlinear ΔC_{p_2} equation associated with the pressure jump boundary condition on the free sheet. The spatial location of the free sheets is not updated and the aerodynamic influence coefficients remain the same throughout the iteration. The Jacobian matrix consisting of only the small perturbation of the functions F due to the singularity strength parameters ($\partial F / \partial \Lambda$) can be easily calculated.

$$\frac{\partial F}{\partial \Lambda} \quad \Delta\Lambda = -\rho F \qquad (8)$$

F is known and denotes the error residual in the satisfaction of the boundary conditions of equation (6) at intermediate steps in the iteration cycle. ρ represents symbolically the step size scaling parameter δ which is a positive number less than 1 and is chosen small enough (by the code) to ensure a decrease in F. Newton's method with this controlled step size is used and convergence is usually achieved in 2 or 3 iterations.

For the second phase, the boundary conditions that the free sheet form a streamsheet, and the zero force condition on the fed sheet are introduced. In general the initial guess, Θ , will not be correct and a full iteration procedure will begin in which the free and fed sheet geometry will be updated. This will require the recalculation of those aerodynamic influence coefficients affected by the perturbation of the free and fed sheet geometry.

Small perturbations of equations (6) and (7) from the initial "starting solution" result in a set of linear equations governing the perturbation variables Λ , Θ .

$$\begin{pmatrix} \frac{\partial F}{\partial \Lambda} & \frac{\partial F}{\partial \Theta} \\ \frac{\partial G}{\partial \Lambda} & \frac{\partial G}{\partial \Theta} \end{pmatrix} \begin{pmatrix} \Delta \Lambda \\ \Delta \Theta \end{pmatrix} = -\rho \begin{pmatrix} F \\ G \end{pmatrix} \qquad (9)$$

As in equation (8) F and G are known and denote the error residual in satisfaction of the boundary conditions at intermediate cycles. These equations are solved iteratively by a Quasi-Newton method with controlled step size (see Appendix G of Volume I). The calculation of a complete Jacobian (left hand side matrix) which includes the effect of the perturbation of geometry, Θ , is quite expensive. A new Jacobian is computed after every three iterations in the iterative process. Five to six iterations are generally sufficient to obtain convergence.

The convergence history of a typical solution is illustrated in Figures 5, 6 and 7. Figure 5 illustrates the normal force and residual history. The subiteration is now shown. Once convergence for the subiteration is achieved the complete boundary conditions are introduced and the full iteration begins. The solution should not be considered complete until the residual is less than 10 . The case shown had a particularly slow convergence with the Jacobian update being made only every 5 iterations. More typical cases tend to converge in 5 to 6 iterations with Jacobian updates occurring every 3 iterations. Figure 6 shows the progress of the free sheet geometry at one station during the iteration. Figure 7 shows the corresponding pressure distribution.

4.3.2 Least Squares Method, LSFLOW

An alternate iteration procedure is also available for those cases for which the Quasi-Newton scheme, ITFLOW, fails to converge. In these cases local flow anomalies on the free sheet may cause instabilities which destroy convergence everywhere in the solution. These instabilities cause excessive panel twist which propagates throughout the free sheet.

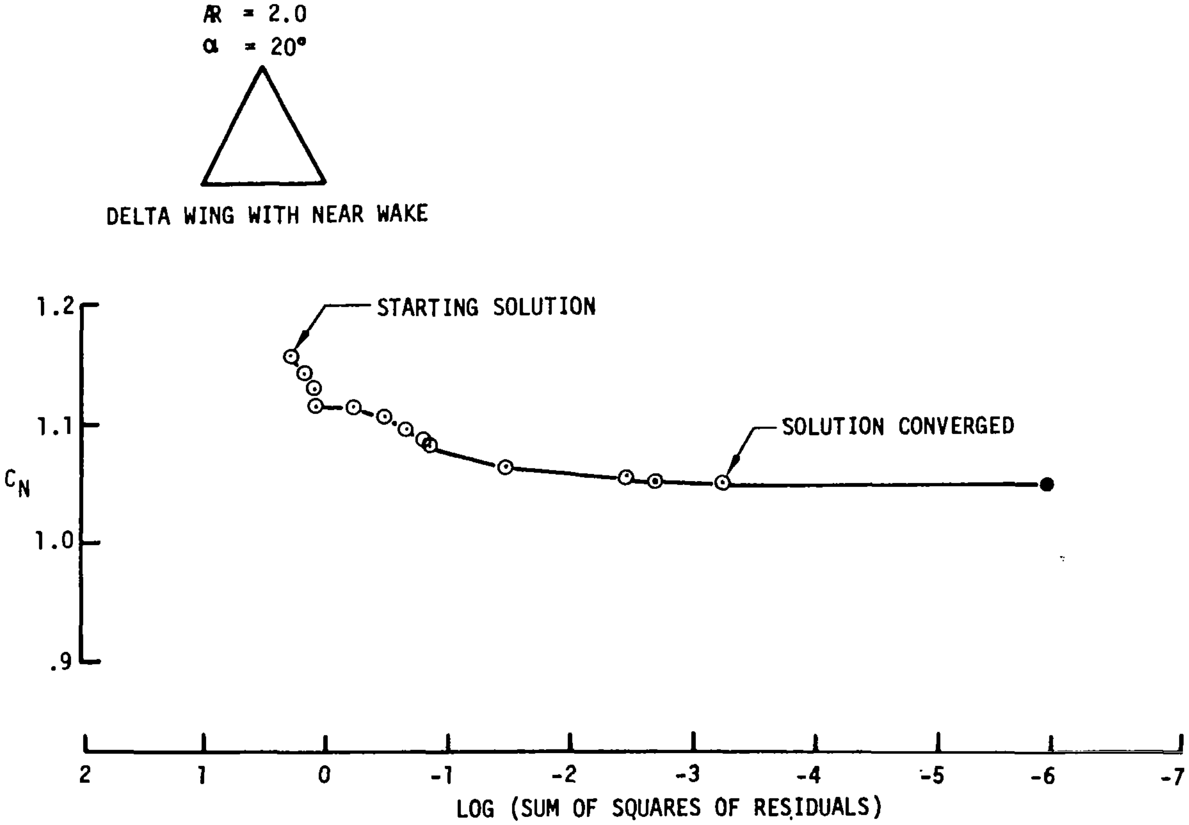


FIGURE 5 CONVERGENCE CHARACTERISTICS - RESIDUALS

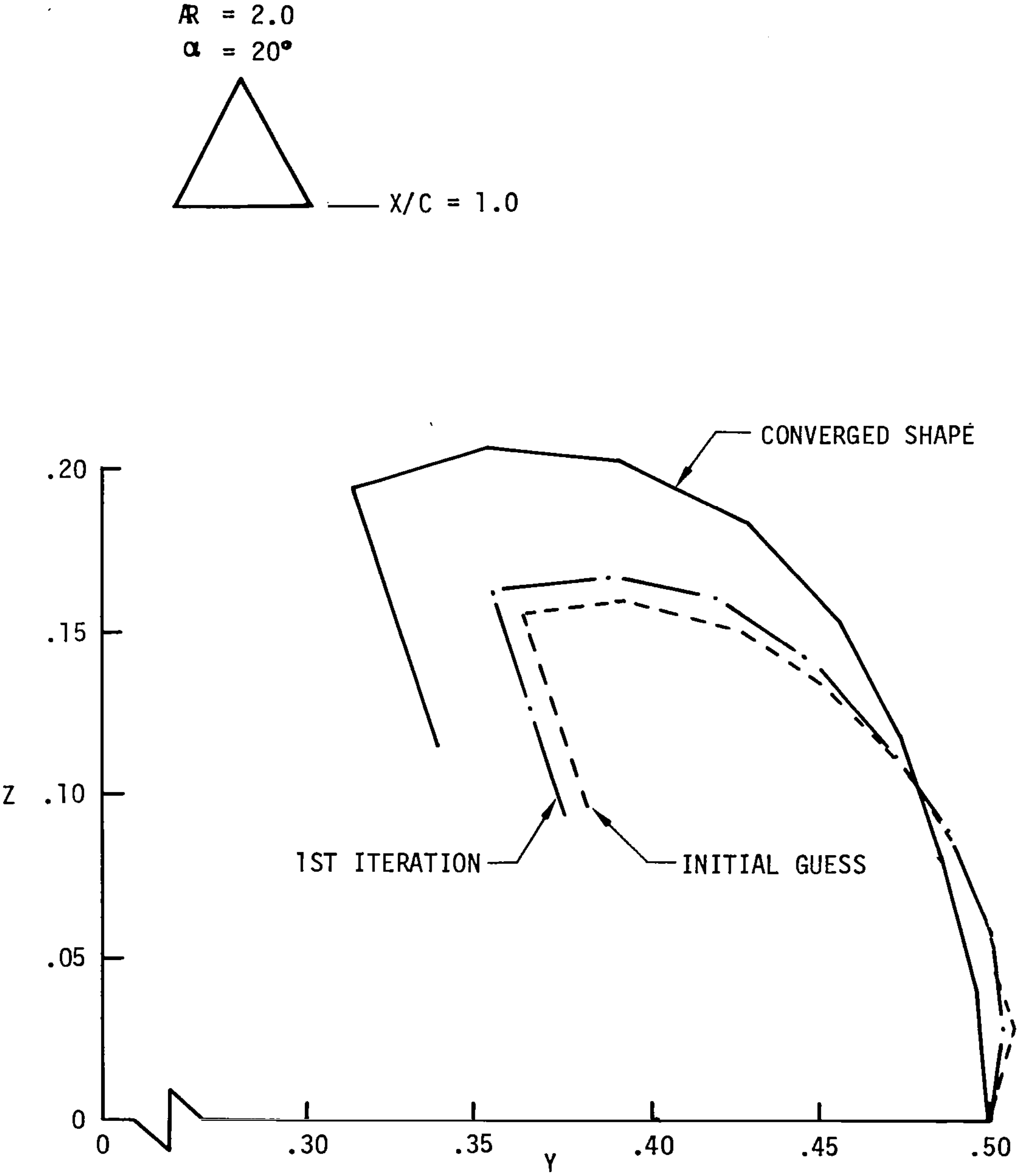


FIGURE 6 CONVERGENCE CHARACTERISTICS - GEOMETRY

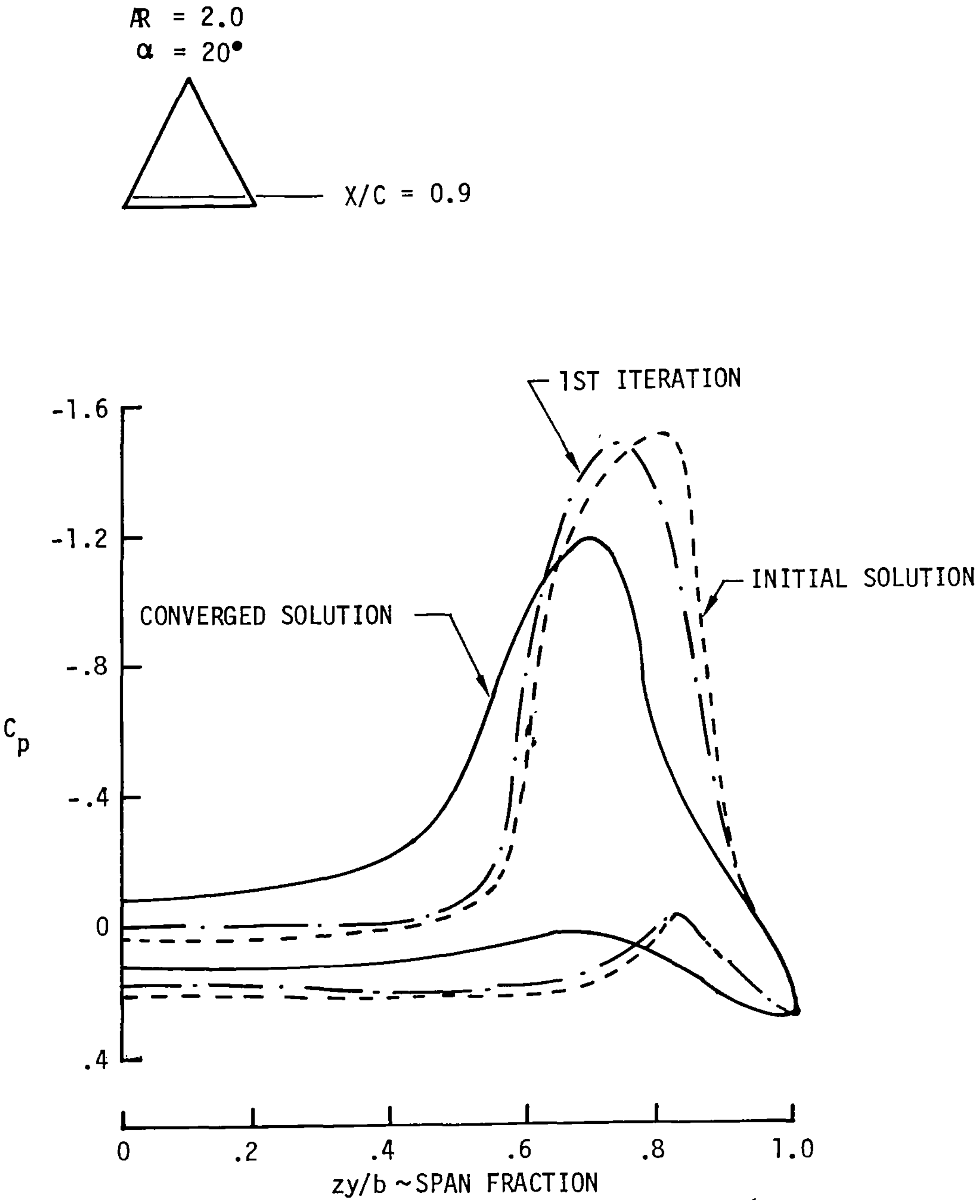


FIGURE 7 CONVERGENCE CHARACTERISTICS - PRESSURES

One of the simplest methods of damping this instability whenever it arises is to limit excessive panel twist. This leads to an additional equation that all free sheet panels be untwisted (flat),

$$K(\Theta) = \frac{\vec{n}\cdot\vec{Q}_{st}}{(\vec{n}\cdot\vec{n})^{3/4}} = 0 \qquad (10)$$

where $\bar{n} = \vec{Q}_s \otimes \vec{Q}_t$ and $\vec{Q}_s$, $\vec{Q}_t$ and $\vec{Q}_{st}$ are hyperboloidal panel defining quantities. Equation (10) combined with equations (6) and (7) creates an overdetermined system of equations for Λ (singularity parameters) and Θ (geometric degrees of freedom).

The system is solved in a least squares sense after suitable normalization to account for dimensional differences as well as desired weighting. Equation (10) governing panel twist is not weighted heavily since a free sheet made up entirely of flat panels may not in general be a good approximation to a stream surface. The instabilities produced by a local flow anomaly are severe enough that a very small penalty on panel twist force relaxation of the boundary condition causing the local anomaly.

The procedure for solving the overdetermined equation set is iterative as before. At the beginning of an iteration, equation (6) is solved for Λ as a function of the current Θ using Newton's method with controlled step size, i.e.,

$$\frac{\partial F}{\partial \Lambda} \Delta\Lambda = -\rho F \qquad (11)$$

This is essentially the subiteration which was discussed previously in Section 4.3.1. Upon obtaining convergence, a new estimate for Θ is calculated by solving the equation

$$\begin{pmatrix} \frac{\partial G}{\partial \Lambda} \frac{\partial f}{\partial \Theta} + \frac{\partial G}{\partial \Theta} \\ \frac{\partial K}{\partial \Theta} \end{pmatrix} \begin{pmatrix} \Delta\Theta \end{pmatrix} = -\rho \begin{pmatrix} G \\ K \end{pmatrix} \qquad (12)$$

in a least square sense, where the Jacobian on the left is evaluated at the point $\Lambda = f(\Theta)$ as determined from (11) and $\partial f / \partial\Theta$ is calculated from

$$\frac{\partial F}{\partial \Lambda} \frac{\partial f}{\partial \Theta} + \frac{\partial F}{\partial \Theta} = 0 \qquad (13)$$

We assume here that G and K have been normalized appropriately.

When using the Least Squares Method, a new Jacobian is computed after every two iterations. If cycle of step size reduction exceeds 3 (see Appendix G of Volume I), then a new Jacobian will also be formed.

5.0 USER'S INPUT GUIDE

In this section instructions are given to enable the user to properly set up a flow model and prepare the program input data. Since proper formulation of the flow model is paramount in obtaining a solution, considerable description of the networks and their characteristics is given. Several examples are given illustrating the proper network placement for various configuration planforms. A complete listing of the Input Formats and two example cases are also included.

5.1 Capabilities and Restrictions

The Leading Edge Vortex (LEV) program is a versatile tool for calculating flows about a class of configurations with leading edge vortex separation. The wing geometry may be arbitrary in the sense that leading edge and trailing edge may be curved or kinked and the wing may have arbitrary camber and twist. The limiting factor on planform shape is that only a single primary vortex system be formed. Configurations for which a strong well defined vortex system does not exist in real flow will probably encounter convergence difficulties during the solution. This includes configurations with less than 60 leading edge sweep, configurations with discontinuities in the leading edge which will promote the formation of more than one vortex system, and solutions at low angles of attack where a well defined vortex has not yet formed in real flow.

Planforms for which successful solutions have been obtained include delta, arrow, and diamond wings with pointed or cropped wing tips, and also gothic and ogee planforms. Several of these examples may be found in Volume I - Engineering Document, Sections 6 and 7. A variety of camber and twists have also been successfully analyzed. Several of these examples may be found in reference 4. Again the key requirement in any of these solutions is that a single well formed vortex exist in the real flow. (Note that it may be possible to obtain a solution on a configuration with more than one vortex system on each side of the plane of symmetry as long as the systems never coalesce. However, this capability has not been explored at the time of this writing).

The program has a symmetry condition option (NSYMM, card 9) which must be set in the input. Normally solutions are obtained assuming a plane of symmetry. For asymmetric configurations or configurations at yaw the symmetry condition must be defeated and both sides of the configurations specified. (For these cases two vortex systems will be specified). The network setup for asymmetric cases will be discussed in section 5.4.6, results are shown in Figure 23, section 7.1.2, Volume I - Theory Document.

An often overlooked capability of the LEV program is to analyze attached flow models. The setup of such models is identical to that of the separated case except that the free and fed sheet networks are deleted. Use of this option allows direct comparisons between solutions that assume attached or separated flow. An example of this type comparison is shown in Figure 28b in Volume I - Theory Document.

The program is valid only for subsonic Mach numbers. The Gothert rule is applied to transform the problem to the equivalent incompressible case for solution. The flow model size restrictions are given in Table 1 which appears in section 5.5. Restrictions are given both for the Quasi-Newton scheme (section 4.3.1) and for the Least Squares method (section 4.3.2). Note that the number of singularity strength parameters does not correspond to the number of panels. This is because in the higher order panel method used there is not a one-to-one correspondence between singularity unknowns and panels. Control point placement on the various types of networks which corresponds to the number of singularity unknowns will be illustrated in the next section. Also note that for the Quasi-Newton scheme the number of singularity parameters (which could be used for an attached flow solution) is greater than the combined number of singularity parameters, panel orientation angles, and geometry parameters which can be used for a separated flow solution.

5.2 Network Description

5.2.1 Network Nomenclature

A network is defined as a portion of the boundary surface on which a certain distribution of source or doublet strength is specified, together with properly posed analysis (Neumann) or design (Dirichlet) boundary conditions. The true surface is assumed to have continuous position, slope and curvature. Discontinuities in these quantities are therefore limited to network edges. The networks are logically independent in that each network contributes as many equations as unknowns to the overall boundary value problem, hence networks can be added or dropped without total reformulation of the problem.

Every network is specified by giving the coordinates of an array of grid points which is basically quadrilateral as illustrated in Figure 8. That is, the array consists of M "rows" or grid points which each contain N points. N is the number of columns of grid points. A triangular shaped network is achieved by allowing one edge of the quadrilateral collapse into a single point. This is accomplished by letting a single grid point belong to several rows or columns.

The sense of M and N defines the orientation of a paneling network. Side numbering, corner numbering, grid point indexing and outward direction are all defind by the sense of M and N. The vector N corresponds to a column of grid points directed in the direction of increasing points, while the vector M corresponds to a row of grid points in the direction of increasing points. The vector NxM is directed out of the surface. The outward sense of a network is important when using source type networks. The outward side of a source network must always bound the flow. In setting up the geometry for a solution it is also important to know the proper side numbering nomenclature. Wake and design type networks such as those used for the free and fed sheets and the trailing wake demand a specific orientation when being attached to the configuration type networks (side 1 must attach). Figure 8 illustrates the proper nomenclature for a network. Several data preprocessors are included in

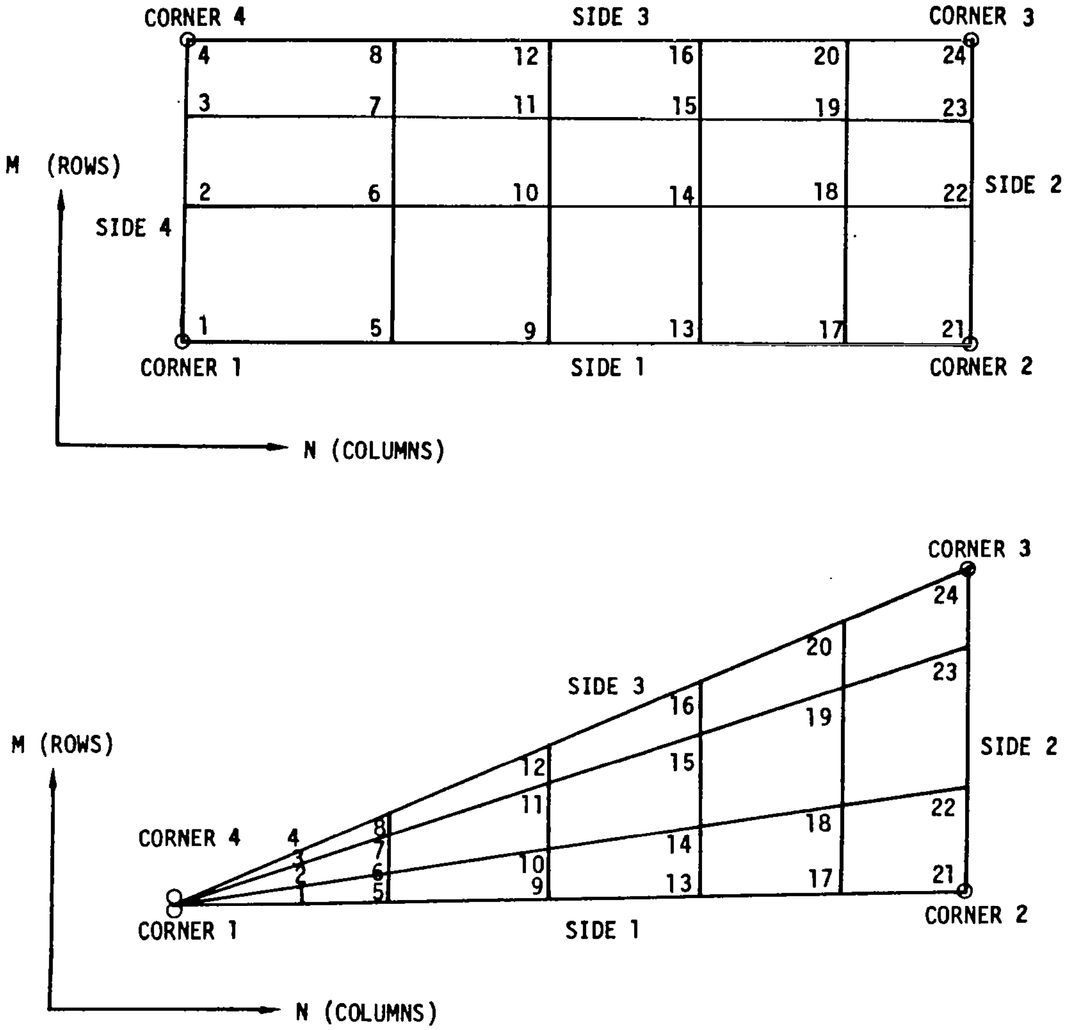


FIGURE 8 NETWORK NOMENCLATURE

the LEV code to aid the user in defining the appropriate network input data. Use of these preprocessors will be discussed in a later section.

5.2.2 Network Paneling

Generally two types of network paneling may be employed, although other arrangements are possible. The two basic types illustrated in Figure 9 are conical paneling and streamwise paneling. Conical paneling is used mainly for wing, free and fed sheet networks, while streamwise paneling is used mainly for wake networks. Streamwise paneling may also be used on wing networks but may require the use of the more expensive least squares method, LSFLOW to obtain a solution. Further discussion on the use of streamwise paneling on wing networks is given in sections 5.2 and 6.2 in Volume I - Theory Document.

5.2.3 Network Abutments

A typical problem will consist of several different networks, representing different types of singularity and boundary conditions. Control points located at the junction of two doublet networks are assigned to match singularity strength across the junction. If only one control point exists, doublet value is matched. If there are two opposing control points the component of vorticity along the junction is also matched.

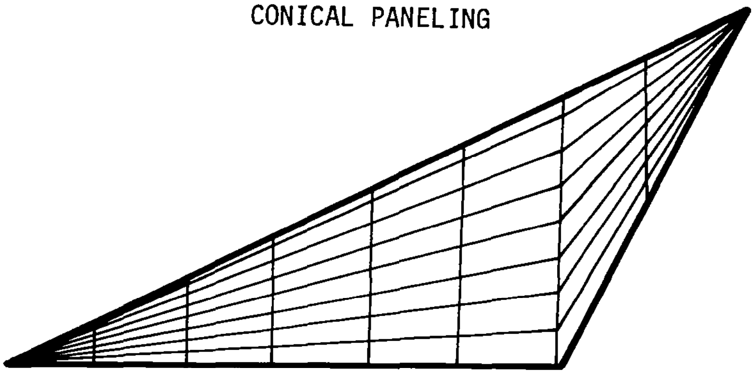
Proper edge matching is dependent on correct abutments between networks. In order to ensure correct abutments it is absolutely necessary that network paneling match identically along adjacent edges. This means that adjacent panel grid points across an abutment must be identical to the accuracy of the computer. An additional restriction is that network abut along complete edges, i.e., their network corner grid points must coincide. Examples of acceptable and unacceptable paneling abutments are shown in Figure 10.

Because of the necessity of achieving proper abutments between networks before a valid solution may be obtained, a data check procedure (card 15, $DATA CHECK) has been incorporated into the program. It is imperative that the data check be performed to confirm proper abutment between networks before committing a problem to solution. A discussion of the abutment data check output will be given in section 6.1.3.

5.2.4 Network Types and Uses

The various network types and their uses are illustrated through the following example. The paneling scheme of Figure 2 is schematically shown in Figure 11. The network type used for each network is summarized in Table 2. Several different singularity types and boundary conditions are necessary to properly specify the problem. In the present program eight network types are available for modeling a given configuration along with its separated vortex system. Each network type represents a different source or doublet distribution accompanied by a properly posed set of boundary conditions. These network types are distinguished by the index NT. A brief description of each available type is presented below.

CONICAL PANELING



STREAMWISE PANELING

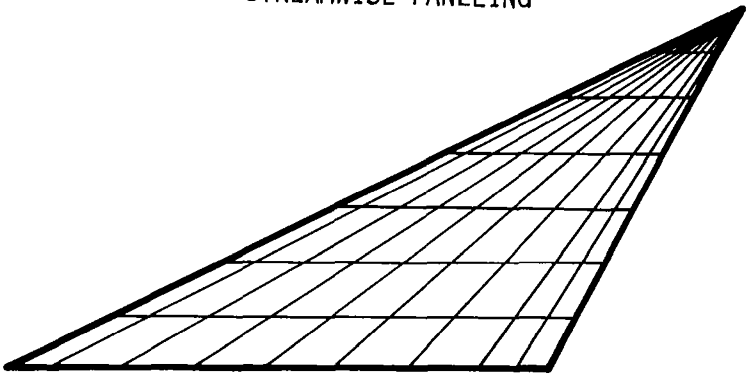
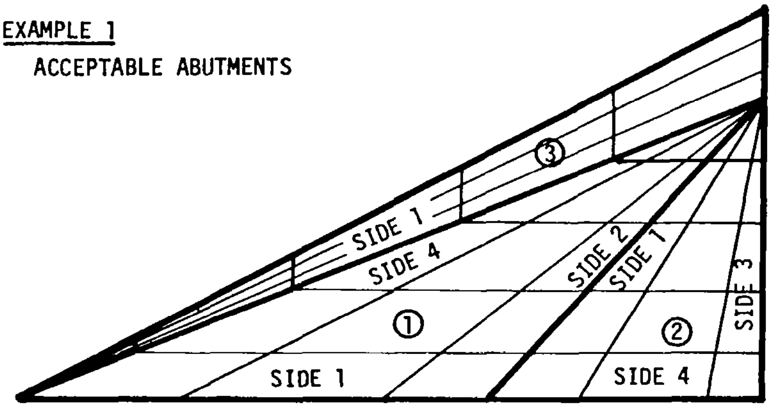


FIGURE 9 NETWORK PANELING ARRANGEMENTS

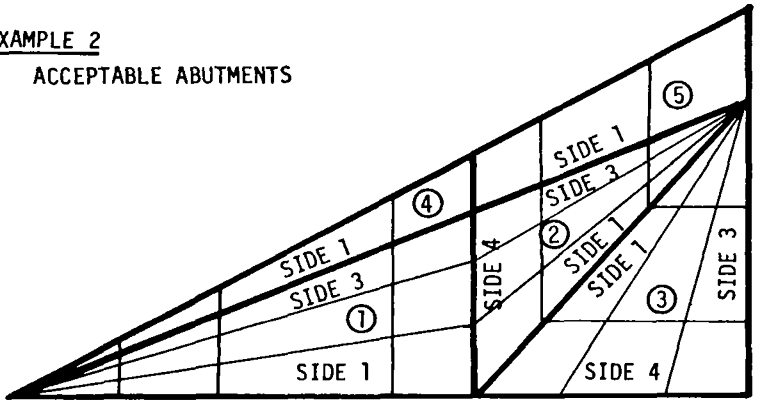
EXAMPLE 1

ACCEPTABLE ABUTMENTS



EXAMPLE 2

ACCEPTABLE ABUTMENTS



EXAMPLE 3

UNACCEPTABLE ABUTMENT

PARTIAL ABUTMENT ALONG SIDE 1
OF NETWORK 1 IS ILLEGAL

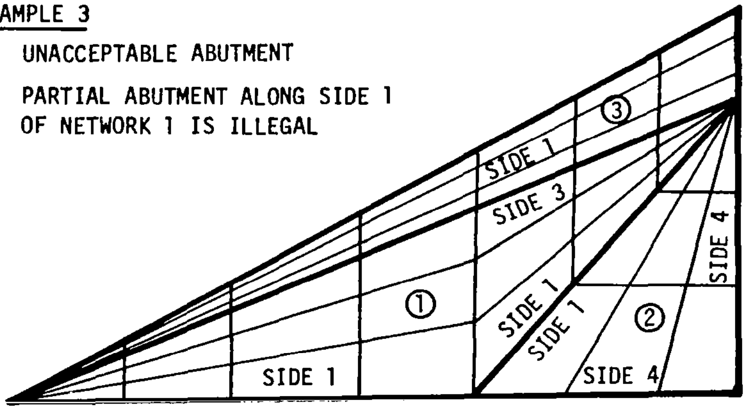


FIGURE 10 ABUTMENT EXAMPLES

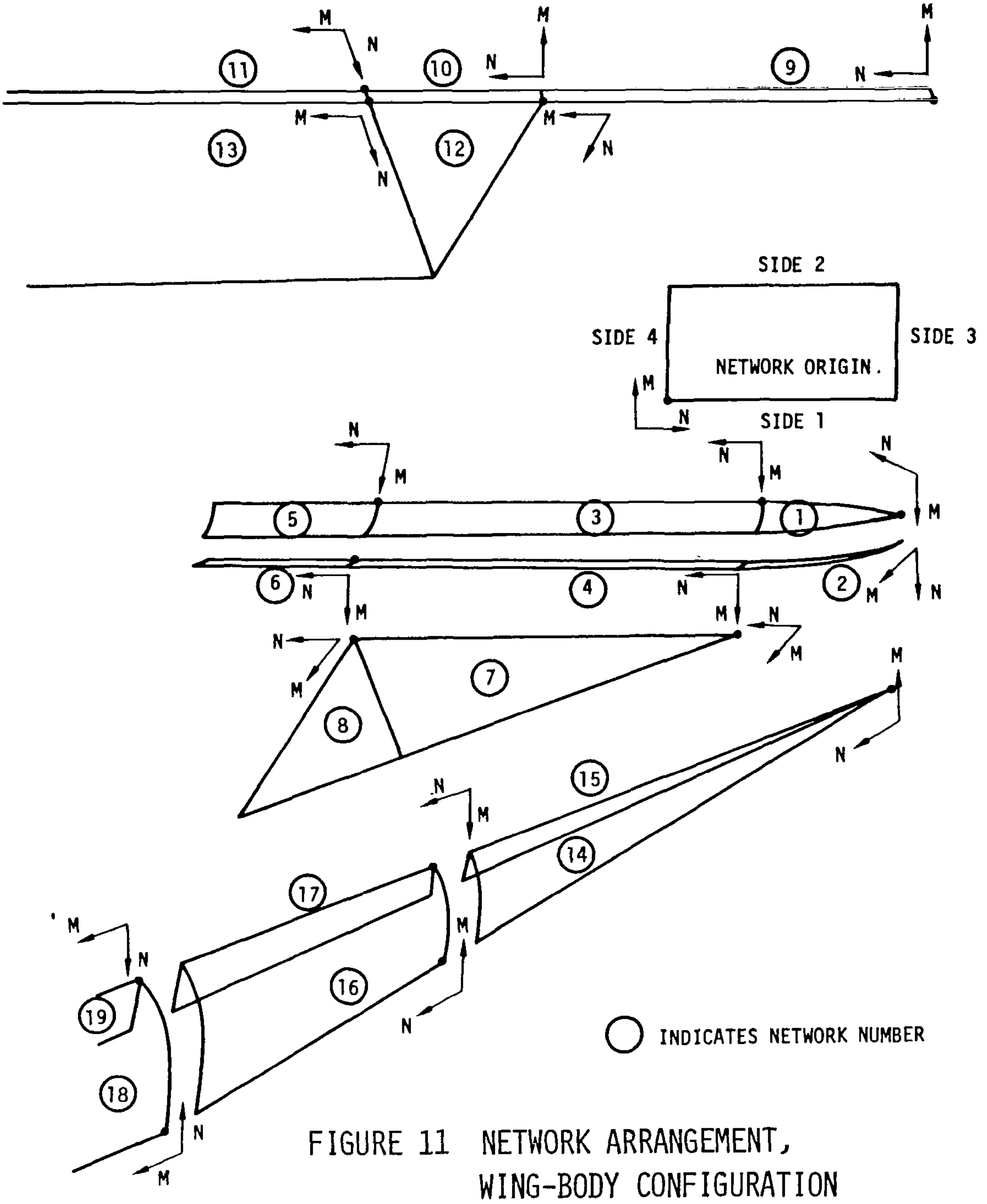


FIGURE 11 NETWORK ARRANGEMENT, WING-BODY CONFIGURATION

TYPE AND USE OF EACH NETWORK OF ARROW WING-BODY
TABLE 2

Network Sequence Number	Network Type	Use
1	NT = 1	Upper Forebody
2	NT = 1	Lower Forebody
3	NT = 1	Upper Midbody
4	NT = 1	Lower Midbody
5	NT = 1	Upper Aftbody
6	NT = 1	Lower Aftbody
7	NT = 2	Wing
8	NT = 2	Wing
9	NT = 8	Carry Over Lifting System
10	NT = 8	Carry Over Lifting System
11	NT = 10	Wake of Carry Over System
12	NT = 6	Near Wake
13	NT = 8	Trailing Wake of Near Wake
14	NT = 4	Free Sheet
15	NT = 14	Fed Sheet
16	NT = 4	Free Sheet
17	NT = 14	Fed Sheet
18	NT = 16	Wake of Free Sheet
19	NT = 10	Wake of Fed Sheet

NT = 1: Source/Analysis Network

This network is used primarily to represent the exterior surfaces of thick wings and bodies. See network numbers 1 to 6 of Figure 11 as examples.

When inputting source type networks one should always be careful that the surface normal (N x M) points out into the flow.

The singularity parameters and control point locations for the Source/Analysis network are illustrated in Figure 12.

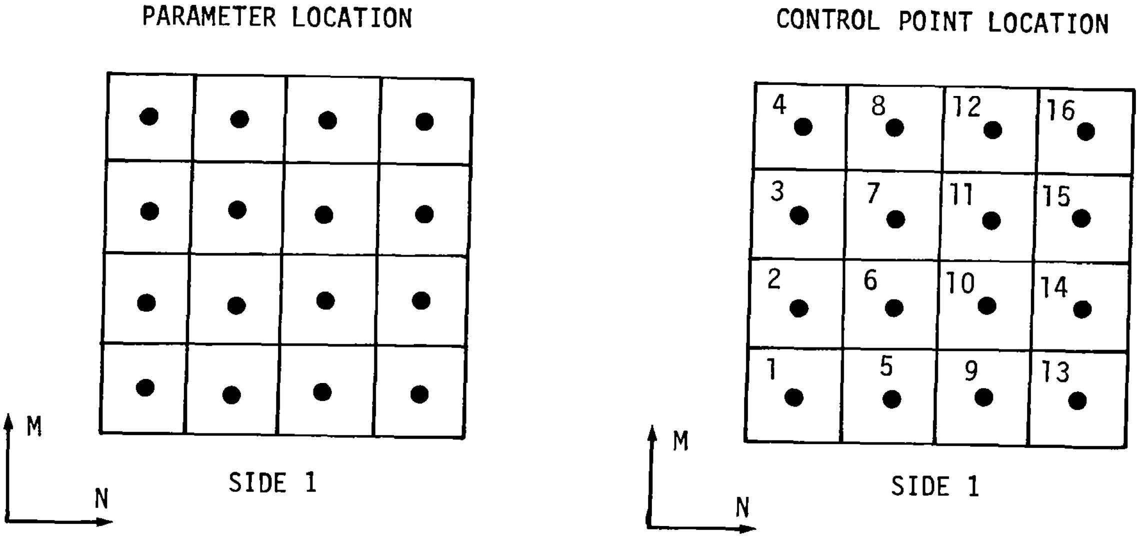


FIGURE 12 PARAMETER AND CONTROL POINT LOCATION SOURCE/ANALYSIS NETWORK

NT = 2: Doublet/Analysis Network

This network is used primarily to represent a thin wing and is placed on the camber surface of the wing (e.g., networks 7 and 8 of Figure 11). This network type is also used as a lifting system for a thick wing. Here the network is placed on the camber surface in the same fashion as for a thin wing. However, Source/Analysis (NT = 1) networks are then added to form the upper and lower wing surfaces.

The singularity parameter and control point locations for the Doublet/Analysis networks are illustrated in Figure 13.

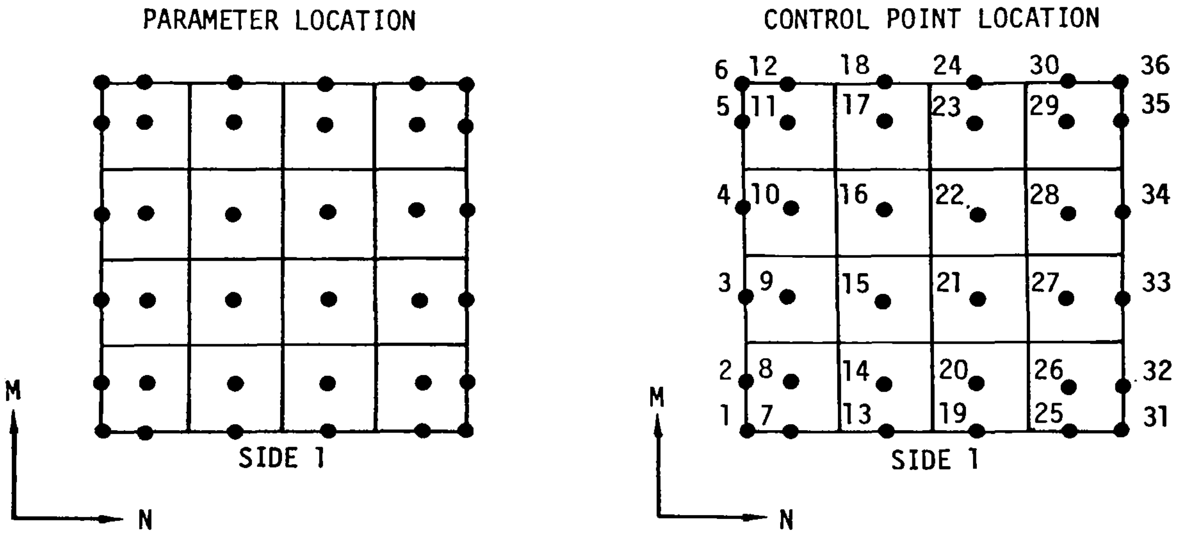


FIGURE 13 PARAMETER AND CONTROL POINT LOCATION
DOUBLET/ANALYSIS NETWORK (NT = 2)

NT = 4: Doublet/Design #1 Network

This network is used as a free sheet, that is, a sheet which has $\Delta Cp = 0$ boundary conditions and is updated to be a stream surface. (Cp here is calculated using the second order formula, equation 18, section 6.2.2.) See networks 14 and 16 of Figure 11 as examples. These examples illustrate two important rules concerning the corner point input of a free sheet network. First, the apex or collapsed side of a free sheet must be side 4. Secondly, the side adjoining the wing (or adjoining another free sheet attached to the wing) must be side 1.

The singularity parameter and control point locations for the Doublet/Design #1 network are illustrated in Figure 14.

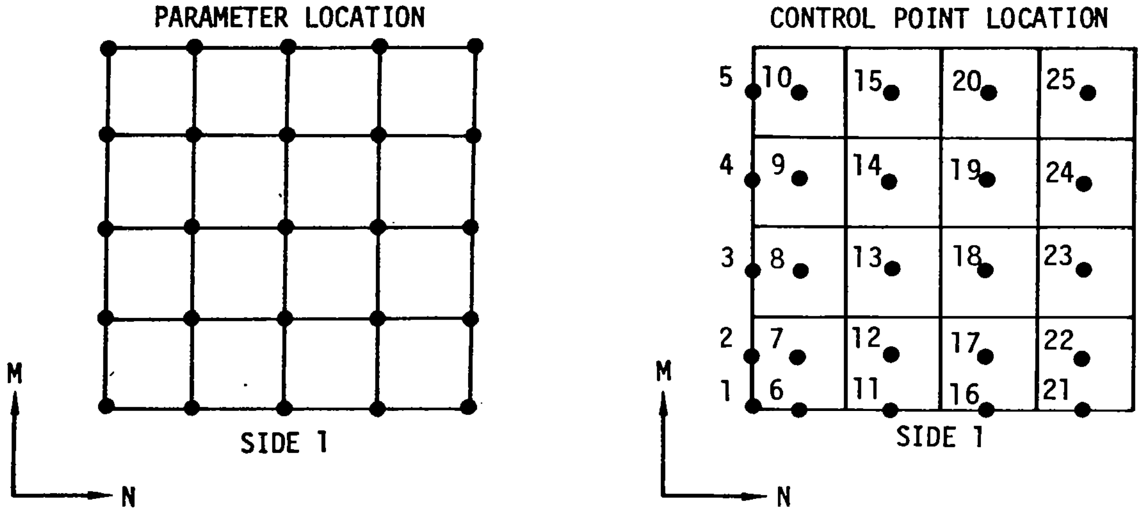


FIGURE 14 PARAMETER AND CONTROL POINT LOCATION DOUBLET/DESIGN #1 NETWORK (NT = 4)

NT = 6: Doublet/Design #2 Network

This network is used for a wake in place of a type NT = 8 network when the approximation of the linearized pressure formulas is deemed insufficient (see discussion in section 7.1.1, Vol. 1). The boundary condition $\Delta Cp = 0$ (where Cp is calculated using the second order formula, equation 18, section 6.2.2), is applied on each panel. In contrast to the type NT = 4 network, this network must remain fixed. See network 12 of Figure 11 as an examaple. If an additional wake is attached to a type 6 network as in Figure 11, the wake should adjoin side 3 of the type 6 network.

The singularity parameters and control point locations for the Doublet/Design #2 network are illustrated in Figure 15.

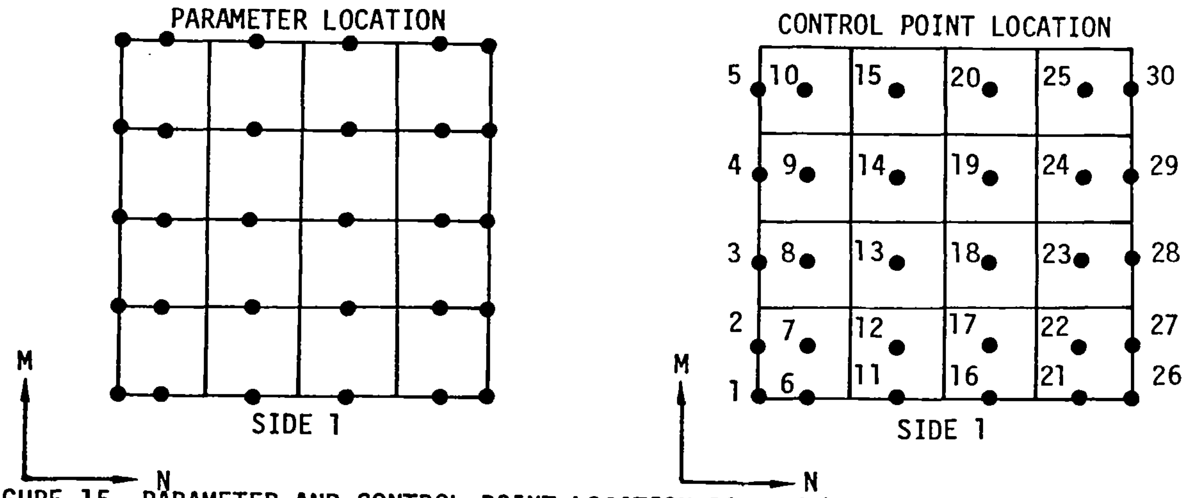


FIGURE 15 PARAMETER AND CONTROL POINT LOCATION DOUBLET/DESIGN #2 NETWORK (NT = 6)

NT = 8: Doublet/Wake #1 Network

This network is used as a wake behind a wing. It satisfies a built-in boundary condition, namely that $\Delta Cp = 0$, (where Cp is calculated using the linearized pressure formula equation 16, section 6.2.2). This is achieved by making doublet strength constant along columns (which are presumed to be in the stream direction). See network 13 of Figure 11 as examples. One rule concerning corner point inputs for an NT = 8 network is that side 1 must always be placed next to the wing or near wake trailing edge.

