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NUMERICAL DESIGN OF TRANSONIC CASCADES

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ABSTRACT:

The method developed by Bauer, Garabedian, and Korn [2] for the design of wing sections which exhibit shock-free flow at high subsonic speeds has been applied to the problem of cascade design. A cascade is a periodic distribution of two dimensional blade cross sections which serves as a basis for the design of axial flow compressors and turbines.

Those aspects of the design procedure which are used for both airfoil and cascade design are reviewed briefly in this paper. Emphasis has been made on the differences, namely in the form of the singular solution in the hodograph plane. The singular solution for flow around an airfoil consists of a pole and a nearby branch point in the hodograph plane. The singular solution for the cascade is formed by two logarithmic singularities resembling a source and sink.

A listing of the computer program used to design transonic cascades with this method has been included. Details omitted from the text of this paper can be found by careful examination of the computer program. In order to make it possible to run this program a description of the input needed to execute this program has also been included. The output listing for the blade shown in Figures 2 and 3 which has been included contains the list of input parameters necessary to regenerate this case.

1. Introduction

In recent years there has been a growing concern about the availability and utilization of our energy resources. Considerable effort has gone into the development of new resources and into methods of more efficient use of existing energy supplies. We will describe here a procedure which can be used to design more efficient high speed turbomachinery which could result in significant fuel conservation. In particular, this technology could be the basis for the design of improved axial flow compressors used for the production of enriched uranium at gaseous diffusion plants. Also, it can be used to design lighter weight and more efficient airplane engines.

In this paper we used a technique developed by Bauer, Garabedian and Korn [2] which has been used to design airplane wing sections and apply it to the problem of designing transonic turbine and compressor blades used in axial flow compressors. The method is applicable to two-dimensional problems and therefore our model for design will be a periodic distribution of two dimensional blade cross-sections called a cascade. As the distance between blades increases our solution must approach that of the isolated airfoil and therefore we can view this paper as an extension of the airfoil design method.

As with the airfoil problem, our concern is to find smooth, transonic steady state solutions to the equations of irrotational motion of an inviscid compressible fluid about some object. In this case the object will be a periodic distribution of blades. The equations of motion are the same as those used for the airfoil design problem, therefore, the same technique of using conjugate characteristic coordinates extended into the complex domain can be employed. A more detailed description of this method can be found in reference [2].

The main differences between designing a compressor blade and an airfoil are the locations and types of singularities of the solution in the hodograph plane. In the airfoil case, the basic singularity was a pole in the hodograph plane at some prescribed free stream velocity. For the cascade problem the velocity far upstream of the cascade, called the inlet velocity, is different from the velocity far downstream of the cascade, called the exit velocity. In fact the purpose of the cascade is to change the inlet velocity in some prescribed way. Thus, in the hodograph plane there are two velocities which correspond to infinity in the physical plane. The appropriate singularities in this case are logarithms at the inlet and exit velocities. As the distance between these logs decreases the spacing between blades increases approaching the isolated airfoil case. The logarithmic singularities behave like a dipole and, therefore, approach the correct singularity for flow around an airfoil in the limit.

For the cascade design problem, as with the airfoil design problem, we solve the inverse problem; that is, we generate solutions to the equations of motion with the prescribed singularity and examine the streamline passing through the stagnation point. This streamline describes the shape of the body. To generate solutions to the flow equations we choose a set of parameters which define physical quantities and describe the initial analytic function. We also prescribe where in the hodograph plane we would like the blade to lie. The program finds a solution to the equations of motion whose stagnation streamline matches the prescribed one in a least square sense. If this curve which represents the body is not closed or if it is not physically realizable in the physical plane, for example negative thickness, the input parameters must be changed and the program rerun.

In Section 2 the equations of motion are presented and rewritten in characteristic coordinates which are extended into the complex domain. A formulation of a method to generate solutions with the appropriate singularity for a cascade appears in Section 3. In Section 4 we discuss the problem of choosing the initial function. In Section 5 a description is given of the numerical technique which has been programmed on a CDC 6600 computer. We have enumerated many of the modifications of the design procedure of reference [2] and presented some results in Section 6. Finally, a listing of the FORTRAN program used to generate the results of Section 6 has been included, which should help explain many of the details. A sample run has been included along with glossaries describing input specifications. This should make it possible for someone to copy and execute this program. We intend to send a copy of this program for inclusion in the library at the Argonne National Laboratory.

The author would like to thank the many people who in one way or another assisted me in this work. The idea of extending the design procedure to cascades was suggested independently by Milton Plessit and A. J. Acosta of the California Institute of Technology and Julian Prince of United Aircraft. I am deeply indebted to Paul Garabedian for the aid and encouragement which was given to me at all stages of development of this work. Eldon McIntyre has assisted in the preparation of this paper by carefully reading an early draft of this paper and correcting numerous errors in many of the formulas. Frances Bauer read a later draft and made numerous helpful suggestions. Farnella Graham patiently typed and retyped this manuscript. Finally, I would like to thank my family whose patience and understanding has not gone unnoticed.

2. Equations of Motion

Let x and y be Cartesian coordinates and let u and v be the corresponding velocity components. Then the steady state equations of motion for an inviscid polytropic gas with isentropic, irrotational flow is

$$(2.1) \quad (c^2 - u^2)\phi_{xx} - 2uv\phi_{xy} + (c^2 - v^2)\phi_{yy} = 0$$

where ϕ is the velocity potential, $\phi_x = u$, $\phi_y = v$, and c is the local sound speed.

Let p denote pressure and ρ density. The local speed of sound, c , is defined by

$$(2.2) \quad c^2 \equiv \frac{dp}{d\rho} = \gamma \frac{p}{\rho}$$

where γ is a gas constant. Conservation of energy is expressed by Bernoulli's equation

$$(2.3) \quad c^2 = c_0^2 - \frac{\gamma-1}{2} q^2; \quad q^2 = u^2 + v^2$$

where c_0 is the sound speed at stagnation velocity. Equation (2.3) shows that c , hence ρ and p are functions only of the speed q .

Introducing characteristic coordinates ξ and η , equation (2.1) can be written as a system of four linear equations for u , v , x , and y [cf. 2].

Computing the characteristic directions

$$(2.4) \quad \lambda_{\pm} = \frac{uv \pm c\sqrt{q^2 - c^2}}{c^2 - v^2}$$

we can write the equations of motion in characteristic form as follows:

$$(2.5a) \quad v_{\xi} = \lambda_{+} u_{\xi} \quad ; \quad v_{\eta} = \lambda_{-} u_{\eta}$$

$$(2.5b) \quad \lambda_{-} y_{\xi} + x_{\xi} = 0 \quad ; \quad \lambda_{+} y_{\eta} + x_{\eta} = 0$$

We define the local Mach number M as q/c . The equations of motion are hyperbolic when $\lambda_{\pm}$ are real and unequal which occurs when the flow is supersonic, $M > 1$. For $M < 1$ the flow is subsonic and the complex conjugate roots in $\lambda_{\pm}$ mean that the equations of motion are elliptic. The set of points where $M = 1$ is called the sonic line and is a circle in the hodograph plane $q = \text{constant}$. This constant is called the critical speed, which we denote by q_{*} .

Since we are interested in solutions to these equations in a region of the hodograph plane where both subsonic and supersonic flow is to occur we must use a method applicable to both regions. The method of complex extension [4] is ideally suited since in the complex domain there is no distinction of type, in fact, $\lambda_{\pm}$ need not be real or complex conjugate. The only theoretical difficulty which arises in using complex extension is along the set of points where $\lambda_{+} = \lambda_{-}$, i.e. $M = 1$, since equations (2.5b) are coincident there. It has been shown that this problem is easily treated (cf. [2, 9]).

With the method of complex extension the independent variables ξ and η are each extended into the complex domain so the solution u , v , x and y must be allowed to take on complex values. Since both ξ and η have real and imaginary components this amounts to enlarging the independent domain from two dimensions to four dimensions. We are interested in the solution only in the real hodograph. We would like to compute the solution in as small a

subset of the extended space as possible in order to obtain the solution in the real hodograph plane. It turns out to be possible to choose characteristic coordinates ξ and η so that the set of points $\xi = \bar{\eta}$ includes the real subsonic hodograph plane. We call this choice of characteristic coordinates, conjugate characteristic coordinates as described in [2].