A type 8 network is also used as a carry-over lifting system which extends the wing lifting system into the body (see networks 9 and 10 in Figure 11). For this purpose the type 8 network is turned sideways. Note that side 1 must adjoin the wing lifting system root edge.

The singularity parameters and control point locations for the Doublet/Wake #1 networks are illustrated in Figure 16.

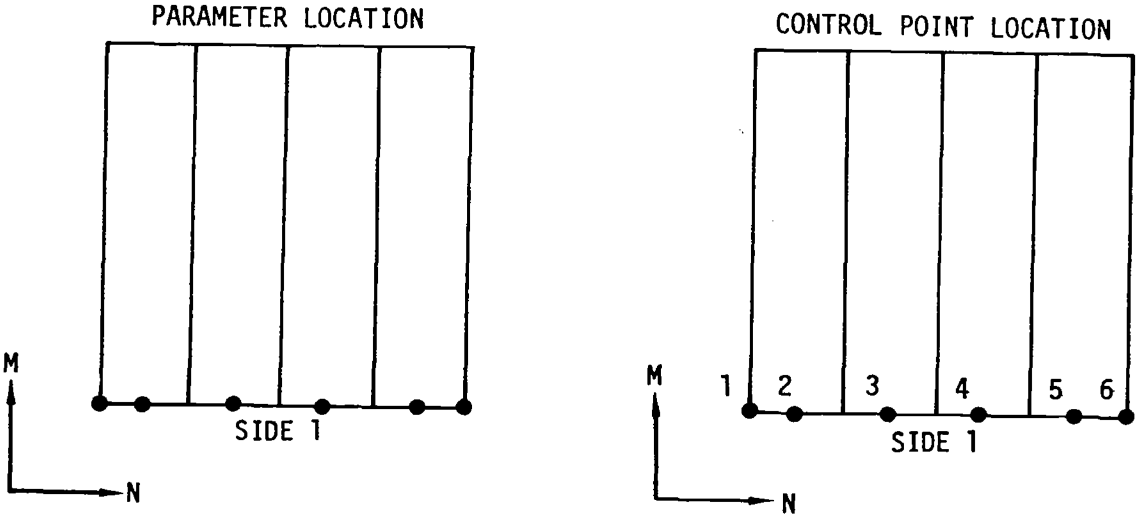


FIGURE 16 PARAMETER AND CONTROL POINT LOCATION
DOUBLET/WAKE #1 NETWORK (NT = 8)

NT = 10: Doublet/Wake #4 Network

This network is used as a wake behind a carry-over lifting system or a fed sheet. It has constant doublet strength and therefore, carries no shed vorticity. As examples see networks 11 and 19 of Figure 11. Note that side 1 is always placed next to the carry-over lifting system or fed sheet trailing edge.

The singularity parameter and control point locations for the Doublet/Wake #4 network are illustrated in Figure 17.

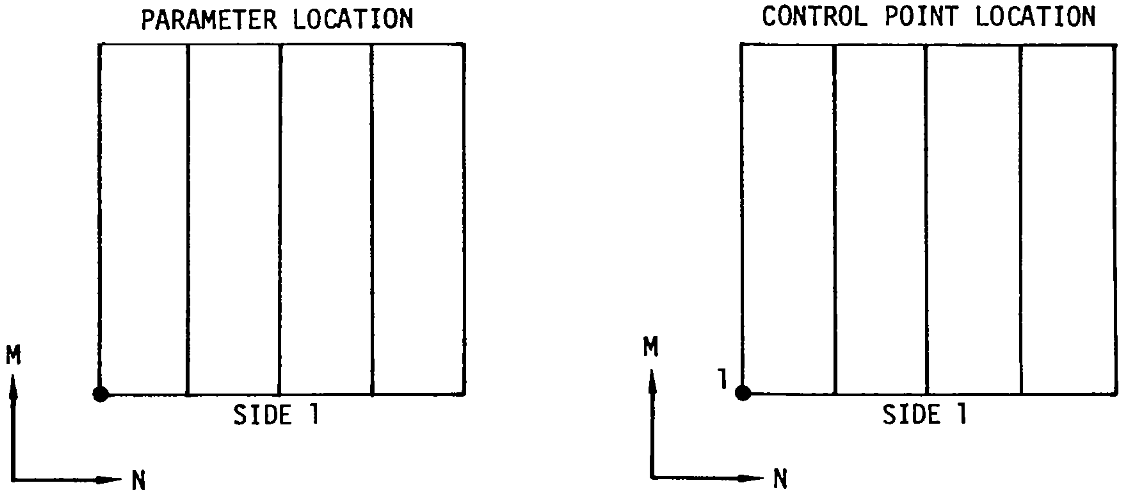


FIGURE 17 PARAMETER AND CONTROL POINT LOCATION

DOUBLET/WAKE # 4 NETWORK (NT = 10)

NT = 14: Fed Sheet Network (Doublet/Wake # 2)

This network is of the same basic construction as the type NT = 8 network but has special panel center and terminated edge velocity evaluation points for the calculation of the total force on the network. See networks 15 amd 17 of Figure 11 as an example. Note that side 1 must adjoin the free sheet.

The singularity parameters and control point locations for the Fed Sheet network are illustrated in Figure 18.

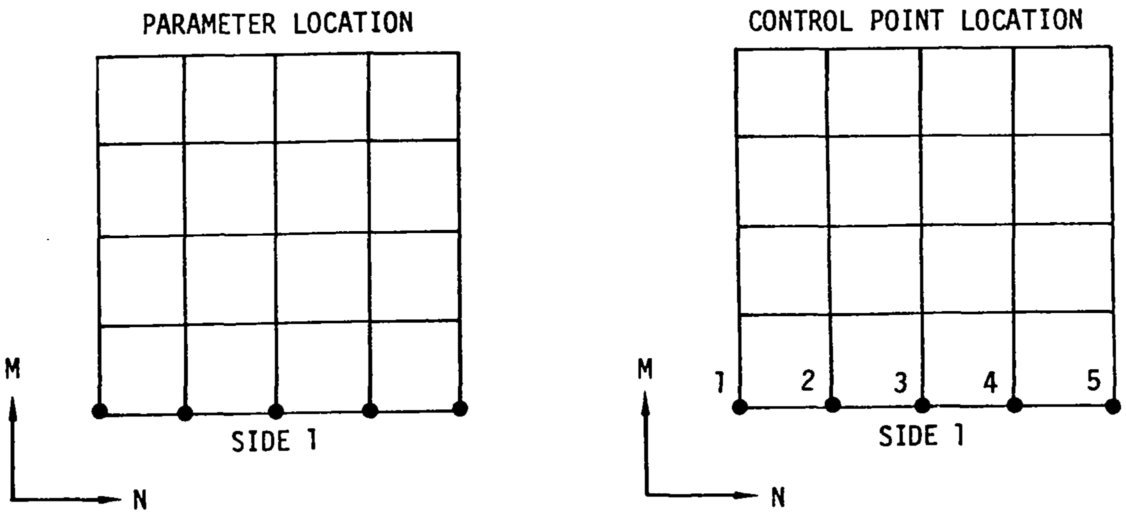


FIGURE 18 PARAMETER AND CONTROL POINT LOCATION
DOUBLET/WAKE #2 NETWORK (NT = 14)

NT = 16: Doublet/Wake #3 Network

This network is used as a wake behind a free sheet. It is just like a Doublet/Wake #1 network (type 8) except that its degrees of freedom are associated with its edge corner points so that it can be used behind a free sheet. It satisfies a built-in boundary condition, namely that Δ Cp = 0 (where Cp is calculated using the linearized pressure formula, equation 16). This is achieved by making doublet strength constant along columns (which are presumed to be in the stream direction). See network #18 of Figure 11 as an example. Note that side 1 is always placed next to the free sheet trailing edge.

The singularity parameter and control point locations for the Doublet/Wake #3 networks are illustrated in Figure 19.

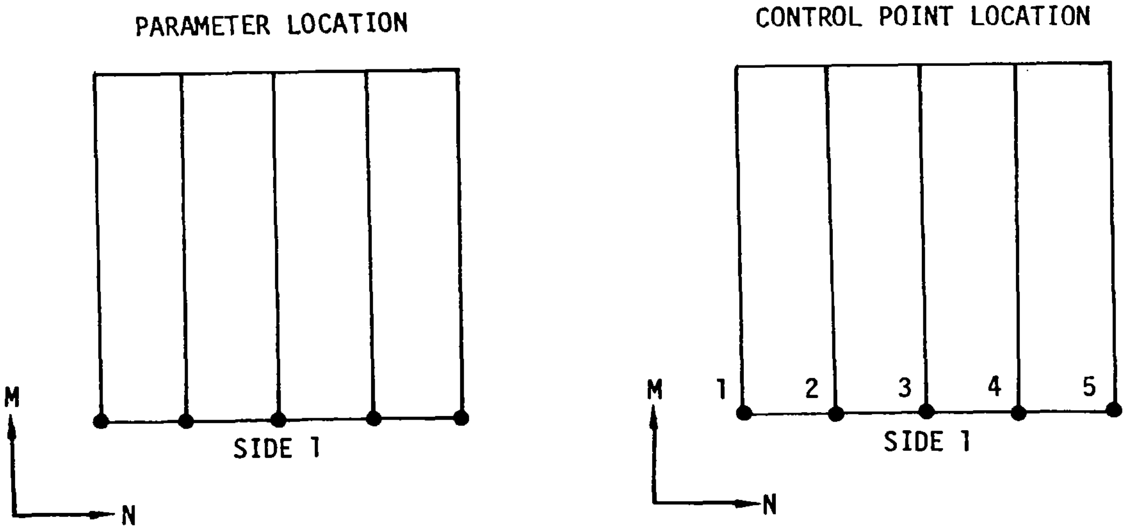


FIGURE 19 PARAMETER AND CONTROL POINT LOCATION

DOUBLET/WAKE #3 NETWORK (NT = 16)

5.2.5 Network Geometry Preprocessors

In order to facilitate the definition of the various networks in the program input several geometry data preprocessors have been included in the code. These preprocessors will greatly simplify the user's task by generating the network grid point geometry for most cases. A preprocessor option ($POINTS) is also included to allow completely general grid point definition by some outside source. The following preprocessors are available within the code.

$POINTS
$QUADRILATERAL
$GOTHIC
$TRAILING WAKE
$VORTEX

In addition, a sixth preprocesor called $CAMBERED WING is also available for use with $QUADRILATERAL or $GOTHIC for the simplified input of cambered or twisted surfaces.

A description and discussion of the various preprocessors follows.

$POINTS - This option allows the input of a user defined array of XYZ points in 6E10.0 format. It can be used to define any type of network and is the most general input for planform and camber shapes. The input formats for $POINTS are given in section 5.5. Users may find some difficulty in obtaining proper abutments between networks defined using $POINTS and networks defined using $GOTHIC or $QUADRILATERAL. This may occur because of the requirement for adjacent grid points across abutments being identical not being met. The abutments may appear identical in the program printout but it must be realized that the grid point coordinates calculated by $GOTHIC or $QUADRILATERAL may have more significant figures than shown in the output format. In such cases it may be convenient to dispose the network geometry (which is saved on TAPE14) as punch card output, and reinput the networks using $POINTS.

$QUADRILATERAL - This option allows the definition of a network by specifying the network corner points and the internal percentage arrays to define the paneling distribution. This option is useful in defining simple wing planforms and design wakes. The input formats for $QUADRILATERAL are given in section 5.5. $CAMBERED WING may be used with this option to define a camber and a twist for the network. $QUADRILATERAL may be used to generate any type network.

$GOTHIC - This option allows the definition of a network with a straight or curved edge. A longitudinal array of XYZ points is input which defines both the edge geometry and the longitudinal panel spacing. A percentage array defines a lateral panel spacing. The input formats for $GOTHIC are given in section 5.5. $CAMBERED WING may be used with this option to define a camber and twist for the network. $GOTHIC may be used to generate any type network.

$TRAILING WAKE - This option is used to define a simple network paneling which consists of a single row of panels. This network attaches to another specified network edge and extends straight back (parallel to the X-axis) to a specified distance. This option is used exclusively to generate wake networks. The network and edge to which the wake attaches is defined to ensure a proper abutment. The input formats for $TRAILING WAKE are in section 5.5 .

$VORTEX - This option will automatically generate a free and fed sheet network and their associated trailing wakes. The shapes of the free and fed sheet networks are based on Smith's conical results which are discussed in section 5.3. The network edge to which the free sheet attaches is defined to assure proper edge abutment. More than one set of free and fed sheet networks may be specified in tandem in order to satisfy the edge abutment constraints when more than one network has been used to define the wing. This option may only be used to define free (NT=4) and fed (NT=14) sheet (and associated wake) networks. The input formats for $VORTEX are given in section 5.5.

$CAMBERED WING - This option is used in conjunction with $GOTHIC or $QUADRILATERAL to generate network goemetry for cambered or twisted surfaces. Camber lines can be defined independent of the network arrays to define a 3-D cambered surface. Linear spanwise interpolation is used to generate the cambered surface at the network grid points.

$CAMBERED WING can also be used to generate conical camber of the form used by Wentz (ref. 5) or conical camber where the wing is a portion of a circular arc.

5.3 Starting Solution

The iterative process used in the solution of the leading edge vortex problem required an initial guess for the free and fed sheet goemetry. A reasonable guess may be based on the conical solution of Smith (ref. 3). Smith's results are reproduced in Figure 20, which shows the shape of the free sheet and the size of the fed sheet for various values of the parameter "a". This parameter is defined as

$$a = \frac{\alpha}{\tan \gamma} \tag{14}$$

where α denotes the angle of attack in radians and γ is one-half of the apex angle of a delta wing. The sheet geometries of Figure 20 represent

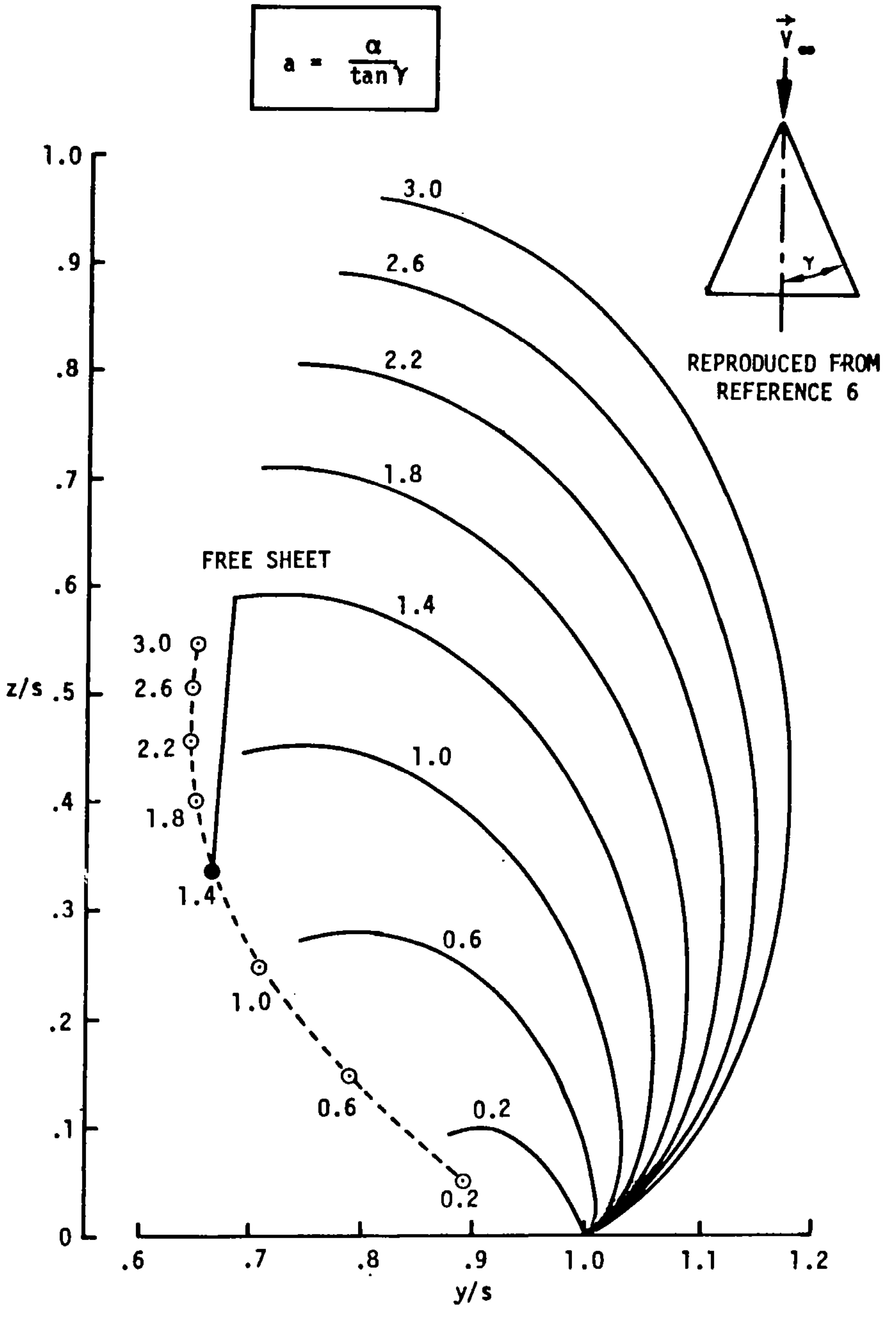


FIGURE 20 INITIAL FREE-SHEET GEOMETRY AND SIZE OF FED SHEET FOR VARIOUS 'a'

transverse cuts through the configuration normal to the wing surface. The y,z-coordinates are nondimensionalized by the wing semispan s. The locations of the line vortex along the terminated edge of the fed sheet are given for several values of a ($0.2 \leq a \leq 3.0$) and are connected by a dashline. The straight line between the last point on the free sheet and the line vortex is the trace of the fed sheet. An example is shown for "a" = 1.4.

Smith's results are available within the LEV program through a network preprocessor called $VORTEX. Here Smith's solution in tabulated form is used to form the network goemetry for the initial guess on the free and fed sheet shape. Figure 21 illustrates how an initial free-sheet geometry is obtained for a nonconical wing geometry. For this purpose the assumption is made that initially the shape of the free sheet at a particular chordwise station is the same as that of a certain delta wing. This delta wing is locally equivalent to the considered nonconical wing geometry and is defined as a wing that has the same apex position and the same local semispan at that chordwise station where the initial free-sheet geometry is to be computed. Thus, the parameter a can be calculated at each transverse cut for a given angle of attack and a given angle γ = arc tan (s/x). Linear interpolation of Smith's data provides the desired initial free-sheet geometry for a chosen number of free-sheet panels. All free-sheet segments of a transverse cut (y,z-plane) have approximately the same chord length.

The described procedure also provides the size of the fed sheet at all geometry defining transverse cuts. During the iteration process the shape of the free and fed sheet may change dramatically as shown in Figure 22. Here a transverse cut through the free and fed sheet at the trailing edge of an aspect ratio 2.0 delta wing is shown. The initial guess is generated by the $VORTEX preprocessor based on Smith's conical solution. The converged position shows considerable growth of the free and fed sheet.

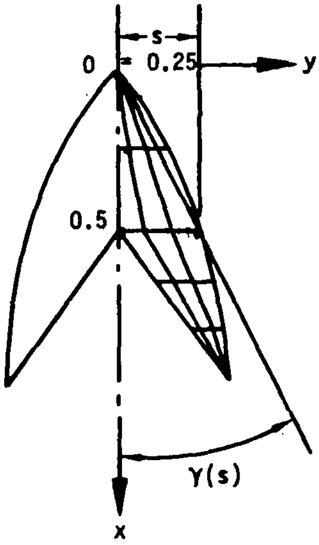
It should be emphasized that Smith's conical data provide only the initial free-sheet geometry. This is a convenient choice and a good guess for wing geometries that are not too different from flat delta wings. The computed doublet distributions and the sheet geometries computed in subsequent cycles of the iteration procedure are, in general, not conical.

The choice of initial and fed sheet shape is in general not critical to the converged solution. However, the choice will affect the number of iterations necessary for a solution to achieve convergence and may preclude convergence in some cases. Figure 23 illustrates a case in which an asymmetric initial guess was used. Eight iterations later, the solution had converged to a symmetric solution.

Initial guesses other than those based on the Smith's results can be used. The most general option available is the use of the $POINTS preprocessor. $POINTS allow a network definition by xyz panel corner points, which gives the user complete freedom in specifying free and fed sheet shape. Sometimes it is desirable only to grow the Smith guess in order to increase the clearance between the fed sheet termination and the

$x = 0.50,\ s = 0.25,\ \alpha = 0.25 \approx 14.3^\circ$

NONCONICAL WING GEOMETRY



INTERPOLATION OF TABULATED DATA

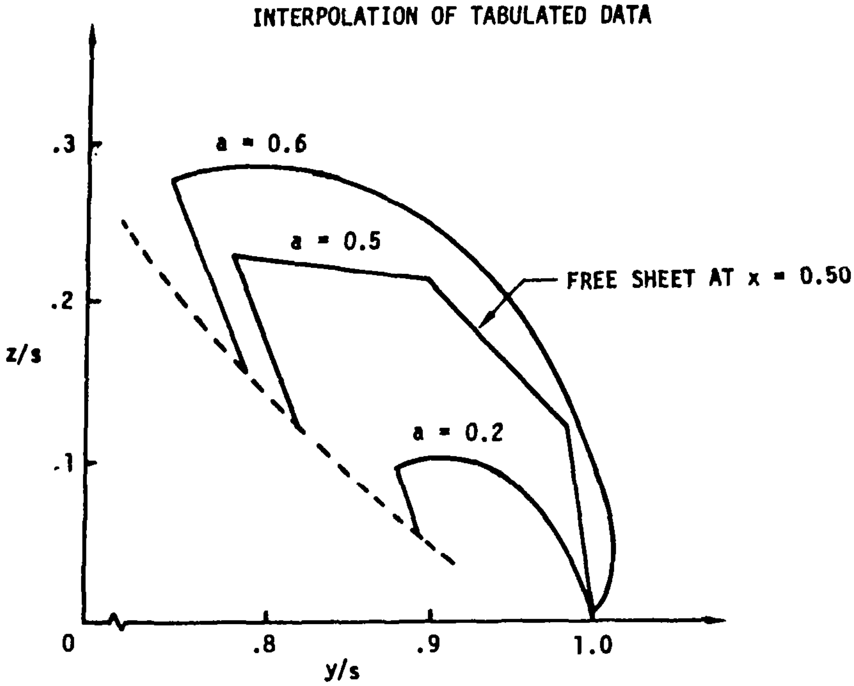


FIGURE 21 SELECTION OF INITIAL GEOMETRY

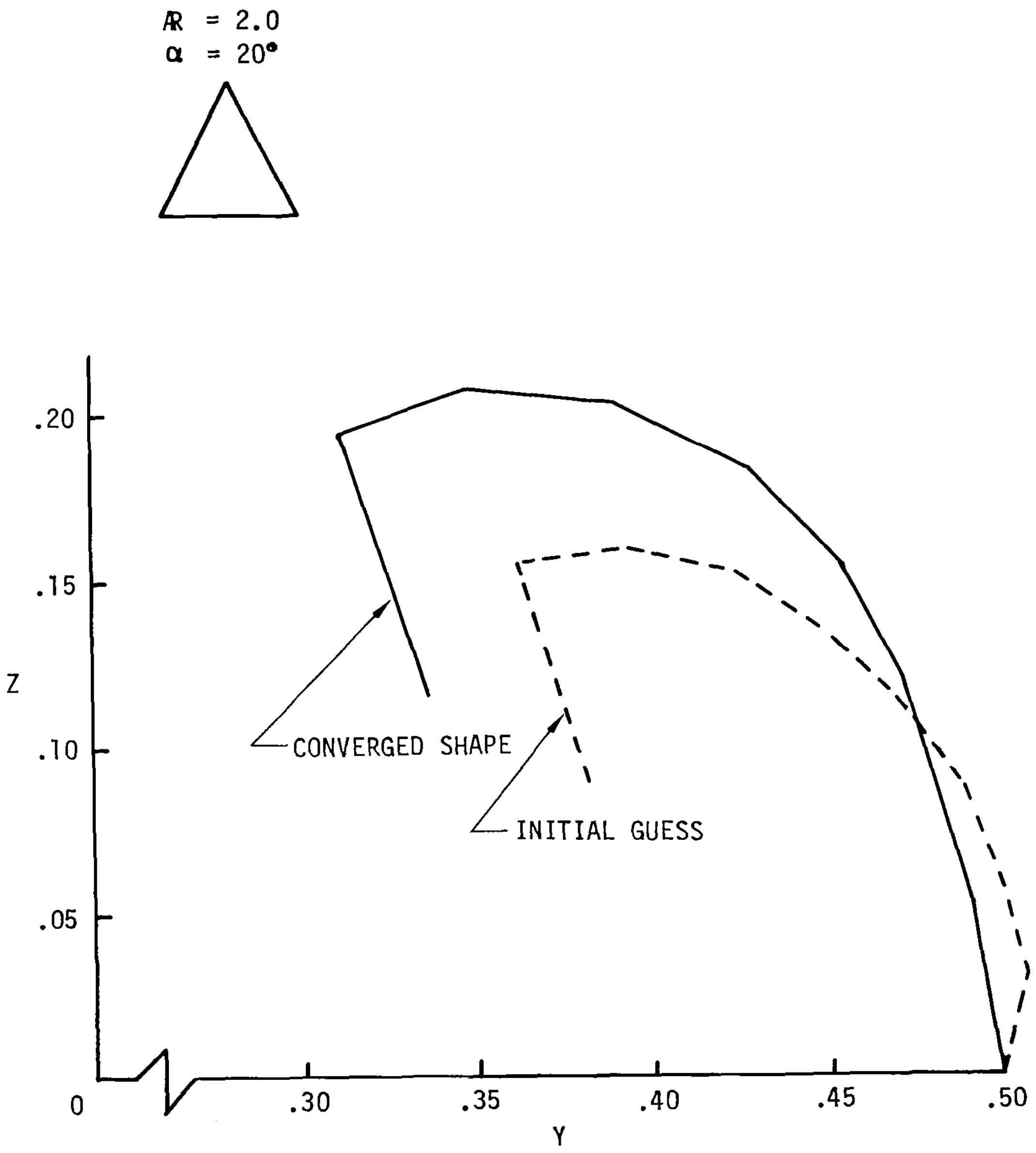
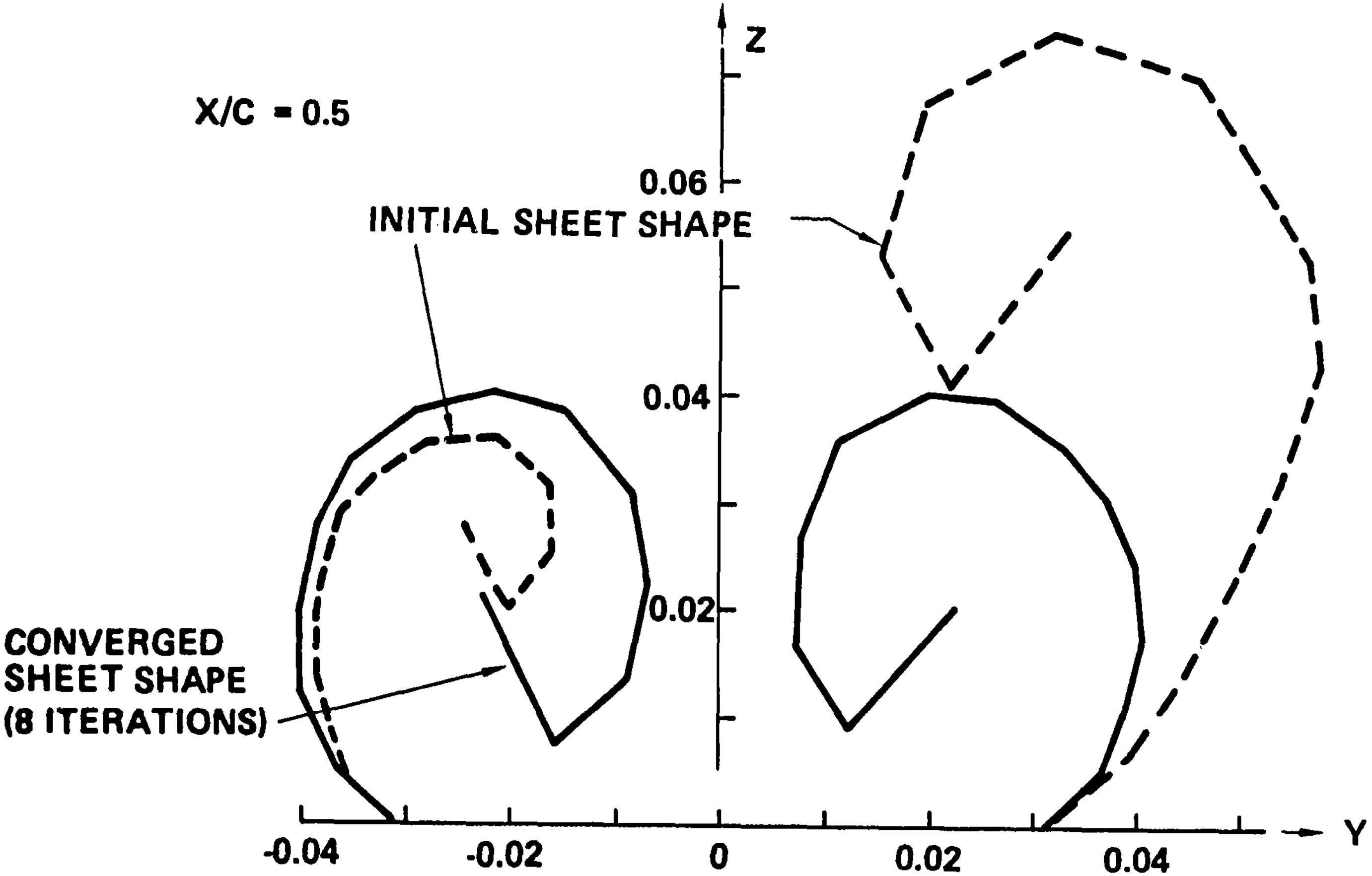


FIGURE 22 FREE AND FED SHEET SHAPE



a. VORTEX SYSTEM GEOMETRY

FIGURE 23 ASYMMETRIC INITIAL SHEET SHAPE wing surface (i.e., on a highly cambered wing). This may be accomplished within the $VORTEX preprocessor by use of the APC parameter on card V5. APC is an increment to the "a" parameter of equation 14. A positive value for APC will result in a larger free and fed sheet. In general it is easier for a large free sheet/fed sheet to contract to a converged position than for a small initial guess to grow into a converged position.

5.4 Example Network Arrangements

A series of examples illustrating the proper network arrangement for various configurations are presented. The purpose of these examples is to aid the user in the proper use and placement of the various types of network in formulating a flow model. These examples do not necessarily represent the only possible modeling for the various configurations. In explaining these various network arrangements it is of particular importance to note the network orientation. For those network for which the orientation is important, network side number one has been identified along with its M and N vector orientation.

5.4.1 Delta Wing Without Near Wake

A delta wing without a near wake is about the simplest model for which a leading edge solution can be obtained. This model is in general not a good model because of the inadequacy of the doublet/wake 1 (NT=8) network in satisfying the Kutta condition (see section 7.1, Vol. 1 - Theory Document). Its use, if at all, should be limited to delta wings of aspect ratio less than 1.0 and angles of attack greater than 15 .

The network formulation schematically is shown in Figure 24 with the vortex system rolled out flat in the plane of the wing. The flow model is made up of: 1, a doublet/analysis (NT=2) network for the wing; 2, a doublet/wake #1 (NT=8) network for the wake from the wing; 3, a doublet/design #1 (NT=4) network for the free sheet; 4, a doublet/design #3 (NT=14) network for the fed sheet; 5, a doublet/wake #4 (NT=16) network for the wake from the free sheet; and 6, a doublet/wake# 2 (NT=10) network for the network for the wake from the fed sheet.

In setting up this model $POINTS, $QUADRILATERAL, or $GOTHIC could be used to define the wing network, $TRAILING WAKE to define the wake from the wing network and $VORTEX to define the remaining four networks representing the free and fed sheets and their associated wakes.

5.4.2 Delta Wing With Near Wake

This is the recommended model for most wing planforms. The network arrangement is shown in Figure 25. The near wake is actually a doublet/design #2 (NT=6) network, which satisfies the boundary condition $\Delta Cp = 0$ where Cp is calculated using the second order formula, equation 17, section 6.2.2. Unlike the simpler doublet/wake #1 (NT=8) network which only satisfies the linear $\Delta Cp = 0$ boundary condition, the design wake network accommodates a spanwise shedding of vorticity at the trailing edge which is necessary to properly satisfy the Kutta condition.

NETWORK	TYPE	USE
1	NT = 2	WING
2	8	WAKE
3	4	FREE SHEET
4	14	FED SHEET
5	16	FREE SHEET WAKE
6	10	FED SHEET WAKE

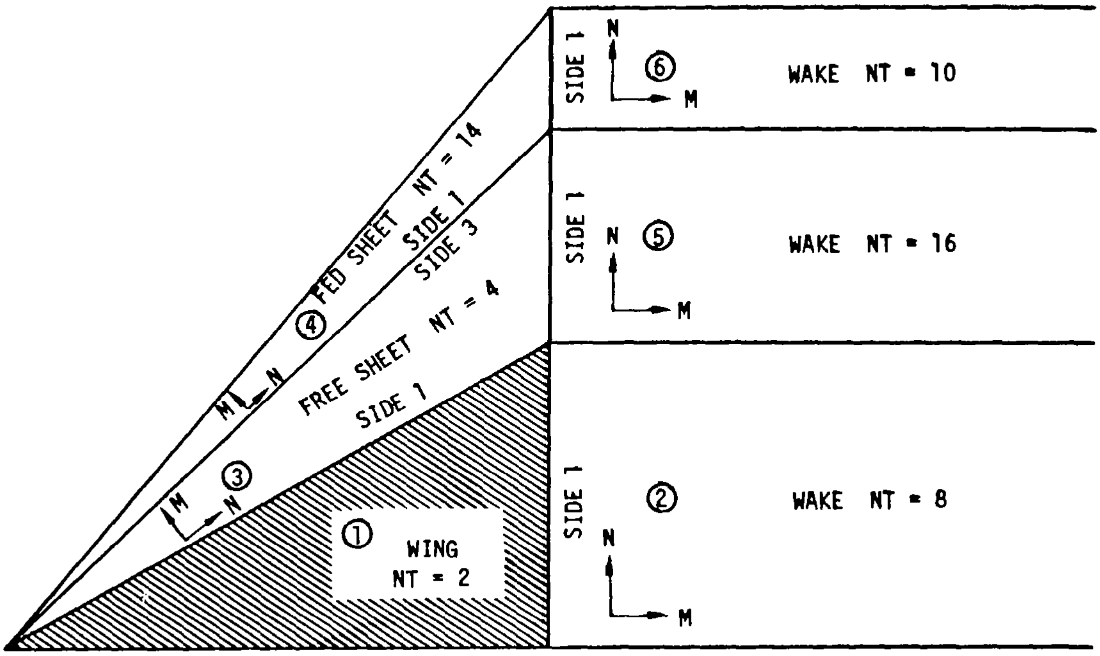


FIGURE 24 DELTA WING NETWORK ARRANGEMENT

NETWORK	TYPE	USE
1	NT = 2	WING
2	6	NEAR WAKE
3	8	WAKE
4	4	FREE SHEET
5	14	FED SHEET
6	4	FREE SHEET
7	14	FED SHEET
8	16	FREE SHEET WAKE
9	10	FED SHEET WAKE

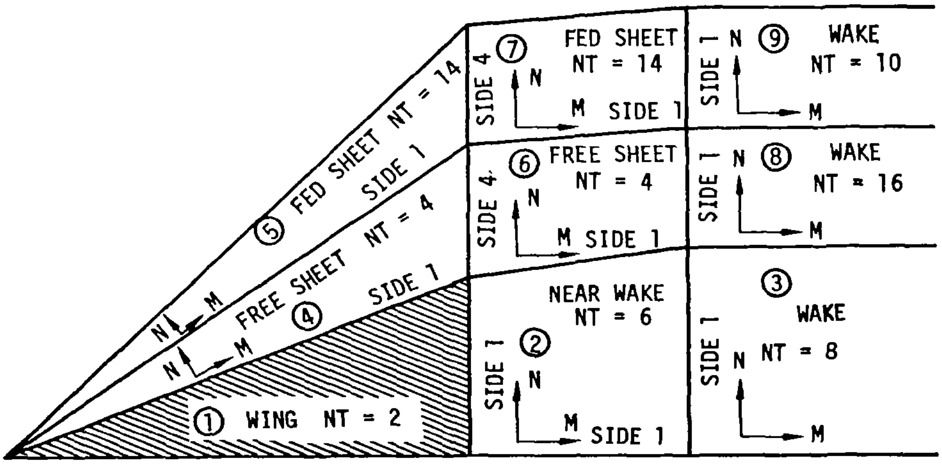


FIGURE 25 DELTA WING WITH NEAR WAKE NETWORK ARRANGEMENT

Studies (Section 7.1.1, Vol. I - Theory Document) have shown that the design wake can be as short as 0.1 root chords and only two rows of panels deep (in the x-direction). The planform may correspond to a simple extension of the wing planform or may increase the sweep of the edge from which the free sheet abuts. It is not recommended that the free sheet edge become parallel to the x-axis as this can make convergence more difficult. The free and fed sheets must extend to the end of the near wake. Because of the requirement that abutments occur along complete network edges it is necessary to split the free and fed sheets into two segments as shown in Figure 25.

$POINTS, $QUADRILATERAL, or $GOTHIC may be used to generate the wing and near wake geometry. $TRAILING WAKE will take care of the wake network number 3 in the example. $VORTEX can be used to generate the remaining networks, numbers 4, 5, 6, 7, 8 and 9. Two calls to $VORTEX will be necessary to generate the six networks. First, networks 4 and 5 will be generated without trailing wakes (KW=0, Card V2). Then networks 6, 7, 8 and 9 can be generated. NATF (Card V4) will assure connection of networks 6 and 7 to networks 4 and 5. JNAT (Card V5) will be referenced to the vortex apex network (Network 4) to assure a proper starting solution.

5.4.3 Arrow Wing

A network arrangement for an arrow wing planform is shown in Figure 26. The need to split the wing, free and fed sheets into two networks depends on the type of paneling used to define the wing. If a conical type paneling (see Figure 9, example 2) is used, then the split in the wing, free, and fed sheets is necessary as shown in Figure 26 and is due to the constraint that networks abut along entire edges (section 5.2.3). If a steamwise paneling scheme (see Figure 9, example 1) is used then the wing and free and fed sheets could be single networks.

5.4.4 Rectangular Wing

A network arrangement for a rectangular wing is illustrated on Figure 27. Limited studies (section 7.2 - Vol. I - Theory Document) have not indicated a need for a design wake on rectangular wings. Some problems have been encountered with the convergence on rectangular wings associated with the starting solution generated by $VORTEX when APC=0. (card V5). Setting APC = 0.5 to 1.0 helped to avoid the convergence problems.

5.4.5 Wing With Cropped Tip

Figure 28 shows a network arrangement for a wing with a cropped wing tip. The presence of the tip does not by itself introduce any new network arrangement procedures. The arrangement shown assumes that the tip has been defined as part of the leading edge so that the leading edge and the tip together form only one edge. Conical type paneling would then be necessary and could be defined by use of $GOTHIC. Planforms with tips cropped parallel to the x-axis have experienced convergence difficulty using the standard ITFLOW iteration procedure, necessitating use of the more expensive LSFLOW procedure.

NETWORK	TYPE	USE
1	NT = 2	WING
2	2	WING
3	4	FREE SHEET
4	14	FED SHEET
5	4	FREE SHEET
6	14	FED SHEET
7	16	FREE SHEET WAKE
8	10	FED SHEET WAKE
9	6	NEAR WAKE
10	18	WAKE

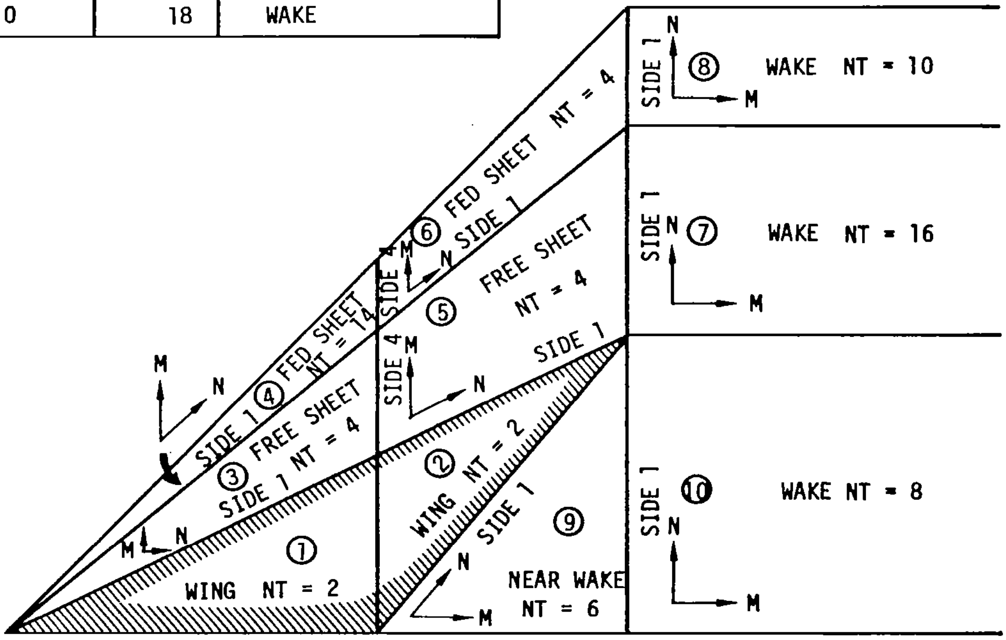


FIGURE 26 ARROW WING NETWORK ARRANGEMENT

NETWORK	TYPE	USE
1	NT = 2	WING
2	8	WAKE
3	4	FREE SHEET
4	14	FED SHEET
5	16	FREE SHEET WAKE
6	10	FED SHEET WAKE

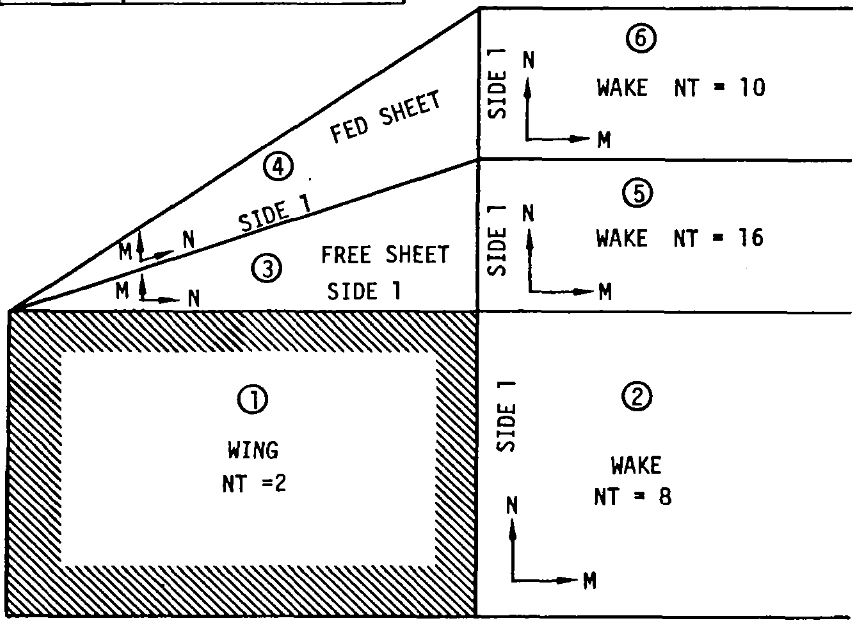


FIGURE 27 RECTANGULAR WING NETWORK ARRANGEMENT

NETWORK	TYPE	USE
1	NT = 2	WING
2	6	NEAR WAKE
3	8	WAKE
4	4	FREE SHEET
5	14	FED SHEET
6	4	FREE SHEET
7	14	FED SHEET
8	16	FREE SHEET WAKE
9	10	FREE SHEET WAKE

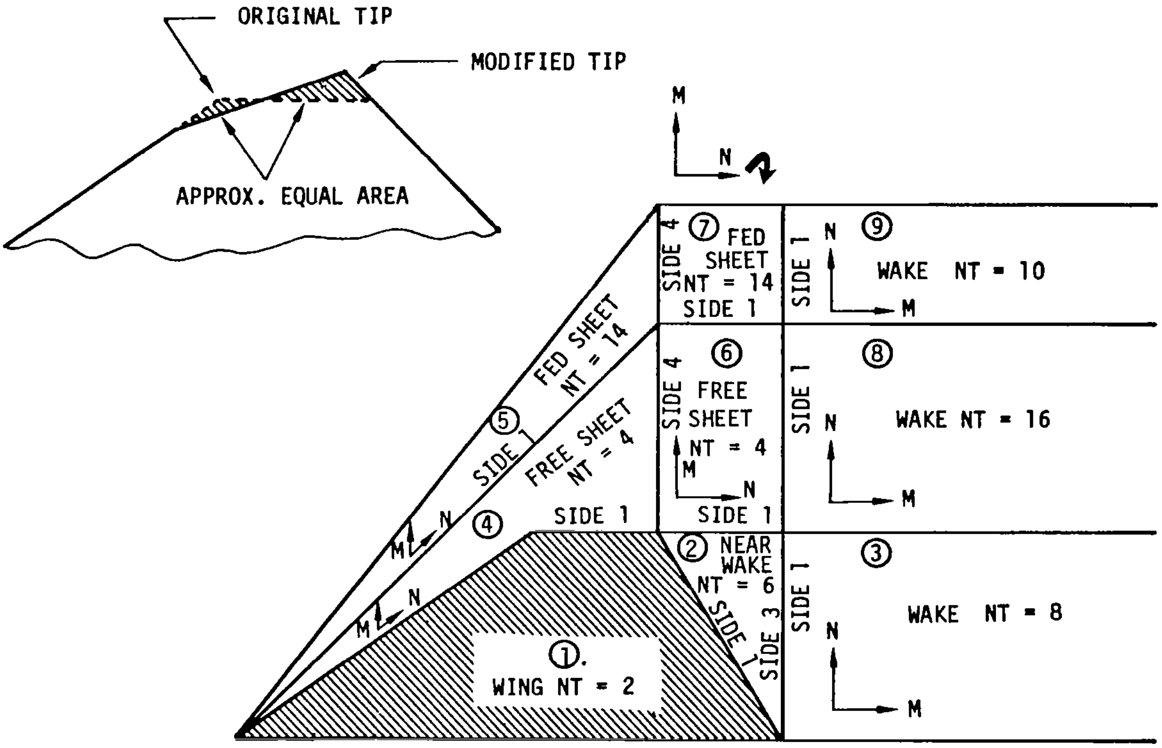


FIGURE 28 WING WITH CROPPED TIP NETWORK ARRANGEMENT

A simple gambit which tends to alleviate the convergence problems is to modify the tip as shown in Figure 28. Instead of a tip with an edge parallel to the x-axis, the tip is modified to have a high sweep but still retain the same planform area.