Equations (2.5a) are independent of x and y and therefore $u(\xi, \eta)$ and $v(\xi, \eta)$ depend only on our choice of characteristic coordinates, not on the solution to our equations. We may therefore view ξ and η as being generalized hodograph variables. We can actually write closed form expressions for conjugate characteristic coordinates in terms of the hodograph variables u and v and thus solve (2.5a) explicitly. By integrating (2.4) (cf. [11]) we find that s and s^* are conjugate characteristic coordinates by choosing

$$(2.6) \quad s = h(q)e^{-i\theta} \quad ; \quad s^* = h(q)e^{i\theta}$$

where

$$(2.7) \quad h(q) = K q [(c - \sqrt{c^2 - q_*^2})^{1/\mu} (\sqrt{c^2 - q^2} + c)]^{-1}$$

where $\mu^2 = (\gamma-1)/(\gamma+1)$, $\theta = \tan^{-1} v/u$ and K is a constant chosen so that $h(1) = 1$. Note that as the critical speed q_* becomes infinite $h(q)$ approaches q . Thus for incompressible flow s approaches $w = u-iv$ and it follows that s is an extension for compressible flow of the complex velocity. The function h is real when q is real and subsonic so that s and s^* are complex conjugates in the subsonic region. We choose coordinates ξ and η and consider mappings

of the form

$$(2.8) \quad s = F(\xi) ; \quad s^* = \overline{F(\bar{\eta})}$$

where F is an arbitrary analytic function. For any function F , ξ and η are characteristic coordinates since any function of a characteristic coordinate is itself a characteristic coordinate. Also, it is clear from (2.8) that whenever $s = \overline{s^*}$ we have $\xi = \bar{\eta}$ so that ξ and η are also conjugate coordinates for any analytic function F .

In previous work on airfoil design we have found it sufficient to choose a two parameter family of transformations

$$(2.9) \quad s = F(\xi) = 1 - 2B\xi - \xi^2$$

for the parameter B which is suggested by considering incompressible flow around an elliptic cylinder. This led to a class of solutions which had a single branch point in the hodograph plane at $\xi = -B$. Moreover, design in the ξ -plane is simpler than in the w -plane because a simple closed curve representing the body streamline is transformed into the two-sheeted hodograph. Turbine and compressor blades generally have a high degree of camber and may require more than one branch point. Therefore we have chosen

$$(2.10) \quad s = 1 + C_1\xi + C_2\xi^2 + C_3\xi^3 + C_4\xi^4$$

which can have as many as three branch points. Locating the branch points can be done by examining their location for incompressible flow around a cambered Joukowski profile.

Work is presently underway to investigate a rational method for the selection of the function F to achieve the desired design objectives. The selection of a suitable transformation F for turbine design will be the subject of a future report [10].

3. Singular Solution for the Cascade Problem

We apply the method of complex extension to equations (2.5) in order to generate solutions which represent flow around a cascade. We will do this by setting up an appropriate characteristic initial value problem in the extended hodograph plane.

For the characteristic initial value problem in the extended variables we chose two characteristic planes $\xi = \xi_0$ and $\eta = \eta_0$ and assign initial data for either x or y along each of them. Equation (2.5b) is a set of ordinary differential equations along a characteristic which can be integrated to get the other independent variable. The solution at points not on the characteristic initial planes can be found by the numerical technique described in Section 5. The solution will be analytic as long as the initial data is analytic.

For flow through a cascade we would like a solution which has an inlet velocity at $-\infty$ and an exit velocity at $+\infty$ in the physical plane. Let $w_B = u_B - iv_B$ and $w_A = u_A - iv_A$ denote the complex upstream and downstream velocities respectively. Let (ξ_B, η_B) and (ξ_A, η_A) be the corresponding values of the characteristic coordinates which are found by solving (2.6) and (2.8) once the transformation function F has been prescribed. It follows that $\eta_A = \bar{\xi}_A$ and $\eta_B = \bar{\xi}_B$ since ξ and η are conjugate coordinates and u_A, u_B, v_A and v_B are real quantities. We require that the solution in the physical plane have infinities at the two points $(\xi_A, \bar{\xi}_A)$ and $(\xi_B, \bar{\xi}_B)$. In other words we have a source at ξ_B and a sink at ξ_A in the real hodograph plane. We further require that the solution be periodic in the physical plane.

Any closed loop in the hodograph plane surrounding both ξ_A and ξ_B corresponds to a closed loop in the physical plane enclosing a blade. We will modify this enclosure requirement for our wake model of the trailing edge. One can verify that a solution of the form

$$(3.1a) \quad x = \text{Re}[X^1 \log(\xi - \xi_A) + X^2 \log(\xi - \xi_B) + X^3]$$

$$(3.1b) \quad y = \text{Re}[Y^1 \log(\xi - \xi_A) + Y^2 \log(\xi - \xi_B) + Y^3]$$

satisfies the above requirements for suitable choices of the regular functions X^1 , X^2 , X^3 , Y^1 , Y^2 and Y^3 . The assumption that X^3 and Y^3 are regular lead to the requirement that X^1, Y^1 and X^2, Y^2 be solutions to the partial differential equations (2.5b) with initial conditions

$$(3.2a) \quad \lambda_- Y^1 + X^1 = 0$$

$$(3.2b) \quad \lambda_- Y^2 + X^2 = 0$$

on $\xi = \xi_A$ and $\xi = \xi_B$ respectively. This can be verified by substituting equations (3.1a-b) into (2.5b). From this construction we can see that X^1 , Y^1 and X^2 , Y^2 are essentially Riemann functions for equations (2.5b).

Equations (3.2a-b) can be solved with (2.5b) to obtain X^1 along $\xi = \xi_A$ and X^2 along $\xi = \xi_B$. We must define X^1 and X^2 along the corresponding characteristics of the other family $\eta = \eta_A$, $\eta = \eta_B$ to obtain a well-posed characteristic initial problem for the determination of X^1 , X^2 , Y^1 and Y^2 everywhere. We can save computation if we define the data on the other family of characteristics by reflection, i.e. $X^1(\xi, \eta_A) = \overline{X^1(\xi_A, \bar{\xi})}$; $Y^2(\xi, \eta_B) = \overline{Y^2(\xi_B, \bar{\xi})}$, etc. This is not always possible since X^1 , X^2 , Y^1 , Y^2 need not be real at

ξ_A , η_A and ξ_B , η_B . However, since equations (2.5b) admit constants as solutions we can find solutions for X^1 , X^2 , Y^1 and Y^2 of the form

$$(3.3a) \quad X^1 = \hat{X}^1 + iX_A ; \quad X^2 = \hat{X}^2 + iX_B$$

$$(3.3b) \quad Y^1 = \hat{Y}^1 + iY_A ; \quad Y^2 = \hat{Y}^2 + iY_B$$

where X_A , X_B , Y_A and Y_B are real constants and $\hat{X}^1$, $\hat{X}^2$, $\hat{Y}^1$ and $\hat{Y}^2$ are symmetric solutions to equations (2.5b) satisfying (3.2a-b) along the initial characteristics.

The equations for X^3 and Y^3 obtained by inserting (3.1a-b) into (2.5b) are

$$(3.4a) \quad \lambda_{-Y}^3 + X_{\xi}^3 = \frac{(\lambda_{-Y}^1 + \hat{X}^1) + i(\lambda_{-Y_A} + X_A)}{\xi_A - \xi} + \frac{(\lambda_{-Y}^2 + \hat{X}^2) + i(\lambda_{-Y_B} + X_B)}{\xi_B - \xi}$$

$$(3.4b) \quad \lambda_{+Y}^3 + X_{\eta}^3 = 0$$

where the regularity of the right hand side of (3.4a) is assured by the initial conditions (3.2a-b). In order to formulate a well-posed problem for the evaluation of X^3 and Y^3 it is necessary to assign initial data along a pair of initial characteristics. We choose initial characteristics, $\xi = \xi_C$, $\eta = \eta_C$, so that their intersection is a point in the real subsonic domain. This means that $\eta_C = \bar{\xi}_C$. To avoid difficulties in the numerical calculation of the right hand side of (3.4a) we choose ξ_C safely away from both ξ_A and ξ_B . We assign

$$(3.5) \quad X^3(\xi_C, \eta) = G(\eta) ; \quad X^3(\xi, \eta_C) = G(\eta_C)$$

on the initial characteristics $\xi = \xi_C$ and $\eta = \eta_C$ respectively where G is an analytic function. The selection of G is the subject of the next section. Since the solution for X and Y uses only the real parts of X^3 and Y^3 we can prescribe many combinations of initial data which will yield the same real parts. In particular, the symmetric set

$$(3.6) \quad X^3(\xi_C, \eta) = \frac{1}{2} [G(\eta) + \overline{G(\eta_C)}] ; \quad X^3(\xi, \eta_C) = \frac{1}{2} [G(\eta_C) + \overline{G(\xi)}]$$

has been used to reduce computation in the subsonic portion of the flow.