5.4.6 Asymmetric or Yaw Configurations

The network arrangements for the preceding configuration all assumed a plane of symmetry and therefore zero yaw. The paneling arrangement for an asymmetric configuration or configuration at yaw demands that the entire (both sides) configuration be represented. Such an arrangement is illustrated in Figure 29, NSYMM (Card 9) must be set equal to zero. The wing may be represented by one of two networks split along the x-axis. When two networks are used for the wing, care must be taken to keep the upward sense (NxM) of the networks the same.

5.4.7 Wing Body Configuration

A network arrangement for a wing-body configuration has already been shown in Figure 11. This figure was used as an example to discuss the various network types and their uses in section 5.2.3. Table 2 summarizes the use of the various networks. One alternative possible over what is shown in Figure 11 is to combine all the source networks (1-6) into one network. Source networks are exempt from the edge matching requirements of the doublet networks.

5.5 Input Format Specifications

The input data sequence is illustrated in Figure 30. The data sequences consists of several cards defining the flow conditions, configuration reference values, program execution mode, etc. These are followed by a series of network data blocks which define the flow model. A network data block consists of any one of several data preprocessors such as $POINTS, $QUADRILATERAL, $GOTHIC, $TRAILING WAKE, and $VORTEX. Two of these preprocessors can also include a call to $CAMBERED WING for simplified input of camber surfaces.

Program size limitations have been summarized in Table 1. A summary of the various types of networks and their uses is given in Table 3.

All numerical inputs are read in 6E10.0 floating point format. Some input variables are named in traditional integer format. These designations are internal designations and the data should be input as a floating point number. All literal words are read in A4 format. Only the first four characters need be input. A description of the data input follows.

NETWORK	TYPE	USE
1	NT = 2	WING
2	8	WAKE
3	4	FREE SHEET
4	14	FED SHEET
5	16	FREE SHEET WAKE
6	10	FED SHEET WAKE
7	4	FREE SHEET
8	14	FED SHEET
9	16	FREE SHEET WAKE
10	10	FED SHEET WAKE

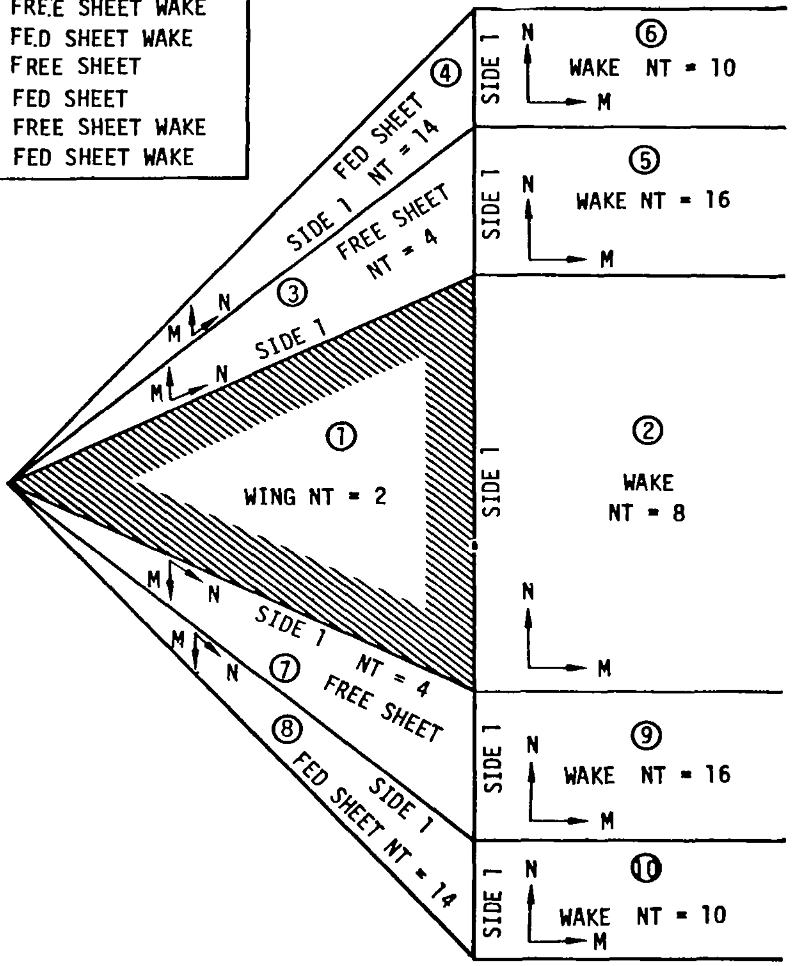


FIGURE 29 ASYMMETRIC OR YAW CONFIGURATION NETWORK ARRANGEMENT

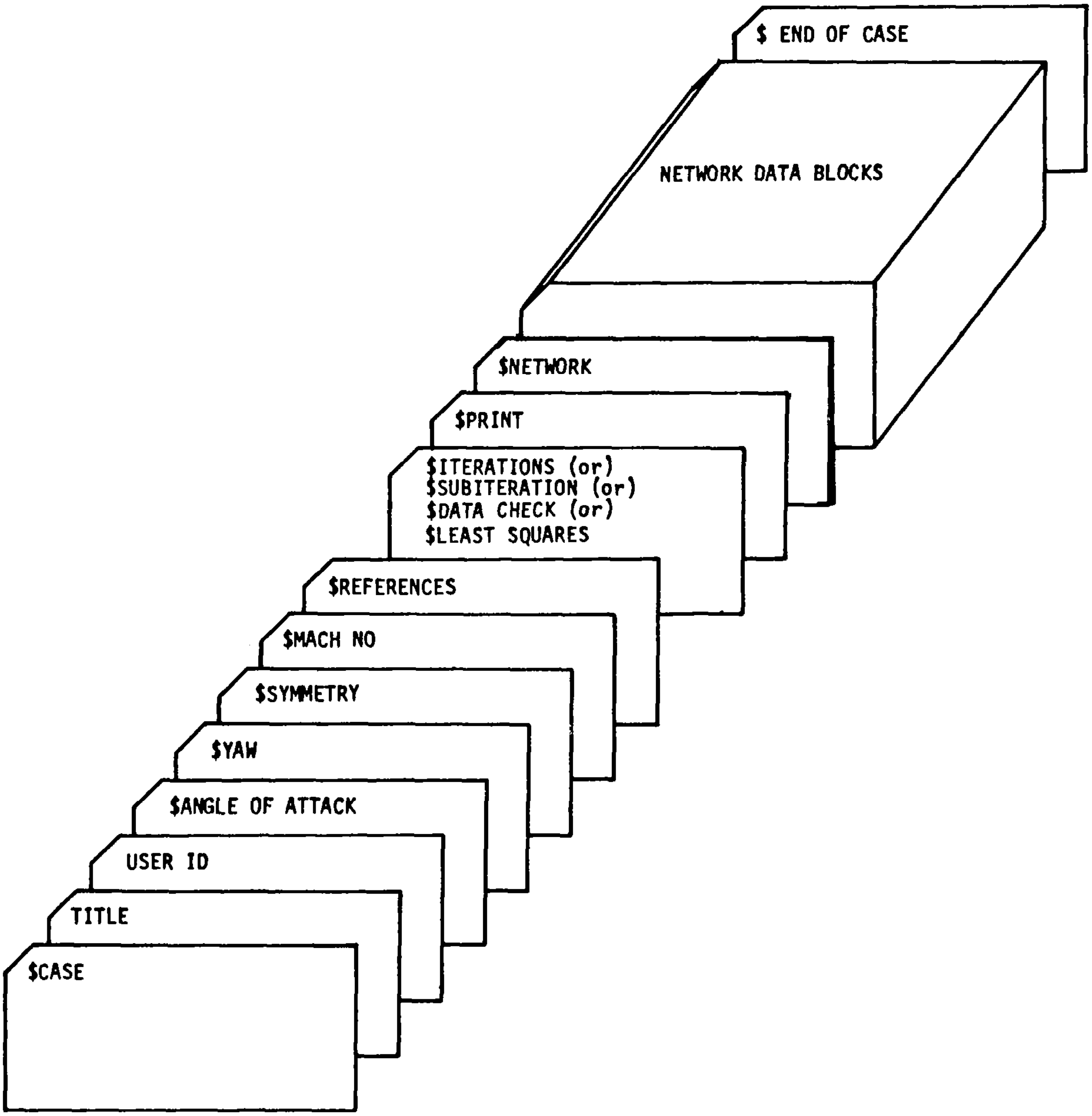


FIGURE 30 INPUT DATA SEQUENCE

PROGRAM SIZE RESTRICTIONS
TABLE 1

Restriction on total number of networks

$NNETT \leq 20$

Restrictions for Quasi-Newton Scheme, ITFLOW

NF (No. of singularity strength parameters) $\leq$ 750

NG (No. of free sheet panels) $\leq$ 300

= No. of panel orientation angles

NH (No. of fed sheet panels) $\leq$ 50

= No. of geometry parameters

$NF + NG + NH \leq 500$

Restrictions for Least Squares Method, LSFLOW

$NF \leq 400$

$NG + NH \leq 80$

$NG + NH + NK \leq 144$

Where NK (=NG) is the number of twist function equations

$NF + NG + NH \leq 480$

NETWORK TYPES AND THEIR USES
TABLE 3

	Type	Common Use
NT = 1	Source/Analysis	Exterior surface of thick wings and bodies
NT = 2	Doublet/Analysis	Camber surface of wing
NT = 4	Doublet/Design #1	Free sheet
NT = 6	Doublet/Design #2	Near Wake
NT = 8	Doublet/Wake #1	Simple wake or carry over lifting system
NT = 10	Doublet/Wake #4	Wake behind carry over lifting system or fed sheet
NT = 14	Doublet/Wake #2	Fed sheet
NT = 16	Doublet/Wake #3	Wake behind free sheet

Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
1			$CASE
2	1-80		Title information
3	1-80		User information
4			$ANGLE OF ATTACK
5	1-10	ALPHA	Angle of attack in degrees
6			$YAW ANGLE
7	1-10	BETA	Yaw angle in degrees; if NSYMM = 0. both sides of the configuration must be defined
8			$SYMMETRY
9	1-10	NSYMM	1. for symmetry about X-Z plane; 0. otherwise
10			$MACH NUMBER
11	1-10	AMACH	Mach number; must be less than 1.0
12			$REFERENCES
13	1-10 11-20 21-30	XREF, YREF, ZREF	XREF, YREF, ZREF are the x,y,z coordinates of the moment center.
14	1-10	SREF,	SREF is the configuration area. (Half area if only half is panelled, NSYMM=1.)
	11-20	BREF,	BREF = span reference length
	21-30	CREF,	CREF = chord reference length
	31-40	DREF	DREF = height reference length
15			$ITERATION or $LEAST SQUARES ITERATION or $SUBITERATION or $DATA CHECK

IF $ITERATION or $LEAST SQUARES ITERATION is specified then follow with ITMX on next card

Number	Column	Name	Description/Comment
16	1-10	ITMX	Maximum number of iterations allowed for the iterative procedure. IF ITMX < 0, the program will read corner points and singularity strength parameters data (from previous run) on disk file TAPE14 provided by the user.

IF $ITERATION is specified then the program will use Quasi-Newton scheme to find an iterative solution of the flow problem. A new Jacobian will be computed after every 3 iterations.

Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
			If $LEAST SQUARES ITERATION is specified then the progrm will use Least Squares method to find an iterative solution of the flow problem. A new Jacobian is computed after every 2 iterations. However, if cycle of step size reduction exceeds 3 (see Section 4.3.2), a new Jacobian will also be formed.
			IF $SUBITERATION is specified then program will stop after completing subiteration phase of solution. No ITMX card is required.
			IF $DATA CHECK is specified then program will set up network mesh points only. No ITMX card is required. An output file (TAPE14) with the network mesh points will be created for external graphics. processing. (Also see statement after card 22-END OF CASE).
17	1-10		$PRINT
18	1-10	ITPRIN	Printing output occurs at every ITPRIN iterations.
	11-20	ITVRCP	= 1. for printout of variables, residuals and corrections resulting from full iteration
	21-30	IPLOTP	= 1. for printer plot of cuts of vortex system
	31-40	IPTIME	= 1. for printout of elapsed CPU time from various programs and subroutines
	41-50	IPNPIC	= 1. for printout of near field and far field information
	51-60	IPSOLV	= 1. for printout of out-of-core equations solver information
19	1-10	ISINGS	= 1. for printout of resultant values of singularity strength and gradient at panel corners, centers, and edge midpoints
	11-20	IGEOMP	= 1. for printout of geometry diagnostic data
	21-30	ISINGP	= 1. for printout of singularity spline diagnostic data
	31-40	ICONTP	= 1. for printout of control points diagnostic data
	41-50	IBCONP	= 1. printout of boundary condition diagnostic data (not used)
	51-60	IEDGEP	= 1. for printout of edge matching diagnostic data
20			$NETWORK
21	1-10	NNETT	Total number of networks; each call of $VORTEX counts two or four networks (see $VORTEX), NNETT $\leq$ 20

****

Each network is now defined in turn by a network data block which is headed by one of the preprocessor options

Data Card Variable (Numeric data are input in 6E10.0 format)

Number Column Name Description/Comment

$POINTS
$QUADRILATERAL
$GOTHIC
$VORTEX
$TRAILING WAKE

The sequence in which the networks are to be input into the program is irrelevant except for the following restrictions.

1) The sequence number of the networks must be in proper sequential order.

2) A network which will be updated must be input after a network to which it is attached.

3) Moreover, the data cards ($QUADRILATERAL, $GOTHIC, $POINTS) for setting up wing and/or body networks should precede those ($VORTEX, $TRAILING WAKE, $POINTS) for generating free and fed sheets and the trailing wakes.

****

Input data for the complete case is terminated by the following card

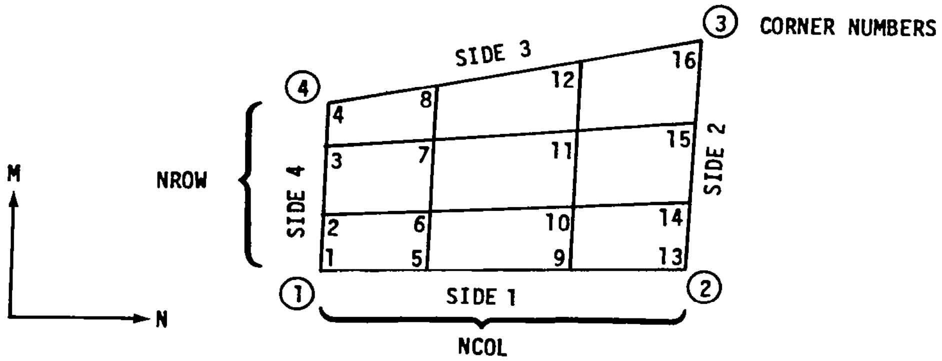
22 $END OF CASE

If $DATA CHECK is used, additional sets of data cases can be input following immediately the $END OF CASE card.

****

P1 $POINTS

An input format for x,y,z coordinates of all corner points of a network is provided for a general cambered wing geometry or any other network such as body, special wake, or vortex sheets.

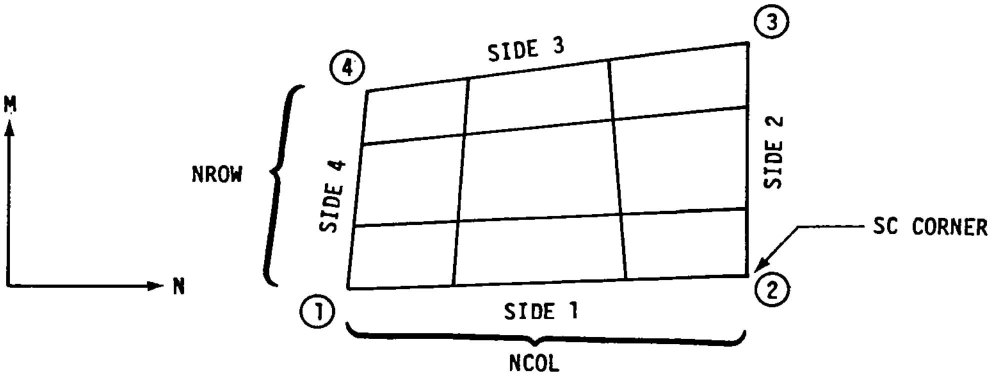


Data Card Variable (Numeric data are input in 6E10.0 format

Number	Column	Name	Description/Comment
P2	1-10	KN	Network no.
	11-20	NT	Type of network
	21-30	NUP	Update index = 0. Fixed network 1. Trailing wake enamating from free or fed sheet 2. Fed sheet 3. Free sheet to which no fed sheet is attached 4. Free sheet to which a fed sheet is attached
P3	1-10 11-20	NROW NCOL	Number of rows and columns of the specified network
P4	1-60	ZM(1,I,J) ZM(2,I,J) ZM(3,I,J) (I=1,NROW)	x,y,z coordinates of corner points input by column (J=1, NCOL). Corner points are input sequentially (see figure above), two points per card and continuous per point column. Start each column on a new card.

****

Number	Column	Name	Description/Comment
Q1	1-4		$QUADRILATERAL This data card calls for using Quadrilateral preprocessor to generate mesh points for a specified network no. with the given four corner points.



Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
Q2	1-10	KN	Network no.
	11-20	NT	Type of network
	21-30	NUP	Update index = 0. Fixed network 1. Trailing wake enanating from free or fed sheet 2. Fed Sheet 3. Free sheet to which no fed sheet is attached 4. Free sheet to which a fed sheet is attached
Q3	1-60	SC(1,J) SC(2,J) SC(3,J) (J=1,2)	x,y,z coordinates of corner pts. 1 and 2 input by the following order, x_1,y_1,z_1, x_2,y_2,z_2.
Q4	1-60	SC(1,J) SC(2,J) SC(3,J) (J=3,4)	x,y,z coordinates of corner pts. 3 and 4 input by the following order, x_3,y_3,z_3, x_4,y_4,z_4.

If any z coordinate of the given four corner points is not zero, a simple twisted wing will be set up using linear interpolation.

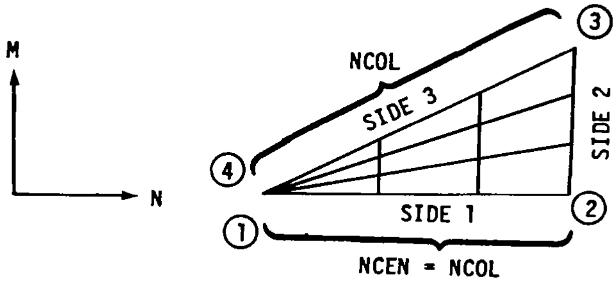
Number	Column	Name	Description/Comment
Q5	1-10	NROW	Number of rows
Q6	1-60	YPC(I) (I=1,NROW)	Percent values (100% = 1.) for cuts along column, i.e., side 2 and 4.
Q7	1-20	NCOL	Number of columns
Q8	1-60	XPC(J) (J=1,NCOL)	Percent values (100% = 1.) for cuts along row, i.e., side 1 and 3.
Q9			$CAMBERED WING (OPTIONAL)

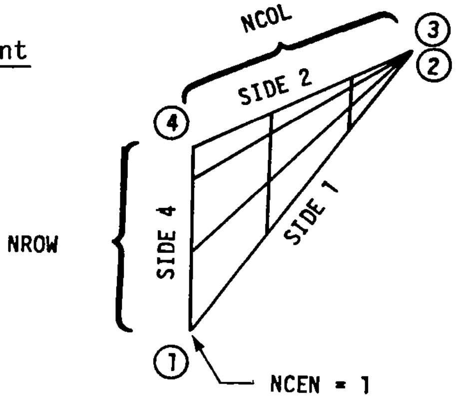
Input $CAMBERED WING data block for simplified camber definition. If this option is chosen, the network mesh points generated by $QUAD must have corner 1 at the apex.

****

Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
G1		$GOTHIC	





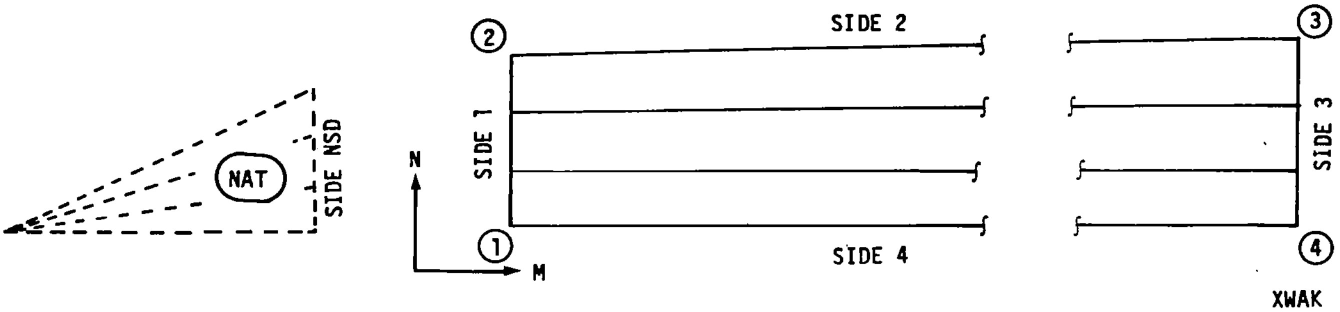
G2	1-10 11-20 21-30	KN NT NUP	Network no. Type of network Update index = 0. Fixed network 1. Trailing wake emanating from free or fed sheet 2. Fed sheet 3. Free sheet to which no fed sheet is attached 4. Free sheet to which a fed sheet is attached
G3	1-10	NCOL	Number of corner points along leading edge
G4	1-60	SC(1,J) SC(2,J) SC(3,J) (J=1,NCOL)	x,y,z coordinates of corner pts. along leading edge from nose to tail
G5	1-10	NROW	Number of spanwise cuts
G6	1-60	YPC(I) (I=1,NROW)	Percent values (100% =1.) for spanwise cuts.
G7	1-10	NCEN	Number of corner pts. of wing network along centerline; NCEN should be less or equal to NCOL. If NCEN<NCOL, then wing geometry with swept trailing edge will result. This option is presently invalid for analysis due to abutment restrictions. It can be used to generate a set of data which upon proper manipulation can be reinput using $POINTS.
G8			$CAMBERED WING (OPTIONAL)

Input $CAMBERED wing data block for simplified camber definition

****

Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
T1			$TRAILING WAKE The data card calls for using Trailing Wake preprocessor to generate mesh points for the trailing wake network attached to wing

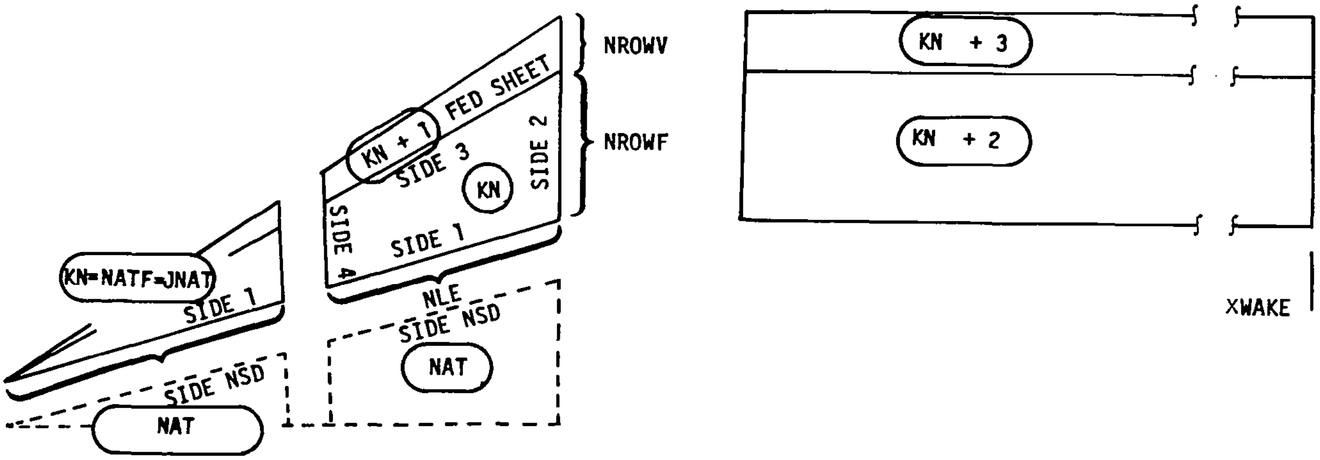


T2	1-10	KN	Network no.
	11-20	NT	Type of network
	21-30	NUP	Update index
			= 0. Fixed network 1. Trailing wake emanating from free or fed sheet 2. Fed sheet 3. Free sheet to which no fed sheet is attached 4. Free sheet to which a fed sheet it attached
T3	1-10	NAT	Sequence number of network to which side 1 of trailing network is attached
	11-20	NSD	Side of network to which side 1 of trailing network is attached
T4	1-10	XWAKE	X coordinate of corner pt. of downstream of the trailing wake; should be about 50 times of the X-coordinates of the trailing edge along centerline. It is essential that this value should be the same as the one given in card no. V6 under $VORTEX.

****

Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
V1			$VORTEX This data card calls for using Vortex preprocessing to generate mesh points for free sheet, fed sheet, and as an option the attached trailing wakes. Either two or four networks will be generated.



Number	Column	Name	Description/Comment
V2	1-10	KN	Network no. for free sheet, the fed sheet will have network no. KN+1.
	11-20	KW	If KW = 1., then the trailing wake networks attached to free sheet and fed sheet will also be formed. Their network numbers will be KN+2 and KN+3 respectively. If KW=0. then no trailing wake networks are formed
V3	1-10	NROWF	Number of rows on free sheet
	11-20	NROWV	Number of rows on fed sheet
V4	1-10	NAT	Sequence number or network to which side 1 of the free sheet is attached
	11-20	NSD	Side of network which side 1 of free sheet is attached

Data Card Variable (Numeric data are input in 6E10.0 format)

Number	Column	Name	Description/Comment
	21-30	NATF	Sequence number of another free sheet network to which side 4 of the free sheet is attached Set NATF=0 if side collapses to a point
V5	1-10	APC	Perturbation parameters for size of free and fed sheets. The parameter a is reset to a + APC. If the user wants the original initial guess, APC should be set to 0.
	11-20	JNAT	Sequence number of the vortex network to which the apex of the complete vortex system resides. JNAT will differ from KN when more than one set of networks are used to define the free and fed sheets. See figures 25 and 26 as examples.
V6	1-10	XWAKE	This card is required only if KW = 1. X-coordinates of corner pt. at downstream of the trailng wake; should be about 50 times of the X-coordinate of the trailing edge along centerline. (also see T4)

****

$CAMBERED WING

A deck must first be prepared to generate the desired networks for the flat plate representation of the configuration to be studied. The wing plan view itself will be generated either through use of the $QUADRILATERAL preprocessor or the $GOTHIC preprocessor.

The three-dimensional character of the wing can be defined by use of the $CAMBERED WING preprocessor. This preprocessor generates the z coordinate for the (x,y) coordinates of the flat wing representation of the desired 3-D wing through interpolation. In general, the cambered surface is defined through a set of input data specifying the wing mean lines in the chordwise direction at a limited number of spanwise stations (no more than 50). It is also possible to input a fixed mean line shape valid for all span stations scaled to the local chord. The $CAMBERED WING preprocessor also can generate the camber surface for wings with circular arc spanwise camber. This preprocessor was originally developed in reference 6.

Thus, the current technique for generation for three-dimensional wing networks consists of two steps:

(1) Generate wing plan view, with desired paneling density using $GOTHIC or $QUADRILATERAL.

(2) Generate wing z coordinates using $CAMBERED WING.

It is essential that the card set $CAMBERED WING should follow immediately the card set $QUADRIALATERAL or $GOTHIC.

A description of the input card preparation, as part of the $GOTHIC or $QUADRILATERAL input cards is as follows (data are input in 6E10.0 format):

Number	Column	Name	Description/Comment
C1			$CAMBERED WING
C2	1-10	CNTRL	CNTRL controls which type of wing is generated: CNTRL = 1. is for a single mean line for all span stations, CNTRL = 2. is for varying camber and twist with span, CNTRL = 3. generates the Wentz (ref. 5) conical cambered delta, and CNTRL = 4. generates the Barsby conical cambered deltas (see equation (15)).

The input cards hereafter differ and will be described for each of the 4 possible values of CNTRL.

(1) If CNTRL = 1, a 3-D wing with a single camber shape will be generated. The necessary input cards are as follows:

C3	1-10	NPCT	Number of x/c's (of which z/c's will be defined) on card C4.
C4	1-60	PCTX(I) (I=1,NPCT)	PCTX(I) is a table of percent local chord at which the z percent local chord is to be specified on the following cards. (100% = 1.0)
C5	1-60	PCTZ(I) (I=1,NPCT)	PCTZ(I) is a table of the z values in z/c.

This completes the necessary input for a general wing with a single mean line shape. The desired z values for the paneling generated in $GOTHIC or $QUADRILATERAL are then found through linear interpolation.

(2) If CNTRL = 2., a 3-D wing with camber and twist varying with span station will be generated. (Note that for CNTRL = 1. or 2., it is not necessary to specify NPCT = NROW or NTST = NCOL for the network in question.) The only restrictions are NPCT, NYST ≥ 50. The necessary input cards are:

Number	Column	Name	Description/Comment
C3	1-10	NPCT1	Number of x/c's at which z/c's will be defined on card C4
	11-20	NYST	Number of y stations at which z/c's will be defined. The x/c array will apply at each y station

Number	Column	Name	Description/Comment
C4	1-60	PCTX(I) (I=1,NPCT)	PCTX(I) is a table of percent local chord at which the z percent local chord is to be specified on the following cards. (100% = 1.0)
C5	1-10	YSTA	Y-location at which array of z/c's will be defined. Input NYST sets of C5 and C6 data cards
C6	1-60	PCTZ(I) (I=1,NPCT)	PCTZ(I) is a table of the z values in z/c.

This completes the necessary input for a general wing with varying twist and camber shape. The desired z values for the paneling generated in $GOTHIC or $QUADRILATERAL are then found through linear interpolation.

(3) If CNTRL = 3., a conically cambered delta wing will be generated where the first (0.805) b/2 is flat and at the maximum z, and the remainder of the wing semispan is a portion of a circular arc. The maximum z is 0.105 of the wing local semispan. See reference 5 for a description of these wings. When CNTRL = 3., <u>no</u> further data cards are required.

(4) If CNTRL = 4., a conically cambered delta wing will be generated, where the wing is a portion of a circular arc in the spanwise direction determined by the equation:

$$z_{local} = \frac{(b/2)_{local}}{2p} \left\{ \sqrt{(1 + p^2)^2 - \left(\frac{2p\, y_{local}}{(b/2)_{local}} \right)^2} - \sqrt{(1 + p^2)^2 - (2p)^2} \right\} \tag{15}$$

where p = 0.0 corresponds to a flat wing an p = 1.0 corresponds to a wing which is one-half of a cone. One further card is then required to specify the value of p.

Number	Column	Name	Description/Comment
C3	1-10	p1	$0.0 < p1 \leq 1.0$

****

5.6 Example Input Case

As an aid to the user in understanding the proper application of the input format specifications, two example input cases are provided. The first case consists of an aspect ratio 1.15 flat delta wing with a design wake. The network arrangement is shown in Figure 25, section 5.4.2. The inputs for this case are given in Figure 31.

The second case is a 70 panel twisted arrow wing. The network arrangement is shown in Figure 26, section 5.4.3. The inputs for this case are given in Figure 32.

5.7 Practical Instructions

The preceding sections have given sufficient instructions to properly set up a solution, here practical hints are given to aid in their use.

1. Always submit a data check ($DATA CHECK, Card 15) before submitting the solution to iteration. Check abutment data (described in section 6.1.3) to ensure proper network arrangement.

2. Use $SUBITERATION (Card 15) for further checking of unusual cases. If solution does not converge in subiteration it will not converge in the full iteration process. Use of $SUBITERATION is not necessary for typical cases.

3. Most well posed cases using conical type paneling on the lifting surface will converge using $ITERATION (Card 15). Try 5 iterations (ITMX, Card 16) and save results on TAPE14. If case appears to be converging but residual (SSR) are greater than 10^{-3}, repeat iterations starting with saved results (set ITMX negative).

4. Cases which appear to have difficulty in converging using $ITERATION may respond to the least squares solver, $LEAST SQUARES. This will include most cases with streamwise lifting systems. Save data on TAPE14 in case more iterations are necessary. Remember that $LEAST SQUARES is more expensive than $ITERATION. Also remember the paneling limitations given in Table 1.

5. Reasonable results have been obtained using 60-70 panels on the wing, 7-9 rows (NROWF, Card V3) on the free sheet, and 3 rows (NROWV, Card V3) on the fed sheet. More wing panels may be necessary to obtain desired simulation of wing camber and resolutuion of the pressure distribution.

```
                      A COMPUTER PROGRAM
                             FOR
         A THREE DIMENSIONAL SOLUTION OF FLOWS OVER WINGS
              WITH LEADING EDGE VORTEX SEPARATION


                  - LIST OF INPUT DATA CARDS -

NO.    CARD IMAGES

 1     $CASE
 2     ASPECT RATIO 1.15 DELTA  WING  WITH DESIGN WAKE
 3     TINOCO AND LU
 4     $ANGLE
 5     20.
 6     $YAW
 7     0.
 8     $SYMMETRY
 9     1.
10     $MACH
11     0.6
12     $REFENCES
13     0.        0.        0.
14     .14375    1.        1.        1.
15     $ITERATIONS
16     0.
17     $PRINT
18     3.        1.        1.
19     1.        1.        1.        1.        0.        1.
20     $NETWORK
21     9.
22     $QUAD
23     1.        2.        0.
24     0.        0.        0.        1.        0.        0.
25     1.        .2875     0.        0.        0.
26     7.
27     0.        .3        .5        .625      .75       .875
28     1.
29     6.
30     0.        .2        .4        .6        .8        1.0
31     $QUAD
32     2.        6.        0.
33     1.        0.        0.        1.        .2875     0.
34     1.1       .31625    0.        1.1       0.        0.
35     3.
36     0.        .5        1.0
37     7.
38     0.        .3        .5        .625      .75       .875
39     1.
40     $TRAIL
41     3.        0.        0.
42     2.        3.
43     50.
44     $VORTEX
45     4.        0.
46     9.        3.
47     1.        3.        0.
48     1.        4.
49     $VORTEX
50     6.        1.
51     9.        3.
52     2.        2.        4.
53     1.        4.
54     50.
55     $END OF CASE
```

FIGURE 31 INPUT SPECIFICATION - AR = 1.15 DELTA WING

```
                         A COMPUTER PROGRAM
                                FOR
          A THREE DIMENSIONAL SOLUTION OF FLOWS OVER WINGS
                 WITH LEADING EDGE VORTEX SEPARATION


                    - LIST OF INPUT DATA CARDS -

NO.     CARD IMAGES

  1     $CASE
  2     70 PANEL TWISTED ARROW WING OF MANROE
  3     TINOCO AND LU
  4     $ANGLE OF ATTACK
  5     15.9
  6     $YAW
  7     0.
  8     $SYMMETRY
  9     1.
 10     $MACH NO.
 11     0.40
 12     $RFFERENCES
 13     28.777    0.          0.
 14     489.713   1.          29.652     1.0
 15     $DATA CHECK
 16     $PRINT
 17     1.          1.          1.
 18     0.          0.          0.          0.          0.          0.
 19     $NETWORK
 20     10.
 21     $POINTS
 22     1.          2.          0.
 23     8.          1.
 24        3.51020   0.00000   0.00000   3.51020   0.00000   0.00000
 25        3.51020   0.00000   0.00000   3.51020   0.00000   0.00000
 26        3.51020   0.00000   0.00000   3.51020   0.00000   0.00000
 27        3.51020   0.00000   0.00000   3.51020   0.00000   0.00000
 28        9.76610   0.00000   0.00000   9.76610    .29813   -.00992
 29        9.76610    .76662   -.02618   9.76610   1.21382   -.04248
 30        9.76610   1.51195   -.05377   9.76610   1.72490   -.06204
 31        9.76610   1.95914   -.07133   9.76610   2.12950   -.09286
 32       18.00000   0.00000   0.00000  18.00000    .69054   -.01605
 33       18.00000   1.77566   -.04493  18.00000   2.81147   -.14472
 34       18.00000   3.50200   -.23210  18.00000   3.99524   -.29902
 35       18.00000   4.53781   -.38965  18.00000   4.93240   -.45796
 36       26.60000   0.00000   0.00000  26.60000   1.10039   -.01407
 37       26.60000   2.82956   -.06644  26.60000   4.48014   -.23916
 38       26.60000   5.58053   -.37778  26.60000   6.36652   -.49201
 39       26.60000   7.23111   -.63322  26.60000   7.85990   -.74483
 40       35.00000   0.00000   0.00000  35.00000   1.50070   -.00385
 41       35.00000   3.85895   -.06739  35.00000   6.11000   -.22973
 42       35.00000   7.61070   -.39398  35.00000   8.68263   -.53159
```

FIGURE 32 INPUT SPECIFICATION - ARROW WING

```
  35.00000   9.86176   -.70224  35.00000  10.71930   -.82589
  40.00000   0.00000   0.00000  40.00000   1.73898    .00608
  40.00000   4.47167   -.02067  40.00000   7.08014   -.16643
  40.00000   8.81912   -.33143  40.00000  10.06125   -.47759
  40.00000  11.42760   -.64781  40.00000  12.42130   -.77641
  45.21610   0.00000   0.00000  45.21610   1.98757    .01949
  45.21610   5.11088    .06109  45.21610   8.09223   -.05161
  45.21610  10.07980   -.21367  45.21610  11.49949   -.35829
  45.21610  13.06115   -.53012  45.21610  14.19690   -.65902
$POINTS
2.         2.         0.
8.         5.
  45.21610   0.00000   0.00000  45.21610   1.98757    .01949
  45.21610   5.11088    .06109  45.21610   8.09223   -.05161
  45.21610  10.07980   -.21367  45.21610  11.49949   -.35829
  45.21610  13.06115   -.53012  45.21610  14.19690   -.65902
  50.00000   5.01431    .15601  50.00000   6.52785    .16834
  50.00000   8.90626    .10163  50.00000  11.17657   -.05564
  50.000    12.69011  -.19566   50.00    13.77121  -.30487
  50.00000  14.96042   -.42570  50.00000  15.82530   -.51511
  55.00000  10.25512    .27657  55.00000  11.27323    .21775
  55.00000  12.87311    .09550  55.00000  14.40026   -.04357
  55.00000  15.41837   -.14196  55.00000  16.14559   -.21413
  55.00000  16.94557   -.29509  55.00000  17.52730   -.35508
  60.00000  15.49554    .18161  60.00000  16.01862    .13249
  60.00000  16.83999    .05359  60.00000  17.62401   -.02349
  60.00000  18.14670   -.07615  60.00000  18.52004   -.11541
  60.00000  18.93072   -.15998  60.00000  19.22940   -.19332
  65.27500  21.02500   -.00004  65.27500  21.02500   -.00004
  65.27500  21.02500   -.00004  65.27500  21.02500   -.00004
  65.27500  21.02500   -.00004  65.27500  21.02500   -.00004
  65.27500  21.02500   -.00004  65.27500  21.02500   -.00004
$VORTEX
3.         0.
8.         3.
1.         3.         0.
0.         3.
$VORTEX
5.         1.
8.         3.
2.         3.         3.
0.         3.
2500.
$POINTS
9.         6.         0.
4.         5.
45.2161    0.         0.         52.5       0.         0.
60.        0.         0.         65.275     0.         0.
50.        5.01431    .15601     55.        5.1014     .156
60.        5.014      .156       65.275     5.014      .156
55.        10.25512   .27657     57.5       10.26      .277
62.5       10.26      .277       65.275     10.26      .277
60.        15.49594   .18161     62.        15.50      .182
64.        15.50      .182       65.275     15.50      .182
65.275     21.025     -.00004    65.275     21.025     -.00004
65.275     21.025     -.00004    65.275     21.025     -.00004
$TRAILING WAKE
10.        8.         0.
9.         3.
2500.
$END OF CASE
```

FIGURE 32 CONCLUSION

6.0 OUTPUT GUIDE

In this section the organization of the computer output is described. The nomenclature employed in the output is summarized in Table 4. A typical output (with the appropriate print options) will consist of a copy of the program inputs, printer plots of the initial free/fed sheet, network coordinates, and network abutment data. If the $DATA CHECK option had been used the program would terminate at this point. If the $SUBITERATION option is used then printout will also include results from the initial solution. If a complete solution is sought the singularity parameters, corrections, and residuals, and updated geometry can be printed every iteration. Printout of the solution results (pressure coefficients, velocities, etc) can be deferred until the final iteration, printed every so many iterations, or every iteration.

Additional print options provide for the printing of detailed diagnostics which can be of use to a user intimately familiar with the workings of the code. Although of not much use to the typical user a brief description will be given of these options.

The program also creates a file (TAPE14) which can be saved and used to restart the iterations if convergence is not achieved in the first solution attempt. A description will be given of TAPE14 in section 6.4.

Examples of the output will be presented to aid in its description. The examples used are from the aspect ratio 1.15 flat delta wing case used to illustrate the inputs in section 5.6. Since the program always prints out the inputs, the first part of the output will appear as shown in Figure 31. The input formats are described in section 5.5.

6.1 Data Check Output

In this section the print out typically associated with a data check will be described. This print out is included in every solution.

6.1.1 Free and Fed Sheet Printer Plots (OPTIONAL, IPLOTP=1)

Printer plots of the free and fed sheets geometry are shown in Figure 33. These plots are created when IPLOTP=1 (Card 18). The network arrangement, Figure 25, contained two sets of free and fed sheet networks which results in the two plots. A different symbol is used for each transverse cut. The poor resolution of the printer plots results in a somewhat ragged look of the cuts but will at least give the user an idea of the initial geometry. Note the change in the horizontal scale for the plots of networks 6 and 7.

6.1.2 Mesh Point Data

The program always prints the mesh point data. An example of the mesh point data printout is shown in Figure 34. Only a partial list is shown for the sake of brevity. The mesh point data is organized by network.