We have the four real constants X_A , Y_A , X_B and Y_B to determine. First we consider the requirement that the solution be single-valued for any real closed path encircling a blade. We find

$$(3.7a) \quad \oint dx = \text{Re} \left[\oint \left(\frac{\hat{X}^1 + iX_A}{\xi - \xi_A} + \frac{\hat{X}^2 + iX_B}{\xi - \xi_B} \right) d\xi \right] = -2\pi(X_A + X_B)$$

$$(3.7b) \quad \oint dy = \text{Re} \left[\oint \left(\frac{\hat{Y}^1 + iY_A}{\xi - \xi_A} + \frac{\hat{Y}^2 + iY_B}{\xi - \xi_B} \right) d\xi \right] = -2\pi(Y_A + Y_B)$$

where the path of integration is around both ξ_A and ξ_B in the plane $\xi = \bar{\eta}$. Therefore, $X_B = -X_A$ and $Y_B = -Y_A$ if we are to have a single-valued solution. We further require that the stream function ψ defined by

$$(3.8) \quad d\psi = (\rho u)dy - (\rho v)dx$$

be single-valued for any similar path. Since ρu and ρv are real in the real domain we have

$$(3.9) \quad \oint d\psi = 2\pi[\rho_A u_A Y_A + \rho_B u_B Y_B - \rho_A v_A X_A - \rho_B v_B X_B] = 0.$$

Making use of the closure conditions (3.7a-b) and (3.9) we have

$$(3.10) \quad (\rho_A u_A - \rho_B u_B) Y_A = (\rho_A v_A - \rho_B v_B) X_A$$

From (3.1a-b) we see that the solution is periodic with a period of X_B and Y_B in x and y respectively. We define the stagger angle β and the gap g by

$$(3.11) \quad \beta = \tan^{-1} \frac{Y_A}{X_A} ; \quad g^2 = X_A^2 + Y_A^2$$

Given the inlet and exit velocities the stagger angle is computed from (3.11). Therefore, it is convenient to measure the inlet and exit velocity vectors relative to β . If we require that the blades be stacked vertically, $\beta = \pi/2$, we can prescribe only three of the four parameters for the inlet and exit velocity. For example we may prescribe the inlet and exit Mach numbers and the turning angle, and then determine the inlet and exit flow angle from (3.11) using $\beta = \pi/2$. To have physical significance the gap must be measured relative to some suitable distance measurement such as the blade chord. Since this is not known until the solution has been found we have instead chosen to normalize the solution by requiring that the gap g have magnitude $|\xi_A - \xi_B|^{-1}$. As a result of this normalization the chord length will change slowly as $\xi_A \rightarrow \xi_B$. Moreover in the limiting case the isolated blade will have the same singularity as the one used in our previous work on airfoil design.

The wake model of the trailing edge which was formulated in [1] to correct for boundary layer displacement can easily be incorporated into this cascade design procedure. This is done by requiring that the residues of (3.7a-b) be non-zero. In fact, they should be proportional to X_B and Y_B respectively so that the blades will have a vertical gap when stacked vertically. The constant of proportionality is the ratio of the thickness of

the trailing edge outside the boundary layer to the gap and is chosen to be small. It should be noted that equation (3.10) will have to be modified accordingly.

The problem of flow through a cascade of blades can therefore be solved by generating the solution of two characteristic initial value problems for the homogenous equations (2.5b), one along $\xi = \xi_A$, $\eta = \bar{\xi}_A$, the other along $\xi = \xi_B$, $\eta = \bar{\xi}_B$, and by solving a characteristic initial value problem for the inhomogeneous equations (3.4a-b) for arbitrary initial data chosen along some initial characteristics $\xi = \xi_C$, $\eta = \eta_C$. The initial data for the homogenous equations is determined by solving ordinary differential equations along the initial characteristics reminiscent of the Riemann functions. The four constants X_A , X_B , Y_A and Y_B are completely determined by three closure conditions and normalization. The solution for x and y is formed from the solution of these three problems using (3.1a-b) and has the singularities necessary for flow through a cascade.

4. The Selection of Initial Data

Solutions to the equations of motion of the form (3.1a-b) will have the appropriate singular solution for flow through a cascade but will not necessarily generate solutions with a physical interpretation for arbitrary initial data assigned along the characteristic initial planes $\xi = \xi_0$ and $\eta = \eta_0$. Once the transformation from the hodograph variables to characteristic coordinates has been selected the design problem centers on choosing the initial data so that the resulting design will achieve as many of the design objectives as possible. Many design objectives, such as boundary layer control, cannot be stated in precise terms within the context of this inviscid model. Other design objectives may be impossible to achieve within the class of shockless solutions. Therefore we should expect the problem of choosing initial data to require some degree of trial and error.

To find the shape of the blade we generate a solution and examine the level curve $\psi = \psi_0$ where ψ_0 is the value of the stream function at stagnation. In general, this shape will not resemble a blade and in fact does not have to be a closed curve. The shape of this curve will depend upon the initial data we choose. We now discuss a procedure for selecting the initial data which attempts to minimize the chances of obtaining extraneous solutions. To do this we make use of most of the ideas that have been used for the airfoil design problem described in [1, 2].

We pick the initial characteristic $\xi = \xi_0$ away from ξ_A and ξ_B to avoid computational difficulties in evaluating the right hand side of (3.4a).

The characteristic $\eta = \bar{\xi}_C$ is selected for symmetry reasons. Since we need only the real part of the solution to equations (3.4a-b) we can symmetrize the equations in a manner that saves half the computation in the subsonic region. Using equation (3.6) the initial data on $\eta = \bar{\xi}_C$ will be the complex conjugate of the initial data along $\xi = \xi_C$ which we prescribe. In keeping with the procedure followed for airfoil design we choose the initial function G on the initial characteristic $\xi = \xi_C$ as

$$(4.1) \quad G(\eta) = \sum_{j=1}^{NL} (L_{j1} + i L_{j2}) \log (\eta - L_{j3} - i L_{j4}) + E_t \eta + E_{tsq} \eta^2 + E_{tcu} \eta^3$$

The constants that appear determine the resulting solution. The last three terms are polynomial terms while the remaining NL terms are logarithms located at $\eta = L_{j3} + i L_{j4}$. They can be placed anywhere inside the blade to simulate sources or sinks. Their influence is primarily local when their coefficients are small and can therefore be used to effect small changes without much change to the overall solution.

Selection of the linear parameters has been automated by a least squares process. Instead of prescribing the linear parameters we select a curve or set of arcs in the hodograph plane where we would like the blade to lie. We choose the linear constants in (4.1) so that the solution it generates minimizes

$$(4.2) \quad \int W \psi^2 d\xi$$

where the integration is taken along the prescribed arcs and where the weighting function W can be chosen to achieve a better fit along any given arc.

By prescribing the automation arcs in the characteristic planes we are in effect prescribing the body streamline in the hodograph plane. This is very convenient for boundary layer control since we can select arcs for the least square automation which have sufficiently small pressure gradients in order to avoid separation. If we prescribe an arc so that it approaches the trailing edge along a line of constant speed we can eliminate boundary layer separation or delay it until the last per cent of chord in most cases. In addition we narrow the choice of initial data by placing constraints on the solution. We prescribe the curvature at the leading edge and the angle between the inlet velocity and the central streamline. We choose a velocity for the trailing edge and require the stream function to assume its stagnation value there. We further require that its first and optionally its second derivative vanish. This is our model of the Kutta-Joukowski condition in the hodograph plane.

The above constraints and the least square conditions greatly reduce the effort in selecting meaningful initial data. It should be noted that we have overprescribed the problem and therefore cannot expect good agreement between the prescribed arcs and the resulting streamline unless they are chosen in a manner consistent with the given compression and turning. For a description of how to locate the logarithms the reader is referred to [1, 2] since there appears to be little difference between compressors and airfoils in this aspect of the design problem.

5. Numerical Method of Solution

The same numerical technique that was successfully used to design airfoils described in [2] has been used with minor modifications for the cascade design problem. In the real domain this technique is often called the method of characteristics or Massau's Method [3] and is essentially a predictor corrector scheme. The method is applied in the complex domain merely by performing all operations using complex arithmetic.

In Section 3 we explained how to construct the appropriate singular solution. In doing so we must find the solutions for X^1 , Y^1 , X^2 , Y^2 and X^3 , Y^3 . The functions X^1 , Y^1 and X^2 , Y^2 satisfy the equations of motion (2.5b) with initial data given by (3.2a-b) on the initial characteristics while X^3 , Y^3 satisfy the inhomogeneous equations (3.4a-b) whose right hand side is computed from X^1 , Y^1 and X^2 , Y^2 . Therefore, we will apply the method of Massau to each of these three sets of unknowns. The hodograph variables may be obtained explicitly from equations (2.8), (2.6) and (2.7). However, it is faster to use this numerical method to solve for them as well, using these equations only to generate characteristic initial data.

The characteristic initial value problem for X^1 and Y^1 starts on initial characteristics ξ_A , η_A . The characteristic initial value problem for X^2 , Y^2 starts on initial characteristics ξ_B , η_B and the characteristic initial value problem for X^3 , Y^3 uses initial characteristics ξ_C , η_C along which it is necessary to know X^1 , Y^1 , X^2 and Y^2 in order to evaluate the inhomogeneous terms. To apply the method of Massau we must select a path along each of the initial characteristics, as illustrated in Figure 1a. Each path starts at the

point of intersection of the two initial characteristics. Let r and t be real parameters. We assign initial data along a path $\eta = \eta(t)$ from η_A^1 on the initial characteristic $\xi = \xi_A$ and along another path $\xi = \xi(r)$ from ξ_A on the other initial characteristic. The initial data along these paths determine the solution on the two-dimensional surface consisting of the points of intersection $\xi(r), \eta(t)$. To find the solution at a given point ξ_P, η_P we choose a path on $\xi = \xi_A$ from $\eta = \eta_A$ to $\eta = \eta_P$ and a path on $\eta = \eta_A$ from $\xi = \xi_A$ to $\xi = \xi_P$. The solution at the point ξ_P, η_P will be independent of path if the data along the initial characteristics is analytic. In order to be able to solve for X^1, Y^1, X^2, Y^2 simultaneously we choose each initial path on η_A so that it starts from $\xi = \xi_A$ passes through $\xi = \xi_B$ and then through $\xi = \xi_C$. Similarly the initial path along $\xi = \xi_A$ begins at $\eta = \eta_A$ and passes through η_B and η_C . Thus the values for the right hand side of (3.4a) are available as they are needed. This arrangement is illustrated in Figure 1b.