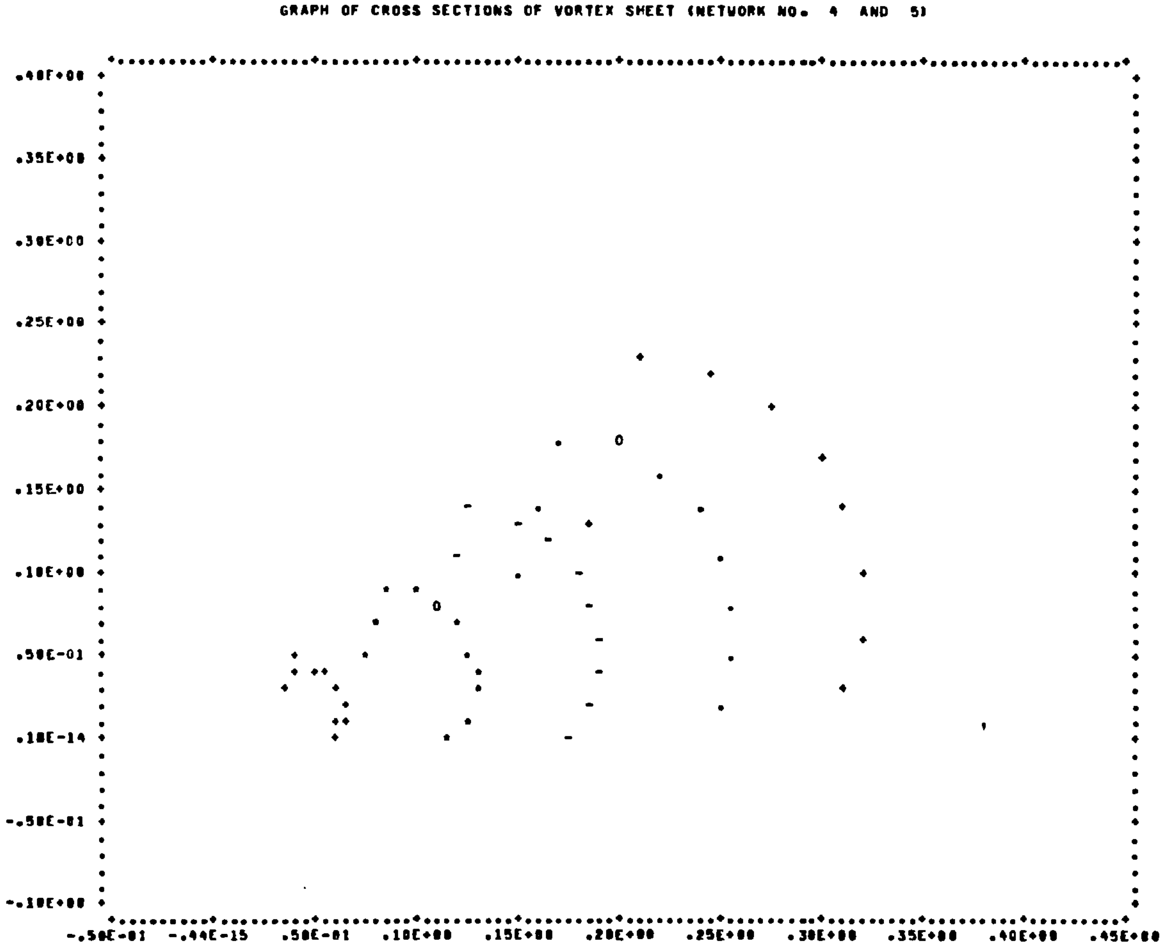


FIGURE 33 PRINTER PLOT OF VORTEX SHEET

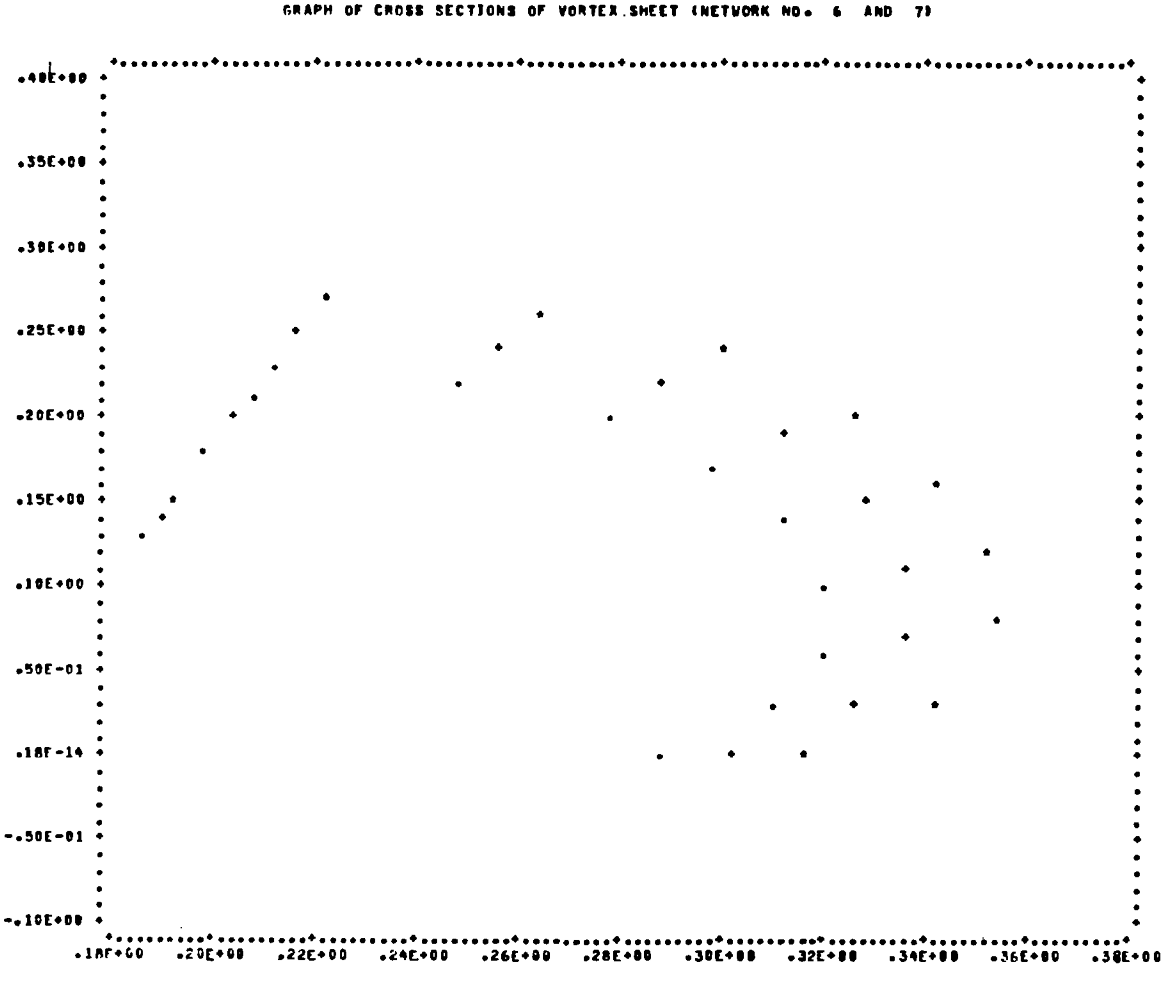


FIGURE 33 CONCLUDED

```
INPUT NETWORK MESH POINTS DATA

NETWORK NO.  1       (NUMBER ROWS =  7   NUMBER COLUMNS =  6)
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000     .20000    0.00000    0.00000
    .20000     .01725    0.00000     .20000     .02875    0.00000
    .20000     .03594    0.00000     .20000     .04313    0.00000
    .20000     .05031    0.00000     .20000     .05750    0.00000
    .40000    0.00000    0.00000     .40000     .03450    0.00000
    .40000     .05750    0.00000     .40000     .07188    0.00000
    .40000     .08625    0.00000     .40000     .10063    0.00000
    .40000     .11500    0.00000     .60000    0.00000    0.00000
    .60000     .05175    0.00000     .60000     .08625    0.00000
    .60000     .10781    0.00000     .60000     .12938    0.00000
    .60000     .15094    0.00000     .60000     .17250    0.00000
    .80000    0.00000    0.00000     .80000     .06900    0.00000
    .80000     .11500    0.00000     .80000     .14375    0.00000
    .80000     .17250    0.00000     .80000     .20125    0.00000
    .80000     .23000    0.00000    1.00000    0.00000    0.00000
   1.00000     .08625    0.00000    1.00000     .14375    0.00000
   1.00000     .17969    0.00000    1.00000     .21563    0.00000
   1.00000     .25156    0.00000    1.00000     .28750    0.00000

NETWORK NO.  2       (NUMBER ROWS =  3   NUMBER COLUMNS =  7)
   1.00000    0.00000    0.00000    1.05000    0.00000    0.00000
   1.10000    0.00000    0.00000    1.00000     .08625    0.00000
   1.05000     .09956    0.00000    1.10000     .09488    0.00000
   1.00000     .14375    0.00000    1.05000     .15094    0.00000
   1.10000     .15813    0.00000    1.00000     .17969    0.00000
   1.05000     .18867    0.00000    1.10000     .19766    0.00000
   1.00000     .21563    0.00000    1.05000     .22641    0.00000
   1.10000     .23719    0.00000    1.00000     .25156    0.00000
   1.05000     .26414    0.00000    1.10000     .27672    0.00000
   1.00000     .28750    0.00000    1.05000     .30188    0.00000
   1.10000     .31625    0.00000

NETWORK NO.  3       (NUMBER ROWS =  2   NUMBER COLUMNS =  7)
   1.10000    0.00000    0.00000   50.00000    0.00000    0.00000
   1.10000     .09488    0.00000   50.00000     .09488    0.00000
   1.10000     .15813    0.00000   50.00000     .15813    0.00000
   1.10000     .19766    0.00000   50.00000     .19766    0.00000
   1.10000     .23719    0.00000   50.00000     .23719    0.00000
   1.10000     .27672    0.00000   50.00000     .27672    0.00000
   1.10000     .31625    0.00000   50.00000     .31625    0.00000

NETWORK NO.          (NUMBER ROWS =  9   NUMBER COLUMNS =  6)
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   0.00000    0.00000    0.00000     .20000     .05750    0.00000
    .20000     .06211     .00563     .20000     .06398     .01277
    .20000     .06392     .02015     .20000     .06241     .02731
    .20000     .05969     .03410     .20000     .05545     .04015
    .20000     .04943     .04439     .20000     .04233     .04617
    .40000     .11500    0.00000     .40000     .12472     .01126
    .40000     .12796     .02554     .40000     .12783     .04038
    .40000     .12483     .05461     .40000     .11938     .06820
    .40000     .11090     .08029     .40000     .09685     .08677
    .40000     .08457     .09233     .60000     .17250    0.00000
    .60000     .18632     .01689     .60000     .19195     .03831
    .60000     .19175     .06845     .60000     .18724     .08192
    .60000     .17906     .10230     .60000     .16635     .12044
    .60000     .14828     .13316     .60000     .12788     .13850
    .80000     .23000    0.00000     .80000     .24843     .02251
    .80000     .25593     .05108     .80000     .25567     .08861
    .80000     .24965     .10923     .80000     .23075     .13640
```

FIGURE 34 MESH POINT DATA

Each network is identified followed by the number of rows and columns (M and N). Paired mesh points coordinates are presented by row in 6F10.5 format in X Y Z order.

6.1.3 Abutment Data

The program always prints the abutment list, abutment intersection list and the update index arrays. These data are vital to determining whether the networks have been properly defined to ensure the appropriate matching along their edges. Unless proper matching occurs along all network edges the flow model and the resulting solution will be in error. Every network arrangement should be run through data check and have its abutment list thoroughly checked before being committed to solution.

The abutment list is shown in its entirety in Figure 35. The corresponding network arrangement is illustrated in Figure 36. A similar sketch should always be prepared to aid the user in the abutment checks. The abutment list consists of the abutment number, side and network involved, and a characterization of the control points. The user should refer to section 5.2.4 for the control point placement for the various types of networks. To facilitate understanding of the abutment list a walk through of the list follows.

Abutment 1 concerns side 1 of network 1 which is on the plane of symmetry. These control points satisfy their appropriate boundary conditions. Side 4 of network 1 collapses to a point and has no abutment. Abutments 2 and 3 concern the remaining two sides of network 1. These sides both abut to other networks, side 2 to the near wake network 2 and side 3 to the free sheet network 4. Proper matching is indicated by the characterization "control points peform doublet matching." In both cases the control points on network 1 satisy the boundary conditions while the control points on networks 2 and 4 do the matching. Abutment 4 between networks 2 and 6 is similar.

Abutments 5, 10, 11, 14, and 15 are between networks in which one edge has no control points. In each case the proper abutment is indicated by the edge with the control points performing doublet matching. Abutments 7, 12, 16 and 18 have no control points on their coincident edges. Here proper abutments are indicated by the network pairing. Abutments 8, 13, 17, 19, 20 and 21 are not actually abutments but free edges. If an error is made in the network definition such that the proper abutment is not made between two adjacent networks, the program will not pair the networks and regard them as free edges.

The Abutment Intersection List is shown in Figure 37. This list is similar to the abutment list except that it characterizes the control point behavior at network corners. If the abutment list checks out for the configuration the user need not concern himself with the intersection list.

The Update Index Arrays are shown in Figure 38. These arrays list the various control parameters which regulate the geometry update during

```
                                        ABUTMENT LIST
ABUTMENT             SIDE             NETWORK                        CHARACTERIZATION

    1                  1                 1                CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS

    2                  2                 1                CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS
    2                  1                 2                CONTROL POINTS PERFORM DOUBLET MATCHING

    3                  3                 1                CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS
    3                  1                 4                CONTROL POINTS PERFORM DOUBLET MATCHING

    4                  2                 2                CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS
    4                  1                 6                CONTROL POINTS PERFORM DOUBLET MATCHING

    5                  3                 2                NO CONTROL POINTS
    5                  1                 3                CONTROL POINTS PERFORM DOUBLET MATCHING

    6                  4                 2                CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS

    7                  2                 3                NO CONTROL POINTS
    7                  4                 8                NO CONTROL POINTS

    8                  3                 3                NO CONTROL POINTS

    9                  4                 3                CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS

   10                  2                 4                NO CONTROL POINTS
   10                  4                 6                CONTROL POINTS PERFORM DOUBLET MATCHING

   11                  3                 4                NO CONTROL POINTS
   11                  1                 5                CONTROL POINTS PERFORM DOUBLET MATCHING

   12                  2                 5                NO CONTROL POINTS
   12                  4                 7                NO CONTROL POINTS

   13                  3                 5                NO CONTROL POINTS

   14                  2                 6                NO CONTROL POINTS
   14                  1                 8                CONTROL POINTS PERFORM DOUBLET. MATCHING

   15                  3                 6                NO CONTROL POINTS
   15                  1                 7                CONTROL POINTS PERFORM DOUBLET MATCHING

   16                  2                 7                NO CONTROL POINTS
   16                  1                 9                NO CONTROL POINTS

   17                  3                 7                NO CONTROL POINTS

   18                  2                 8                NO CONTROL POINTS
   18                  4                 9                NO CONTROL POINTS

   19                  3                 8                NO CONTROL POINTS

   20                  2                 9                NO CONTROL POINTS

   21                  3                 9                NO CONTROL POINTS
```

FIGURE 35 ABUTMENT LIST PRINTOUT

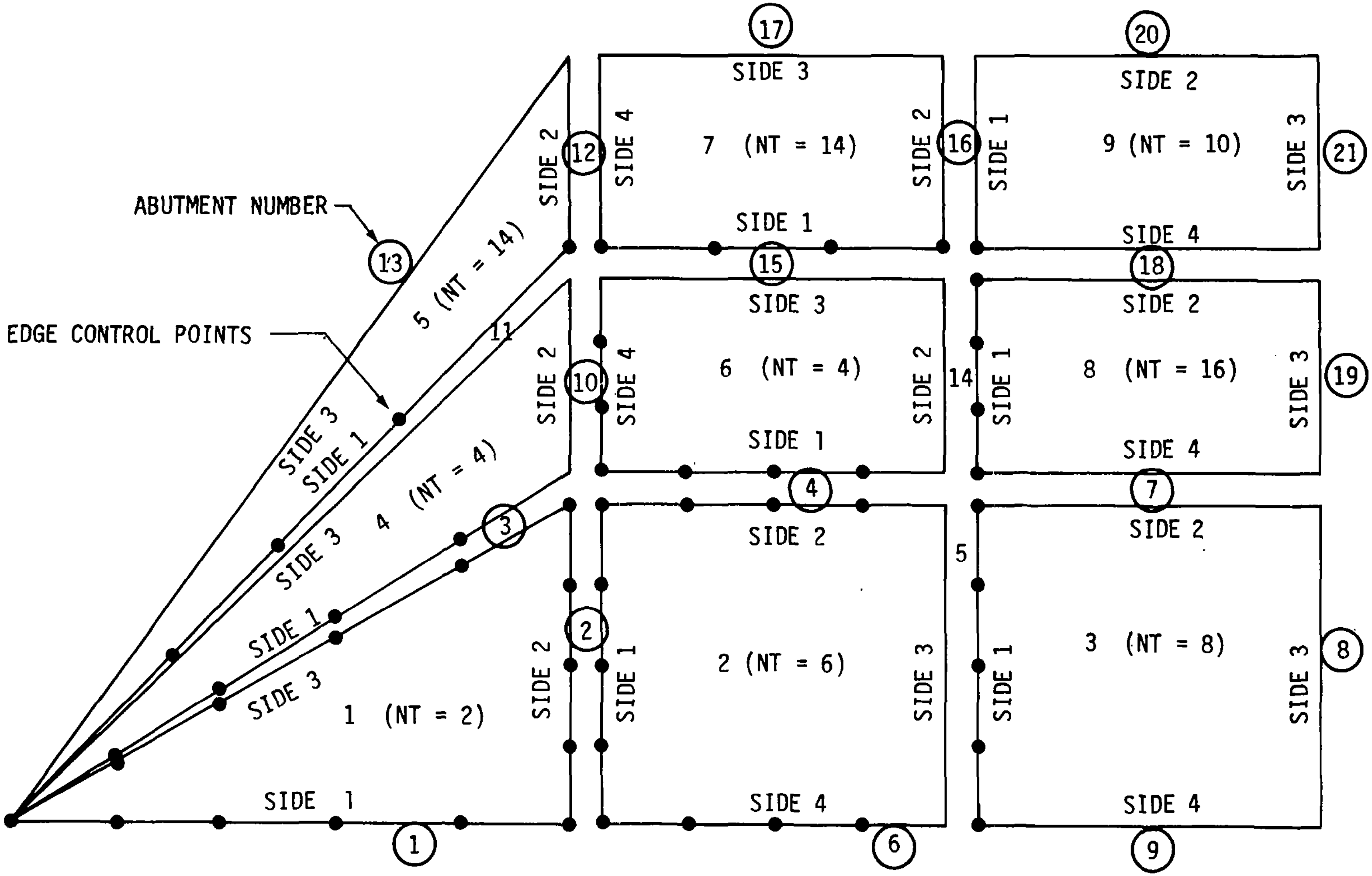


FIGURE 36 ABUTMENT CHECK

```
                              ABUTMENT INTERSECTION LIST

INTERSECTION         CORNER          NETWORK                        CHARACTERIZATION


     1                 1                1               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  3
     1                 1                4               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  3
     1                 1                5               CONTROL POINT PERFORMS DOUBLFT MATCHING ON SIDE  3

     2                 2                1               CONTROL POINTS (IF ANY) USE ORIGINAL BOUNDARY CONDITIONS
     2                 1                2               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  1

     3                 3                1               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  3
     3                 2                2               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  1
     3                 2                4               NO CONTROL POINT
     3                 1                6               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  1

     4                 3                2               NO CONTROL POINT
     4                 2                3               CONTROL POINT PFRFORMS DOUBLET MATCHING ON SIDE  1
     4                 2                6               NO CONTROL POINT
     4                 1                8               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  4

     5                 4                2               NO CONTROL POINT
     5                 1                3               CONTROL PCINT PFRFORMS DOUBLFT MATCHING ON SIDE  1

     8                 3                4               NO CONTROL POINT
     8                 2                5               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  1
     8                 4                6               NO CONTROL POINT
     8                 1                7               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  4

    10                 3                6               NO CONTROL POINT
    10                 2                7               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  1
    10                 2                8               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  2
    10                 1                9               CONTROL POINT PERFORMS DOUBLET MATCHING ON SIDE  1
```

FIGURE 37 ABUTMENT INTERSECTION LIST PRINTOUT

```
                                                   UPDATE INDEX ARRAYS

NET  NUP  NAT1 NAT2 NSD1 NSD2 NCR1 NCR2 IEDGA1 IEDGA2 KEDG1  KEDG2  MEDG1I MEDG1F MEDG2I MEDG2F NEDG1I NEDG1F NEDG2I NEDG2F

 1    0*****************************       0      0     1      1      7      7      7      9      1      6      1      1
 2    0*****************************       0      0     1      1      7      9      7      7      1      1      1      3
 3    0*****************************       0      0     1      1      7      9      7      7      1      1      1      2
 4    4    1    0    3*****    4*****      0      6     1      4      7      7      9      3      1      6      1      7
 5    2    4    0    3*****    4*****      6     12     4      2      9      9      1      3      1      6      7      7
 6    4    2    4    2    2    2    2     12     15     2      4      1      3      1      9      7      7      6      6
 7    2    6    5    3    2    4    2     24     27     6      5      9      9      1      3      1      3      6      6
 8    1    6    3    2    2    2    2     30     39     6      3      1      9      1      2      3      3      7      7
 9    1    7    8    2    2    2    2     41     44     7      8      1      3      1      2      3      3      9      9
```

FIGURE 38 UPDATE INDEX ARRAYS PRINTOUT

iteration. These data define how the various networks are connected together. Table 4 lists the definitions of the various headings. The general user need not be concerned with this print out.

6.2 Solution Output

In this section the printout typically associated with an iteration solution will be described. For every main iteration the following is printed.

Iteration Summary
- Iteration No.
- Sum of Squares of Residuals (SSR) =
- No. of Function called =
- Fraction of Newton Step taken =
- Step Size (Length of Correction Vector) =
- Force and Moment Data for NT = 1 or NT = 2 Networks
- Network Mesh Point Data

For every ITPRINT (Card 18) iterations the detailed physical quantities are printed.

When IPLOTP = 1 (Card 18)
- Printer Plot of Vortex Sheet

When ITVRCP = 1 (Card 18)
- Values of Variables
- Residuals
- Corrections

6.2.1 Iterative Results Summary

These data are printed every main iteration and serve to summarize the progress of the solution during the iteration process.

Iteration No. - Counter on the number of iterations taken. Starts with "0" for the initial guess solution.

Sum of Squares of Residuals (SSR) - This is the sum of the squares of the residuals. When using ITFLOW, $SSR = F^2 + G^2$ (refer to equation 9, section 4.3.1). In using the Quasi-Newton, ITFLOW, SSR is a reliable indicator of the goodness of the solution. A solution may be considered acceptable when $SSR < 10^{-3}$.

When using the least squares solution procedure LSFLOW, $SSR = G^2 + K^2$ (subiteration drives F to zero, also, refer to equation 12, section 4.3.2). A solution is acceptable when $SSR < 10^{-3}$. For higher values of SSR the residual is not a reliable indicator. Many converged solutions will have residuals larger than 10^{-3}. This may result because the panel twist residual K is included in the sum. A more reliable indicator in this case may be the residuals of G.

No. of Function called - Cumulative number of function residual calculations for the iterations performed.

Fraction of Newton Step Taken - Refer to Appendix G, Volume I - Theory Document.

$$X^{(i+1)} = X^{(i)} + \delta \Delta X^{(i)}, \qquad 0 < \delta \leq 1$$

where δ is the fraction of Newton step taken and ΔX^{i} is the correction vector.

Step Size (Length of Correction Vector) - Refer to Appendix G, Volume I - Theory Document

$$\|\delta \Delta X^{(i)}\| = \delta \|\Delta X^{(i)}\|$$

where $\|\quad\|$ is the euclidean length.

Force and Moment Data for NT = 1 or NT = 2 Networks - This is a force and moment summary on all source/analysis (NT = 1) and doublet/analysis (NT = 2) type networks. These type networks are used to define configuration surfaces and this summary will give the total forces acting on the configuration. An example of this printout is shown in Figure 39. The force and moments are with respect to the configuration axis system. Also printed is the network surface area. Three sets of data are printed for each quantity. The top values represent forces and moments calculated integrating pressures (based on the isentropic formula, section 6.2.2, equation 19) on the upper side of the network, middle values represent the lower surface totals, and the bottom values represent the sum of upper and lower. The upper and lower sense is determined by the NxM vector (points out from the upper surface).

Network Mesh Point Data - Updated mesh point geometry. See 6.1.2 for details.

6.2.2 Detailed Physical Quantities

For every ITPRINT (Card 18) iterations, the detailed physical quantities are printed. These are also printed for the initial solution and the final iteration. An example of these results are shown in Figure 40. The quantity headings are defined in Table 4. The printout is organized by network. For every panel center-control point the following quantities are listed:

Source strength
Doublet strength
Doublet strength gradient
Perturbation velocity potential*
Total velocity potential*
Perturbation mass flux vector*
Total mass flux vector*

```
   MACH NUMBER =          .60000    ANGLE OF ATTACK =       20.00000                 YAW ANGLE =        0.00000


   FORCE / MOMENT   DATA     (NETWORK NUMBER =  1     NETWORK TYPE =  2)  -  ITERATION NO.  4

TOTALS FOR NETWORK                         AREA           FX            FY            FZ            MX            MY             MZ

                                            .14375       0.00000       0.00000       .59312        .05932       -.34511        0.00000
                                            .14375       0.00000       0.00000       .20483        .01494       -.11862        0.00000
                                            .14375       0.00000       0.00000       .79795        .07426       -.46372        0.00000
```

FIGURE 39 FORCE AND MOMENT SUMMARY

```
NETWORK NUMBER =    1          NETWORK TYPE =    2          NUMBER ROWS =    6          NUMBER COLUMNS =    5

JC    IP        X          Y          Z          D0         DX         DY         DZ         S0        FSVX       FSVY       FSVZ
 PHIU          WXU        WYU        WZU        PHEU       PWXU       PWYU       PWZU      CPLINU     CPSLNU     CP2NDU     CPISNU
 PHIL          WXL        WYL        WZL        PHEL       PWXL       PWYL       PWZL      CPLINL     CPSLNL     CP2NDL     CPISNL
  WNU          WNL        WTU        WTL        PHIUI      PHILI      PWNU       PWNL      CPLIND     CPSLND     CP2NDD     CPISND


 3     1      .1000      .0043     0.0000      .0299      .0736      .2974     0.0000     0.0000      .9397     0.0000      .3420
  .1120     1.0970     -.0131      .0000      .0181      .1573     -.0131     -.3420     -.0963     -.2373     -.2388     -.2345
  .0822      .8983      .0605      .0000     -.0118     -.0414      .0605     -.3420      .4872      .3892      .3512      .3397
  .0000      .0000     1.0971      .9003      .1618      .1319     -.3420     -.3420     -.5836     -.6265     -.5900     -.5742

 4     2      .1000      .0115     0.0000      .0290      .1700      .3057     0.0000     0.0000      .9397     0.0000      .3420
  .1119     1.0973     -.0158      .0000      .0180      .1576     -.0158     -.3420     -.0973     -.2384     -.2399     -.2356
  .0829      .8930      .1542      .0000     -.0111     -.0466      .1542     -.3420      .5025      .3855      .3450      .3318
  .0000      .0000     1.0974      .9063      .1613      .1323     -.3420     -.3420     -.5998     -.6238     -.5849     -.5673

 5     3      .1000      .0162     0.0000      .0280      .2731      .3205     0.0000     0.0000      .9397     0.0000      .3420
  .1118     1.0994     -.0368      .0000      .0179      .1597     -.0368     -.3420     -.1035     -.2463     -.2480     -.2434
  .0838      .8853      .2363      .0000     -.0102     -.0544      .2363     -.3420      .5254      .3779      .3337      .3175
  .0000      .0000     1.1000      .9163      .1608      .1328     -.3420     -.3420     -.6289     -.6241     -.5817     -.5609

 6     4      .1000      .0198     0.0000      .0268      .4091      .3456     0.0000     0.0000      .9397     0.0000      .3420
  .1116     1.1055     -.0852      .0000      .0177      .1658     -.0852     -.3420     -.1212     -.2714     -.2738     -.2683
  .0848      .8745      .3239      .0000     -.0092     -.0652      .3239     -.3420      .5570      .3626      .3129      .2924
  .0000      .0000     1.1087      .9326      .1602      .1334     -.3420     -.3420     -.6782     -.6340     -.5867     -.5618

 7     5      .1000      .0234     0.0000      .0250      .6313      .3947     0.0000     0.0000      .9397     0.0000      .3420
  .1112     1.1182     -.1714      .0000      .0172      .1785     -.1714     -.3420     -.1586     -.3342     -.3383     -.3302
  .0862      .8545      .4600      .0000     -.0078     -.0852      .4600     -.3420      .6158      .3188      .2581      .2286
  .0000      .0000     1.1312      .9704      .1594      .1343     -.3420     -.3420     -.7744     -.6530     -.5964     -.5568

 8     6      .1000      .0270     0.0000      .0222     1.1258      .5225     0.0000     0.0000      .9397     0.0000      .3420
  .1104     1.1444     -.3226      .0000      .0165      .2047     -.3226     -.3420     -.2355     -.4928     -.5016     -.4840
  .0882      .7953      .8032      .0000     -.0058     -.1444      .8032     -.3420      .7896      .0705     -.0292     -.0847
  .0000      .0000     1.1890     1.1303      .1579      .1357     -.3420     -.3420    -1.0252     -.5633     -.4724     -.3953

11     7      .3000      .0129     0.0000      .0869      .0626      .2786     0.0000     0.0000      .9397     0.0000      .3420
  .3334     1.0892     -.0079      .0000      .0515      .1495     -.0079     -.3420     -.0734     -.2122     -.2130     -.2095
  .2465      .9030      .0547      .0000     -.0354     -.0367      .0547     -.3420      .4733      .3749      .3391      .3282
  .0000      .0000     1.0892      .9047      .4839      .3970     -.3420     -.3420     -.5466     -.5871     -.5521     -.5376

12     8      .3000      .0345     0.0000      .0846      .1605      .2875     0.0000     0.0000      .9397     0.0000      .3420
  .3332     1.0897     -.0120      .0000      .0513      .1500     -.0120     -.3420     -.0749     -.2139     -.2148     -.2112
  .2486      .8576      .1485      .0000     -.0333     -.0421      .1485     -.3420      .4892      .3729      .3346      .3220
  .0000      .0000     1.0898      .9098      .4828      .3982     -.3420     -.3420     -.5641     -.5868     -.5494     -.5332

13     9      .3000      .0485     0.0000      .0817      .2569      .3019     0.0000     0.0000      .9397     0.0000      .3420
  .3329     1.0917     -.0303      .0000      .0510      .1520     -.0303     -.3420     -.0808     -.2212     -.2222     -.2184
  .2512      .8900      .2265      .0000     -.0307     -.0497      .2265     -.3420      .5116      .3676      .3257      .3115
  .0000      .0000     1.0921      .9184      .4813      .3996     -.3420     -.3420     -.5924     -.5888     -.5479     -.5288

14    10      .3000      .0593     0.0000      .0783      .3853      .3263     0.0000     0.0000      .9397     0.0000      .3420
  .3324     1.0975     -.0757      .0000      .0505      .1578     -.0757     -.3420     -.0979     -.2445     -.2461     -.2415
  .2541      .8795      .3097      .0000     -.0278     -.0602      .3097     -.3420      .5422      .3559      .3088      .2896
  .0000      .0000     1.1001      .9324      .4796      .4013     -.3420     -.3420     -.6401     -.6004     -.5549     -.5311
```

40 PHYSICAL QUANTITIES PRINTOUT

Normal and tangential components of total
Mass flux vector*
Normal component of perturbation mass flux vector*
Pressure coefficient*

Quantities starred are listed for both the upper and lower surfaces of the network. Four different pressure formulas are used for the pressure coefficient:

$$C_p = -2u \text{ (Linearized)} \tag{16}$$

$$C_p = -2u - v^2 - w^2 \text{ (Slender Body)} \tag{17}$$

$$C_p = -2u - (1 - M_\infty^2)\, u^2 - v^2 - w^2 \text{ (Second Order)} \tag{18}$$

$$C_p = \frac{2}{\gamma M_\infty^2} \left\{ \left[1 - \frac{\gamma - 1}{2} M_\infty^2 (2u + u^2 + v^2 + w^2) \right]^{\frac{\gamma}{\gamma - 1}} - 1 \right\} \text{ (Isentropic)} \tag{19}$$

Here (u,v,w) is the perturbation velocity vector, referred to the compressibility axis which is aligned with the freestream vector. Also listed are the differences in the four pressure coefficients across the network (upper surface value minus lower), the control point label, the panel label, the control point coordinates, and the components of the freestream velocity. The results for each network are followed by summaries of the forces and moments similar to those shown in Figure 39 and described in the previous section. In addition to the total forces for the network, forces and moments are also given for each column of the network.

6.2.3 Free and Fed Sheet Printer Plots (OPTIONAL, IPLOTP= 1)

When IPLOTP=1 (Card 18) printer plots of the updated free and fed sheet are produced. These plots have been illustrated in Figure 33 and are discussed in section 6.1.1.

6.2.4 Variables, Residuals, and Corrections (OPTIONAL, ITVRCP=1)

When ITVRCP=1 (Card 18) values of the program variables, the residuals at each control point, and corrections for the iteration are listed. These data are organized by type and by network. Figure 41 illustrates a partial printout of these quantities. The singularity strengths, the corrections to these strengths, and the associated residuals are ordered by control point order. See section 5.2.4 on network types and uses for proper ordering. The orientation angles, corrections and associated residuals are ordered one per panel and are given in degrees. Geometry parameters lamda and nu, corrections, and residuals are ordered by free/fed sheet column. Note that the residuals are identified as to type and that the sum of the squares of the residuals is given for each network.

```
                                                        /CORRECTIONS/

  SINGULARITY STRENGTH

    (NETWORK NO.  1)
 -.2498E-14  -.1730E-02  -.1806E-02  -.2176E-02  -.2137E-02  -.1503E-02  -.6581E-03  -.1614E-03  -.7312E-04  -.5255E-02
 -.5495E-02  -.6653E-02  -.6624E-02  -.4761E-02  -.2202E-02  -.7119E-03  -.4794E-03  -.8517E-02  -.8913E-02  -.1081E-01
 -.1082E-01  -.7844E-02  -.3673E-02  -.1224E-02  -.8118E-03  -.1134E-01  -.1186E-01  -.1439E-01  -.1450E-01  -.1076E-01
 -.5436E-02  -.2245E-02  -.1651E-02  -.1340E-01  -.1404E-01  -.1721E-01  -.1806E-01  -.1526E-01  -.1062E-01  -.7135E-02
 -.6164E-02  -.1365E-01  -.1436E-01  -.1793E-01  -.1980E-01  -.2517E-01  -.2853E-01  -.1408E-01  -.1054E-01

    (NETWORK NO.  2)
  .1365E-01   .1357E-01   .1342E-01   .1436E-01   .1429E-01   .1420E-01   .1793E-01   .1801E-01   .1781E-01   .1908E-01
  .1974E-01   .1894E-01   .2517E-01   .3128E-01   .3555E-01   .2853E-01   .3886E-01   .4989E-01   .1488E-01   .1854E-01
  .2224E-01   .1054E-01   .1321E-01   .1575E-01



    (NETWORK NO.  9)
  .3140E-02

  PANEL ORIENTATION ANGLE  (NETWORK NO.  4)
  .4031E+01   .3517E+01   .1385E+01   .2559E+00  -.4067E+00  -.8076E+00  -.8367E+00  -.1317E+01   .5125E+01   .3809E+01
  .1054E+01  -.7569E-01  -.7748E+00  -.1108E+01  -.8820E+00  -.1145E+01   .4556E+01   .3463E+01   .1176E+01   .6090E-01
 -.6790E+00  -.1138E+01  -.9784E+00  -.1157E+01   .5379E+01   .3276E+01   .4729E+00  -.2398E+00  -.6972E+00  -.1054E+01
 -.1025E+01  -.1090E+01   .6212E+01   .2966E+01  -.4099E-01  -.8099E+00  -.1047E+01  -.1162E+01  -.9640E+00  -.5998E+00

  GEOMETRY - LAMBDA AND NU  (NETWORK NO.  4 AND  5)
 -.7429E-02  -.2605E-01  -.7668E-02  -.2290E-01  -.6965E-02  -.2053E-01  -.8925E-02  -.1078E-01  -.5079E-03  -.2741E-01

  PANEL ORIENTATION ANGLE  (NETWORK NO.  6)
  .1927E+01   .3093E+01  -.1062E+01   .3724E-01  -.1282E+00  -.2201E+01  -.6752E-01  -.2424E+00  -.1546E+00   .3751E+01
 -.2746E+01  -.5350E+01   .6388E+01  -.3084E+01  -.1632E+01   .2771E+01

  GEOMETRY - LAMBDA AND NU  (NETWORK NO.  6 AND  7)
  .6580E-02  -.4501E-01   .1603E-01  -.8196E-01




                                                   ITERATION NO.  3

SUM OF SQUARES OF RESIDUALS (SSR) =   .258462E+00
NO. OF FUNCTION CALLED =   5
FRACTION OF NEWTON STEP TAKEN =   .100000E+01
STEP SIZE (LENGTH OF CORRECTION VECTOR) =   .185417E+02


                                                 /VALUES OF VARIABLES/

  SINGULARITY STRENGTH

    (NETWORK NO.  1)
  .9171E-15   .4352E-01   .4392E-01   .4615E-01   .4967E-01   .5358E-01   .5704E-01   .5848E-01   .5778E-01   .1228E+00
  .1230E+00   .1292E+00   .1394E+00   .1510E+00   .1614E+00   .1657E+00   .1636E+00   .1914E+00   .1929E+00   .2027E+00
  .2190E+00   .2378E+00   .2546E+00   .2617E+00   .2585E+00   .2489E+00   .2509E+00   .2641E+00   .2860E+00   .3110E+00
  .3337E+00   .3436E+00   .3398E+00   .2867E+00   .2890E+00   .3043E+00   .3294E+00   .3576E+00   .3841E+00   .3975E+00
  .3947E+00   .2931E+00   .2949E+00   .3066E+00   .3260E+00   .3392E+00   .3654E+00   .3982E+00   .4095E+00

    (NETWORK NO.  2)
 -.2931E+00  -.2935E+00  -.2932E+00  -.2949E+00  -.2947E+00  -.2946E+00  -.3066E+00  -.3036E+00  -.3013E+00  -.3260E+00
 -.3185E+00  -.3137E+00  -.3392E+00  -.3230E+00  -.3893E+00  -.3654E+00  -.3491E+00  -.3330E+00  -.3982E+00  -.3930E+00
 -.3886E+00  -.4075E+00  -.4001E+00  -.4053E+00
```

FIGURE 41 CORRECTIONS, VARIABLES, AND RESIDUALS

```
   (NETWORK NO.  9)
-.3703E+00


 PANEL ORIENTATION ANGLE  (NETWORK NO.  4)
 .6271E+02   .8589E+02   .9774E+02   .1079E+03   .1207E+03   .1344E+03   .1506E+03   .1696E+03   .6522E+02   .8697E+02
 .9779E+02   .1086E+03   .1203E+03   .1339E+03   .1501E+03   .1691E+03   .6370E+02   .8593E+02   .9808E+02   .1090E+03
 .1206E+03   .1340E+03   .1501E+03   .1691E+03   .6545E+02   .8401E+02   .9600E+02   .1077E+03   .1199E+03   .1330E+03
 .1490E+03   .1691E+03   .6665E+02   .8290E+02   .9389E+02   .1053E+03   .1180E+03   .1325E+03   .1494E+03   .1691E+03


 GEOMETRY - LAMBDA AND NU  (NETWORK NO.  4 AND  5)
 .6810E+00   .9640E+00   .6684E+00   .9675E+00   .6718E+00   .9678E+00   .6796E+00   .9703E+00   .7208E+00   .9711E+00


 PANEL ORIENTATION ANGLE  (NETWORK NO.  6)
 .8857E+02   .7824E+02   .9816E+02   .1050E+03                                     .1502E+03   .1706E+03   .6375E+02   .6780E+02

                                                    /RESIDUALS/

IMPERMEABLE B.C. AND KUTTA CONDITION FOR NETWORK NO.  1              (SSR =   .1506E-01)

0.          0.          -.2999E-02   .1565E-01   .4283E-01   .2515E-01  -.1293E-01  -.2332E-01   .5537E-02  0.
-.3065E-02   .1499E-01   .4247E-01   .2628E-01  -.1174E-01  -.2203E-01   .6529E-02  0.          -.2653E-02   .1451E-01
 .4091E-01   .2577E-01  -.1092E-01  -.2189E-01   .6590E-02  0.          -.1034E-02   .1392E-01   .3709E-01   .2275E-01
-.1024E-01  -.2007E-01   .6004E-02  -.1421E-13  -.2100E-03   .1523E-01   .3483E-01   .2017E-01  -.9600E-02  -.1912E-01
 .4712E-02  0.          -.3553E-14  0.          0.           .3553E-14  -.1776E-14   .3553E-14  0.

ZERO PRESSURE JUMP B.C. AND KUTTA CONDITION FOR NETWORK NO.  2      (SSR =   .1507E+00)

-.3553E-14  -.7105E-14   .7105E-14  -.5329E-14  -.7247E-03  -.7390E-03  -.5329E-14  -.6605E-02  -.5921E-02  -.7105E-14
-.8151E-01  -.9117E-01  -.8882E-14  -.2450E+00  -.2030E+00  -.7105E-14  -.3302E-01  -.3656E-01  -.5329E-14   .2802E-01
 .1943E-01  0.          -.3867E-03   .1262E-03

IMPERMEABLE B.C. AND KUTTA CONDITION FOR NETWORK NO.  3              (SSR =   .1073E-27)

-.3553E-14  -.3553E-14  -.3553E-14  -.3553E-14  -.7105E-14  0.                .1776E-14  -.1776E-14

ZERO PRESSURE JUMP B.C. AND KUTTA CONDITION FOR NETWORK NO.  4      (SSR =   .6754E-01)

 .5996E-16   .3553E-14  -.2154E-01  -.5423E-01  -.5080E-01  -.4103E-01  -.3378E-01  -.3419E-01  -.5612E-01  -.8573E-01
 .8882E-14  -.2162E-01  -.5748E-01  -.5019E-01  -.4167E-01  -.3371E-01  -.3341E-01  -.5626E-01  -.8308E-01  -.5329E-14
-.1667E-01  -.5296E-01  -.4524E-01  -.3745E-01  -.3017E-01  -.2895E-01  -.5054E-01  -.7386E-01   .1776E-14  -.1017E-01
-.4006E-01  -.3084E-01  -.2350E-01  -.1766E-01  -.1710E-01  -.3540E-01  -.5376E-01   .5329E-14  -.1063E-01  -.2662E-01
-.1824E-01  -.1196E-01  -.6306E-02  -.5857E-02  -.1809E-01  -.2745E-01



IMPERMEABLE B.C. AND KUTTA CONDITION FOR NETWORK NO.  9              (SSR =   .3155E-29)

 .1776E-14

IMPERMEABLE B.C. FOR NETWORK NO.  4                                  (SSR =   .9528E-03)

-.7128E-02  -.4464E-02  -.7837E-02  -.7589E-02  -.4021E-02   .9164E-03   .1375E-02   .4620E-02  -.5821E-02  -.3022E-02
-.6996E-02  -.6979E-02  -.3092E-02   .2402E-02   .1391E-02   .2397E-02  -.5875E-02  -.4383E-02  -.6803E-02  -.6556E-02
-.2279E-02   .4020E-02   .3122E-02   .3004E-02  -.6365E-02  -.5349E-02  -.7192E-02  -.6726E-02  -.2646E-02   .3380E-02
 .3105E-02   .2782E-02  -.6258E-02  -.5807E-02  -.6825E-02  -.6010E-02  -.2617E-02   .1915E-02   .1169E-02  -.3013E-03

IMPERMEABLE B.C. FOR NETWORK NO.  6                                  (SSR =   .3792E-02)

-.1895E-01  -.2236E-01  -.1556E-01  -.1645E-01  -.8558E-02   .4873E-02   .3126E-02   .9967E-02  -.1643E-01  -.2501E-01
 .4794E-02  -.5395E-02  -.3000E-01   .9809E-02   .1140E-01   .7062E-02

FORCE B.C. FOR NETWORK NO.  5                                        (SSR =   .7565E-03)

 .1079E-01  -.4501E-02   .1193E-01  -.4459E-02   .1098E-01  -.3902E-02   .1106E-01  -.3621E-02   .1264E-01  -.5092E-02

FORCE B.C. FOR NETWORK NO.  7                                        (SSR =   .1040E-03)

-.1321E-02  -.3074E-02  -.8771E-02  -.3330E-02
```

FIGURE 41 CONCLUDED

6.3 Diagnostic Printouts

In this section the various optional diagnostic printouts will be briefly described. These printouts were used in the early program development and are as such not much use to the typical user.

6.3.1 Geometry Data (OPTIONAL, IGEOMP=1)

An alternate form of the geometry data is printed when IGEOMP=1, (Card 19). An example of this printout is shown in Figure 42. The program lists the coordinates of all grid points along with its number, row number, column number, and network number. Panel data is also included listing panel number.

6.3.2 Singularity Distribution Definitions (OPTIONAL, ISINGP=1)

Panel distribution quantities shown in Figure 43 are printed when ISINGP=1 (Card 19). This printout lists the singularity parameter numbers and coefficients for the nine canonical points on each panel. Refer to Appendix B, Volume I - Theory Document, for further discussion of these parameters.

6.3.3 Control Point Data (OPTIONAL, ICONTP=1)

Control point data, shown in Figure 44, are printed when ICONTP=1 (Card 19). These data list the control point index, network number of control point, panel number of control point, side number of edge control point, control point index along an edge, edge control point characterization, global coordinates of control point, and upper surface normal at control point.

6.3.4 Edge Control Point Data (OPTIONAL, IEDGEP=1)

Edge control point data, shown in Figure 45, are printed when IEDGEP=1 (Card 19). These data list the edge control point index, panel number of control point, influencing panel number, side of influencing panel, and global coordinates of control point.

6.3.5 Singularity Grid Data (OPTIONAL, ISINGS=1)

Singularity grid data, shown in Figure 46, is printed when ISINGS=1 (Card 19). The program prints out the source strength, the doublet strength, and the components of the surface vorticity vector along the row and column directions and in direction normal thereto as well as along the global coordinate axis. This is done for the nine canonical points: the four corners, the mid points of each side, and the panel center. These data are useful in checking the continuity of the doublet strength from one network to another. Data are organized by network.

6.3.6 Elapsed CPU Time (OPTIONAL, IPTIME=1)

When IPTIME=1 (Card 18), the program prints the elapsed CPU time from various programs and subroutines.

```
                                        GEOMETRY DATA


                                       MESH POINT DATA

NUMBER     ROW    COLUMN   NET. NO.        X                    Y                    Z

   1        1       1         1      0.0000000000         0.0000000000         0.0000000000
   2        2       1         1      0.0000000000         0.0000000000         0.0000000000
   3        3       1         1      0.0000000000         0.0000000000         0.0000000000
   4        4       1         1      0.0000000000         0.0000000000         0.0000000000
   5        5       1         1      0.0000000000         0.0000000000         0.0000000000
   6        6       1         1      0.0000000000         0.0000000000         0.0000000000
   7        7       1         1      0.0000000000         0.0000000000         0.0000000000
   8        1       2         1       .2000000000         0.0000000000         0.0000000000
   9        2       2         1       .2000000000          .0172500000         0.0000000000
  10        3       2         1       .2000000000          .0287500000         0.0000000000
  11        4       2         1       .2000000000          .0359375000         0.0000000000
  12        5       2         1       .2000000000          .0431250000         0.0000000000
  13        6       2         1       .2000000000          .0503125000         0.0000000000
  14        7       2         1       .2000000000          .0575000000         0.0000000000
  15        1       3         1       .4000000000         0.0000000000         0.0000000000
  16        2       3         1       .4000000000          .0345000000         0.0000000000
```

FIGURE 42 MESH POINT DATA

```
                         SINGULARITY DISTRIBUTION DEFINITION



                           PANEL DISTRIBUTION QUANTITIES


     IS - SINGULARITY PARAMETER NO.
 A1...A9 - COEFFICIENTS FOR THE 9 CANONICAL PANEL LOCATIONS


PANEL NO. =    1     NETWORK NO. =    1     DISTRIBUTION ORDER =    2     NUMBER OF SINGULARITY PARAMETERS =   12

 IS       A1          A2          A3          A4          A5          A6          A7          A8          A9

   1   .10000E+01 -.41096E-01 -.58065E-01  .10000E+01 0.          -.85571E-01 -.29138E-16  .10000E+01 0.
   2  0.           .45205E+00 -.54246E-02 0.           .10000E+01  .49728E-02 -.26909E-02 0.          0.
   3  0.          0.           .14668E+00 0.          0.           .53159E+00  .40235E+00 0.           .10000E+01
   4  0.          0.           .34868E+00 0.          0.          -.11156E-02  .60335E+00 0.          0.
   5  0.          0.          -.60603E-02 0.          0.          0.          -.30063E-02 0.          0.
  10  0.           .69863E+00 -.48822E-01 0.          0.           .27273E-01 -.12806E-01 0.          0.
  11  0.          0.           .34804E+00 0.          0.           .59667E+00  .12171E-01 0.          0.
  12  0.          0.           .43275E+00 0.          0.           .19097E-01  .13435E-01 0.          0.
  13  0.          0.          -.54543E-01 0.          0.          0.          -.12799E-01 0.          0.
  18  0.          -.10959E+00 0.          0.          0.          -.10017E-01 0.          0.          0.
  19  0.          0.          -.51613E-01 0.          0.          -.76063E-01 0.          0.          0.
  20  0.          0.          -.51613E-01 0.          0.          -.68302E-02 0.          0.          0.

PANEL NO. =    2     NETWORK NO. =    1     DISTRIBUTION ORDER =    2     NUMBER OF SINGULARITY PARAMETERS =   14

 IS       A1          A2          A3          A4          A5          A6          A7          A8          A9

   1   .10000E+01 -.58065E-01 -.58065E-01  .10000E+01 -.29136E-16 -.85425E-01 -.30840E-14  .10000E+01 0.
   2  0.          -.54246E-02 0.          0.          -.26909E-02 0.          0.          0.          0.
   3  0.           .14668E+00 -.26362E-02 0.           .40235E+00 -.49277E-03 -.19255E-02 0.          0.
   4  0.           .34868E+00  .13254E+00 0.           .60335E+00  .53091E+00  .38899E+00 0.           .10000E+01
   5  0.          -.60603E-02  .35409E+00 0.          -.30063E-02  .47507E-02  .61361E+00 0.          0.
   6  0.          0.          -.91869E-03 0.          0.          0.          -.67100E-03 0.          0.
  10  0.          -.48822E-01 0.          0.          -.12806E-01 0.          0.          0.          0.
  11  0.           .34804E+00 -.23726E-01 0.           .12171E-01  .19898E-01 -.44970E-02 0.          0.
  12  0.           .43275E+00  .35412E+00 0.           .13435E-01  .59638E+00  .70071E-02 0.          0.
  13  0.          -.54543E-01  .35530E+00 0.          -.12799E-01  .26940E-01  .32207E-02 0.          0.
  14  0.          0.          -.82682E-02 0.          0.          0.          -.57308E-02 0.          0.
  19  0.          -.51613E-01 0.          0.          0.          -.71435E-02 0.          0.          0.
  20  0.          -.51613E-01 -.51613E-01 0.          0.          -.75934E-01 0.          0.          0.
  21  0.          0.          -.51613E-01 0.          0.          -.98883E-02 0.          0.          0.
```

FIGURE 43 SINGULARITY DISTRIBUTION DEFINITION DATA

```
                                        CONTROL POINT DATA



                                 CONTROL POINT LOCATIONS AND NORMALS

        JCN - CONTROL POINT INDEX (INCLUDING THOSE USED FOR FORCE CALCULATION
         KC - NETWORK NO. OF CONTROL POINT
        IPC - PANEL NO. OF CONTROL POINT
        ISC - SIDE NO. OF EDGE CONTROL POINT
        IZC - CONTROL POINT INDEX ALONG AN EDGE
        ICH - EDGE CONTROL POINT CHARACTERIZATION
              =0  REAL
              =1  DOUBLET VALUE MATCHING
              =2  DOUBLET NORMAL DERIVATIVE MATCHING
              =3  DOUBLET TANGENTIAL DERIVATIVE MATCHING
      X,Y,Z - GLOBAL COORDINATES OF CONTROL POINT
   NX,NY,NZ - UPPER SURFACE NORMAL AT CONTROL POINT (IN GLOBAL COORDINATES)


 JCN    KC    IPC    ISC    IZC    ICH        X            Y            Z            NX           NY           NZ

   1     1      6      3      7      1     -.000000     0.000000     0.000000     0.000000     0.000000     1.000000
   2     1      1      1      2      2      .100000     0.000000     0.000000     0.000000     0.000000     1.000000
   3     1      1      0      0      0      .100000      .004313     0.000000     0.000000     0.000000     1.000000
   4     1      2      0      0      0      .100000      .011500     0.000000     0.000000     0.000000     1.000000
   5     1      3      0      0      0      .100000      .016172     0.000000     0.000000     0.000000     1.000000
   6     1      4      0      0      0      .100000      .019766     0.000000     0.000000     0.000000     1.000000
   7     1      5      0      0      0      .100000      .023359     0.000000     0.000000     0.000000     1.000000
   8     1      6      0      0      0      .100000      .026953     0.000000     0.000000     0.000000     1.000000
   9     1      6      3      6      2      .100000      .028750     0.000000     0.000000     0.000000     1.000000
  10     1      7      1      3      2      .300000     0.000000     0.000000     0.000000     0.000000     1.000000
  11     1      7      0      0      0      .300000      .012538     0.000000     0.000000     0.000000     1.000000
  12     1      8      0      0      0      .300000      .034500     0.000000     0.000000     0.000000     1.000000
  13     1      9      0      0      0      .300000      .048516     0.000000     0.000000     0.000000     1.000000
  14     1     10      0      0      0      .300000      .059297     0.000000     0.000000     0.000000     1.000000
  15     1     11      0      0      0      .300000      .070078     0.000000     0.000000     0.000000     1.000000
  16     1     12      0      0      0      .300000      .080659     0.000000     0.000000     0.000000     1.000000
  17     1     12      3      5      2      .300000      .086250     0.000000     0.000000     0.000000     1.000000


 192     7    117      0      0      0     1.075000      .212122      .232052      .000400      .970317     -.241835
 193     7    118      0      0      0     1.075000      .198091      .175755     -.010926      .970260     -.241820
 194     7    118      3      2      0     1.075000      .191075      .147607     -.016588      .970184     -.241802


 NF (NUMBER OF SINGULARITY STRENGTH PARAMETERS) = 173

 NG (NUMBER OF PANEL ORIENTATION ANGLES) =  56

 NH (NUMBER OF GEOMETRY PARAMETERS - LAMBDA AND NU) =  14
```

FIGURE 44 CONTROL POINT DATA

```
                                                              EDGE CONTROL POINT DATA

          JC - EDGE CONTROL POINT INDEX
         IPC - PANEL NO. OF CONTROL POINT
          IP - INFLUENCING PANEL NO.
          IS - SIDE NO. OF INFLUENCING PANEL
    ZX,ZY,ZZ - GLOBAL COORDINATES OF CONTROL POINT


JC    IPC    IP  IS        ZX               ZY             ZZ
  2     1     1    1  .10000000E+00 0.               0.

JC    IPC    IP  IS        ZX               ZY             ZZ
  1     6     6    3 -.44408921E-15 0.               0.

JC    IPC    IP  IS        ZX               ZY             ZZ
  9     6     6    3  .10000000E+00  .28750000E-01 0.

JC    IPC    IP  IS        ZX               ZY             ZZ
 10     7     7    1  .30000000E+00 0.               0.

JC    IPC    IP  IS        ZX               ZY             ZZ
  1     6    49    1 -.44408921E-15 0.               0.

JC    IPC    IP  IS        ZX               ZY             ZZ
  9     6    49    1  .10000000E+00  .28750000E-01 0.

JC    IPC    IP  IS        ZX               ZY             ZZ
 17    12    12    3  .30000000E+00  .86250000E-01 0.

JC    IPC    IP  IS        ZX               ZY             ZZ
 18    13    13    1  .50000000E+00 0.               0.

JC    IPC    IP  IS        ZX               ZY             ZZ
 25    18    18    3  .50000000E+00  .14375000E+00 0.

JC    IPC    IP  IS        ZX               ZY             ZZ
 26    19    19    1  .70000000E+00 0.               0.

JC    IPC    IP  IS        ZX               ZY             ZZ
 17    12    57    1  .30000000E+00  .86250000E-01 0.
```

FIGURE 45 EDGE CONTROL POINT DATA

```
         IP - PANEL NO.
        I,J - ROW AND COLUMN INDICES OF THE 9 CANONICAL POINTS
      X,Y,Z - GLOBAL COORDINATES OF THE GIVEN POINT
         SO - SOURCE SINGULARITY STRENGTH
         DO - DOUBLET SINGULARITY STRENGTH
   DX,DY,DZ - VORTICITY COMPONENTS IN X,Y,Z DIRECTIONS
      DM,DN - VORTICITY COMPONENTS IN M,N DIRECTIONS
    DMP,DNP - VORTICITY COMPONENTS IN DIRECTIONS PERPENDICULAR TO M,N


NETWORK NO. =   1     NETWORK TYPE =   2


                                                    SINGULARITY GRID

IP  I  J       X         Y         Z        SO         DO        DX         DY        DZ         DM        DN        DMP        DNP


  1  1  1   0.00000   0.00000   0.00000   0.00000    .00000   -.00000    .30504   0.00000   0.00000   -.00000   0.00000    .30504
  1  2  1   0.00000   0.00000   0.00000   0.00000    .00000   -.00000    .30340   0.00000   0.00000    .01307   0.00000    .30312
  1  3  1   0.00000   0.00000   0.00000   0.00000    .00000   -.00000    .29802   0.00000   0.00000    .02561   0.00000    .29692
  1  1  2    .10000   0.00000   0.00000   0.00000    .03004   0.00000    .29579   0.00000    .29579   0.00000   -.00000    .29579
  1  2  2    .10000    .00431   0.00000   0.00000    .02988    .07358    .29744   0.00000    .29744    .08632   -.07358    .29399
  1  3  2    .10000    .00863   0.00000   0.00000    .02941    .14715    .30281   0.00000    .30281    .17263   -.14715    .29905
  1  1  3    .20000   0.00000   0.00000   0.00000    .05916    .00507    .28653   0.00000    .28653    .00507   -.00507    .28653
  1  2  3    .20000    .00863   0.00000   0.00000    .05865    .06574    .28796   0.00000    .28796    .07609   -.06574    .28486
  1  3  3    .20000    .01725   0.00000   0.00000    .05802    .12642    .29312   0.00000    .29312    .15114   -.12642    .28117

  2  1  1   0.00000   -.00000   0.00000   0.00000    .00000    .00000    .29802   0.00000   0.00000    .02561   0.00000    .29692
  2  2  1   0.00000   0.00000   0.00000   0.00000    .00000    .00000    .29457   0.00000   0.00000    .03365   0.00000    .29264
  2  3  1   0.00000   -.00000   0.00000   0.00000    .00000    .00000    .28807   0.00000   0.00000    .04099   0.00000    .28514
  2  1  2    .10000    .00862   0.00000   0.00000    .02941    .08804    .29771   0.00000    .29771    .11330   -.08804    .28905
  2  2  2    .10000    .01150   0.00000   0.00000    .02904    .16996    .30570   0.00000    .30570    .20378   -.16996    .28428
  2  3  2    .10000    .01438   0.00000   0.00000    .02843    .25189    .31673   0.00000    .31673    .29439   -.25189    .27767
  2  1  3    .20000    .01725   0.00000   0.00000    .05802    .10867    .29159   0.00000    .29159    .13332   -.10867    .28117
  2  2  3    .20000    .02300   0.00000   0.00000    .05723    .16686    .29694   0.00000    .29694    .19969   -.16686    .27593
  2  3  3    .20000    .02875   0.00000   0.00000    .05610    .22505    .30533   0.00000    .30533    .26620   -.22505    .27020

  3  1  1   -.00000   -.00000   0.00000   0.00000    .00000   -.00000    .28807   0.00000   0.00000    .04099   0.00000    .28514
  3  2  1   0.00000   0.00000   0.00000   0.00000    .00000   -.00000    .28408   0.00000   0.00000    .04535   0.00000    .26044
  3  3  1   -.00000   -.00000   0.00000   0.00000    .00000   -.00000    .27794   0.00000   0.00000    .04915   0.00000    .27355
  3  1  2    .10000    .01438   0.00000   0.00000    .02843    .18064    .30649   0.00000    .30649    .22241   -.18064    .27767
  3  2  2    .10000    .01617   0.00000   0.00000    .02802    .27310    .32053   0.00000    .32053    .32077   -.27310    .27281
  3  3  2    .10000    .01797   0.00000   0.00000    .02745    .36556    .33672   0.00000    .33672    .41935   -.36556    .26676
  3  1  3    .20000    .02875   0.00000   0.00000    .05610    .19940    .30164   0.00000    .30164    .24029   -.19940    .27020
  3  2  3    .20000    .03234   0.00000   0.00000    .05527    .26417    .31136   0.00000    .31136    .31048   -.26417    .26519
  3  3  3    .20000    .03594   0.00000   0.00000    .05421    .32893    .32323   0.00000    .32323    .38091   -.32893    .25996
```

FIGURE 46 SINGULARITY GRID DATA

6.3.7 Near Field/Far Field Information (OPTIONAL, IPNPIC=1)

When IPNPIC=1 (Card 18) program VINFCC prints a table of panel influence coefficients count for source and doublet. The counts are listed separately for no influence, monopole far field, dipole far field, quadrupole far field, one subpanel intermediate field, two subpanel intermediate field, and eight subpanel near field.

6.3.8 Out-of-Core Solver Information (OPTIONAL, IPSOLV=1)

When IPSOLV=1 (Card 18), the PTSOLV solution package prints a description of the problem being solved and an error analysis report.

6.4 TAPE14 Save File

A data file is set up on TAPE14 which can be used for post processing or for a solution restart. Network mesh point data is generated during a data check which can be used for post processing graphics. The user must provide his own interface and graphics software. During the iterative solution network and singularity data necessary for a solution restart are saved. Section 7.3 describes the file usage. The TAPE14 format is given in Table 5.

TABLE 4 DEFINITION OF OUTPUT QUANTITIES

QUANTITY	DEFINITION	WHEN PRINTED
	Physical Quantities	Every ITPRINT iteration, initial solution, final iteration
JC	Cumulative control point index	
IP	Index of panel containing control point	
(X,Y,Z)	Global coordinates of control point	
DO	Doublet strength	
(DX,DY,DZ)	Global Coordinates of surface vorticity vector	
SO	Source strength	
(FSVX,FSVY, FSVZ)	Freestream velocity vector in global coordinates	
PHIU	Upper surface total potential	
(WXU,WYU, WZU)	Upper surface total mass flux vector in global coordinates	
PHEU	Upper surface perturbation potential	
(PWXU,PWYU, PWZU)	Upper surface perturbation mass flux vector in global coordinates	
CPLINU	Upper surface linearized pressure coefficient	
CPSLNU	Upper surface slender body pressure coefficient	
CPSLNDU	Upper surface second order pressure coefficient	
CPI2NU	Upper surface isentropic pressure coefficient	
PHIL	Lower surface total potential	
(WXL,WYL, WZL)	Lower surface totol mass flux vector in global coordinates	
PHEL	Lower surface perturbation potential	
(PWXL,PWYL, PWZL)	Lower surface perturbation mass flux vector in global coordinates	
CPLINL	Lower surface linearized pressure coefficient	
CPSLNL	Lower surface slender body pressure coefficient	
CP2NDL	Lower surface second order pressure coefficient	
CPISNL	Lower surface isentropic pressure coefficient	
WNU	Normal component of upper surface total mass flux vector	
WNL	Normal component of lower surface total mass flux vector	
WTU	Magnitude of tangential component of upper surface total mass flux vector	
WTL	Magnitude of tangential component of lower surface total mass flux vector	
PHIUI	Upper surface total mass flux potential	
PHILI	Lower surface total mass flux potential	
PWNU	Normal component of upper surface perturbation mass flux vector	
PWNL	Normal component of lower surface perturbation mass flux vector	

TABLE 4 (CONTINUED)

QUANTITY	DEFINITION	WHEN PRINTED
CPLIND	Difference between upper and lower surface linearized pressure coefficient	
CPSLND	Difference between upper and lower surface slender body pressure coefficient	
CP2NDD	Difference between upper and lower surface second order pressure coefficient	
CPISND	Difference between upper and lower surface isentropic pressure coefficient	
	Forces and Moments Data	Always
AREA	Total area of panels	
(FX,FY,FZ)	Global coordinates of force coefficient (Upper surface, lower surface, difference)	
(MX,MU,MZ)	Moment coefficients about global principal axes (Upper surface, lower surface, difference)	
	Update Index Arrays	Always
NET	Network sequence number	
NUP	Network update index	
NAT1	Square number of network to which side 1 of NET is attached	
NAT2	Sequence number of network to which side 4 of NET is attached	
NSD1	Side of NAT1 to which side 1 of NET is attached	
NSD2	Side of NAT2 to which side 4 of NET is attached	
NCR1	Leading corner of NSD1 to which side 1 of NET is attached	
IEDGA1	Cumulative index of points on side 1 which have been assigned matching points	
IEDGA2	Cumulative index of points on side 4 which have been assigned matching points	
KEDG1	Same definition as NAT1 when NAT1 = 0	
KEDG2	Same definition as NAT2 when NAT2 = 0	
MEDG1T	Row index of point on NAT1 to which initial point on side 1 of NET is attached	
MEDG1F	Row index of point on NAT1 to which final point on side 1 of NET is attached	
MEDG2I	Row index of point on NAT2 to which initial point on side 4 of NET is attached	

TABLE 4 (CONCLUDED)

QUANTITY	DEFINITION	WHEN PRINTED
MEDG2F	Row index of point on NAT2 to which final point on side 4 of NET is attached	
MEDG1I	Column index of point on NAT1 to which initial point on side 1 of NET is attached	
NEDGIF	Column index of point on NAT1 to which final point and side 1 of NET is attached	
NEDG2I	Column index of point on NAT2 to which initial point and side 4 of NET is attached	
NEDG2F	Column index of point on NAT2 to which final point and side 4 of NET is attached	
	Singularity Grid Data (ISINGS = 1)	
S	Solution singularity parameters	
IP	Cumulative index of panel on which singularity distribution is evaluated	
I	Local row index of evaluation point	
J	Local column index of evaluation point	
(X,Y,Z)	Global coordinates of evaluation point	
SO	Source strength value at evaluation point	
DO	Doublet strength value at evaluation point	
(DX,DY,DZ)	Global coordinates of surface vorticity vector at evaluation point	
(SM,SN)	Derivative of doublet strength in (row, column) directions respectively	
(SMP,SNP)	Derivative of doublet strength in directions normal to (row, column) directions respectively	

TABLE 5 TAPE14 FORMAT

(1) When $DATA CHECK is specified, the following FORTRAN statements in program INPUT are used to save network mesh points on NSAV=TAPE14 (format 6F10.5):

```
     FNT = NNETT
     WRITE (NSAV, 1030) FNT
1030 FORMAT (6F10.5)
     DO 1070 K = 1, NNETT
     NMK = NM(K)
     NNK = NN(K)
     FM = NMK
     FN = NNK
     WRITE (NSAV, 1030) FM,FN
     DO 1060 J = 1, NNK
     JM = (J-1) * NMK + NZA(K)
     WRITE (NSAV, 1030) (ZM(1,I+JM), ZM(2,I+JM), ZM(3,I+JM), I = 1, NMK)
1060 CONTINUE
1070 CONTINUE
```

(2) When $ITERATION or $LEAST SQUARES ITERATION is specified, the network mesh points and values of singularity parameters for the current iteration (no. JT) are saved on NSAV=TAPE14 (unformatted) using the following FORTRAN statements:

```
     NNETP1 = NNETT + 1
     REWIND NSAV
     WRITE (NSAV) JT
     WRITE (NSAV) NNETT, NSNGT, NZMPT, NNETP1
     WRITE (NSAV) (NZA(I), I = 1, NNETP1)
     WRITE (NSAV) (ZM(1,J), ZM(2,J), ZM(3,J), J = 1, NZMPT)
     WRITE (NSAV) (S(I), I = 1, NSNGT)
```

7.0 COMPUTER PROGRAM DESCRIPTION

This computer program is written in the CDC FORTRAN Extended (FTN4) language for the CDC Network Operating System (NOS). It uses overlay structures and fourteen disk files which include the standard system files INPUT (TAPE5) for card reading and OUTPUT (TAPE6) for printing. The program has been checked out and run on the Langley Research Center's CDC CYBER series computers.

The computer code implements recent advances in the solution of three-dimensional flow over wings with leading edge vortex separation. It has been designed and developed for the purpose of performing numerical experiment studies with the flow model.

The code includes two iterative solution procedures: (i) Quasi-Newton scheme and (ii) Least Squares Method. The least squares procedure for damping vortex sheet geometry update instabilities was developed to alleviate the convergence problem for certain cases using the Quasi-Newton iterative scheme. It is restricted to run smaller problems (see discussion in User's Input Guide) in the present set up and takes more computational time to execute. In the future, we hope to further develop the least squares procedure so that it can be used to execute larger problems as well as taking less computational time.

7.1 Basic Program Structure

The computer program consists of one main overlay, six primary overlays, three secondary overlays and one user library. A schematic diagram of basic program structure is illustrated in Figure 47.

7.2 Description of Overlay Programs

The following is a discussion of the overlay programs. A detailed flow chart of the main overlay program A378 is shown in Figure 48.

7.2.1 OVERLAY (MAIN, 0,0)

Main	OVERLAY (MAIN, 0,0)
Program	A378
Purpose	To perform various tasks by calling the following overlay programs and subroutines:

- o Program INPUT to process the input data and set up network mesh points
- o Program CONFIG to compute panel geometry, panel singularity distribution and panel control points defining quantities
- o Program VINFCC to calculate and store induced potential and velocity coefficients

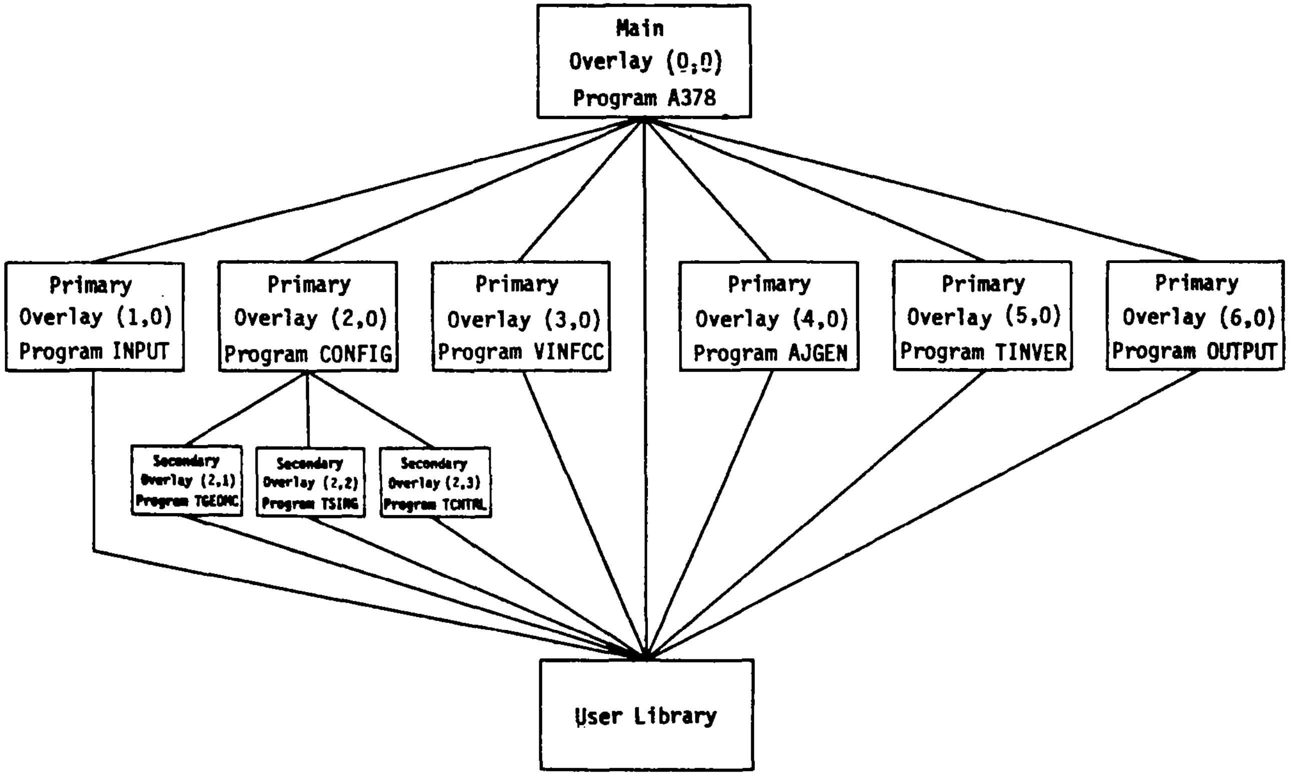


FIGURE 47 BASIC PROGRAM STRUCTURE

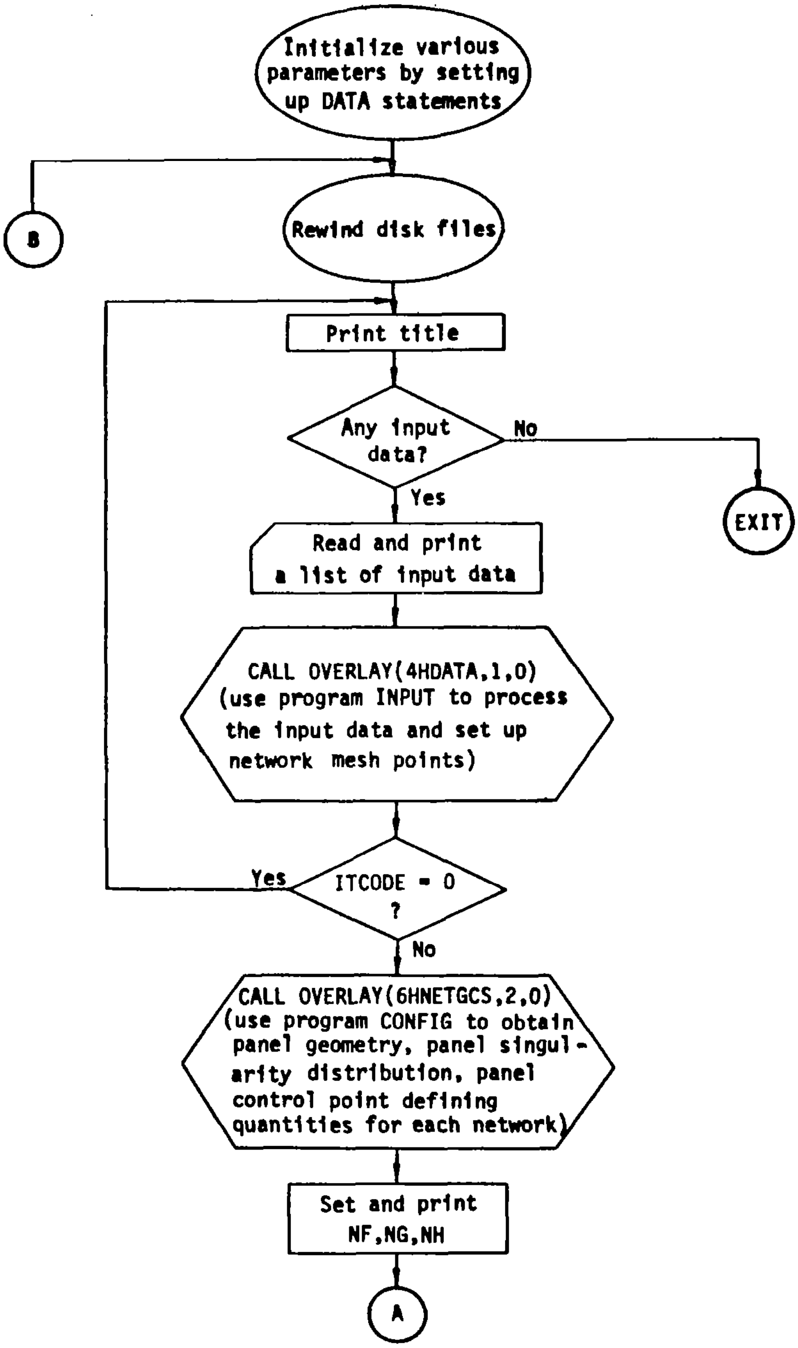


FIGURE 48 FLOW CHART OF MAIN OVERLAY PROGRAM A378

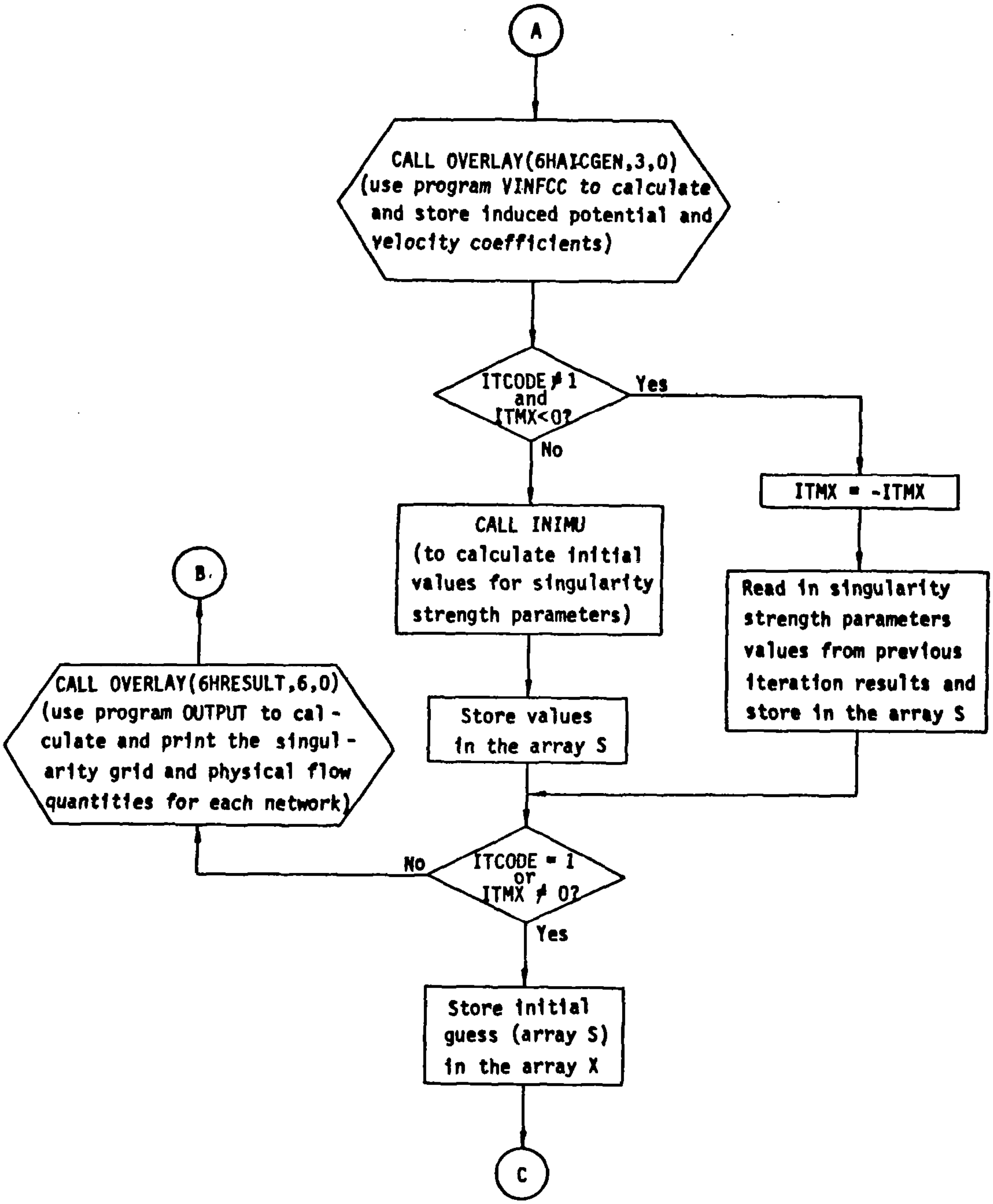


FIGURE 48 CONTINUED

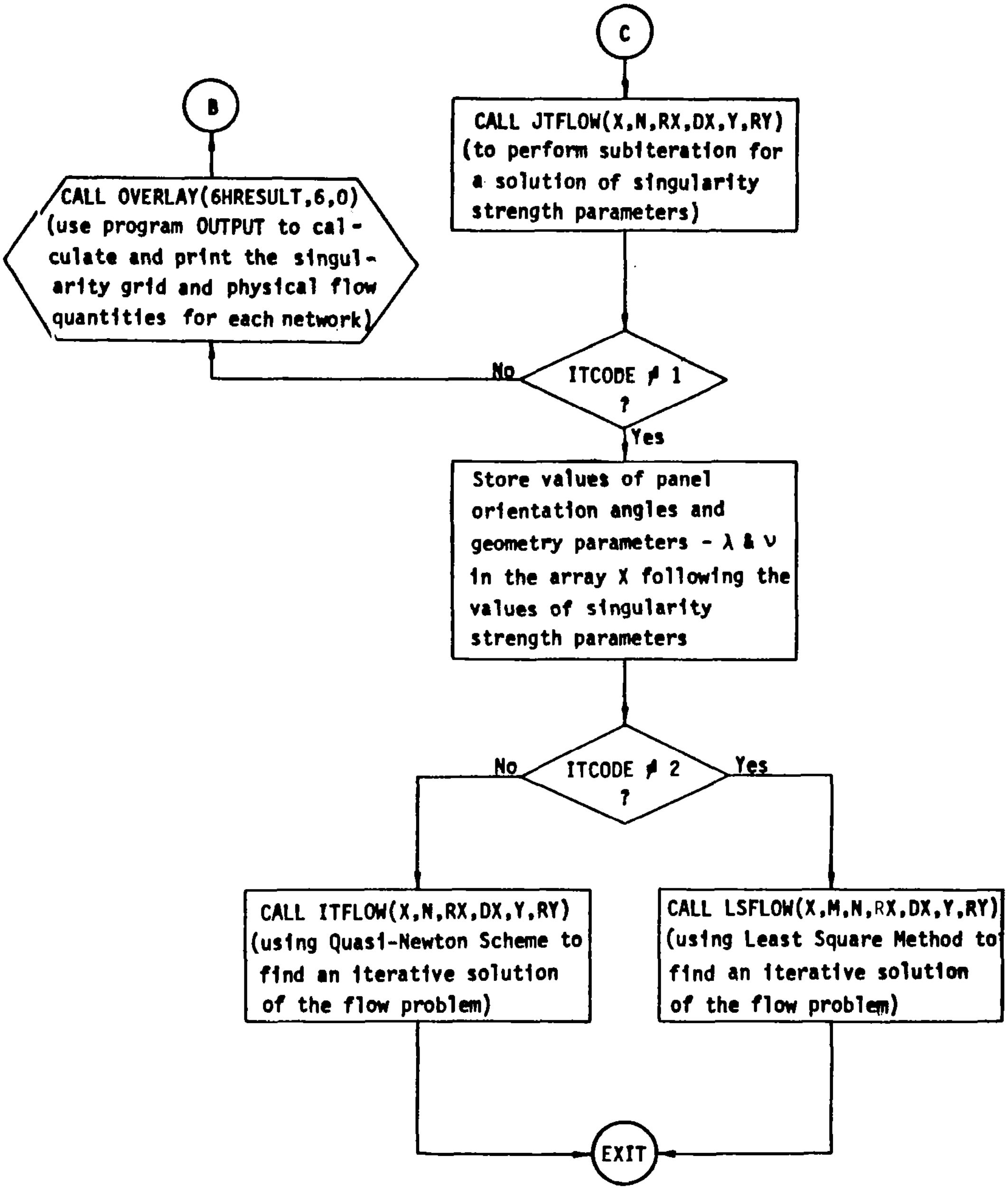


FIGURE 48 CONCLUDED

- Subroutine INIMU to compute initial values for singularity strength parameters
- Program OUTPUT to calculate and print the singularity grid and the physical flow quantities for each network
- Subroutine JTFLOW to perform subiteration for a solution of singularity strength parameters
- Subroutine ITFLOW using Quasi-Newton scheme to find an iterative solution to the flow problem
- Subroutine LSFLOW using Least Squares Method to find an iterative solution to the flow problem

Discussion

The main overlay program A378 first sets up data blocks for transferring among the overlay programs and also initializes the data. At the beginning of the execution of the code, disk files except system files INPUT (TAPE5), OUTPUT (TAPE6), and random access file (TAPE4) are rewound. The code then reads and prints a list of the input data cards. Program INPUT is first called to process the input data and set up network mesh points. Next program CONFIG is called to compute panel geometry, panel singularity distribution and panel control points defining quantities by using the secondary overlay programs TGEOMC, TSING and TCNTRL. Induced potential and velocity influence coefficients, are then calculated via program VINFCC.

If the input data indicates no previous iteration results are to be used, then the code calls subroutine INIMU to calculate the initial singularity strength parameters values. Otherwise, the code reads in the values provided by the user on disk file TAPE14. If no iteration is requested, then program OUTPUT is called to calculate and print the singularity grid, physical flow quantities, and mesh points for each network.

If the user requests only the subiteration then the code calls subroutine JTFLOW for an iterative solution of the singularity strength parameters values, and program OUTPUT for printing the results of physical flow quantities and network mesh points.

When full iteration using Quasi-Newton scheme or least squares method is requested, then the code will proceed after the subiteration being exercised to find an iterative solution to the flow problem by using either subroutine ITFLOW or subroutine LSFLOW.

7.2.2 OVERLAY (DATA, 1,0)

Primary OVERLAY (DATA, 1,0)

Program INPUT

Purpose To read and process the input data as follows:

- Set up network mesh points by using various preprocessors
- Calculate free stream velocity and compressibility direction and metric A and B
- Determine all network edge abutments and abutment intersections
- Obtain initial panel orientation angles and geometry parameters λ and ν

Discussion The input data cards are processed as indicated in the discussion of the User's Input Guide. After reading in the physical quantities such as angle of attack, yaw angle, symmetry or asymmetry, Mach number, and reference values, the code checks which of the following option is requested: (1) data check, (2) subiteration, (3) full iteration using Quasi-Newton scheme, or (4) full iteration using Least Squares Method. The printing options are read in next. Finally, the code reads the number of networks and the specified preprocessor. The preprocessors such as $QUADRILATERAL, $GOTHIC, $VORTEX, and $TRAILING WAKE are then called to set up the network mesh points. The code proceeds to calculate free stream velocity, compressibility direction matrices A and B, and orthogonal transformation matrix from reference coordinates into wing axis coordinates. If previous iteration results are to be used, network mesh points data will be read in from disk file TAPE14. On the other hand, if $DATA CHECK is specified, network mesh points data will be saved on disk file NSAV for external graphic processing. A printer plot of cross sections of the initial vortex system will be produced when this option is chosen. A printout of input network mesh points data is always provided by the program. Before returning the control to the main overlay, the code calls subroutine ABTCAL to determine all network edge abutments, and abutment intersections, and also obtains initial panel orientation angles and geometry parameters and

7.2.3 OVERLAY (NETGCS, 2,0)

Primary	OVERLAY (NETGCS, 2,0)
Program	CONFIG
Purpose	To compute panel geometry, panel singularity distribution, and panel control points defining quantities for all networks.
Discussion	This overlay program serves as a driver for calling the following three secondary overlay programs: o Program TGEOMC to compute panel geometry defining quantities o Program TSING to compute panel singularity distribution defining quantities o Program TCNTRL to compute panel control points defining quantities

7.2.4 OVERLAY (NETGCS, 2,1)

Secondary OVERLAY (NETGCS, 2,1)

Program	TGEOMC
Purpose	To compute panel geometry defining quantities for all networks
Discussion	If diagnostic geometry information is desired (IGEOMP = 1), the code prints mesh points data along with their row and column indices of the network. The main function of the code is to call subroutine GEOMC for each network to compute panel geometry defining quantities. It also sets up arrays containing number of panels in each network (NP(K)), number of mesh points in each network (NZ(K)) and accumulated sum of NP (NPA(K)), and accumulated sum of NZ (NZA(K)); and obtains the total number of panels (NPANT) and the total number of mesh points (NZMPT) for all networks.

7.2.5 OVERLAY (NETGCS, 2,2)

Secondary OVERLAY (NETGCS, 2,2)

Program TSING

Purpose To compute panel singularity distribution defining quantities for all networks

Discussion The code calls various routines depending on the type of each network to compute panel singularity distribution defining quantities:

- Routine SING for type 1 network
- Routine DASPL for type 2 network
- Routine DDSPL for type 4 network
- Routine DSDSPL for type 6 network
- Routine DWSPL for type 8, 10, 14, 16 network

It also sets up arrays containing number of singularity parameters in each network (NS(K)), and accumulated sum of NS(NSA(K)), and obtains the total number of singularity parameters (NSNGT) for all networks.

7.2.6 OVERLAY (NETGCS, 2,3)

Secondary OVERLAY (NETGCS, 2,3)

Program TCNTRL

Purpose To compute panel control points defining quantities for all networks

Discussion The code calls subroutine CONTRL for each network to compute panel control points defining quantities. It also sets up arrays containing number of control points in each network (NC(K)) and accumulated sum of NC (NCS(K)), and obtains the total number of control points (NCTRT) for all networks. Next, defining quantities of some special control points used for calculating fed sheet force are computed by calling subroutine CONFRC. The sum of the total number of these special control points and that of the original control points is given as a parameter NCTRTE.

7.2.7 OVERLAY (AICGEN, 3,0)

Primary	OVERLAY (AICGEN, 3,0)
Program	VINFCC
Purpose	To calculate and store induced potential and velocity coefficients

Discussion

The code first obtains far field moments for hyperboloidal panels by calling subroutine FFHPMG. It starts to compute the potential/velocity influence coefficients by storing defining quantities for a group of control points in the available core of a scratch array. Then it proceeds to calculate panel influence coefficients by looping through all panels for that group of control points. After these calculated influence coefficients are being stored in a random access disk file, the code goes back to store defining quantities for another group of control points and perform the same calculation as described before. This process terminates when it is done with all control points. At the very first call of this overlay, all of the influence coefficients wil be computed and stored in a random access disk file. After that, only the part of the influence coefficients affected by the perturbation of geometry will be calculated and replaced on the random access disk file. This cost saving scheme is controlled by a parameter NRAIC passing through the common block REAIC.

The potential/velocity influence coefficients of those special control points used for fed sheet force calculation are also obtained in this overlay program via subroutine AICFOR. Finally, information for far field, intermediate field, and near field are provided when requested by the user (IPNPIC=1).

7.2.8 OVERLAY (JACGEN, 4,0)

Primary	OVERLAY (JACGEN, 4,0)
Program	AJGEN
Purpose	To calculate and store the analytic Jacobian matrix.

Discussion

The code first sets the row and column dimensions of the Jacobian matrix according to the type of iteration requested:

(i) Subiteration (NDZA=0) - iteration performed only on the singularity strength parameters

(ii) Iteration without force boundary condition (NDZA=1) - iteration performed on the singularity strength parameters and panel orientation angles

(iii) Full iteration (NDZA=2) - iteration performed on the singularity strength parameters, panel orientation angles, and geometry parameters λ and ν.

(iv) Least Squares iteration (NDZA=3) - iteration performed on all the parameters with additional equations consisting of twist function

If it is not subiteration (NDZA=0), a subroutine ZTHET is called to calculate and store perturbation of network mesh points with respect to panel orientation angle and geometry parameters λ and ν . The major part of the code is the loop that ranges over all regular control points to compute the Jacobian corresponding to the equations of the function F (see section 4.3) and store it by row on the disk file NSC3. For those interior control points at the network with update index greater than 3, it also calculates rows of Jacobian corresponding to the function G and saves on a scratch disk file if NDZA is not zero. Later, these rows of Jacobian are transferred and stored behind the Jacobian matrix corresponding to the function F. If full iteration is requested, the code computes rows of Jacobian corresponding to the function H (force boundary condition) via subroutine DFRC and stores also on the disk file NSC3.

The code will compute and store rows of Jacobian corresponding to the function K (twist function) via subroutine DKCAL when it is desired to have least squares iteration.

7.2.9 OVERLAY (SOLVER, 5,0)

Primary	OVERLAY (SOLVER, 5,0)
Program	TINVER
Purpose	To provide an interface for using a large out-of-core equations solver
Discussion	The input coefficient and right-hand side matrices are read in by row, and written into square blocks on a random access disk file via subroutine BLOCKR. The code sets up the argument list and calls the out-of-core equations solver PTSOLV. The solution matrix obtained from the solver is then unblocked and written by row on the disk file NANS via subroutine RBLOCK.

7.2.10 OVERLAY (RESULT, 6,0)

Primary	OVERLAY (RESULT, 6,0)
Program	OUTPUT

Purpose

To compute and print or save on a disk file the following quantities:

- Network mesh points and values of singularity strength parameters for each iteration
- Singularity grid (singularity strength and derivatives at 9 canonical points on each panel) on each network for diagnostic purpose
- Physical flow quantities of interest such as average, upper and lower surface potentials and velocities, singularity strength and gradient, and upper, lower and difference pressure coefficients, force and moment coefficients for each network
- Printer plot for cross sections of vortex systems

Discussion

At the beginning of the code, current iteration number, network mesh points and values of singularity strength parameters are saved on a disk file NSAV. These results could be used to restart another run later for more iterations. If diagnostic option (ISINGS=1) is chosen, singularity strength and derivatives at 9 canonical points on each panel are computed and printed along with the global coordinates of the representative points for each network.

The next major portion of the code is to compute and print various physical flow quantities for all panel center control points on each network. Physical flow quantites of interest include average, upper and lower surface potentials and velocities, singularity strength and gradient, and upper, lower and difference pressure coefficients. The pressure coefficients are also stored for use in computing network force and moment coefficients by calling the subroutine FMCAL.

Finally, a printer plot for cross sections of vortex system (when IPLOTP=1) and a list of network mesh points are given as part of the output for each iteration.

7.3 File Usage

There are fourteen disk files used in the computer program. They all have symbolic names except TAPE4 which is used as a random access file. The following table shows the common block through which the disk file is passed, program or subroutine that uses it, and how it is being used.

Disk No.	Symbolic Name	Common Block	Program Subroutine	Usage
1	NTD	DRWI	IDTRNS	Store singularity spline derivatives
			DTRNS	Retrieve singularity spline
	NTP	PRWI	IPTRNS	Store panel geometry defining quantities
			PTRNS	Retrieve panel geometry defining quantities
2	NTS	SRWI	ISTRNS	Store singularity spline defining quantities
			STRNS	Retrieve singularity spline defining quantities
3	NTC	CRWI	ICTRNS	Store control points defining quantities
			CTRNS	Retrieve control points defining quantities
4				Random access file declared in A378
			VINFCC, AICFOR	Store/retrieve potential and velocity influence coefficients
			FGCAL, HCAL, INIMU, AJGEN, etc.	Retrieve potential and velocity influence coefficients
5	NTSIN	CM03	A378, INPUT,	Standard system file INPUT for card reading
6	NTSOUT	CM03	A378, INPUT, OUTPUT, etc.	Standard system file OUTPUT for printing
7	NAIC	SOLNT	LSFLOW	Store/retrieve information of decomposition for least squares' Jacobian matrix

Disk No.	Symbolic Name	Common Block	Program Subroutine	Usage
8	NRHS	SOLNT	INIMU, ITFLOW, JTFLOW LSFLOW	Store the right-hand side matrix by row; also serve as a scratch file in LSFLOW for temporary storage
			BLOCKR	Retrieve the right-hand side matrix stored by rows for setting up square blocks to be used by the out-of-core equations solver
9	NANS	SOLNT	RBLOCK	Store the solution matrix by row
			A378, ITFLOW, JTFLOW	Retrieve the solution matrix stored by row
			CTRS	Retrieve the solution matrix stored by row, and store it by column
			LSFLOW	Retrieve the solution matrix stored by columns
10	NSC1	SOLNT		Random access file declared in TINVER
			BLOCKR	Store square blocks of the coefficient and the right-hand side matrices for the out-of-core equations solver
			PTDCOM, PTFSUB, etc.	Retrieve square blocks of the coefficient and the right-hand side matrices, and store square blocks of the solution matrix
			RBLOCK	Retrieve square blocks of the solution matrix from the out-of-core equations solver
			CTRS	Serve as a scratch file for storing matrix by blocks
11	NSC2	SOLNT		Random access file declared in BLOCKR
			BLOCKR	Serve as a scratch file for setting up square blocks of input matrixes which are originally stored by row
12	NSC3	SOLNT	INIMU	Store the coefficient matrix by row
			AJGEN	Store the Jacobian matrix by row
			ITFLOW	Retrieve the Jacobian matrix stored by row; also store the updated Jacobian matrix by row
			BLOCKR	Retrieve the coefficient or Jacobian matrix stored by row for setting up square blocks to be used by the out-of-core equations solver

Disk No.	Symbolic Name	Common Block	Program Subroutine	Usage
13	NSCR	SOLNT	ITFLOW	Serve as a scratch file for storing the Jacobian matrix
			LSFLOW	Store the part of the Jacobian matrix corresponding to the function F
			AJGEN	Serve as a scratch file for storing rows of Jacobian corresponding to the function G.
14	NSAV	CM03	INPUT	Save network mesh points when $DATA CHECK is specified
			OUTPUT	Save iteration no., part of network indices, network mesh points, values of singularity parameters
			INPUT	Retrieve iteration no., part of network indices, network mesh points from previous iteration results
			A378	Retrieve values of singularity parameters from previous iteration results

The computer program uses the following CDC system utilities for random access files:

OPENMS - declare a disk file to be random
CLOSMS - close a random access file
READMS - read a random access record
WRITMS - write a random access record

7.4 Common Block Definition

Variables of the more essential common blocks shared by overlay programs and subroutines are defined below.