The solution throughout the four dimensional domain can be computed by selecting appropriate pairs of paths. We are interested in obtaining the solution only in the real hodograph and would like to do so with as few pairs as possible. It has been shown that by choosing complex conjugate sets of paths we can arrive at one line of the solution in the real subsonic domain for each set of paths [9]. One set of paths can be found to find a portion of the solution in the supersonic region bounded by two characteristics and the sonic line. Generally one pair of paths can be chosen so that this region contains the full supersonic portion of the flow outside the blade.

Each set of initial paths is described by the vertices of a polygonal arc and a set of grid points superimposed in such a way that each vertex is a grid point and that the distance between adjacent grid points is less than some prescribed amount. We use the notation $u_{j,k}$ to denote the value of $u(\xi(r_j), \eta(t_k))$ where r and t are real parametric representations of the initial paths. Note that $r = 0$ and $t = 0$ are the initial curves on $\xi = \xi_A$ and $\eta = \eta_A$ respectively. Using this notation we can write the predictor step of the method of Massau for the solution of equation (2.5a) at the point j, k as the two linear equations

$$(5.1a) \quad \tilde{v}_{j,k} - v_{j-1,k} = (\lambda_+)_{j-1,k} (\tilde{u}_{j,k} - u_{j-1,k})$$

$$(5.1b) \quad \tilde{v}_{j,k} - v_{j,k-1} = (\lambda_-)_{j,k-1} (\tilde{u}_{j,k} - u_{j,k-1})$$

for the predicted values $\tilde{u}_{j,k}$ and $\tilde{v}_{j,k}$ which are first order accurate estimates of u and v . The values of u and v along $j = 0$ and $k = 0$ are determined explicitly from the hodograph transformation (2.6 - 2.8).

For the corrector step, we use the values obtained in the predictor step to compute first order accurate midpoint values for $\lambda_{\pm}$ given by

$$(5.2a) \quad \tilde{\lambda}_+ = \frac{1}{2} [(\lambda_+)_{j-1,k} + \lambda_+(\tilde{u}_{j,k}, \tilde{v}_{j,k})]$$

$$(5.2b) \quad \tilde{\lambda}_- = \frac{1}{2} [(\lambda_-)_{j,k-1} + \lambda_-(\tilde{u}_{j,k}, \tilde{v}_{j,k})]$$

and solve

$$(5.3a) \quad v_{j,k} - v_{j-1,k} = \tilde{\lambda}_+ (u_{j,k} - u_{j-1,k})$$

$$(5.3b) \quad v_{j,k} - v_{j,k-1} = \tilde{\lambda}_- (u_{j,k} - u_{j,k-1})$$

for $u_{j,k}$ and $v_{j,k}$ to obtain second order accuracy.

A similar set of equations is solved to obtain X^1, Y^1, X^2, Y^2 and X^3, Y^3 to second order accuracy. Equations (3.1a-b) are evaluated at points in the real hodograph to obtain x and y to second order accuracy. The value of the stream function is obtained by applying a second order accurate difference approximation to (3.8). Points on the blade are identified by the streamline passing through the stagnation point. They are computed by parabolic interpolation along the paths.

The least square automation discussed in Section 4 is accomplished by repeatedly solving equations (3.4a-b) along the prescribed automation arcs with varying initial data. For each automated parameter of function G given by (4.1) we assign initial data which has that particular parameter set to one and all the others set to zero. This set of solutions determines the coefficients of a linear system of equations for the automated parameters as described in [2]. The function G as defined by these automated parameters is then used as initial data which determines the shape of the blade.

The systems of two simultaneous linear equations (5.1a-b) and (5.3a-b) become ill-conditioned whenever λ_+ and λ_- are nearly equal, i.e. near points on the complex sonic line; therefore, we expect our largest errors to occur in the vicinity of the sonic line.

A third order accurate method can be obtained by doing the calculation with two different grid sizes and using Richardson extrapolation to the limit. We have incorporated this option into the computer program in order to obtain more accurate resolution in the vicinity of the leading and trailing edges. We cannot expect improvement near the sonic line because of the singularity of the hodograph transformation there.

6. Refinements to the Design Procedure and Results

A number of improvements have been made in the cascade design program that have not as yet been incorporated in the airfoil design procedure (cf. [2]). These modifications fall into three general overlapping categories.

The first set of modifications was intended to decrease execution time. The cascade design program should take longer to execute than the airfoil design program since each path must connect the inlet and exit velocities in the initial plane. Since the gap to chord ratio varies inversely with the distance between these singularities we expect blades with low gap/chord to take longer to compute. Automation generally takes most of the computing time since the solution for X^3 and Y^3 along each automated path must be computed once for each automated parameter. Weighting for the least square automation was achieved by choosing additional mesh points in the corresponding interval for the airfoil design program. Since the execution time is proportional to the square of the number of points on the initial path, a highly weighted least square automation is very time consuming. In the present program the weighting is achieved by multiplying the value of ψ at the weighted point by the input weight factor. A significant reduction in execution time can be achieved if we compute X^3 and Y^3 for each automated parameter at the same point in the program. The right hand side of (3.4a) and $\lambda_{\pm}$ would only be computed once. To achieve this we would require storage of the set of complex arrays for each X^3 and Y^3 . For fine grids with many automated parameters the required storage would make this procedure prohibitive. A compromise, which allows for a fixed number of solutions of X^3 and Y^3

at each pass has been incorporated. A typical run for the solution with ten automation parameters obtained at each pass has decreased execution time for the automation by a factor of about five using less than twice the storage.

A second set of modifications was made in order to improve accuracy. The automation procedure was modified to ensure that it was second order accurate. The integration for least squares (cf. (4.2)) was modified so that only half the prescribed weight was used at the endpoint of each given interval. The automation near the leading edge was made second order accurate by adding an extra point on the path to the leading edge beyond the stagnation point so that central differences could be used for derivative approximations.

An optional third order accurate scheme is provided which has been achieved by repeating the calculation at a finer grid and using Richardson extrapolation. Finally we note that the definition of λ_+ (See equation 2.4) has been changed from reference [2] and so have the ensuing equations. This change avoids the inaccuracy which occurs when the denominator is small since for the flows considered u is greater than v throughout the supersonic zone.

The final set of modifications was made to make the program easier to use. Some of these modifications have been achieved by more sophisticated computer coding such as the free-form input. Other modifications have been added so that more of the input parameters have a physical meaning. For example, instead of giving the values of x_u and y_u at the stagnation point we now supply the leading edge radius of curvature and the angle between the

central streamline and the inlet flow vector. Similarly the location of the trailing edge in the hodograph can be specified by prescribing the Mach number and the angle relative to the exit velocity vector. A number of changes have been incorporated in an effort to allow more general transformations for the hodograph plane as discussed in Section 2. An improved technique for the location of cuts of the logarithms in the initial plane removes the distinction between nose logs, tail logs, and side logs that was made in [2].

A computer program for cascade design has been written which incorporates these ideas. It has been used to generate a few designs. Each design required many runs in order to succeed but the time for each run is small so that computing time is not prohibitive. It takes about half a minute of central processor time on the CDC 6600 for a coarse mesh run. An intermediate grid and fine grid take about 2 and 8 minutes respectively. The third order option increases computing time by a factor of about 5.

Figure 2 is a Calcomp plot of a blade which has been designed with this program in about 50 runs. All but the last few runs were made on a coarse grid. The inlet flow angle, measured relative to the vertical stacking direction, is 45° and the turning angle is 29° . The gap chord ratio is 1.07. The Mach number distribution over the blade and the characteristics or Mach lines in the supersonic region have been plotted. With this Mach number distribution no separation is predicted for Reynold's number 1.6 million.

The corresponding initial plane is illustrated in Figure 3. The input paths and sonic locus have been plotted. The plus signs represent the pre-images of points on the body and the arrows illustrate the location of logarithmic singularities in the initial function and the direction of their

cuts. An asterisk is placed at the points corresponding to the inlet and exit velocities. We point out the similarity between this figure and those we have obtained previously with the airfoil design program (cf. [1, 2]).

A number of experiments performed on airfoils designed by this procedure (cf. [5,6,7,8]) have proven the usefulness of this method. In the near future we expect a blade designed by this technique to be tested in a cascade wind tunnel at the Pratt and Whitney Division of United Aircraft. This test should verify the relevancy of this theory in this lower Reynolds number regime.