Common Block	Variables	Description
ACASE	ALPHA	Angle of attack in degrees
	BETA	Yaw angle in degrees
	FSVM	Magnitude of free stream velocity
	FSV	Free stream velocity vector
	OMEG	Roll rate vector
	RC	Center of rotation
ADR	RTD	Degrees in unit radian
	DTR	Radians in unit degree
AICQ	Q	Q(I,K) = dependence of Ith Taylor's series coefficient of panel doublet distribution on Kth canonical panel doublet value
	B	Dependence of coefficient of linear distribution on triangle on values at vertices
	C	Dependence of coefficients of quadratic distribution on triangle on values at vertices and edge lambdas
	D	Dependence of coefficients of reduced cubic distribution on triangle on values at vertices and center and edge lambdas
	AR	Transformation matrix from global to local coordinates
	ARI	Inverse of AR
	ARP	Matrix transforming combined potential/velocity vector from local to global coordinates
	X	Local coordinates of control point
	DU	Dependence of potential/velocity vector in local coordinates on source distribution coefficients
	DV	Dependence of potential/velocity vector in local coordinates on doublet distribution coefficients
	DVP	Dependence of potential/velocity vector in global coordinates on doublet distribution coefficients
	PC	Hyperboloidal panel geometry coefficient vectors
	EN	Unit normal (in global coordinates) to plane panel
	P	Local coordinates of panel corner points

Common Block	Variables	Description
	ZET	Hyperboloidal panel geometry coefficient vectors in local coordinates
	ZSTP	Parameter values corresponding to ZP
	ZP	Average of triangle corner points
	R	Dependence of coefficients of reduced cubic doublet distribution on 9 canonical panel doublet parameters
	DS	Dependence of doublet strength and vorticity at a point on 9 canonical doublet parameters
ANGLEN	ZA	Panel orientation angles for free sheet network
	ZL	Panel edge length along spanwise cut for free sheet network
	ZAF	Panel orientation angles for fed sheet network
	ZLF	Panel edge lengths along spanwise cut for fed sheet network
	ALAM	Geometry parameter λ
	ANU	Geometry parameter ν
	NZAT	Total number of panel orientation angles for free sheet networks
	NZAFT	Total number of panel orientation angles for fed sheet networks
BCARY	XX	(1) - Potential (2,3,4) - Velocity vector (5) - Source strength (6) - Doublet strength (7,8,9) - Vorticity vector (10,11,12) - Unit upper surface normal $\hat{n}$ (13,14,15) - Control point $\bar{z}$ (16,17,18) - Upper surface normal $\bar{n}$ (19,20,21) - Normal vector to panel edge ν (22,23,24) - Panel edge vector $\hat{\ell}$
	F	Value of analysis boundary condition (ANLBC), or design boundary condition (DESBC), or edge matching condition (MATBC)
	FX	Perturbation of boundary condition with respect to each of the variables XX
	GG	Vector of panel force boundary condition (SFCBC and EGFBC)
	GX	Perturbation of panel force boundary condition with respect to each of the variables XX
	EX	(1,J) - Perturbation of force boundary condition f_y with respect to Jth variable of XX

Common Block	Variables	Description
		(2,J) - Perturbation of force boundary condition f_z with respect to Jth variable XX
	NX	24
	NX2	48
	NX3	72
CM03	NTSIN	Standard system file INPUT for card reading
	NTSOUT	Standard system file OUTPUT for printing
	NSAV	Disk file to save intermediated iteration results
CM05	ERROR	Error code from subroutine RHEAD or WHEAD
	IPASS	Code for by passing the opening of random access file NSC2
	JPASS	Code for by passing the opening of random access file NSC2
CNTRL	ZC	Control point $\vec{z}$
	ENC	Upper surface normal $\vec{n}$
	ZNC	Unit upper surface normal $\hat{n}$
	ZNCG	$\hat{n} \otimes \nabla f$
	ZCP	Perturbation of control point with respect to panel corner points $\vec{P}_i$
	ENCP	Perturbation of $\vec{n}$ with respect to panel corner points $\vec{P}_i$
	ZNCP	Perturbation of $\hat{n}$ with respect to panel corner points $\vec{P}_i$
	ZNCGP	Perturbation of $\hat{n} \otimes \nabla f$ with respect to panel corner points $\vec{P}_i$
	AN	Normal vector to panel edge $\vec{\nu}$
	EL	Panel edge vector $\vec{\ell}$
	ANP	Perturbation of $\bar{\nu}$ with respect to panel corner points $\vec{P}_i$
	ELP	Perturbation of $\vec{\ell}$ with respect to panel corner points $\vec{P}_i$
CNTRQ	ZSTC	Parameters s and t of control point $\vec{Q}_0$, $\vec{Q}_s$, $\vec{Q}_t$, $\vec{Q}_{st}$ for the hyperboloidal panel of control point
	ICH	Edge control point characterization = 0 Real = 1 Doublet value matching = 2 Doublet normal derivative matching = 3 Doublet tangential derivative matching
	IPC	Panel no. of control point
	ISC	Side no. of edge control point
	IZC	Control point index along an edge
	JCN	Control point index

Common Block	Variables	Description
	KC	Network no. of control point
COMPRS	AMACH	Mach number M_∞
	BETAMS	$1 - M^2_\infty$
	BETAM	$\sqrt{1 - M^2_\infty}$
	ALPC	Angle of attack in degrees
	BETC	Yaw angle in degrees
	COMPD	Compressibility direction unit vector
	ACOMP	Compressibility matrix for metric A
	BCOMP	Compressibility matrix for metric B
	AROTC	Orthogonal matrix transforming reference coordinates into wing axis coordinates
CPLOT	XMX	Maximum X scale for the printer plot
	YMX	Maximum Y scale for the printer plot
	XMN	Minimum X scale for the printer plot
	YMN	Minimum Y scale for the printer plot
	KFP	Network no. of free sheet to be plotted
	NPLT	Number for free sheet networks to be plotted ≤ 4
	ISY	Symbols used in printer plot
CRWI	NCDQ	Number of control point defining quantities per block
	NSC	Number of control point defining quantity blocks in buffer
	NRC	Current record in buffer
	NTC	File on which control point defining quantity blocks are stored
DMUDZ	DMU	Perturbation of panel singularity spline with respect to neighboring panel corner points
DRWI	NDDQ	Number of singluairty spline derivatives per block
	NSD	Number of singularity spline derivative blocks in buffer
	NRD	Current record in buffer
	NTD	File on which singularity spline derivative blocks are stored
EDGIN	KEDG	Network of point which abuts given point
	MEDG	Row index of point which abuts given point
	NEDG	Column index of point which abuts given point
	IEGDA	Cumulative index of points which abut other points

Common Block	Variables	Description
EGMTCH	ISDCHR	Network edge control point characterization = 0 No control point = 1 to 4 Control point matches doublet strength along abutment to which side 1 to 4 belongs = 5 Control point forces doublet strength to vanish = -1 to -4 Control point matches vorticity parallel to edge along abutment to which side 1 to 4 belongs
	IRCHR	Network corner control point characterization = 0 No control point = 1 to 4 Control point matches doublet strength along abutment to which side 1 to 4 belongs = 5 Control point forces doublet strength to vanish = -1 to -4 Control point matches vorticity parallel to edge along abutment to which side 1 to 4 belongs
FMCOF	XREF YREF ZREF	X, Y, Z coordinates of moment center
	SREF	Configuration reference area
	BREF	Reference span
	CREF	Reference chords
	DREF	Reference height
INDEX	NT	Network type
	NM	Network row number
	NN	Network column number
	NZ	Network mesh points number
	NP	Network panels number
	NS	Network singularity strength parameters number
	NC	Network control points number
	NZA	Accumulated network mesh points number
	NPA	Accumulated network panel numbers
	NSA	Accumulated network singularity strength parameters number
	NCA	Accumulated network control points number
	NNETT	Total number of networks
	NZMPT	Total number of mesh points

Common Block	Variables	Description
	NPANT	Total number of panels
	NSNGT	Total number of singularity strength parameters
	NCTRT	Total number of regular control points
	NCTRTE	Total number of regular and special control points
INDX	INDX	Key indices for random access file TAPE4
LSINGC	DSDFS	Vector relating source strength σ to neighboring singularity parameters
	DDDFS	Matrix relating doublet strength μ and $\hat{n} \otimes \nabla\mu$ to neighboring singularity parameters
	DD	Matrix relating doublet strength μ and $\hat{n} \otimes \nabla\mu$ to the 9 canonical panel doublet parameters
MSPNTS	ZM	Mesh points coordinates
LSINGV	SLV	Vector consisting of source strength σ , doublet strength μ and $\hat{n} \otimes \nabla\mu$ at a control point
	SLVP	Perturbation of source strength σ , doublet strength μ , and $\hat{n} \otimes \nabla\mu$ with respect to panel corner points
LSQSFC	ZK	X,Y,Z coordinates of mesh points used in least squares fit
	WTK	Weights used in least squares fit
	AK	Generalized inverse from least squares fit
	NO	$= 2$ for quadratic fit (6 terms) < 2 for linear fit (3 terms)
	NPK	Number of data points used in least squares fit
NCONS	PI	π
	PI2	2π
	PI4I	$1/4\pi$
	AKAP	4π
NFAJ	NF	Number of singularity strength parameters
	NG	Number of panel orientation angles
	NH	Number of geometry parameters and
	NFG	NF + NG
	NGH	NG + NH
	NFGH	NF + NG + NH

Common Block	Variables	Description
	NK	Number of equations of twist function
	NGHK	NG + NH + NK
	NKGHK	NF + NG + NH + NK
NITF	JT	Iteration No.
	ITMX	Maximum number of iterations requested by the user
	JTP	= 0 Printing of detail physical flow quantities = 1 Printing of type 1 or 2 force/moment data only
	ITPRIN	Printing of detail physical flow quantities occurs at every ITPRIN iteration
	NDZA	Type of iteration = 0 subiteration = 1 Iteration without force boundary condition = 2 Full iteration using Quasi-Newton scheme = 3 Full iteration using least squares method
	ITCODE	Code for data check and type of iteration = 0 Data check = 1 Subiteration = 2 Full iteration using Quasi-Newton scheme = 3 Full iteration using Least Squares method
	ITVRCP	Printing code for variables, residuals and corrections of full iteration results = 1 Printout = 0 No printout
PANDQ	CP	Corner points of the given panel in reference coordinates
	PC	$\vec{Q}_o$, $\vec{Q}_s$, $\vec{Q}_t$, $\vec{Q}_{st}$ of the given panel
	AQ	Transformation matrix from reference to panel near plane coordinates
	AQI	Inverse of AQ
	DIAM	Diameter of the given panel
	AST	Matrix relating 9 canonical doublet μ or 3 linear source σ to neighboring singularity parameters
	ITS	Index array for neighboring singularity parameters
	INS	Number of neighboring singularity parameters

Common Block	Variables	Description
	NCS	Number of parameters (quadratic or linear coefficients) defining panel doublet or source distribution
	ITS	Panel singularity type = 1 Source = 2 Doublet
	ICS	Index of collasped side, and is equal to 0 if no collapsed side
	IPN	Index of the given panel
	KP	Network number of the given panel
PIVM	DVDS	Potential and velocity vector at a control point induced by singularity distribution on a panel
	AMU	9 canonical doublet μ or 3 linear source σ strength parameters
	DVDZ	Perturbation of potential and velocity vector with respect to the given control point
	DVDP	Perturbation of potential and velocity vector with respect to the corner points of a panel
PRNT		All variables in this common block are printing codes for diagnostic purpose, = 1 Printout = 0 No printout
	IGEOMP	Panel defining quantities
	ISINGP	Panel singularity distribution defining quantities
	ICONTP	Panel control points defining quantities
	IBCONP	Boundary conditions
	ISINGS	Singularity grid on each network
	IPLOTP	Printer plot of cross sections of vortex sheet
	IPTIME	Elapsed CPU time for various programs and subroutines
	IPRAIC	Influence coefficients for each control point
	IPAJAC	Analytic Jacobian
	IPNPIC	Far field and near field information
	IPSOLV	Out-of-core equations solver information

Common Block	Variables	Description
PRWI	NPDQ	Number of panel defining quantities
	NSP	Number of panel defining quantity blocks in buffer
	NRP	Current record in buffer
	NTP	File on which panel defining quantity blocks are stored
REAIC	NRAIC	= 0 All influence coefficients will be computed = 1 Part of the influence coefficients affected by the perturbation of geometry will be recomputed
SKRCHS	PANQ	Buffers containing multiple blocks of panel and singularity distribution defining quantities
	CNTQ	Buffers containing multiple blocks of control point defining quantities
	DMUQ	Buffer containing temporary multiple blocks of panel defining quantities; buffer containing multiple blocks of singularity spline derivatives
SKRCH1	DUMSK1	Scratch array
SOLN	S	Singularity (doublet and/or source) strength
SOLNT	NAIC NRHS NANS NSC1 NSC2 NSC3 NSCR	Disk files (see File Usage)
	IRAY	Array containig input specification for out-of-core equations solver (1) - Number of words in the scratch array (2) - I/O device for the coefficient matrix (3) - File argument for coefficent matrix (4) - I/O device for the solution matrix (5) - File argument for solution matrix (6) - Scratch I/O device (7) - Scratch I/O device

Common Block	Variables	Description
		(8) - Not used (9) - I/O matrix for the right-hand side matrix (10) - File argument for right-hand side matrix
	MTITLE	Title of solution
SRWI	NSDQ	Number of panel and singularity spline defining quantities
	NSS	Number of panel and singularity spline defining quantity blocks in buffer
	NRS	Current record in buffer
	NTS	File on which panel and singularity spline defining quantity blocks are stored
SYMM	NSYMM	= 1 for asymmetric about X-Z plane = 0 otherwise
TFMQ	FC	Accumulated force coefficients of networks
	FMC	Accumulated moment coefficients of networks
	TCA	Accumulated surfaces area of networks
UPDIND	NUP	Network update index
	NAT	(1,K) - Sequence no. of network to which side 1 of Kth network is attached (2,K) - Sequence no. of network to which side 4 of Kth network is attached
	NSD	(1,K) - Side no. of network to which side 1 of Kth network is attached (2,K) - Side no. of network to which side 4 of Kth network is attached
	NCR	(1,K) - Leading corner point no. of network to which side 1 of Kth network is attached (2,K) - Leading corner point no. of network to which side 4 of Kth network is attached
ZMD	ZMTH	Dependence of corner point coordinates on thetas
	ZMAL	Dependence of corner point coordinates on lambdas and nus
	NZMTHA	Cumulative number of thetas in each network
	NZMALM	Cumulative number of lambdas and nus in each network

7.5 Linkage Map of Overlay Programs and Subroutines

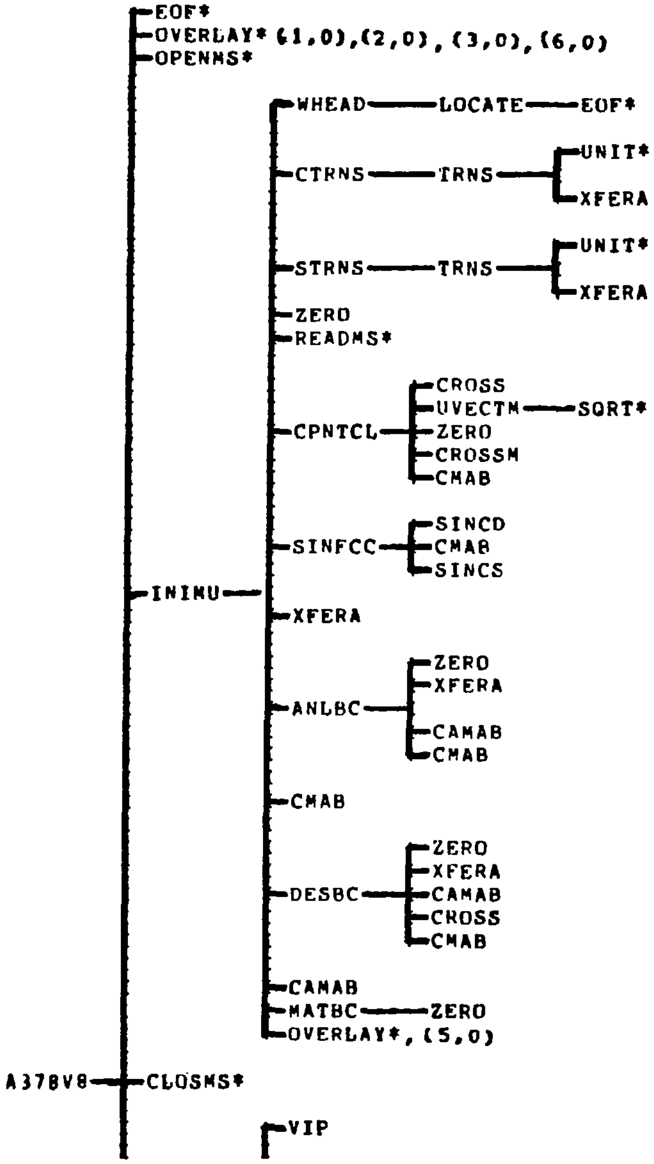
In the following map, the subroutines followed with * are CDC system routines.

(This linkage map is obtained from using a program CALLMAP written by Gary Bills of Boeing Computer Services Company.)

7.5.1 MAP OF OVERLAY (MAIN, 0, 0)

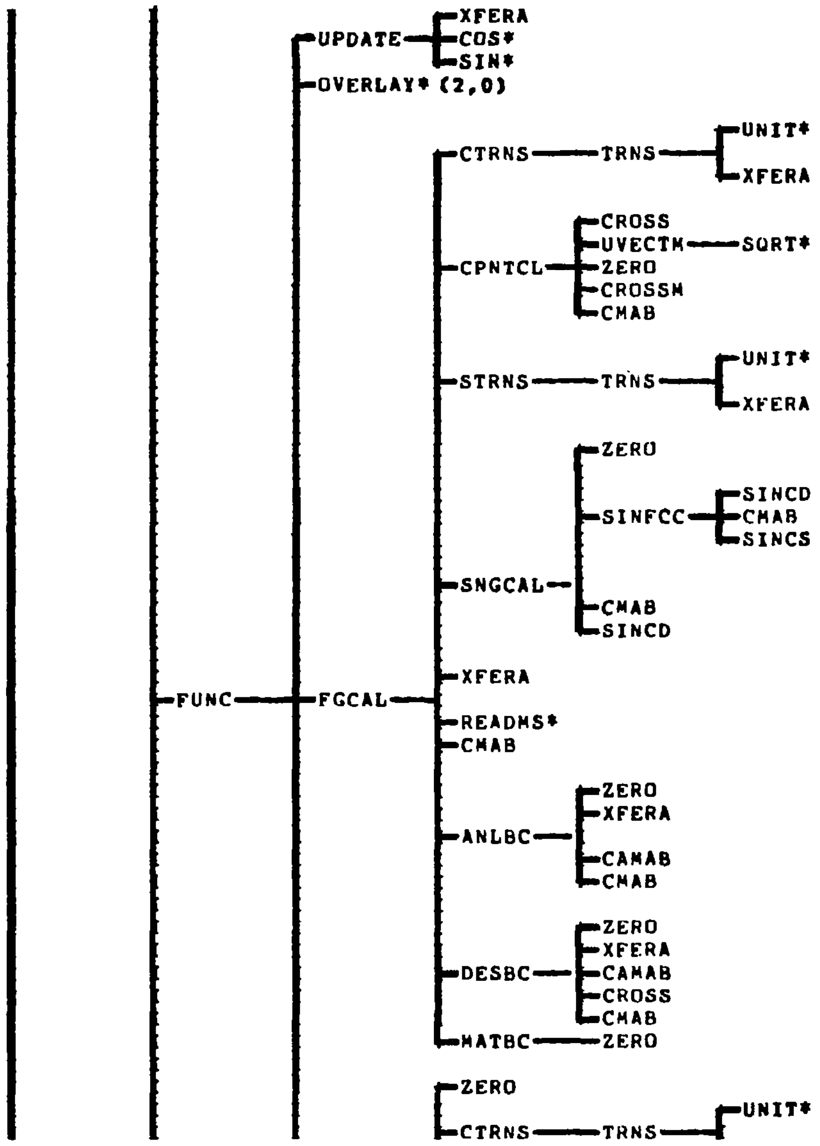
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



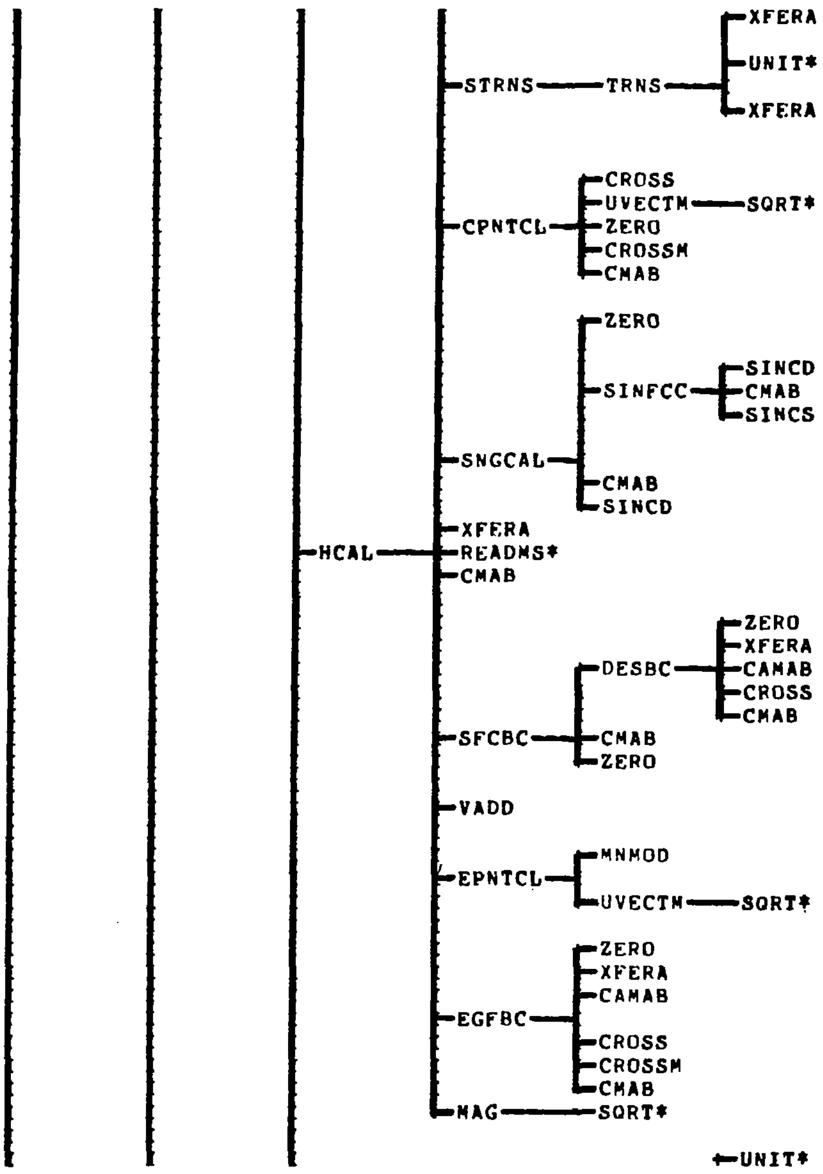
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



MAP OF OVERLAY(MAIN,0,0)

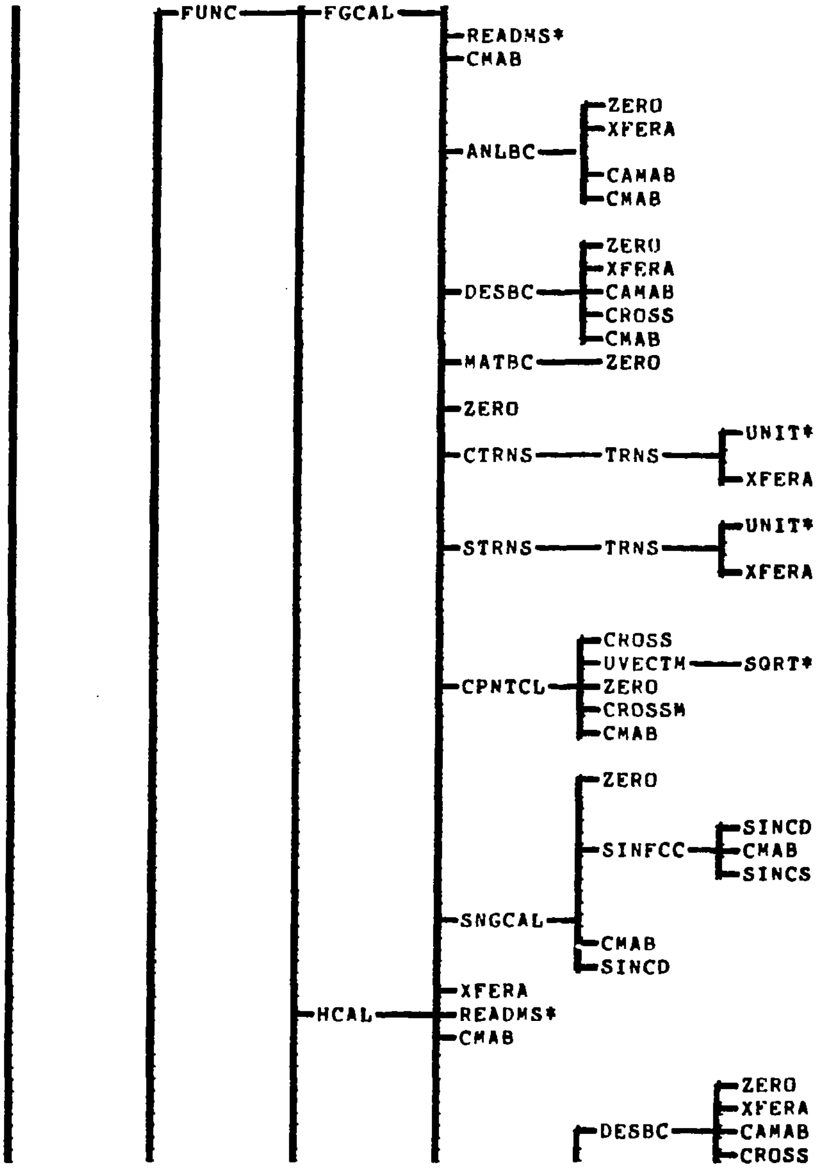
ENTRY PT. A378V8



```
MAP  OF  OVERLAY(MAIN,0,0)

ENTRY PT. A378V8

|         |         |         +-STRNS-----TRNS------+
|         |         |         |                     +-XFERA
|         |         |         |
|         |         |         |         +-CROSS
|         |         |         |         +-UVECTM-----SQRT*
|         |         |         +-CPNTCL--+-ZERO
|         |         |         |         +-CROSSM
|         |         |         |         +-CMAB
|         |         |         |
|         |         +-KCAL----+-MAG-------SQRT*
|         |                   +-SQRT*
|         |                   +-CMAB
|         |
|         +-VRCOUT----VIP
+-JTFLOW--+-OVERLAY* (4,0),(5,0)
|         +-WHEAD-----LOCATE----EOF*
|         +-SORT*
|         +-XFERA
|
|                             +-XFERA
|                   +-UPDATE--+-COS*
|                   |         +-SIN*
|                   +-OVERLAY* (2,0)
|                   |
|                   |                             +-UNIT*
|                   |         +-CTRNS-----TRNS----+
|                   |         |                   +-XFERA
|                   |         |
|                   |         |         +-CROSS
|                   |         |         +-UVECTM-----SQRT*
|                   |         +-CPNTCL--+-ZERO
|                   |         |         +-CROSSM
|                   |         |         +-CMAB
|                   |         |
|                   |         |                   +-UNIT*
|                   |         +-STRNS-----TRNS----+
|                   |         |                   +-XFERA
|                   |         |
|                   |         |         +-ZERO
|                   |         |         |
|                   |         |         |         +-SINCD
|                   |         |         +-SINFCC--+-CMAB
|                   |         |         |         +-SINCS
|                   |         |         |
|                   |         +-SNGCAL--+
|                   |         |         +-CMAB
|                   |         |         +-SINCD
|                   |         |
|                   |         +-XFERA
```

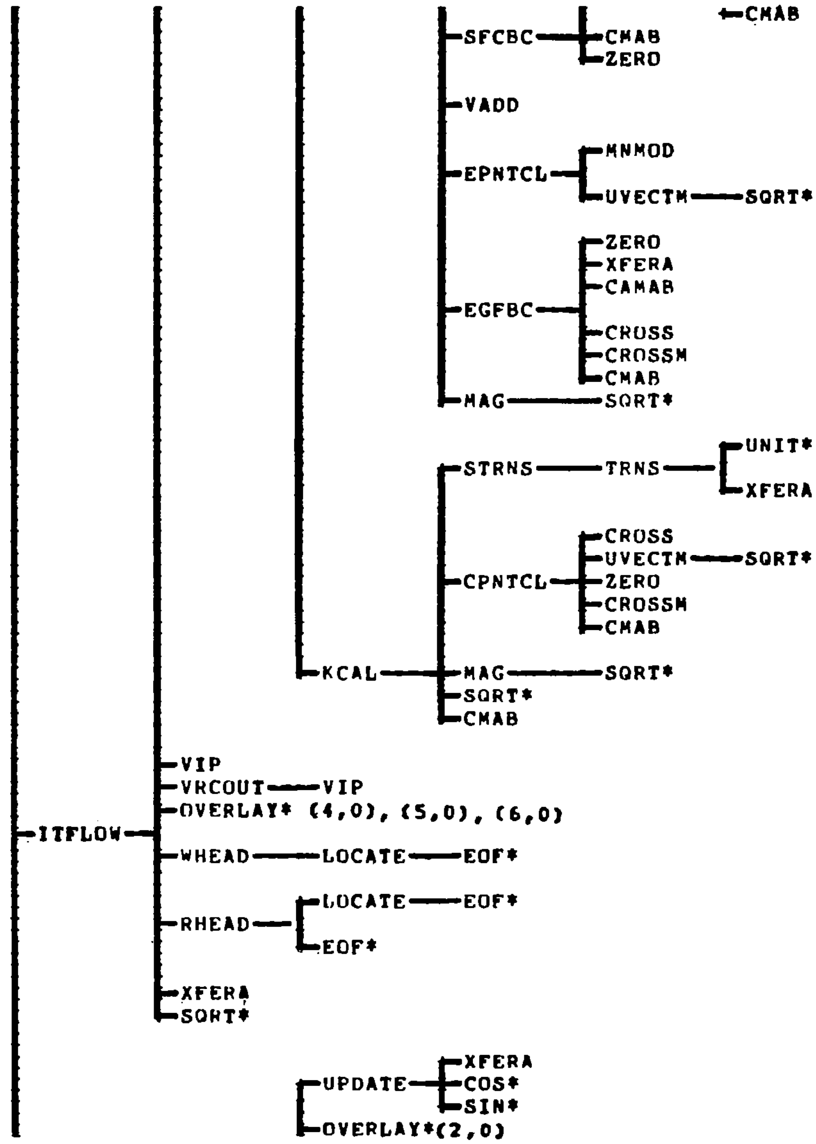
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



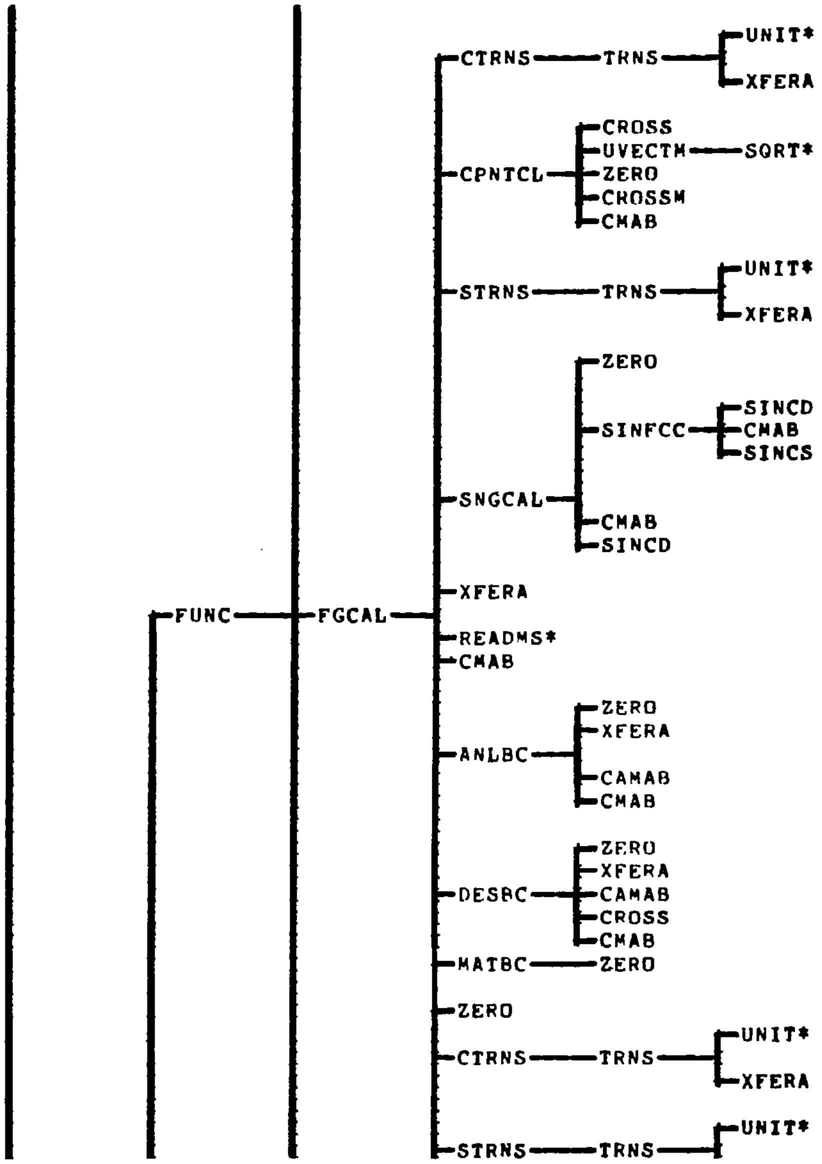
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



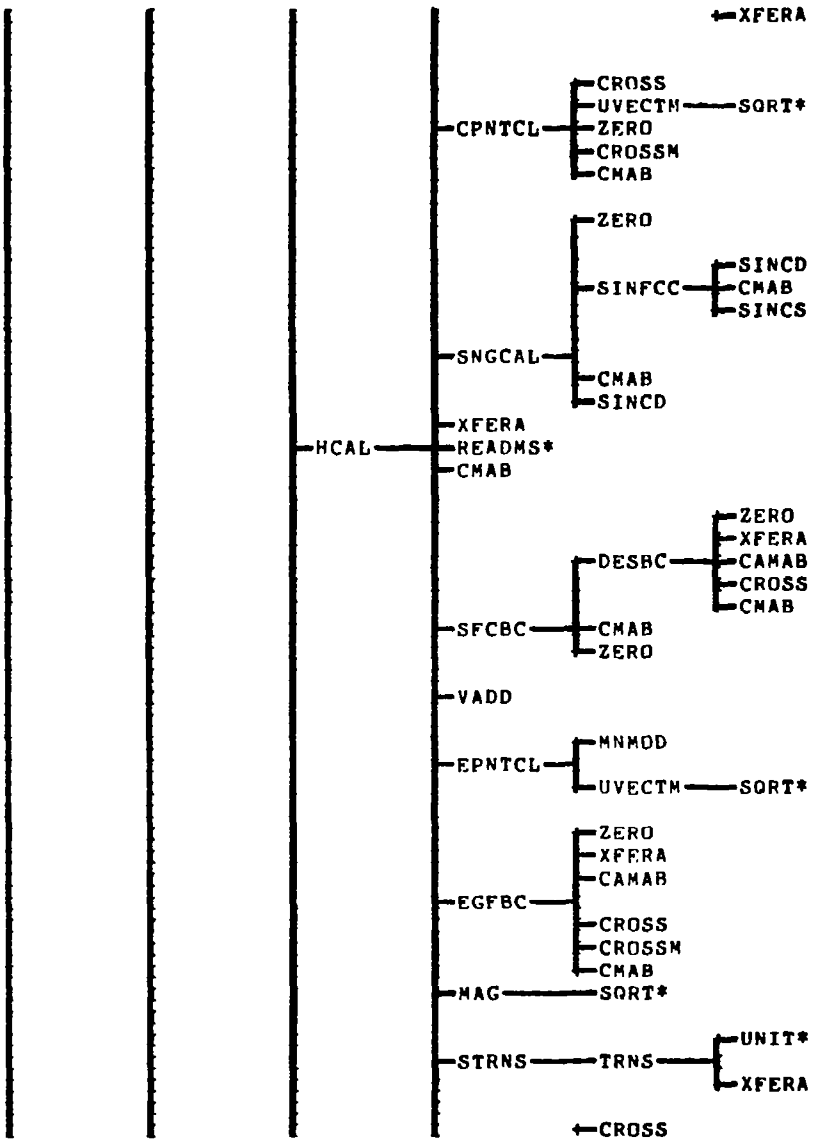
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



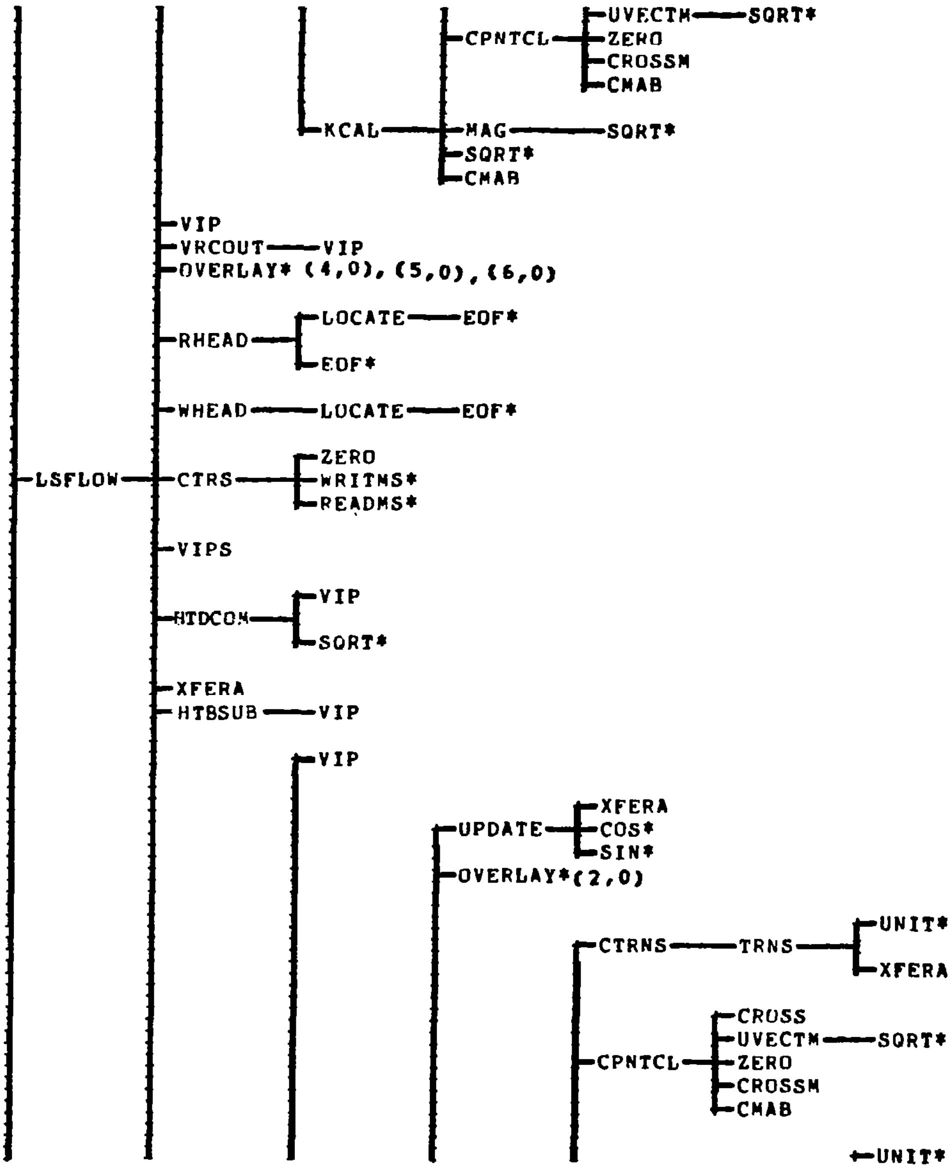
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



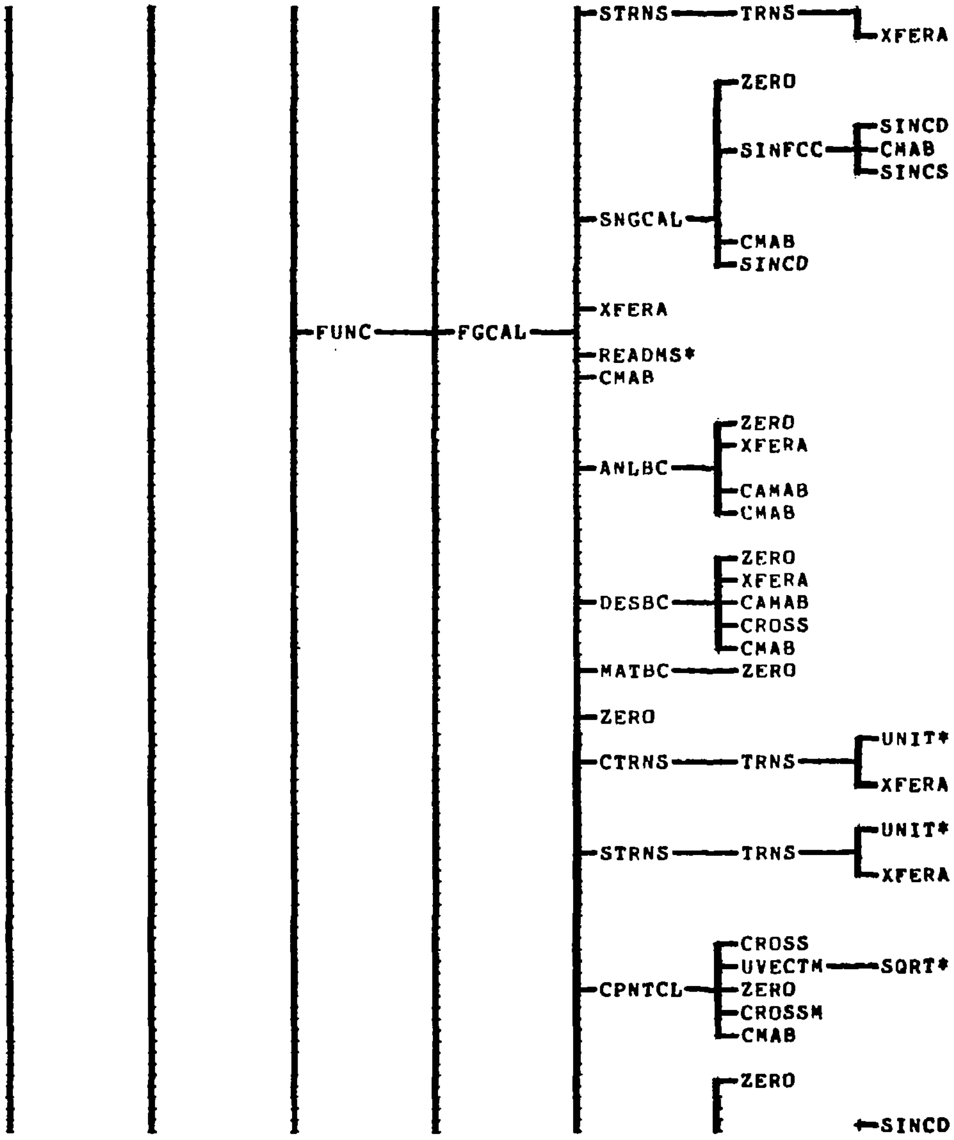
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT, A378V8