Work to simplify the design procedure is in progress. A more detailed report on cascade design with an emphasis on turbine design should appear shortly [10].

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CHARACTERISTIC PLANE $\eta = \text{CONSTANT}$

CHARACTERISTIC PLANE $\xi = \text{CONSTANT}$

FIGURE 1A

- POINTS ON THE FINITE DIFFERENCE GRID
- x POINTS ON THE INITIAL CHARACTERISTICS FOR X^1 AND Y^1
- + POINTS ON THE INITIAL CHARACTERISTICS FOR X^2 AND Y^2
- * POINTS ON THE INITIAL CHARACTERISTICS FOR X^3 AND Y^3
- POINTS OF SOLUTION IN THE REAL DOMAIN

FIGURE 1B

FIGURE 2

M1=.780

M2=.480

DEL TH= 29.00

G/C=1.07

FIGURE 3

INPUT DESCRIPTION

THE INPUT FOR THE CASCADE DESIGN PROGRAM CONSISTS OF TWO DATA FILES WHICH WE CALL TAPE7 AND TAPE6. THESE, OF COURSE, MAY BE DISC FILES OR PUNCHED CARDS. VARIOUS FLOW PARAMETERS SUCH AS THE INLET AND EXIT CONDITIONS ARE SUPPLIED TO THE PROGRAM AS INPUT FROM TAPE7. PARAMETERS DESCRIBING THE INITIAL FUNCTION AND MAPPING FUNCTION ARE ALSO ASSIGNED BY MEANS OF TAPE7. THE INTEGRATION PATHS APPEAR ON TAPE6.

TO SET A VARIABLE LISTED IN THE GLOSSARY OF TAPE7 PARAMETERS WE PUNCH A CARD WITH THE VARIABLE NAME AND ITS VALUE OF THE FORM:

PARAMETER = VALUE

BLANKS ARE IGNORED AND MODE CONVERSION IS AUTOMATIC. WHEN MORE THAN ONE VALUE IS NEEDED TO DESCRIBE A PARAMETER, I.E. COMPLEX PARAMETERS, COMMAS ARE USED TO SEPARATE THE NUMBERS. PARAMETERS TO BE AUTOMATED ARE DESIGNATED BY ASSIGNING THEM ANY NON-NUMERIC VALUE. MORE THAN ONE PARAMETER CAN BE SPECIFIED ON EACH CARD BY USING EITHER A \$ OR ; AS A SEPARATOR. THE DATA FILE FOR TAPE7 MUST TERMINATE WITH A CARD WHICH HAS END= ON IT. ALL PARAMETERS WHICH ARE NOT PRESCRIBED WILL TAKE THEIR DEFAULT VALUES. NOTE THAT THE OUTPUT LISTING OF TAPE7 IS IN THE CORRECT FORMAT TO BE USED AS INPUT TO REGENERATE THE RUN.

TAPE6 CONTAINS THE PATHS OF INTEGRATION. THE FIRST PATH LEADS TO THE STAGNATION POINT THE SECOND TO THE TRAILING EDGE FOLLOWED BY THE NP AUTOMATION PATHS AND AS MANY INTEGRATION PATHS AS DESIRED. THE FIRST PATH WILL ALWAYS BE ADJUSTED SO THAT IT TERMINATES AT STAGNATION. IF THE MACH NUMBER AT THE TRAILING EDGE IS PRESCRIBED THE ENDPOINT OF THE SECOND PATH WILL BE ACCORDINGLY ADJUSTED. ALL THE PATHS ARE PRESCRIBED IN THE PLANE $\xi/\alpha = \xi/\alpha(A)$. FOR SUBSONIC PATHS THE PATH IN THE ξ/α -PLANE

OBTAINED BY REFLECTION. FOR SUPERSONIC PATHS THE PATH IN THE XI-PLANE IS OBTAINED BY CONJUGATING THE FOLLOWING PATH.

EACH PATH IS DESCRIBED BY CARDS OF TWO TYPES. THE FIRST TYPE OF CARD TELLS WHETHER THE PATH IS SUBSONIC OR SUPERSONIC, HOW MANY LINE SEGMENTS DEFINE THE PATH, AND THE NUMBER OF FORKS THE PATH WILL HAVE. CARDS OF THE SECOND TYPE CONTAIN THE ENDPOINT FOR EACH LINE SEGMENT IN THE ETA-PLANE AND A NUMBER WHICH IS USED FOR LEAST SQUARE WEIGHTING OR FOR LOCAL MESH REFINEMENT WITH NON-AUTOMATED PATHS.

CARDS OF TYPE ONE CONTAIN THE FOLLOWING INFORMATION:

NCARDS INTEGER, COLUMNS 1-3. THE NUMBER OF LINE SEGMENTS WHICH FORM THE PATH. THIS WILL BE THE NUMBER OF CARDS OF TYPE TWO WHICH FOLLOW.

NITYPE INTEGER, COLUMNS 4-6. IF NITYPE<0 A STEM FOLLOWS AND -NITYPE IS THE NUMBER OF FORKS ISSUING FROM IT. IF NITYPE=0 A FORK OR BASE STEM FOLLOWS. IF NITYPE>0 A SUPERSONIC PATH FOLLOWS; IF NITYPE=1 THIS PATH IS PLOTTED; IF NITYPE=2 THE SINGULARITIES OF THIS PATH ARE PLOTTED; IF NITYPE>2 PATH IS NOT PLOTTED.

CARDS OF TYPE TWO CONTAIN THE FOLLOWING INFORMATION:

POINT COMPLEX, COLUMNS 1-20 AND 21-40. END POINT OF A LINE SEGMENT ON THE PATH OR FORK.

WGHT REAL, COLUMNS 41-50. FOR AUTOMATION PATHS ABS(WGHT) IS THE WEIGHT OF THIS LINE SEGMENT USED IN THE LEAST SQUARE PROCESS. FOR NON-AUTOMATED PATHS ABS(WGHT) IS A FACTOR USED TO SUBDIVIDE THE FINITE DIFFERENCE GRID ON THIS LINE SEGMENT. WGHT SHOULD BE A WHOLE NUMBER. WGHT=0 MARKS THE BEGINNING OF THE AUTOMATED SEGMENT FOR AUTOMATION PATHS AND THE BEGINNING OF THE PART OF THE PATH ALONG THE SOVIET COAST FOR A SUPERSONIC PATH.

GLOSSARY OF TAPE 7 PARAMETERS

NAME	DEFAULT	DEFINITION	COMMENTS
RUN	1	RUN NUMBER	ABS(RUN) IS THE RUN NUMBER. NEGATIVE VALUES WILL PRODUCE A WHITE PAPER PLOT ON THE CDC 6600 AT THE AEC COMPUTING CENTER AT NYU.
MRF	1	MESH REFINEMENT PARAMETER	DOUBLING THIS PARAMETER CUTS THE GRID IN HALF. A NEGATIVE VALUE IS USED FOR THIRD ORDER ACCURACY.
NP	5	NUMBER OF AUTOMATION PATHS	SINCE THESE PATHS DETERMINE THE RESULTING DESIGN THEY ARE PRINTED.
NCR	7	NUMBER OF CONSTRAINTS	USE NCR=5 FOR SINGLE CRITICAL POINT AT THE TRAILING EDGE.
PLTSIZ	1.	PLOT SIZE	USED TO SCALE THE PLOT OF THE XI PLANE.
IPLT	037	INDEX FOR PLOT CONTROL	THIS IS A THREE DIGIT NUMBER WHICH CONTROLS THE PLOTTING. THE FIRST DIGIT CONTROLS THE FIFTY INCH PLOT AND THE PLOT OF THE REAL CHARACTERISTIC PLANE AS FOLLOWS: 0 NEITHER PLOTTED 1 CHARACTERISTIC PLOT ONLY 2 LARGE PLOT ONLY 3-9 BOTH WILL BE PLOTTED THE MIDDLE DIGIT CONTROLS THE PLOT OF THE PHYSICAL PLANE AS FOLLOWS: 0 NO PLOT GENERATED 1 MACH NUMBER DISTRIBUTION ONLY 2 BLADE AND MACH DISTRIBUTION 3-9 SAME AS 2 PLUS CHARACTERISTICS THE LEAST SIGNIFICANT DIGIT IS USED TO CONTROL THE PLOT OF THE XI-PLANE AS FOLLOWS: 0 XI-PLANE NOT PLOTTED 1 SONIC LOCUS, BODY POINTS, LOGS, BRANCH POINTS, XIA, XIB, XIC, POLE, NOSE AND TAIL ARE PLOTTED. 2 SAME AS 1 PLUS CIRCLES DRAWN AT AUTOMATED POINTS. 3 SAME AS 1 PLUS AUTOMATED PATHS 4 SAME AS 1 PLUS NON-AUTOMATED PATHS 5 SAME AS BOTH 2 AND 4 6 SAME AS BOTH 3 AND 4 WITHOUT SUPERSONIC PATHS 7 SAME AS BOTH 3 AND 4 8-9 SAME AS 7 PLUS CONTOUR CURVES IF IPLT IS NEGATIVE THEN THE FLOW COMPUTATION IS SKIPPED.