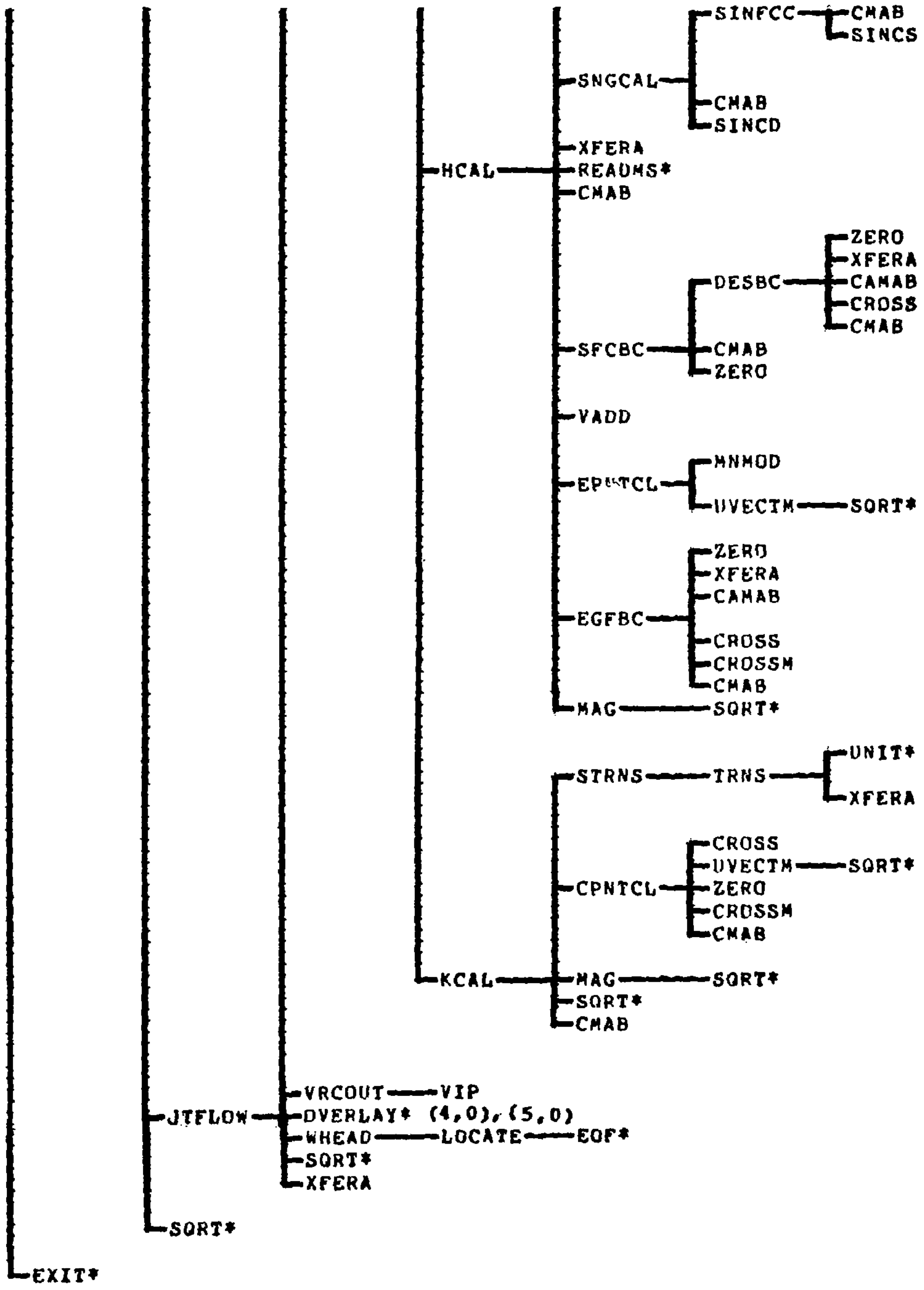
MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8



MAP OF OVERLAY(MAIN,0,0)

ENTRY PT. A378V8

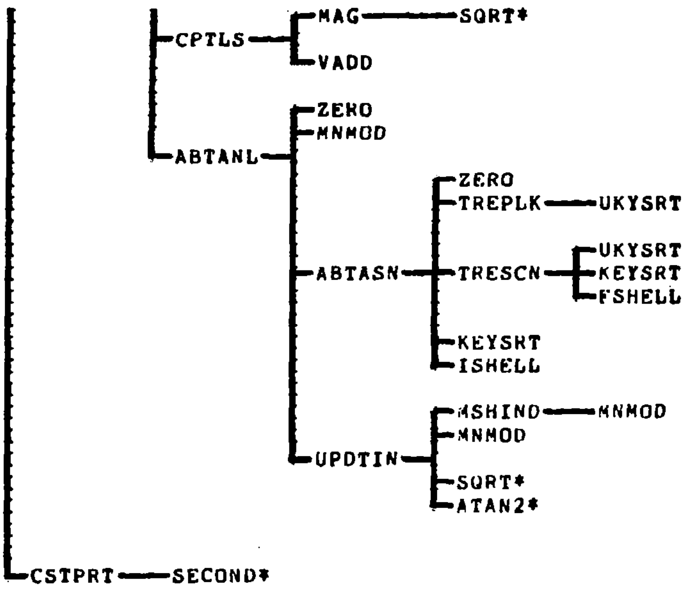


7.5.2 MAP OF OVERLAY (DATA, 1, 0)

```
MAP   OF   OVERLAY(DATA,1,0)

ENTRY PT. INPUT


              ┌─SORT*
              │
              ├─QUADNT─┬─ZERO
              │        └─SQRT*
              │
              ├─GADNET
              │
              │        ┌─XFERA
              ├─VORTEX─┼─SHEGEN────SQRT*
              │        └─TRWAKE────XFERA
              │
              ├─TRWAKE───XFERA
              │
              │        ┌─ISCAL─────PIDENT────SQRT*
              │        ├─XFERA
              ├─CAMBER─┤
              │        │
              │        ├─INTP1───BINSCH
              │        │
              │        │
              │        └─INTP2───BINSCH
              │
              │
              │        ┌─ASIN*
              ├─CONCAM─┼─COS*
              │        └─SQRT*
INPUT─────────┤
              ├─COS*
              ├─SIN*
              │
              ├─ROTATE─┬─COS*
              │        └─SIN*
              │
              ├─SCALE2───ALOG10*
              ├─VSPLOT───SUBPON
              │
              │        ┌─MNMOD
              │        ├─MSHIND────MNMOD
              │        ├─PIDENT────SORT*
              │        ├─VADD
              │        ├─COMPIP
              ├─ABTCAL─┼─CROSS
              │        ├─UVECT─────SORT*
              │        ├─CMAB
              │        ├─ZERO
              │        │
```

MAP OF OVERLAY(DATA,1,0)

ENTRY PT. INPUT

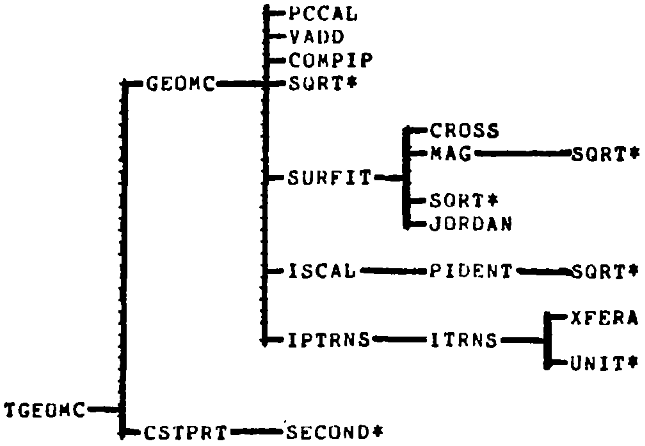


7.5.3 MAP OF OVERLAY (NETGCS, 2, 0)

```
 MAP  OF  OVERLAY(NETGCS,2,0):
ENTRY PT. CONFIG

CONFIG-----OVERLAY* (2,1),(2,2),(2,3)
```

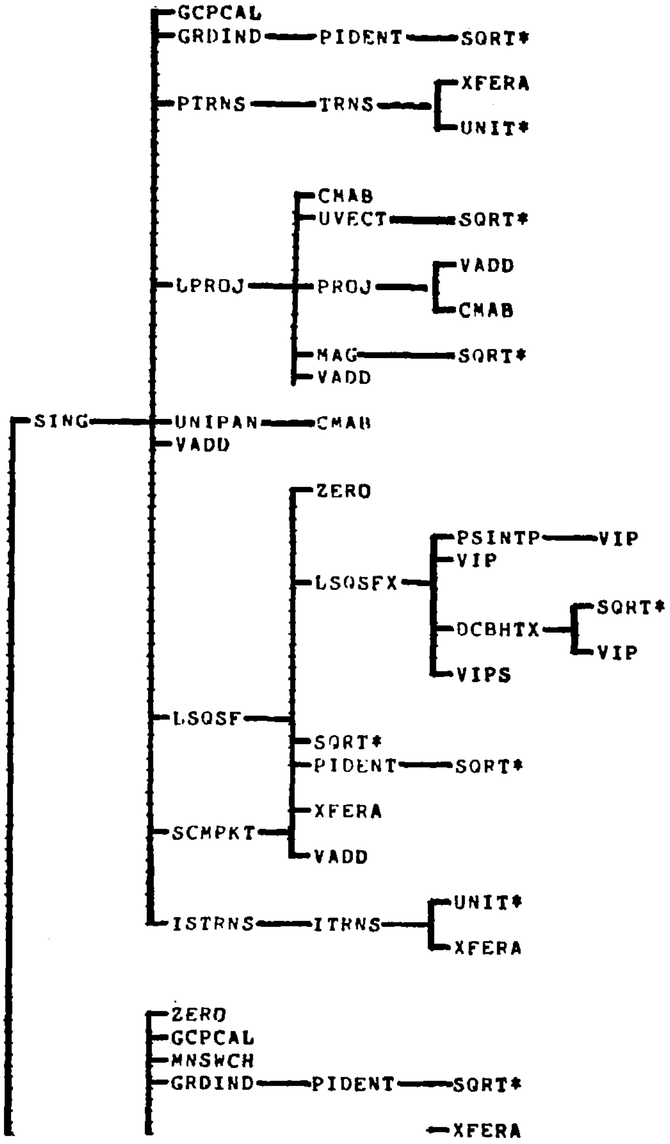
7.5.4 MAP OF OVERLAY (NETGCS, 2, 1)

```
MAP  OF  OVERLAY(NETGCS,2,1):
ENTRY PT. TGEOMC
```



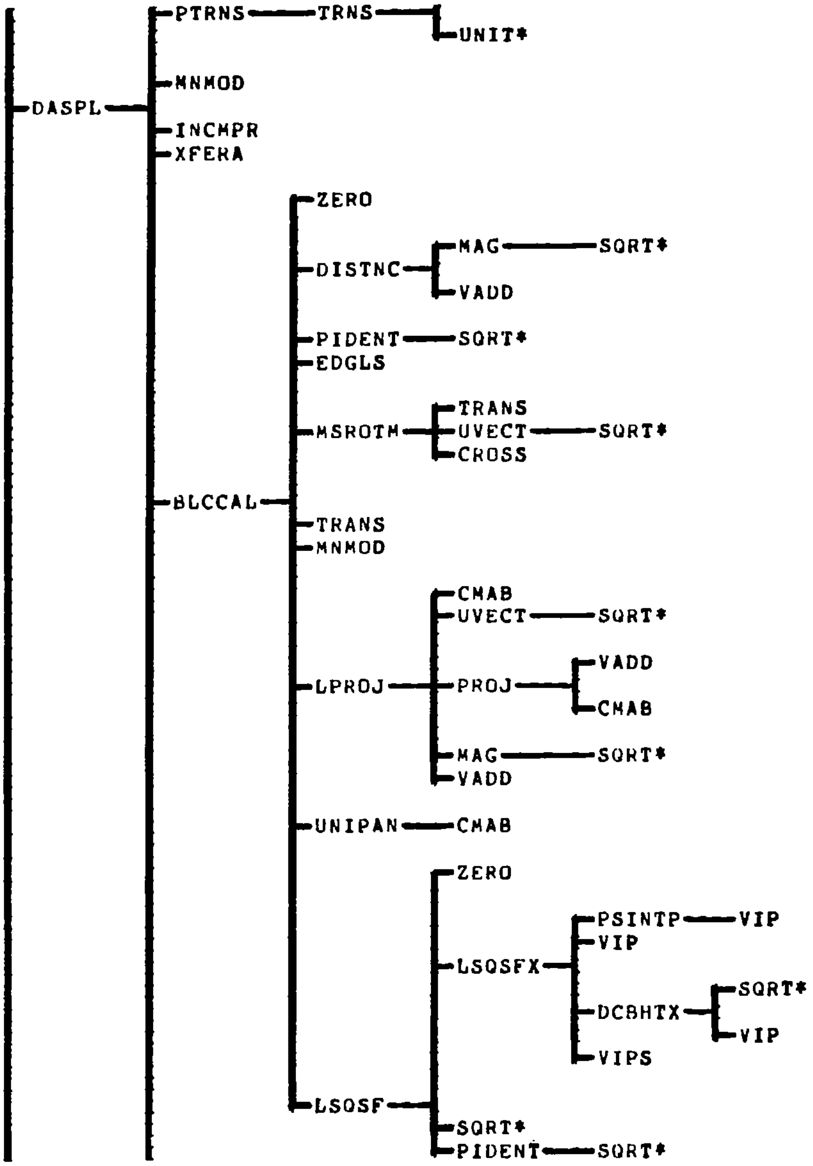
7.5.5 MAP OF OVERLAY (NETGCS, 2, 2)

```
MAP OF OVERLAY(NETGCS,2,2):
ENTRY PT. TSING
```



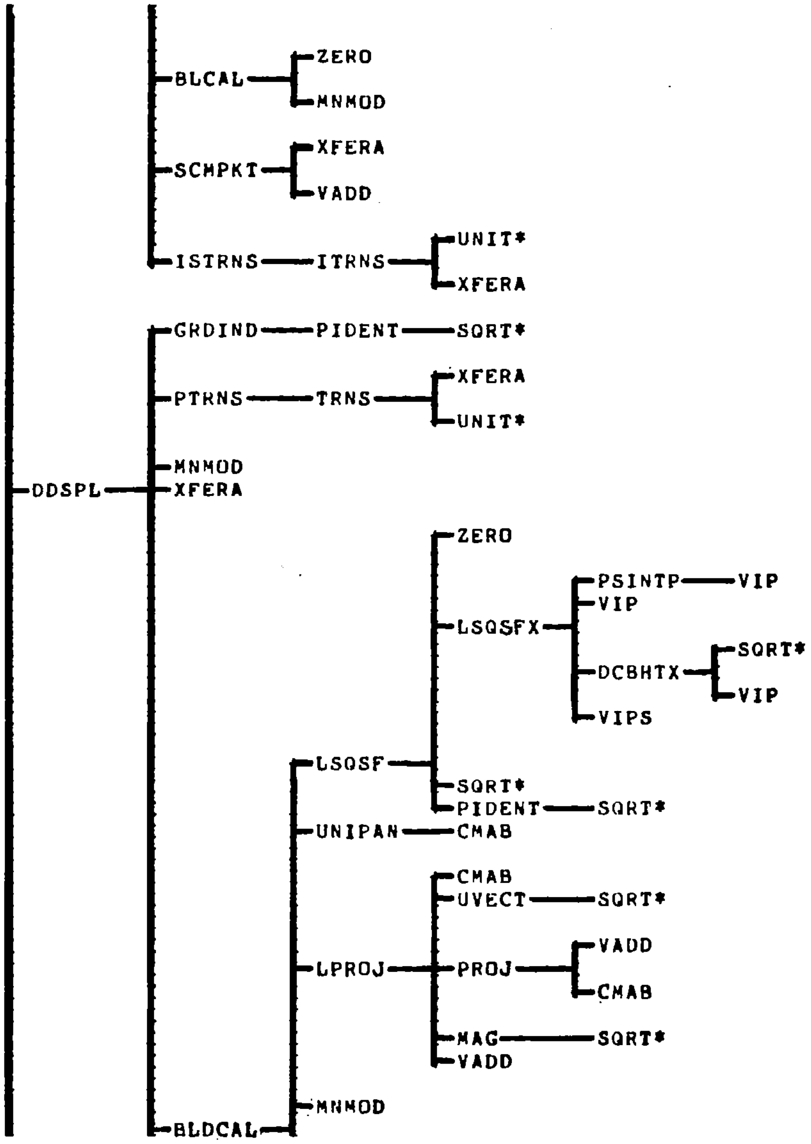
MAP OF OVERLAY(NETGCS,2,2):

ENTRY PT. TSING



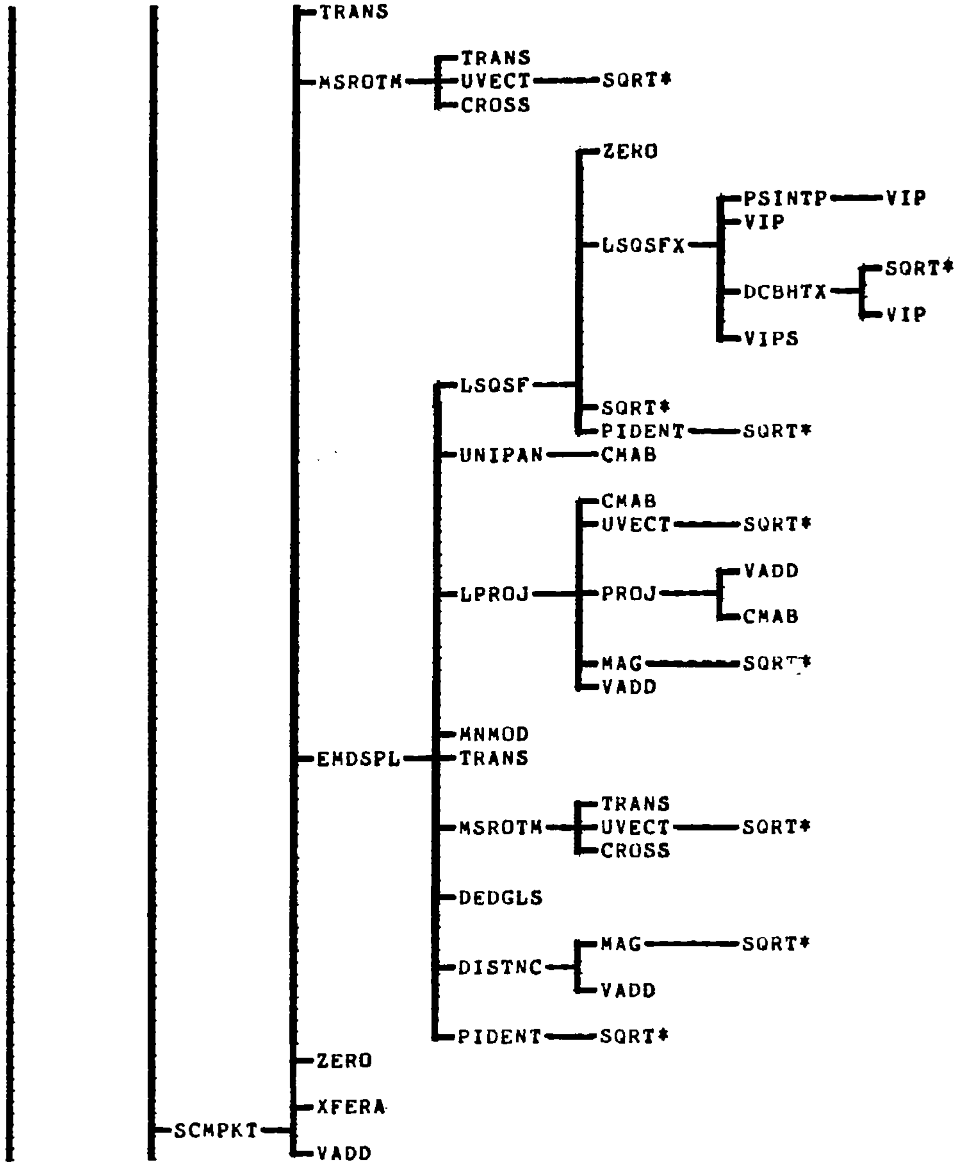
MAP OF OVERLAY(NETGCS,2,2):

ENTRY PT. TSING



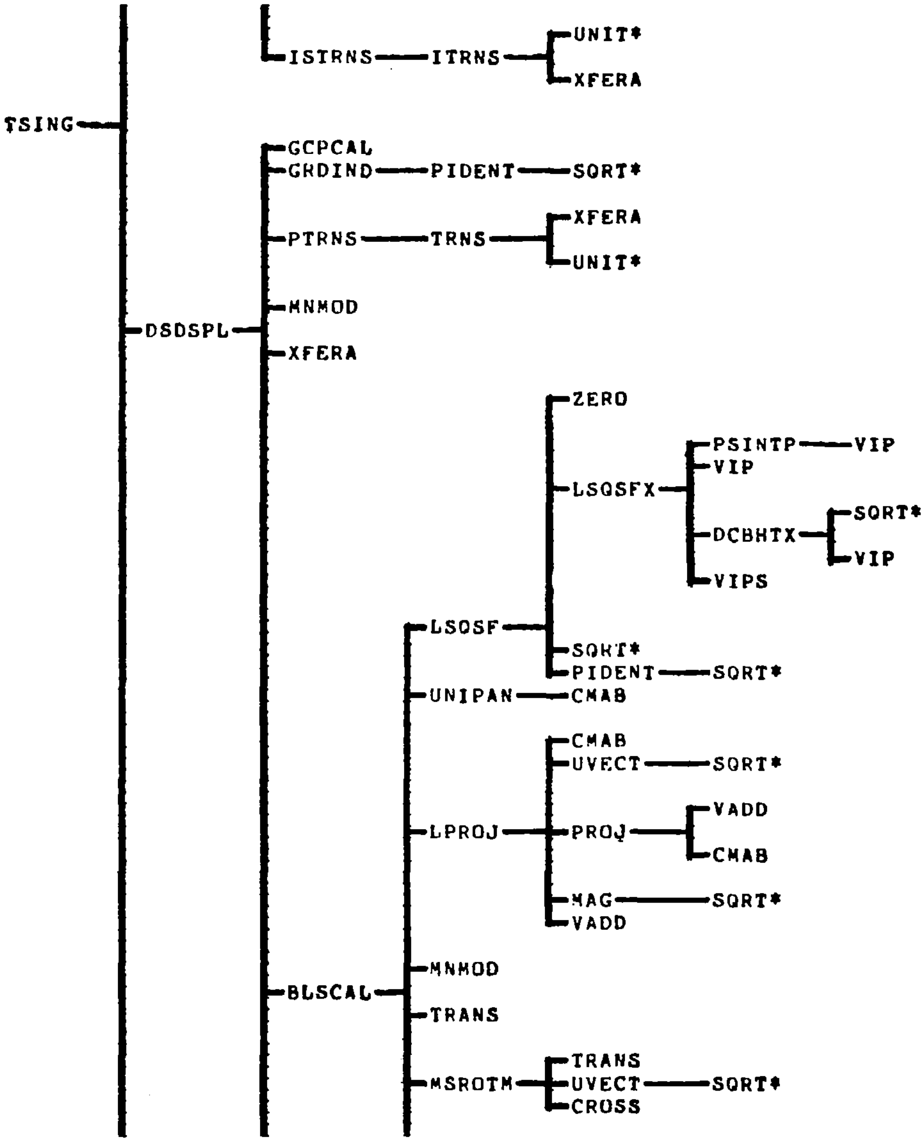
MAP OF OVERLAY(NETGCS,2,2):

ENTRY PT. TSING



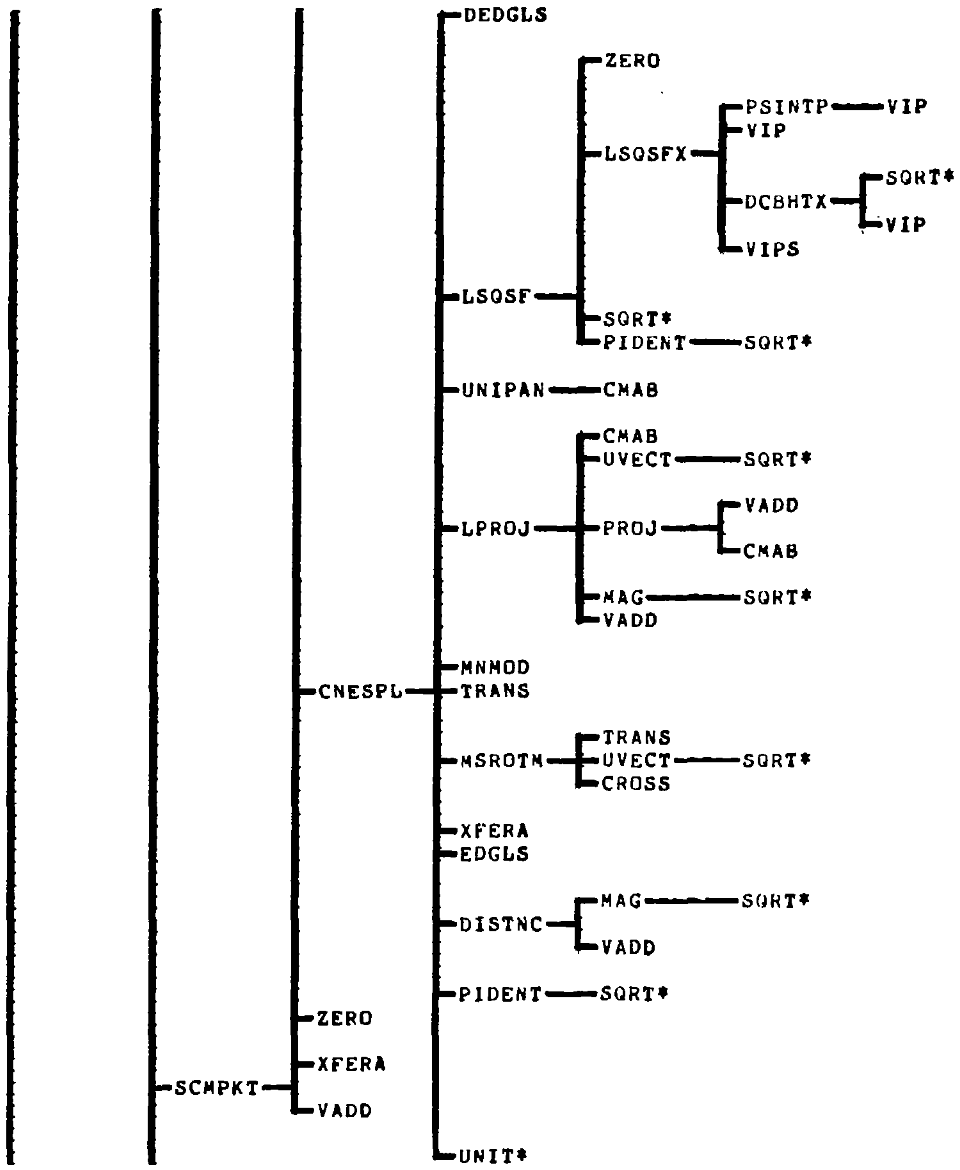
MAP OF OVERLAY(NETGCS,2,2):

ENTRY PT. TSING



MAP OF OVERLAY(NETGCS,2,2):

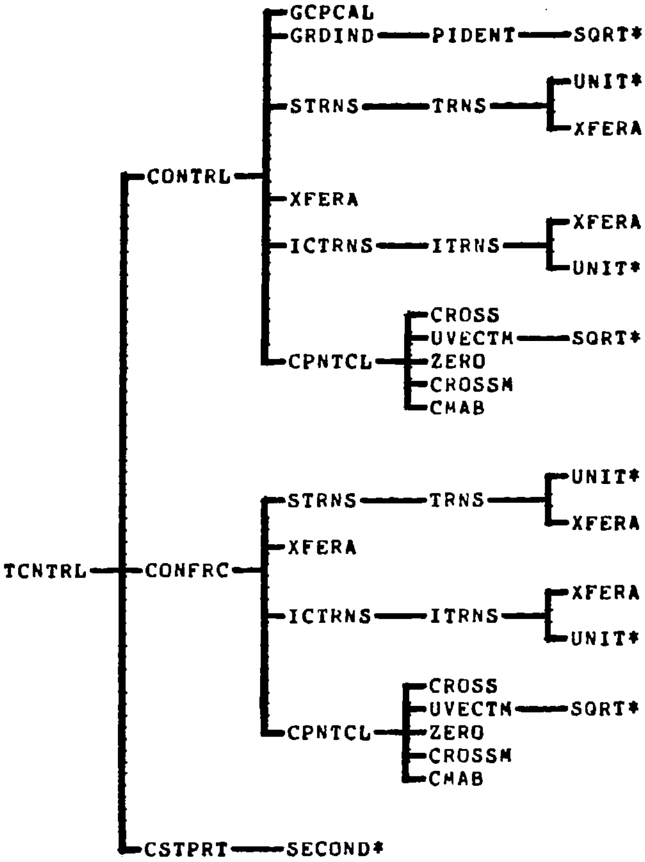
ENTRY PT. TSING



```
 MAP  OF  OVERLAY(NETGCS,2,2):

ENTRY PT. TSING

          |         +-ISTRNS----ITRNS----+
          |         |                    +-XFERA
          |         |
          |         |
          |         +-XFERA
          |         +-PIDENT----SQRT*
          |         |
          |         |                    +-XFERA
          |         +-PTRNS-----TRNS-----+
          |         |                    +-UNIT*
          |         |
          |         +-MNMOD
          |         +-ZERO
          +-DWSPL---+
          |         |         +-MAG------SQRT*
          |         +-DISTNC--+
          |         |         +-VADD
          |         +-EDGLS
          |         +-DEDGLS
          |         |
          |         |         +-XFERA
          |         +-SCMPKT--+
          |         |         +-VADD
          |         |
          |         |                    +-UNIT*
          |         +-ISTRNS----ITRNS----+
          |                              +-XFERA
          |
          +-CSTPRT----SECOND*
```

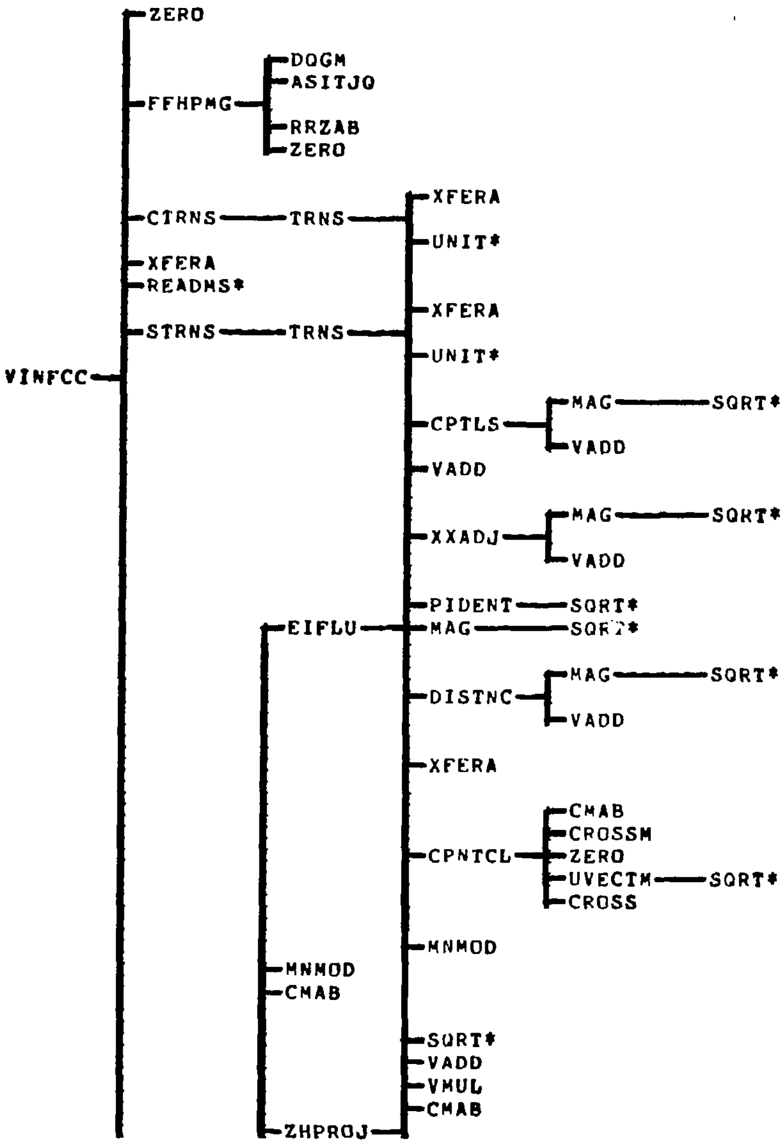
7.5.6 MAP OF OVERLAY (NETGCS, 2, 3)

```
MAP  OF  OVERLAY(NETGCS,2,3):

ENTRY PT. TCNTRL
```



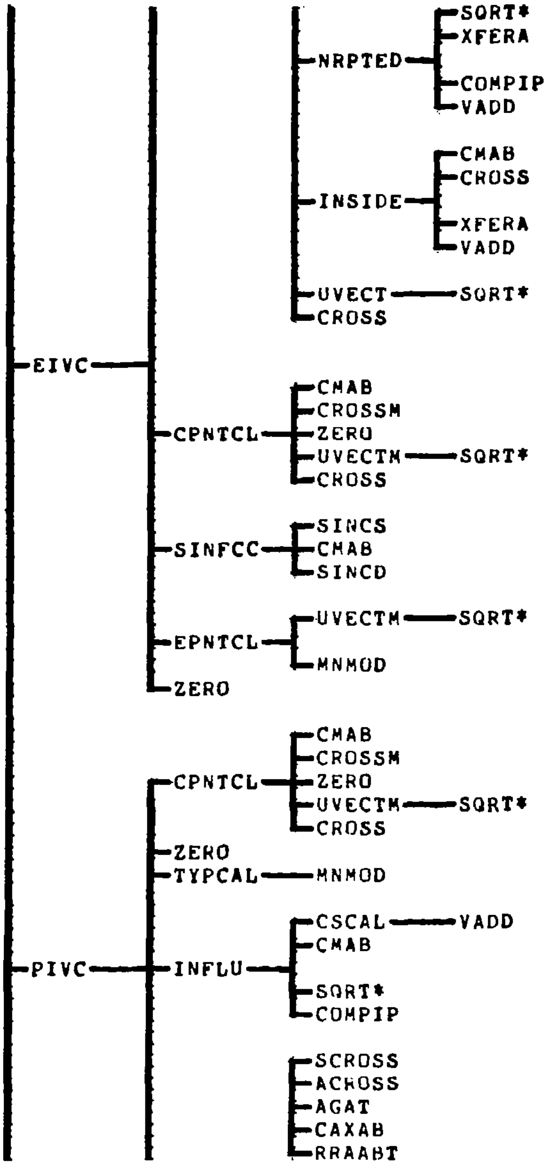
7.5.7 MAP OF OVERLAY (AICGEN, 3, 0)

```
MAP  OF  OVERLAY(AICGEN,3,0):
ENTRY PT. VINFCC
```



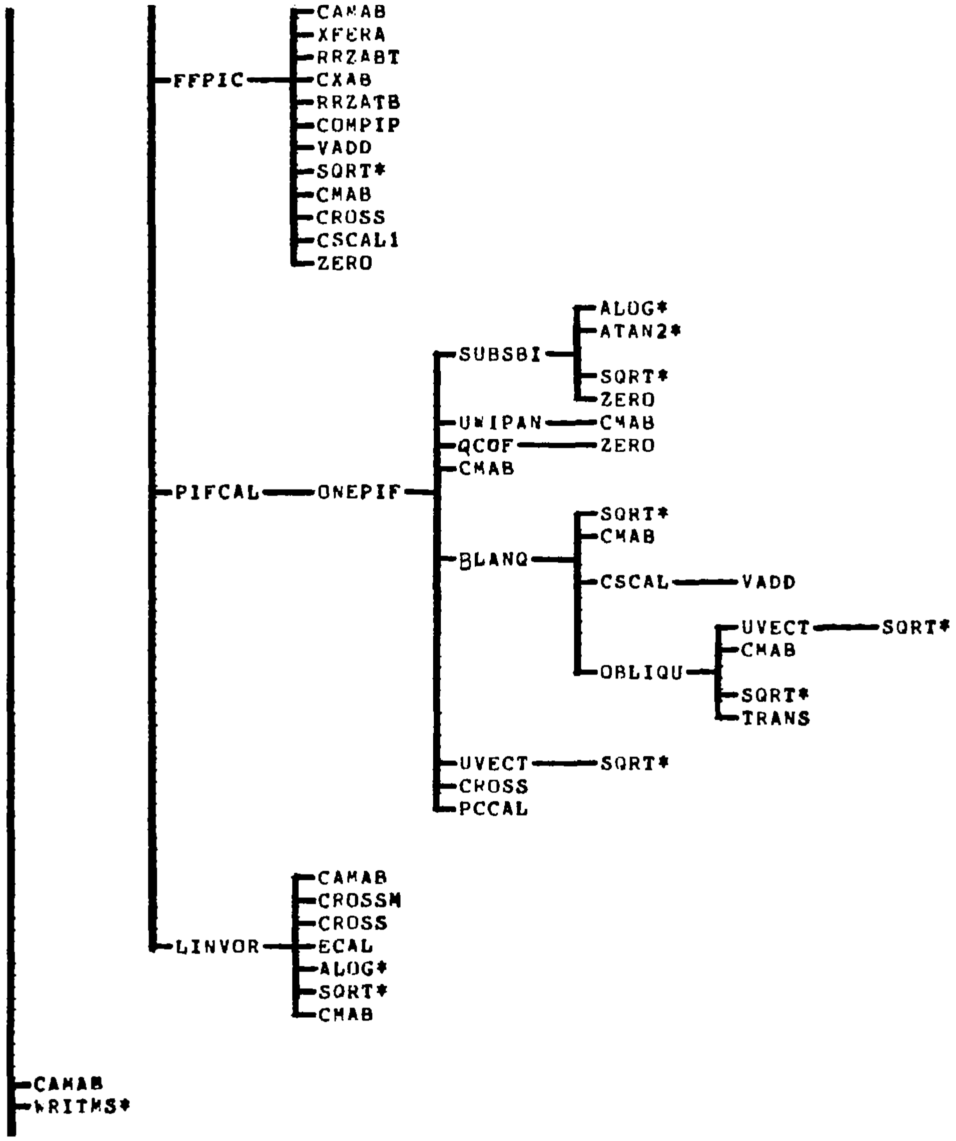
MAP OF OVERLAY(AICGEN,3,0):

ENTRY PT. VINFCC



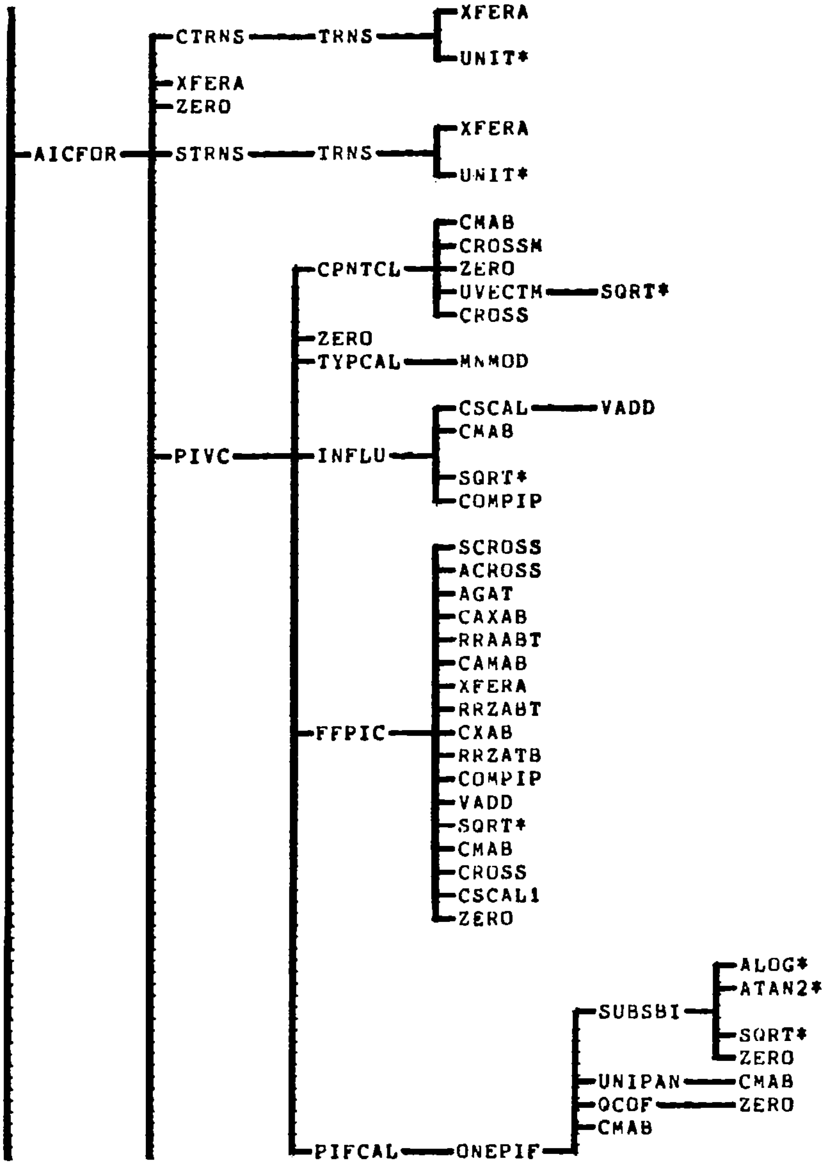
MAP OF OVERLAY(AICGEN,3,0):

ENTRY PT. VINFCC

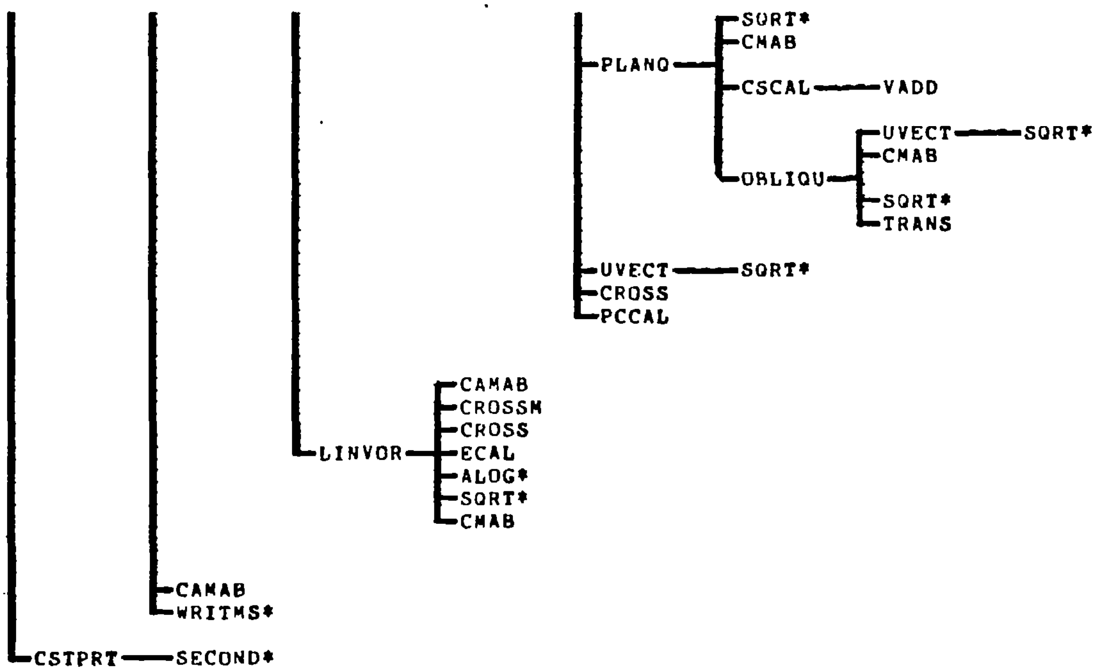


MAP OF OVERLAY(AICGEN,3,0):

ENTRY PT. VINFCC

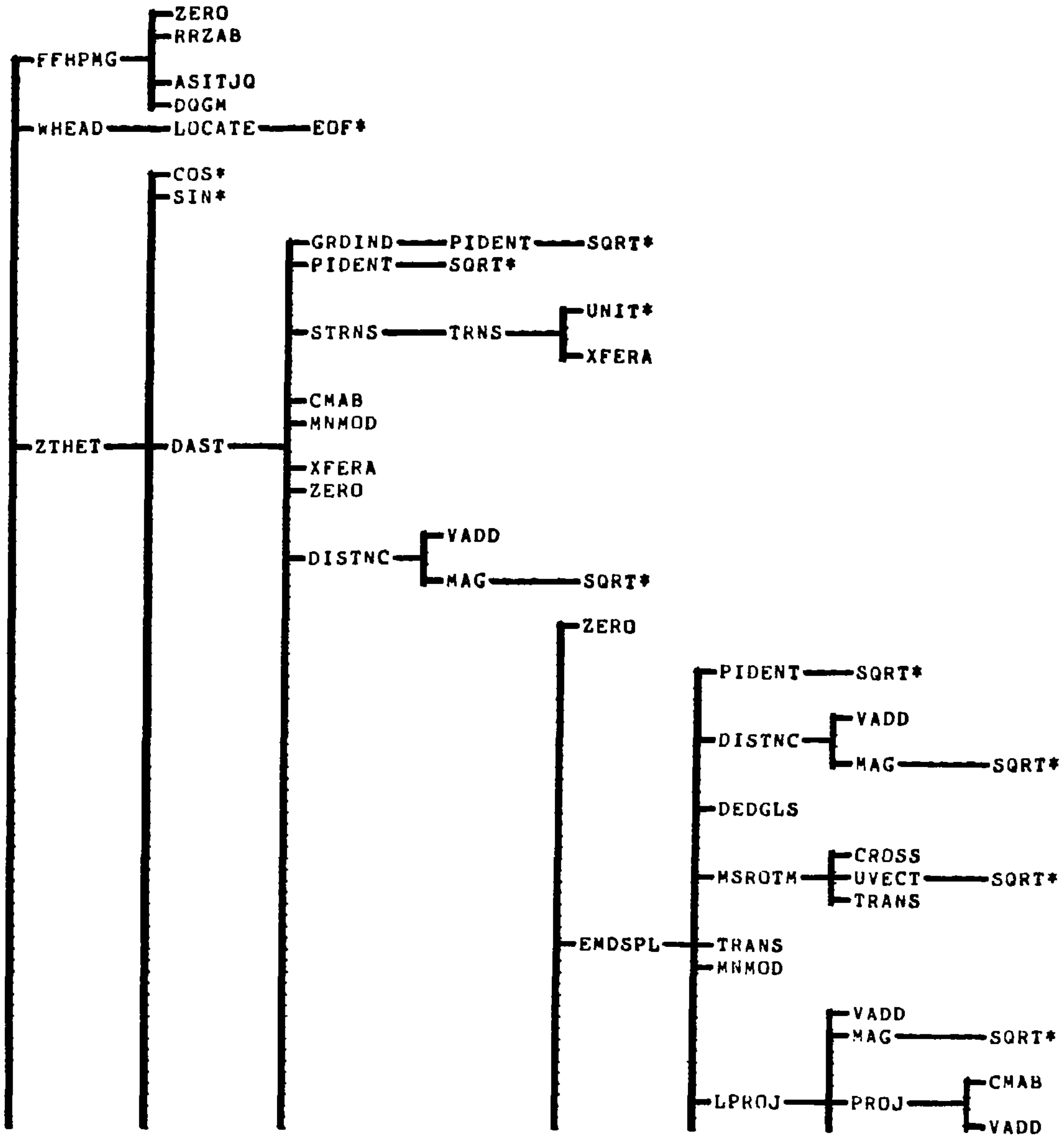


```
 MAP  OF  OVERLAY(AICGEN,3,0):
ENTRY PT. VINFCC
```



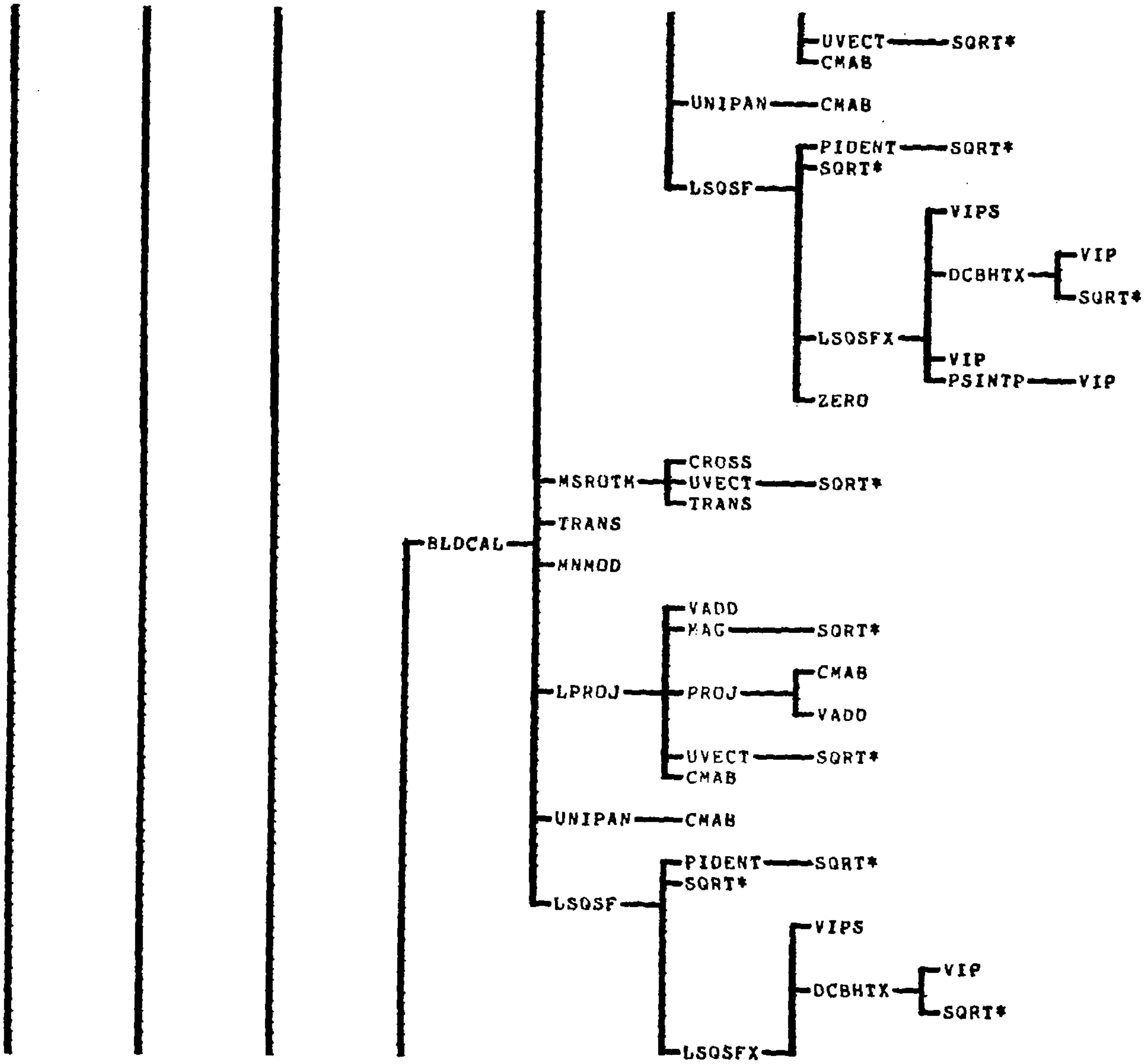
7.5.8 MAP OF OVERLAY (JACGEN, 4, 0)

```
MAP  OF  OVERLAY(JACGEN,4,0):
ENTRY PT. AJGEN
```



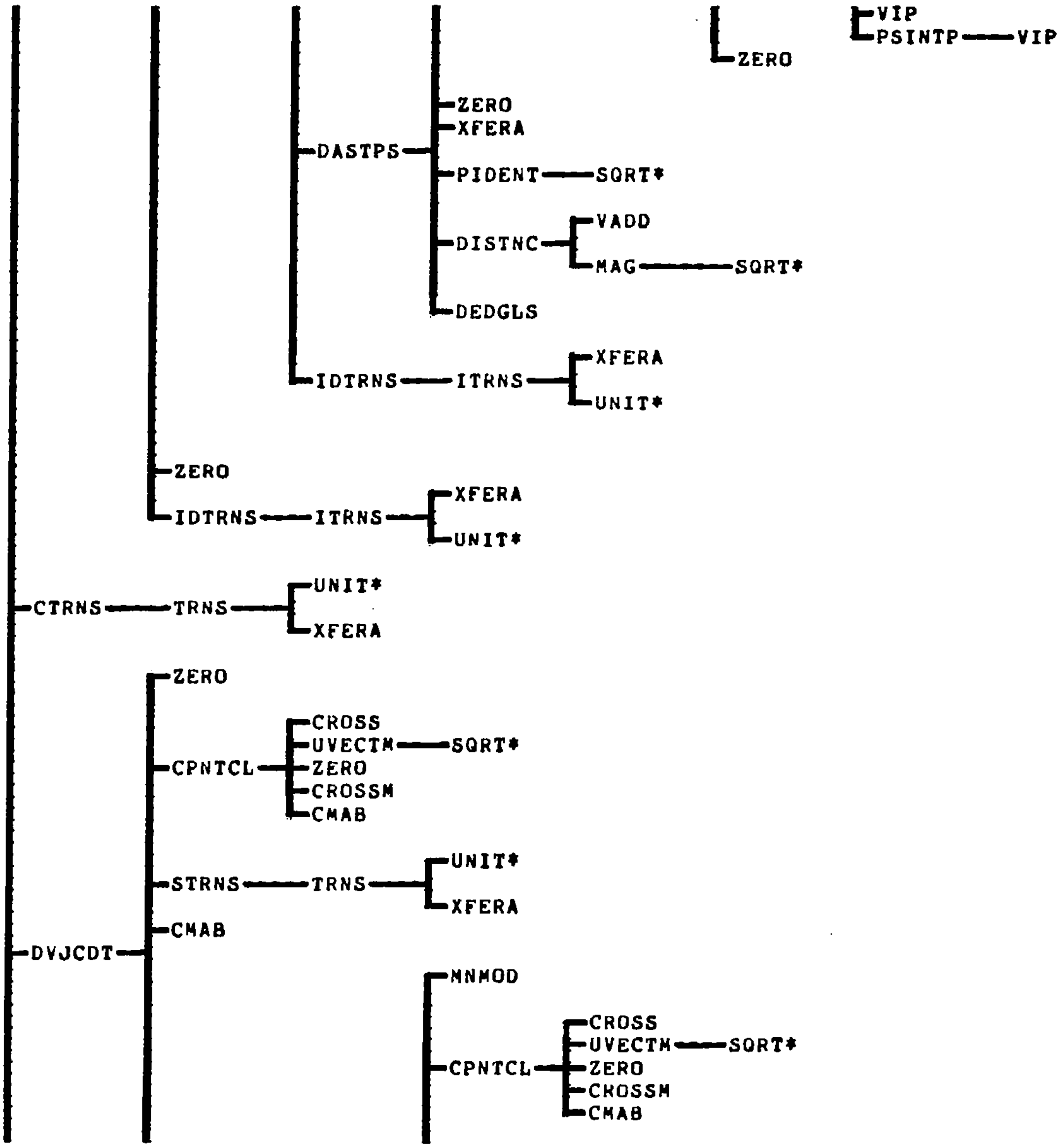
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN



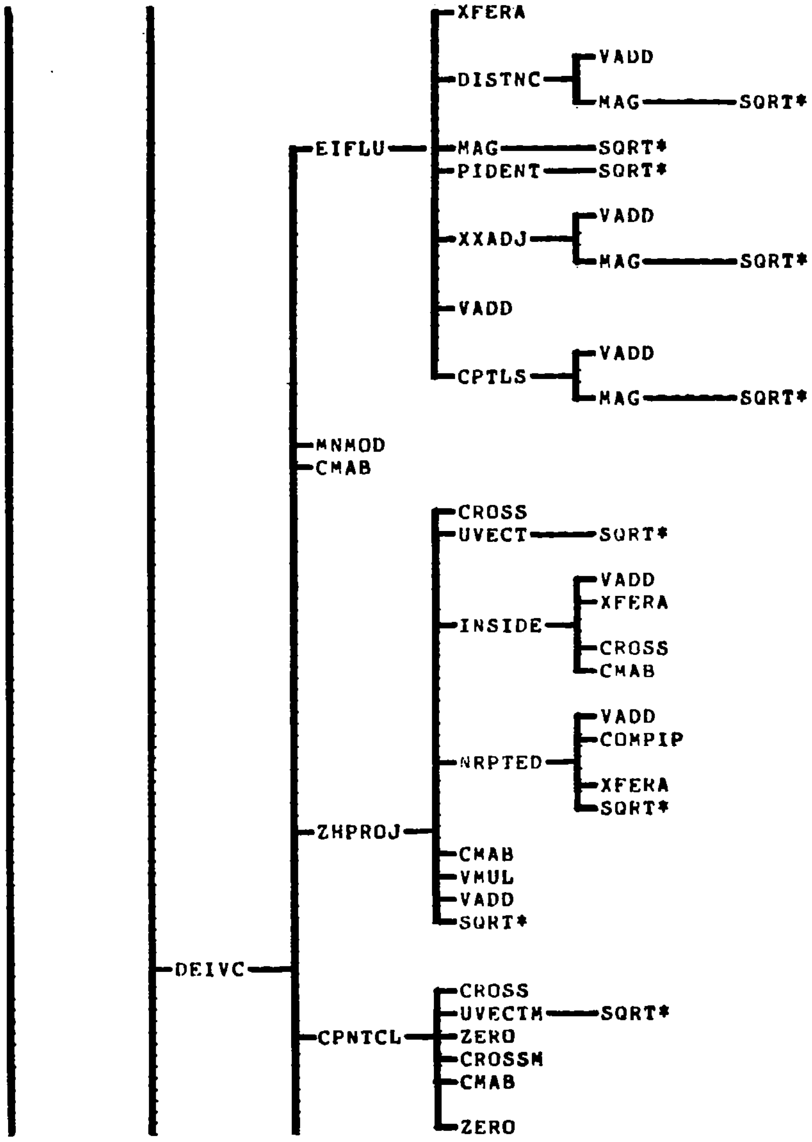
MAP OF OVERLAY(JACGEN,4,0)I

ENTRY PT. AJGEN



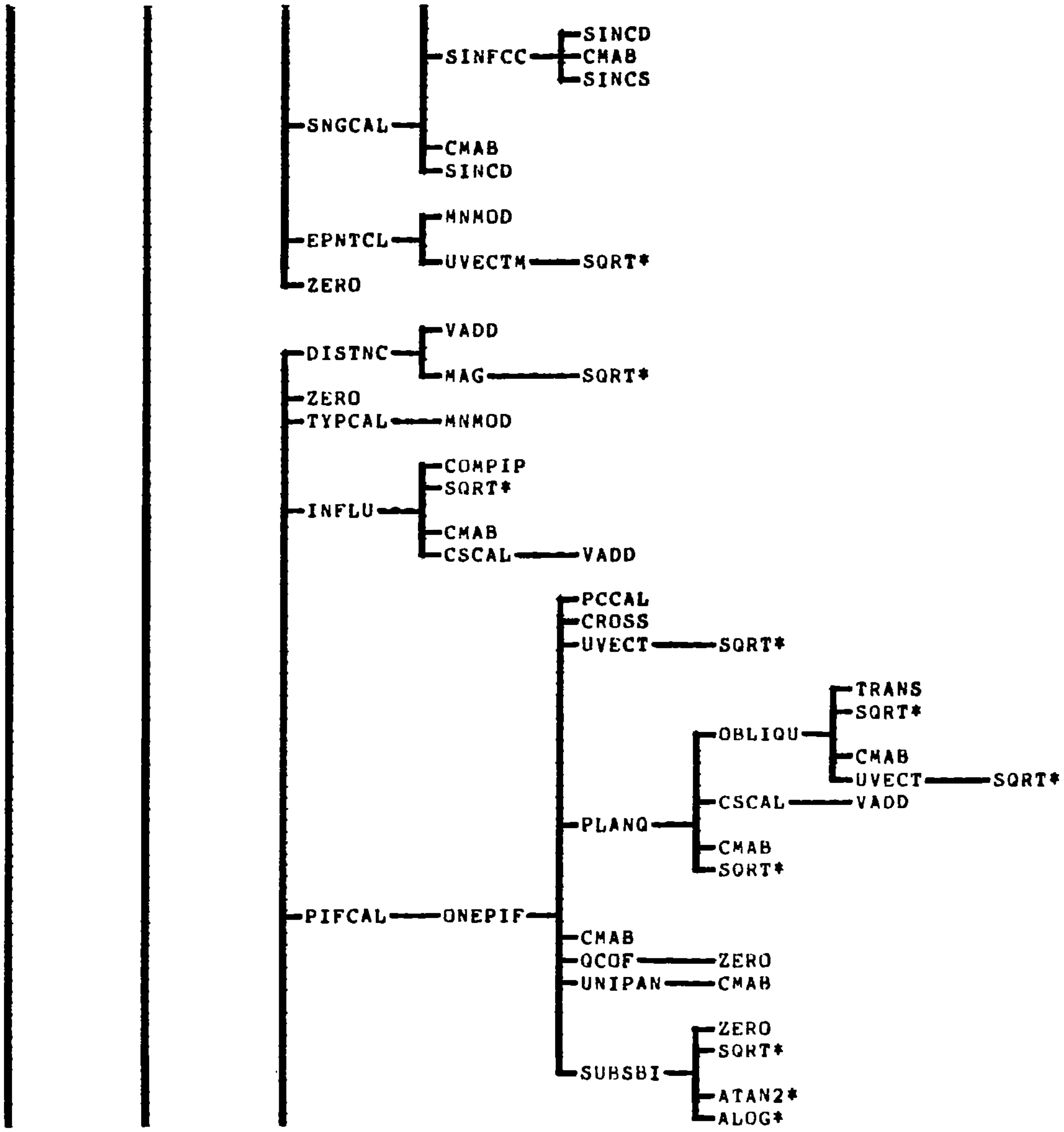
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN



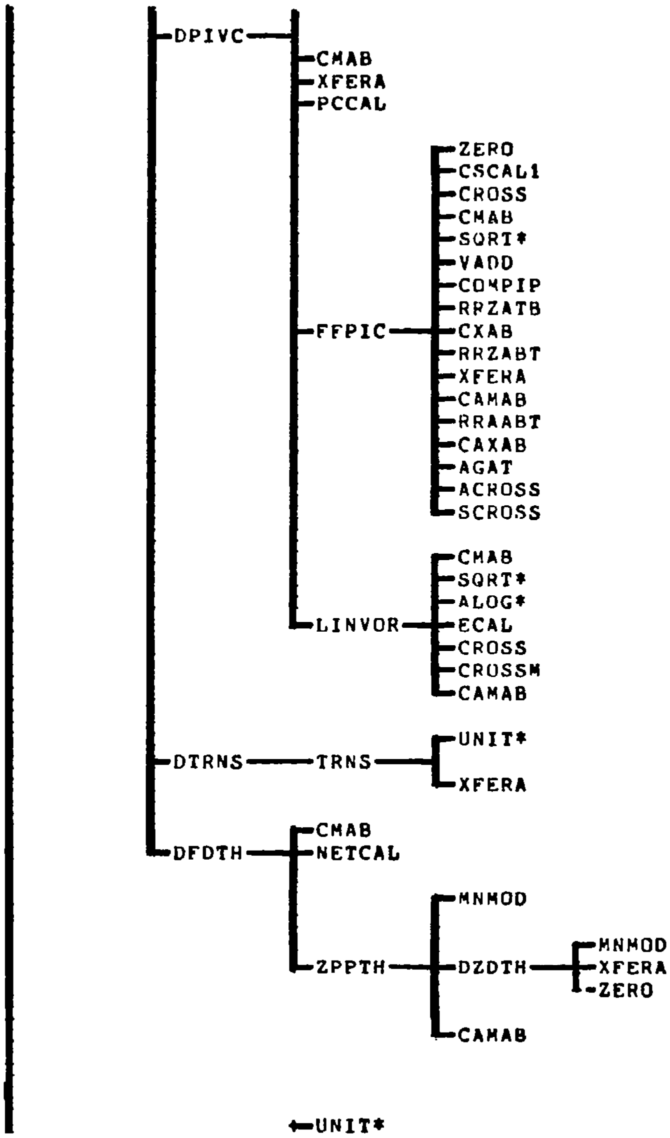
MAP OF OVERLAY(JACGEN,4,0)$

ENTRY PT. AJGEN



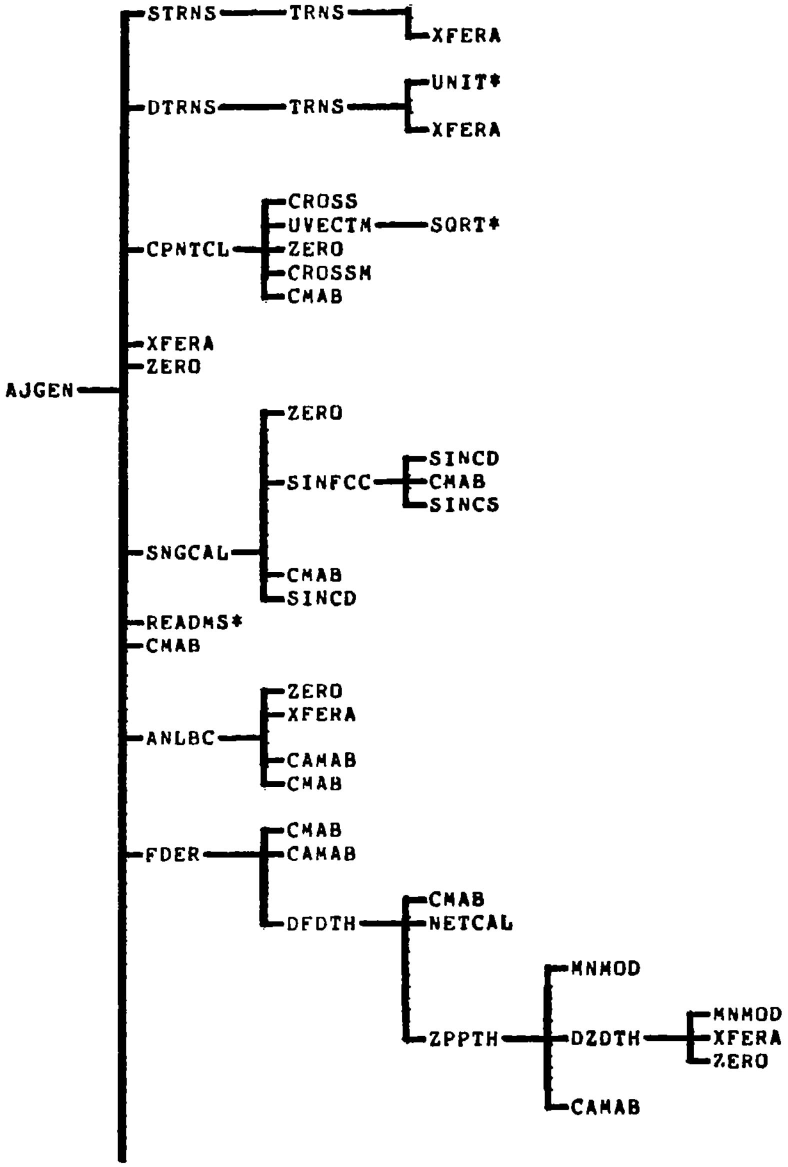
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN



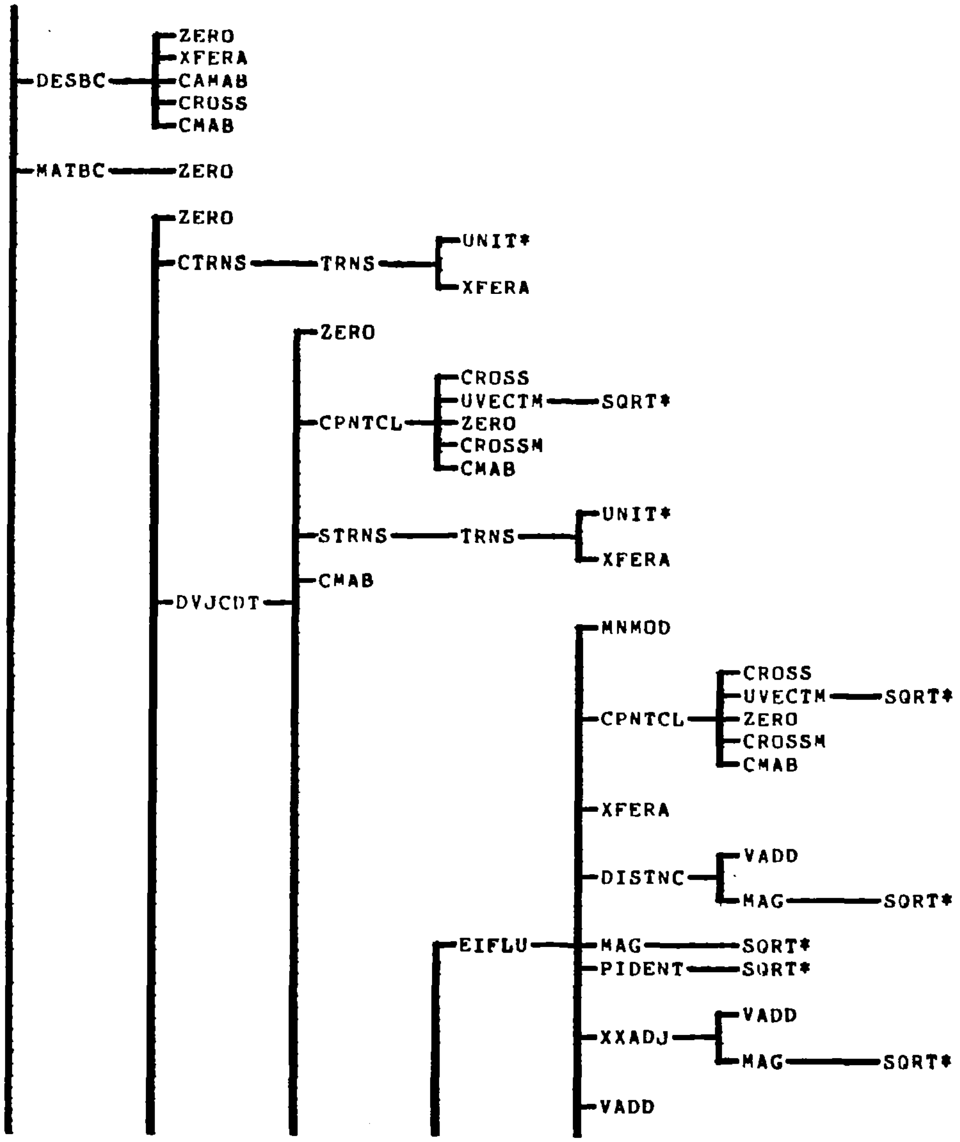
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN



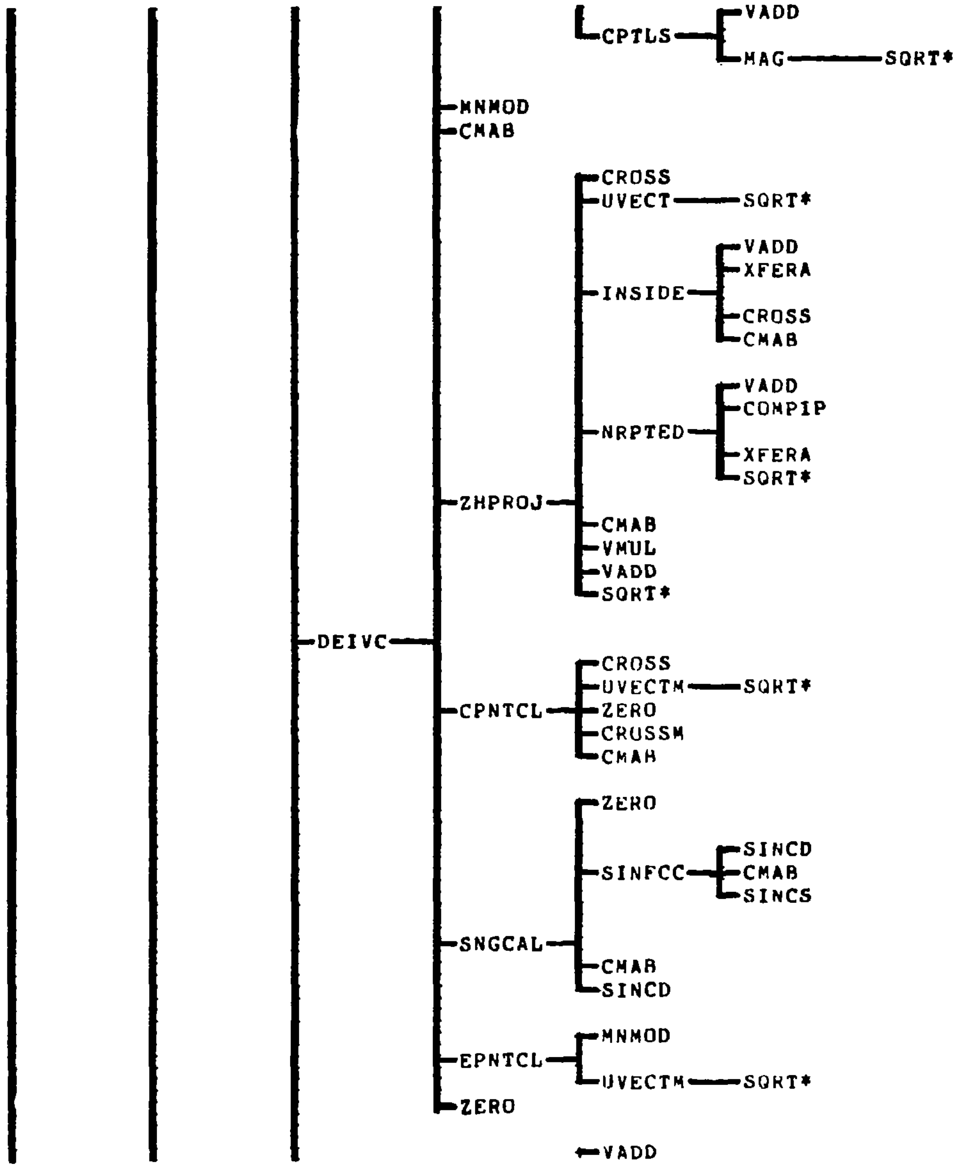
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN



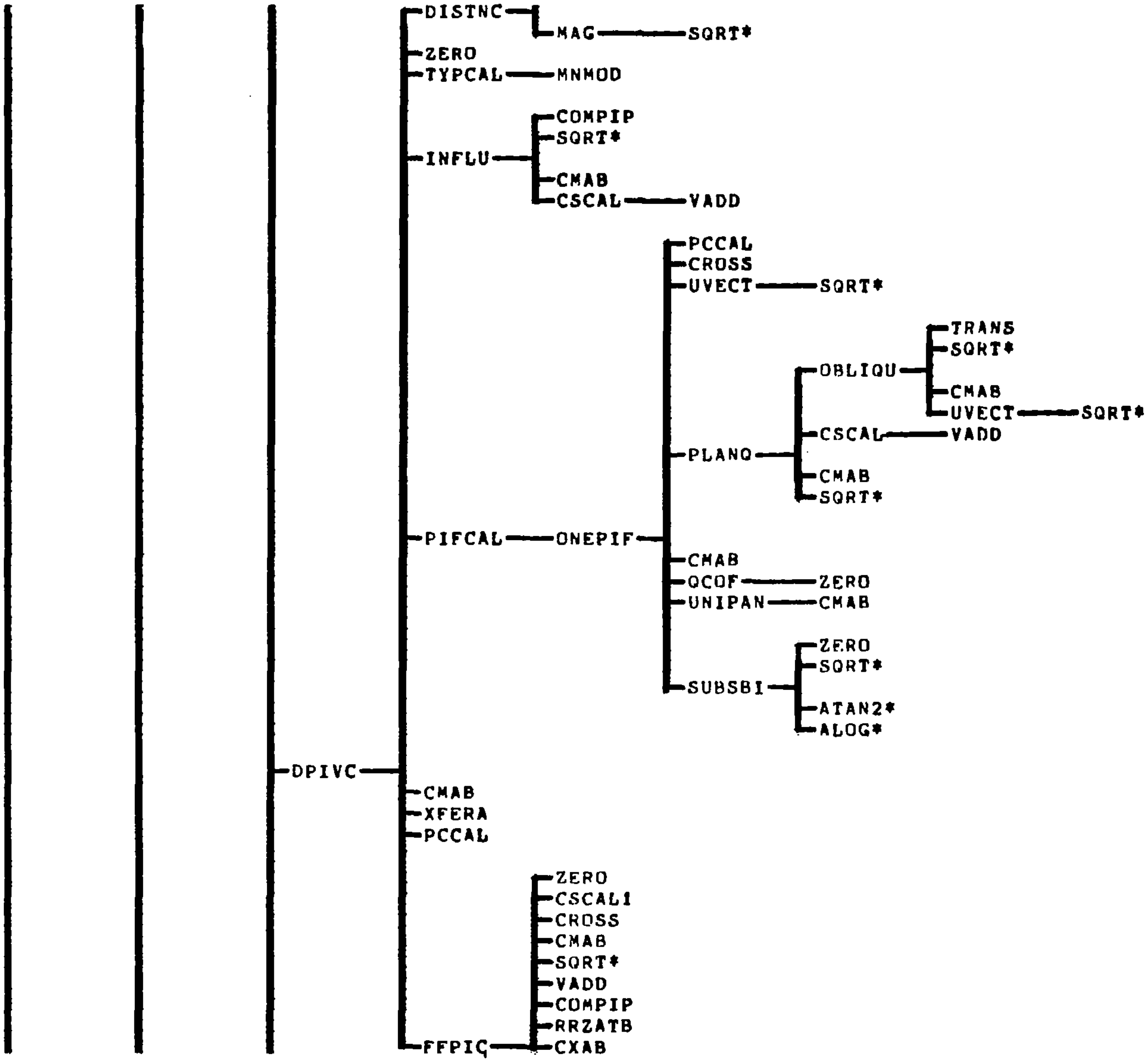
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN



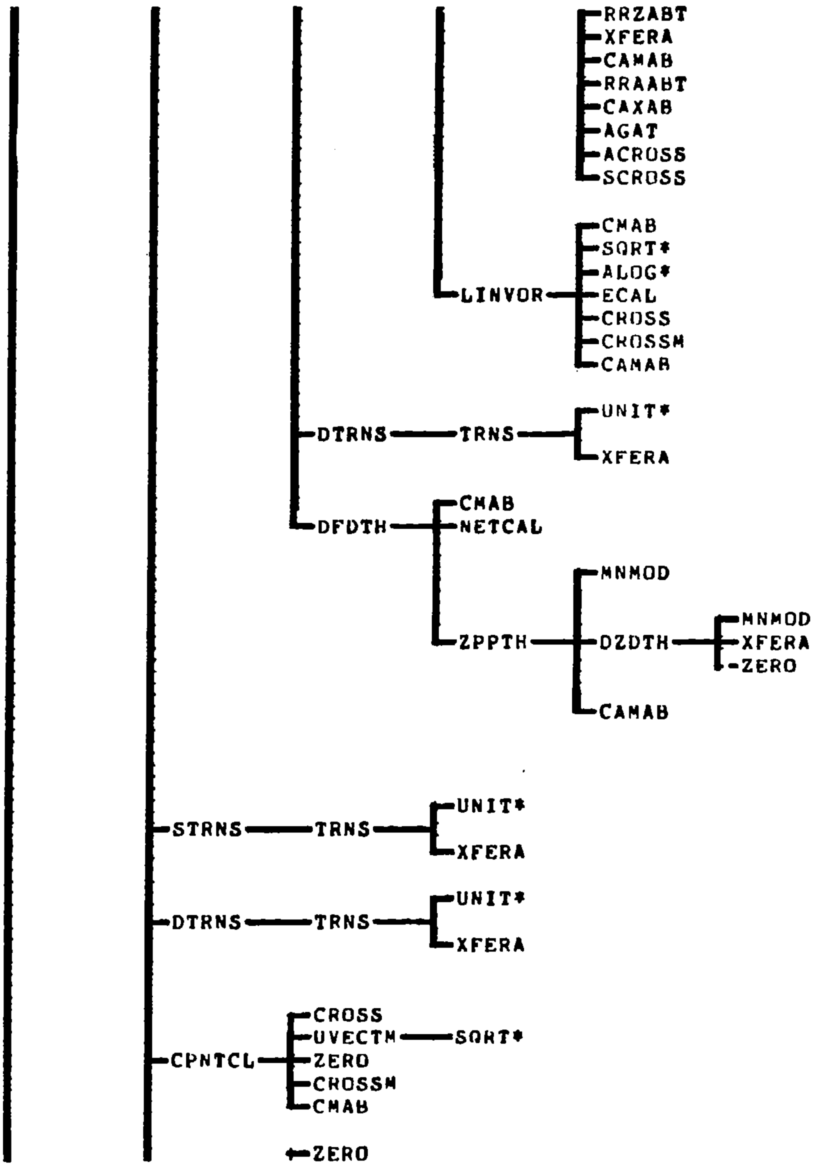
MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN

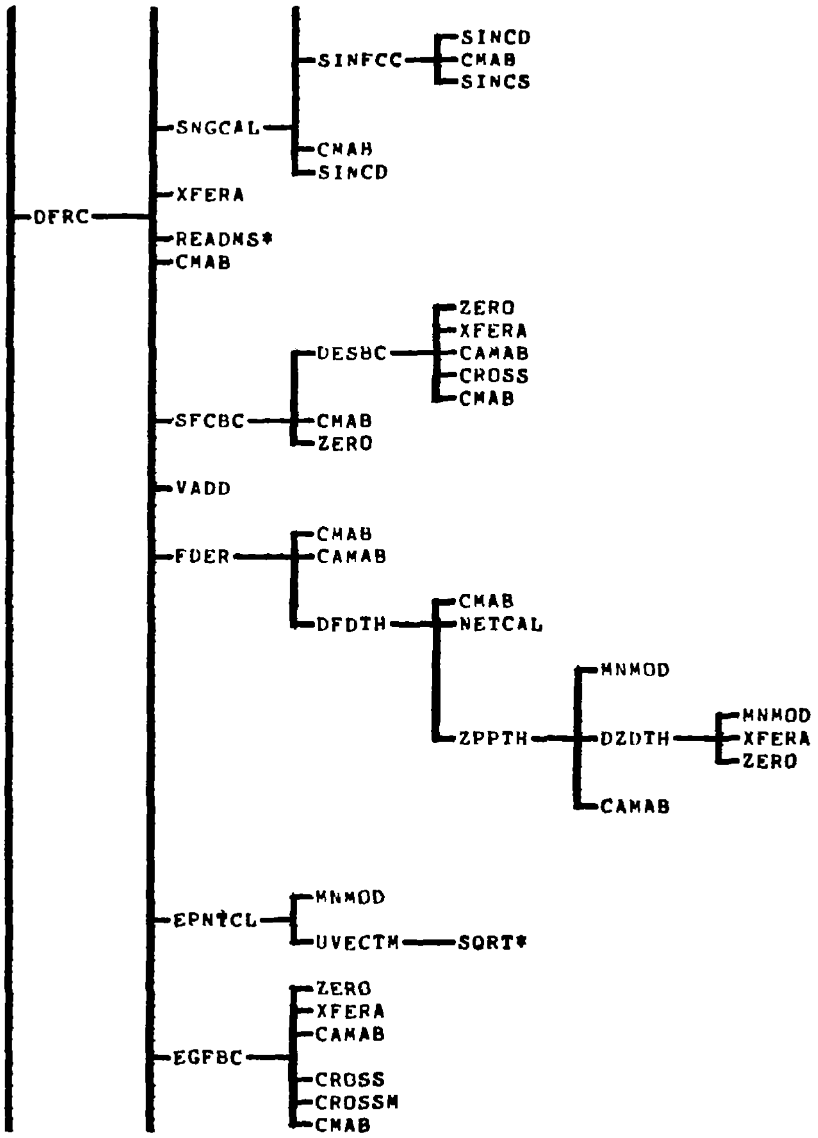


MAP OF OVERLAY(JACGEN,4,0):

ENTRY PT. AJGEN

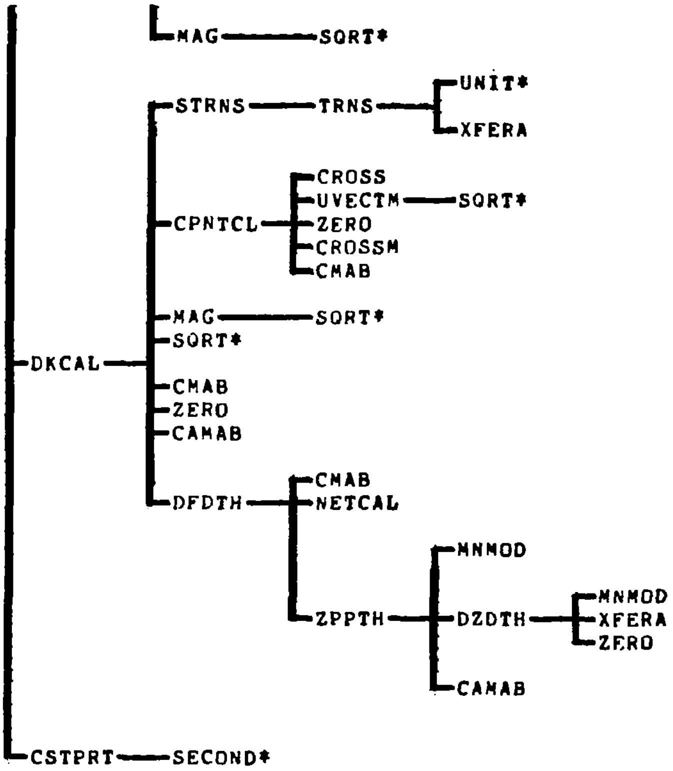


```
MAP  OF  OVERLAY(JACGEN,4,0):
ENTRY PT. AJGEN
```



MAP OF OVERLAY(JACGEN,4,0):

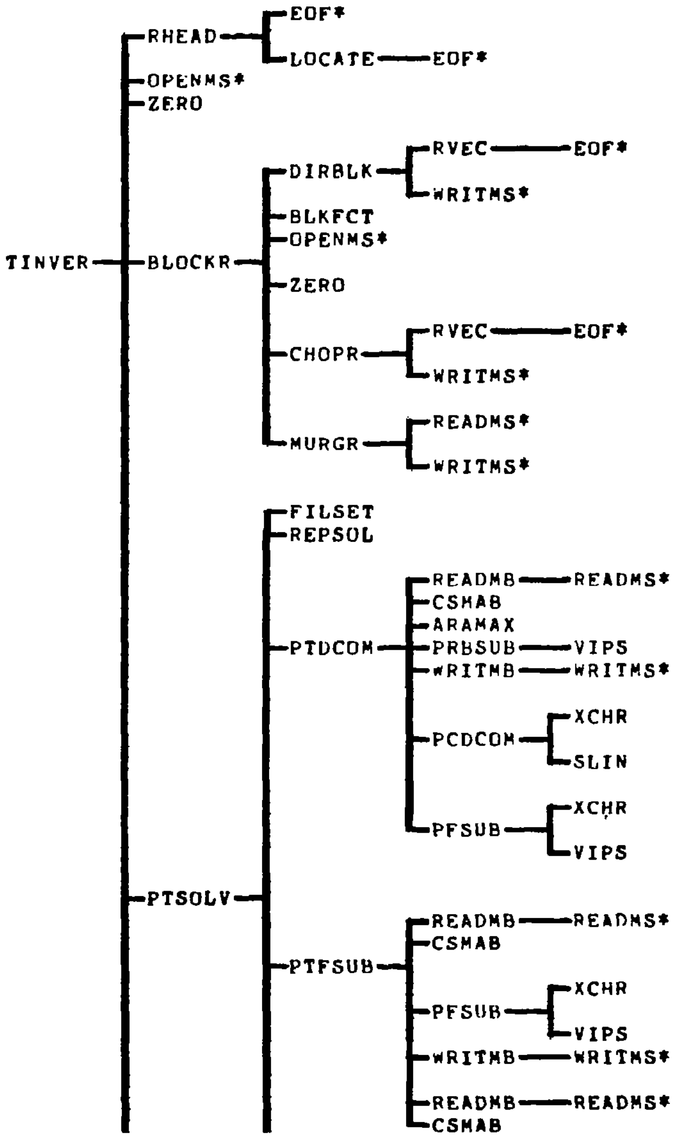
ENTRY PT. AJGEN



7.5.9 MAP OF OVERLAY (SOLVER, 5, 0)

MAP OF OVERLAY(SOLVER,5,0):

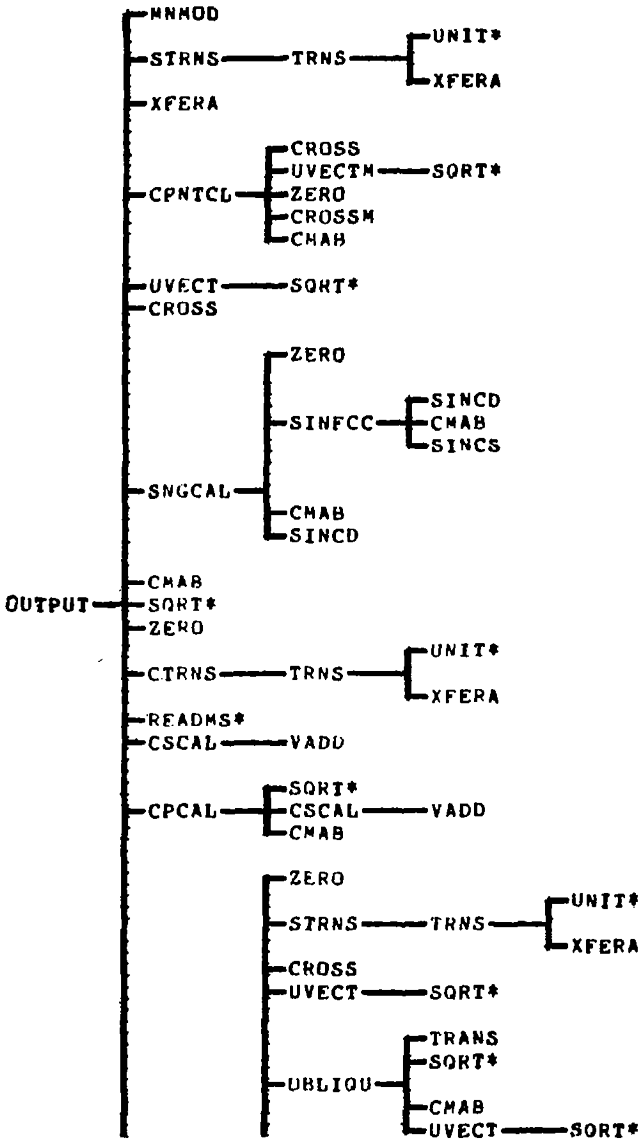
ENTRY PT. TINVER



```
 MAP   OF   OVERLAY(SOLVER,5,0):

ENTRY PT. TINVER

         |          |-TBSUB---|
         |          |         |-BSUB------VIPS
         |          |         |-WRITMB----WRITMS*
         |          |
         |          |-PRPIV-----READMB----READMS*
         |          |
         |          |-WHEAD-----LOCATE----EOF*
         |-RBLOCK---|-READMB----READMS*
         |          |-WVEC
         |
         |-CSTPRT---SECOND*
```

7.5.10 MAP OF OVERLAY (RESULT, 6, 0)

```
MAP  OF  OVERLAY(RESULT,6,0):

ENTRY PT. OUTPUT
```



```
MAP  OF  OVERLAY(RESULT,6,0):

ENTRY PT. OUTPUT

   |                    |
   |                    |-UNIPAN----CMAB
   |                    |
   |                    |                   |-ZERO
   |-FMCAL--------------|-CCAL--------------|
   |                    |                   |-ECAL
   |                    |
   |                    |-CSCAL-------------VADD
   |                    |-CMAB
   |                    |-SQRT*
   |                    |
   |                    |                   |-VADD
   |                    |                   |-MAG-------------SQRT*
   |                    |                   |
   |                    |                   |                 |-CMAB
   |                    |-LPROJ-------------|-PROJ------------|
   |                    |                   |                 |-VADD
   |                    |                   |
   |                    |                   |-UVECT-----------SQRT*
   |                    |                   |-CMAB
   |                    |
   |                    |                   |-PIDENT----------SQRT*
   |                    |                   |-SQRT*
   |                    |-LSQSF-------------|
   |                    |                   |                 |-VIPS
   |                    |                   |                 |
   |                    |                   |                 |                  |-VIP
   |                    |                   |                 |-DCBHTX-----------|
   |                    |                   |                 |                  |-SQRT*
   |                    |                   |                 |
   |                    |                   |-LSQSFX----------|
   |                    |                   |                 |-VIP
   |                    |                   |                 |-PSINTP-----------VIP
   |                    |                   |
   |                    |                   |-ZERO
   |                    |
   |                    |-VADD
   |-VSPLOT-------------SUBPON
   |-CSTPRT-------------SECOND*
```

REFERENCES

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16. Abstract

An improved panel method for the solution of three dimensional flow about wing and wing-body combinations with leading edge vortex separation is presented. The method employs a three-dimensional inviscid flow model in which the configuration, the rolled-up vortex sheets, and the wake are represented by quadratic doublet distributions. The strength of the singularity distribution as well as shape and position of the vortex spirals are computed in an iterative fashion starting with an assumed initial sheet geometry. The method calculates forces and moments as well as detail surface pressure distributions. Improvements include the implementation of improved panel numerics for the purpose of eliminating the highly non-linear effects of ring vortices around doublet panel edges, and the development of a least squares procedure for damping vortex sheet geometry update instabilities.

The documentation is divided up into two parts:

Volume I - Theory Document
Volume II - User's Guide and Programmer's Guide

Volume II contains instructions for the proper set up and input of a problem into the computer code. Program input formats and output are described. A description of the computer program and its overlay structure is also presented.

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Panel Method
Three-Dimensional
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