NAME	DEFAULT	DEFINITION	COMMENTS
ACH	.63	MACH NUMBER	THE FLOW IS NORMALIZED BY ASSIGNING THIS VALUE AT $X1 = 0$.
RN	0.	REYNOLDS NUMBER	TO SKIP BOUNDARY LAYER INTEGRATION SET $RN = 0$.
TRAVU	.05	TRANSITION ON UPPER SURFACE	THE VALUE OF X AT WHICH WE START THE TURBULENT BOUNDARY LAYER INTEGRATION.
TRAVL	.10	TRANSITION ON LOWER SURFACE	THE VALUE OF X AT WHICH WE START THE TURBULENT BOUNDARY LAYER INTEGRATION.
RC	.009	RADIUS OF CURVATURE.	THE RADIUS OF CURVATURE AT STAGNATION BASED ON UNIT CHORD LENGTH.
ANGNOSE	20.00	ANGLE AT NOSE	THE ANGLE BETWEEN THE INLET FLOW VECTOR AND THE CENTRAL STREAMLINE.
MTAIL		MACH NUMBER AT THE TRAILING EDGE	IF THIS IS OMITTED THE VALUE IS COMPUTED FROM THE VALUE OF $X1$ WHICH DEFINES THE ENDPOINT OF THE SECOND PATH PRESCRIBED ON TABLE.
ANGTAIL	-15.00	ANGLE AT THE TRAILING EDGE	THE ANGLE BETWEEN THE TRAILING EDGE AND THE EXIT FLOW VECTOR.
TR	.03	TRAILING EDGE RATIO	THE RATIO OF THE THICKNESS OF THE TRAILING EDGE TO THE GAP
WLS	2.	WEIGHTING FOR LEAST SQUARES	THIS CONTROLS THE RELATIVE WEIGHTING BETWEEN LEAST SQUARES AND MINIMIZATION.
GAMMA	1.40	GAS CONSTANT	GAMMA IS 1.4 FOR AIR. GAMMA IS 1.07 FOR URANIUM HEXAFLUORIDE.
GRID	.02	GRID SPACING PARAMETER	GRID/MRP IS THE MAXIMUM MESH SIZE.
MINLET		MACH INLET	THIS VALUE AND ANGIN ARE USED TO COMPUTE $X13$. IF OMITTED, ITS VALUE AND ANGEXIT ARE DETERMINED FROM $X1A$ AND IT WILL PRINT AS NEGATIVE.
ANGIN	7.00	ANGLE AT INLET	THE ACTUAL INLET ANGLE WILL BE DETERMINED FROM THE TURNING ANGLE. THE TURNING ANGLE IS THE DIFFERENCE $ANGIN-ANGEXIT$.

NAME	DEFAULT	DEFINITION	COMMENTS
MEXIT		MACH EXIT	THIS VALUE AND ANGEXIT ARE USED TO COMPUTE XIA. IF OMITTED, ITS VALUE AND ANGIN ARE DETERMINED FROM XIO AND IT WILL PRINT AS NEGATIVE.
ANGEXIT	-10.00	ANGLE AT EXIT	USED ALONG WITH ANGIN TO DETERMINE THE TURNING ANGLE AND EXIT ANGLE.
XIA	.47+.03	XI AT A	THE POINT IS THE XI-PLANE CORRESPONDING TO THE EXIT VELOCITY. IF MEXIT IS SPECIFIED THE VALUE OF XIA WILL BE COMPUTED BY THE PROGRAM.
XIB	-.1+-.19	XI AT B	THE POINT IS THE XI-PLANE CORRESPONDING TO THE INLET VELOCITY. IF MINLET IS SPECIFIED THE VALUE OF XIB WILL BE COMPUTED.
XIC	-.12+.20	XI AT C	THIS DEFINES THE CHARACTERISTIC INITIAL PLANE FOR X3 AND Y3.
POLE		POLE LOCATION	IF OMITTED THE TRANSFORMATION FROM THE XI-PLANE TO THE HODOGRAPH PLANE WILL BE DETERMINED SOLELY BY THE LOCATION OF THE BRANCH POINTS.
BP	.05+.34	BRANCH POINT1	THE MAPPING FROM THE XI-PLANE TO THE HODOGRAPH PLANE IS DETERMINED BY PRESCRIBING ITS BRANCH POINTS AND OPTIONALLY A POLE. AS MANY AS TEN BRANCH POINTS MAY BE SPECIFIED.
ET	0.+0.	COEFFICIENT OF $\epsilon_1 A$	DETERMINES LINEAR TERM FOR THE INITIAL FUNCTION. THE REAL AND/OR IMAGINARY PARTS CAN BE AUTOMATED.
ETSG	0.+0.	COEFFICIENT OF $\epsilon_1 A^{**2}$	DETERMINES QUADRATIC TERM IN THE INITIAL FUNCTION. THE REAL AND/OR IMAGINARY PARTS CAN BE AUTOMATED.
ETCJ	0.+0.	COEFFICIENT OF $\epsilon_1 A^{**3}$	DETERMINES CUBIC TERM FOR THE INITIAL FUNCTION. THE REAL AND/OR IMAGINARY PARTS CAN BE AUTOMATED.
ETFO	0.+0.	COEFFICIENT OF $\epsilon_1 A^{**4}$	DETERMINES QUARTIC TERM IN THE INITIAL FUNCTION. THE REAL AND/OR IMAGINARY PARTS CAN BE AUTOMATED.
LOG		LOGARITHM TERM	EACH LOG IS DEFINED BY PRESCRIBING FOUR NUMBERS SEPARATED BY COMMAS. THE FIRST TWO SPECIFY THE REAL AND IMAGINARY PARTS OF THE WEIGHT AND EITHER OR BOTH MAY BE AUTOMATED. THE LAST TWO SPECIFY THE LOCATION OF THE LOG IN THE XI-PLANE. AS MANY AS 12 LOGS MAY BE PRESCRIBED.

TAPE 7

7

RUN = -35	:	MRP = 2
NP = 6	:	VCR = 7
PLISIZ = 1.000	:	LPLT = 337
MACH = .630	:	RN = 1.600
TRANU = .050	:	TRAVL = .100
RC = .007	:	ANGNOSE = 25.000
MTAIL = .590	:	ANGTAIL = -15.000
LR = .030	:	MLS = 2.000
GAMMA = 1.400	:	GRID = .080
MINLET = .780	:	AYOIN = 9.000
MLXII = .490	:	ANGMLXIT = -20.000

XIA = .475	*	-.003	:	X13 = -.132	*	-.119
XIL = -.120	*	.200	:	BP = .050	*	.340
BP = 0.000	*	1.200	:			

ETI = .043	*	.246	*	:	ETDQ = .310	*	.021	*
ETCU = .106	*	.020	*	:	ETFO = 0.000	*	0.000	

LOG = .285	*	-.568	*	*	.620	*	.500
LOG = -.996	*	-.724	*	*	.700	*	.100
LOG = .005	*	.043	*	*	.720	*	-.120
LOG = -.010	*	.062	*	*	.520	*	-.340
LOG = .055	*	1.035	*	*	.380	*	-.150
LOG = 0.000	*	.161	*	*	-.070	*	-.380
LOG = .062	*	.171	*	*	-.170	*	-.340
LOG = -.085	*	-.064	*	*	-.550	*	-.650

* AUTOMATED PARAMETERS

TABLE 6. PATH 0

1	0			
	-.874	.087	2	
2	0			
	.550	.100	2	
	.556	-.175	2	

1, 2, 3

AUTOCORRELATION PATHS

3	0			
	-.675	-.310	-1	
	-.580	-.355	2	
	-.465	-.350	10	

4	0			
	-.675	-.310	-1	
	-.755	-.245	2	
	-.015	-.180	1	
	-.855	-.090	1	

3	0			
	.100	.500	-1	
	-.100	.550	1	
	-.400	.530	1	

3	0			
	-.400	.530	-1	
	-.600	.460	1	
	-.750	.370	1	

4	0			
	.100	.500	-1	
	.400	.340	1	
	.550	.180	1	
	.570	-.040	10	

3	0			
	.450	-.110	-1	
	.340	-.110	6	
	.180	-.250	6	

THICKNESS/CHORD= .0805

GAP/CHORD= 1.066

INLET MACH NUMBER= .780

INLET FLOW ANGLE= 45.03

EXIT MACH NUMBER= .480

EXIT FLOW ANGLE= 74.03

TURNING ANGLE= 29.00

COORDINATES FROM LOWER SURFACE TAIL TO UPPER SURFACE TAIL

X	Y	ANG	K	M	THEIA	SEP	X2	Y2
.90273	.45864	1.0	14.15	.5800	.00104	-.08692	.90275	.45991
.90112	.45804	-.4	-2.95	.4912	.00166	-.02800	.90110	.46004
.89558	.45823	.5	-3.58	.4430	.00221	-.01377	.89561	.46083
.88302	.45788	3.1	-3.14	.4069	.00279	-.00780	.88319	.46111
.86973	.45698	5.5	-2.37	.3911	.00308	-.00410	.87007	.46052
.84654	.45599	8.7	-1.80	.3784	.00353	-.00213	.84713	.45790
.82363	.45507	11.1	-1.45	.3726	.00343	-.00098	.82447	.45432
.79444	.44376	13.5	-1.19	.3693	.00347	-.00029	.79553	.44829
.76100	.43506	15.9	-1.02	.3682	.00345	.00007	.76231	.43968
.72680	.42470	18.0	-.92	.3685	.00348	.00029	.72529	.42926
.69448	.41366	19.9	-.87	.3696	.00350	.00049	.69510	.41816
.66491	.40259	21.4	-.81	.3714	.00320	.00060	.66663	.40699
.63793	.39169	22.7	-.79	.3737	.00310	.00077	.63972	.39536
.61436	.38164	23.9	-.77	.3761	.00300	.00088	.61619	.38558
.59395	.37231	24.9	-.76	.3786	.00290	.00099	.59582	.37632
.57217	.36262	25.9	-.73	.3818	.00279	.00108	.57406	.36589
.55374	.35293	26.8	-.70	.3849	.00269	.00121	.55582	.35667
.51937	.33427	28.4	-.65	.3921	.00248	.00131	.52023	.33772
.48491	.31561	29.8	-.59	.4003	.00227	.00134	.48661	.31875
.45573	.29858	31.0	-.54	.4085	.00208	.00135	.45744	.30143
.43078	.28334	31.9	-.49	.4164	.00191	.00129	.43239	.28594
.40963	.27004	32.6	-.45	.4237	.00177	.00124	.41115	.27243
.39150	.25641	33.1	-.41	.4303	.00165	.00118	.39305	.26063
.37627	.24834	33.5	-.36	.4361	.00156	.00113	.37764	.25041
.36172	.23863	33.9	-.34	.4416	.00147	.00108	.36303	.24038
.34395	.22660	34.3	-.31	.4491	.00136	.00101	.34517	.22839
.32758	.21534	34.7	-.28	.4560	.00126	.00094	.32872	.21700
.31443	.20621	34.9	-.25	.4616	.00119	.00089	.31553	.20776
.30206	.19751	35.1	-.23	.4671	.00112	.00084	.30309	.19897
.29042	.18928	35.3	-.20	.4723	.00106	.00080	.29139	.19065
.27954	.18163	35.5	-.19	.4773	.00100	.00075	.28046	.18283
.27103	.17545	35.6	-.17	.4812	.00095	.00072	.27192	.17659
.26250	.16932	35.7	-.15	.4852	.00092	.00069	.26334	.17050
.25395	.16318	35.8	-.13	.4893	.00087	.00066	.25477	.16430
.24544	.15703	35.9	-.11	.4933	.00083	.00063	.24622	.15810
.23699	.15092	35.9	-.09	.4974	.00079	.00060	.23773	.15194
.22864	.14486	36.0	-.07	.5014	.00075	.00057	.22934	.14563
.21614	.13582	36.1	-.03	.5075	.00070	.00052	.21579	.13672
.21215	.12564	36.1	.01	.5144	.00064	.00047	.20273	.12646
.2083	.11739	36.1	.04	.5200	.00059	.00042	.19168	.11814
.18146	.11057	36.0	.08	.5246	.00055	.00039	.18198	.11127

X	Y	ANG	K	M	THEIA	SEP	XS	YS
.17025	.10241	36.0	.12	.5500	.00050	.00050	.17072	.10250
.16039	.09526	35.9	.16	.5547	.00045	.00051	.16083	.09587
.15334	.09017	35.8	.20	.5580	.00044	.00028	.15375	.09073
.14657	.08528	35.7	.23	.5410	.00041	.00028	.14650	.08582
.14038	.08083	35.6	.27	.5438	.00039	.00025	.14075	.08134
.13259	.07527	35.5	.31	.5470	.00036	.00020	.13293	.07574
.12693	.07125	35.5	.35	.5493	.00034	.00018	.12725	.07159
.12081	.06691	35.2	.40	.5516	.00032	.00015	.12110	.06733
.11430	.06234	35.0	.45	.5539	.00029	.00013	.11458	.06273
.10736	.05750	34.8	.52	.5560	.00027	.00010	.10761	.05766
.10018	.05252	34.5	.60	.5579	.00024	.00007	.10041	.05285
.09243	.04721	34.2	.70	.5595			.09243	.04721
.08420	.04165	33.8	.82	.5605	TRANSITION		.08420	.04165
.07713	.03695	33.4	.97	.5608			.07713	.03695
.07005	.03231	32.9	1.15	.5603			.07005	.03231
.06314	.02789	32.4	1.39	.5590			.06314	.02789
.05662	.02350	31.8	1.77	.5566			.05662	.02350
.04787	.01848	30.8	2.43	.5512			.04787	.01848
.03971	.01374	29.4	3.44	.5427			.03971	.01374
.03213	.00959	27.7	4.96	.5297			.03213	.00959
.02629	.00662	25.9	6.95	.5140			.02629	.00662
.02173	.00451	23.9	9.88	.4960			.02173	.00451
.01708	.00259	21.0	14.48	.4686			.01708	.00259
.01293	.00114	17.4	19.77	.4309			.01293	.00114
.01075	.00051	14.6	23.93	.4027			.01075	.00051
.00929	.00015	12.7	28.54	.3794			.00929	.00015
.00796	-.00013	10.3	34.03	.3539			.00796	-.00013
.00653	-.00034	7.9	44.93	.3221			.00653	-.00034
.00405	-.00056	1.3	66.95	.2432			.00405	-.00056
.00202	-.00047	-6.5	87.58	.1489			.00202	-.00047
.00100	-.00031	-11.7	138.60	.0827			.00100	-.00031
0.00000	0.00000	-20.0	143.85	.0000	STAGNATION		0.00000	0.00000
-.00103	.00048	-29.4	154.07	.1083			-.00103	.00048
-.00178	.00098	-37.4	146.06	.2030			-.00178	.00098
-.00246	.00157	-44.9	145.66	.3026			-.00246	.00157
-.00309	.00233	-54.2	169.14	.4256			-.00309	.00233
-.00358	.00308	-61.9	126.37	.5458			-.00358	.00308
-.00386	.00366	-68.7	172.68	.6271			-.00386	.00366
-.00405	.00427	-75.0	141.42	.6916			-.00405	.00427
-.00419	.00492	-80.5	112.98	.7421			-.00419	.00492
-.00428	.00565	-85.2	92.78	.7848			-.00428	.00565
-.00431	.00628	-88.5	77.84	.8154			-.00431	.00628
-.00430	.00705	-92.0	64.00	.8459			-.00430	.00705
-.00424	.00798	-95.4	50.58	.8744			-.00424	.00798
-.00404	.00946	-99.7	37.55	.9081			-.00404	.00946
-.00372	.01122	-103.6	28.95	.9295			-.00372	.01122
-.00327	.01276	-106.2	23.32	.9537			-.00327	.01276
-.00269	.01457	-108.8	16.97	.9719			-.00269	.01457
-.00120	.01645	-112.8	13.94	1.0190			-.00120	.01645
-.00040	.02028	-114.4	11.96	1.0544			-.00040	.02028
.00051	.02223	-115.9	10.55	1.0512			.00051	.02223
.00154	.02428	-117.3	9.74	1.0688			.00154	.02

X	Y	ANG	K	M	INCL A	SEP	XS	YS
.00268	.02643	-118.7	8.65	1.0858			.00268	.02643
.00395	.02869	-119.9	7.78	1.1032			.00395	.02869
.00536	.03109	-121.2	6.89	1.1201			.00536	.03109
.00699	.03372	-122.4	5.87	1.1358			.00699	.03372
.00893	.03671	-123.6	5.05	1.1503			.00893	.03671
.01130	.04020	-124.8	4.34	1.1625			.01130	.04020
.01404	.04406	-126.0	4.46	1.1748			.01404	.04406
.01666	.04761	-127.1	5.40	1.1892			.01666	.04761
.01850	.05000	-128.0	6.99	1.2086			.01850	.05000
.01985	.05164	-128.9	4.07	1.2303			.01985	.05164
.02256	.05486	-129.9	2.11	1.2458			.02256	.05486
.02934	.06275	-131.1	1.38	1.2496			.02934	.06275
.04164	.07649	-132.6	1.00	1.2451			.04164	.07649
.05478	.09475	-134.0	.80	1.2407			.05478	.09475
.07920	.11548	-135.3	.70	1.2396			.07920	.11548
.10153	.13712	-136.5	.66	1.2417			.10153	.13712
.12496	.15878	-137.8	.65	1.2446			.12496	.15878
.14869	.17997	-139.0	.68	1.2475			.14869	.17997
.17274	.20045	-140.2	.78	1.2482			.17274	.20045
.19685	.22006	-141.6	1.06	1.2429			.19685	.22006
.22082	.23848	-143.4	1.71	1.2198			.22082	.23848
.24405	.25491	-146.2	1.90	1.1553			.24405	.25491
.26544	.26838	-149.0	1.68	1.0811			.26544	.26838
.28413	.27927	-151.1	1.35	1.0256			.28413	.27927
.31390	.29479	-153.7	1.12	.9442			.31390	.29479
.32928	.30222	-154.8	.97	.9099			.32928	.30222
.34410	.30706	-155.7	.84	.8797			.34410	.30706
.35761	.31507	-156.4	.72	.8546			.35761	.31507
.37492	.32250	-157.2	.60	.8262			.37492	.32250
.38990	.32850	-157.7	.53	.8057			.38990	.32850
.39987	.33276	-158.0	.46	.7909			.39987	.33276
.41280	.33792	-158.4	.40	.7750			.41280	.33792
.42631	.34322	-158.7	.35	.7599			.42631	.34322
.44128	.34899	-159.1	.31	.7448			.44128	.34899
.45740	.35511	-159.4	.26	.7303			.45740	.35511
.47948	.36336	-159.7	.23	.7128			.47948	.36336
.51245	.37540	-160.2	.21	.6909			.51245	.37540
.54295	.38628	-160.6	.21	.6742			.54295	.38628
.57224	.39649	-160.9	.21	.6606			.57224	.39649
.60479	.40759	-161.4	.22	.6476			.60479	.40759
.62438	.41414	-161.6	.23	.6406			.62438	.41414
.65039	.42269	-162.0	.25	.6323			.65039	.42269
.67237	.42977	-162.3	.27	.6259			.67237	.42977
.70123	.43885	-162.8	.30	.6183			.70123	.43885
.73363	.44872	-163.4	.37	.6107			.73363	.44872
.77796	.46155	-164.3	.47	.6016			.77796	.46155
.81444	.47138	-165.3	.61	.5948			.81444	.47138
.84047	.47800	-166.3	.82	.5903			.84047	.47800
.85870	.48233	-167.2	1.17	.5872			.85870	.48233
.87665	.48628	-168.4	2.16	.5843			.87665	.48628
.9232	.49951	-170.4	14.40	.5615			.9232	.49951
.0273	.49062	-172.0	0.00	.5800			.0273	.49062

TRANSITION

.00023	.000000
.00030	-.000001
.00036	-.000002
.00042	-.000002
.00048	-.000001
.00054	.000000
.00062	.000030
.00073	.000113
.00089	.000175
.00104	.000215
.00135	.000295
.00151	.000287
.00169	.000308
.00186	.000321
.00210	.000338
.00229	.000342
.00245	.000345
.00263	.000347
.00283	.000347
.00304	.000345
.00327	.000341
.00356	.000337
.00393	.000326
.00434	.000303
.00466	.000280
.00500	.000267
.00519	.000252
.00543	.000241
.00563	.000231
.00588	.000222
.00614	.000210
.00647	.000198
.00674	.000192
.00693	.000185
.00706	.000184
.00719	.000182
.00731	.000204
.00738	.000174


```

PROGRAM CASCADE(OUTPUT,TAPE1,TAPE2=OUTPUT,TAPE4=10000,TAPE5=1000
1  5,TAPE7=1028,TAPE3)
  DIMENSION CARD(81)
  COMMON /U/ PI,AA,MRP,MRN,NX,NCR,LBM,IPLT,MODE,NB,NC,MN,II,JJ,KK
  COMMON/G/ M1,N2,N6,N7,N3,V4,M1
C   SECOND IS A CDC 6600 CENTRAL PROCESSOR TIMING ROUTINE
  CALL SECOND(TIME)
  PI = 3.14159265357989
C   CHANGE LBM WHEN CHANGING THE DIMENSION SIZE
  LBM = 200
C   CHANGE KBM WHEN CHANGING THE DIMENSION SIZE OF X3 AND Y3
  KBM = 10
  M1 = N1
  REWIND N4
  MRPFAC = 1
2  REWIND N1
  REWIND N6
  REWIND N7
C   READ IN THE TAPE7 DATA
20 READ (N7,120) (CARD(J) , J = 1,80)
  IF (INCODE(CARD),NE,0) GO TO 20
C   MRP IS NEGATIVE WHEN CHOOSING THE THIRD ORDER ACCURATE METHOD
  MRPOLO = MRP
  MRP = IABS(MRP)*MRPFAC
  IF (MRPOLO,LT,0) MRPFAC = MRPFAC+1
  IF (NP,GE,0) N4=N2
  NP = IABS(NP)
  CALL IN1I
  WRITE (N2,60) MRN
  IF (IPLT,LT,0) GO TO 10
  CALL AUTO1 (N2,KBM)
  DO 40 J = 1,99
  MODE = -J
  CALL MAIN(J)
  IF (MODE,EQ,99) GO TO 45
  WRITE (N2,90) J
40 CONTINUE
45 WRITE (N2,130) JJ
  CALL SECOND (T1)
  TIME = T1-TIME
  WRITE (N2,110) TIME
  N1 = N3
  IF (MRPFAC,EQ,2) GO TO 2
  IF (MRPOLO,GT,0) V1 = M1
  MRP = IABS(MRPOLO)
10 CALL T1ICE
  IPLT = IABS(IPLT)
  MX = 0
  CALL BODYPT(MX)
  CALL BLADE1(MX)
  IF (IPLT,EQ,0) CALL EXIT

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CALL HOGRF(MX)
CALL CPLUT(10.,0.,999)
CALL EXII
80 FORMAT (23H BEGIN EXECUTION OF RUN ,14)
90 FORMAT ( 5H PATH ,13, 9H FINISHED)
110 FORMAT (17H TOTAL CP TIME IS,F6.1,8H SECONDS)
120 FORMAT (80A1)
130 FORMAT (13H OUT OF PATHS/18H LONGEST PATH HAS ,13,7H POINTS)
END

```

```

FUNCTION INCODE (DATA)
DIMENSION DATA(1),VARNAM(7),CHAR(59),VALU(20),VVAL(2),VARLSI(49)
1  +LOCV(40),ARRAY(1),IARRAY(1)
REAL MACH,LOGS
COMMON /A/ GAMMA,MACH,ROU(4)
COMMON /D/ PI,AA,MRP,NRN,VX,NCR,LBM,IPLT,MODE,NB,NC,MV,IL,JJ,KK
COMPLEX ETJ
COMMON /E/ LOGS(4,12),ETJ(4),XR,NLOGS,NK,VP,NJ,LL(32)
COMPLEX XI1AIL,BP,POLE,X1A,X1B,X1C
COMMON /H/ BP(10),POLE,X1A,X1B,X1C,X1TAIL,PLISIZ,NBPS
REAL MACHA,MACHB,MTAIL
COMMON /K/ RN,PCHJ,PCHL,MACHA,ANGLA,MTAIL,ANGLI,MACHB,AVGLB,RC,
1  ANGLN,IR
EQUIVALENCE (ARRAY(1),IARRAY(1))
EQUIVALENCE (ET,ETJ) , (BPR,BP) , (P,POLE)
DATA CHAR /1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,
1  1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HE,1HG,1HI,1HP,
2  1HS,1H4,1H5,1H6,1H7,1H8,1H9,1H+,1H-,1H./
DATA VARLSI /3HEND,2HNP,3HNRN,3HNCR,2HCD,3HMRP,2HTR,3HLOG,2HEI,
14HEISQ,4HETCU,4HETFO,4HPOLE,4HIPLI,2HRN,3HMLS,6HPLISIZ,3HXIA,3HXIB
2  , 3HXIC,7HANGTAIL,5HMTAIL,2HRC,7HANGVUSE,5HGAMMA,2HBP,4HMACH ,
3  3HRUN,5HANGIV,7HANGEXII,4HGRID,5HIRAVU,5HIRANL,6HMINVLEI,5HMAXIT/
DATA NCRD/D/ + NLST /38/ , BL /1H /,STAR /1R*/ , K/1/ , ICMP/2/
LOCV(NLSI+1) = LOCF(LOCV(NLSI+1))
NX = 1
KX = 1
MODE = 1
IF (NCRD.NE.0) GO TO 4
LOCV(2) = -LOCF(VP)
MRP = 6
LOCV(3) = -LOCF(VRV)
NRN = 1
LOCV(4) = -LOCF(NCR)
NCR = 7
LOCV(5) = LOCF(IR)
IR = .03
LOCV ( 6) = -LOCF(MRP)
MRP = 1
LOCV( 7) = LOCF(IR)
LOCV (8) = LOCF(LOGS)
LOCV(9) = LOCF(ET)
LOCV(10) = LOCV( 9) + ICMP

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      LUCV(11) = LUCV(10) + 1CMP
      LUCV(12) = LUCV(11) + 1CMP
      UU 2 J = 1.4
2  E1J(J) = 0.
      LUCV(13) = LUCF(P)
      POLE = 0.
      LUCV(14) = -LUCF(IPLI)
      IPLI = 37
      LUCV(15) = LUCF(RV)
      RN = 0.
      LUCV(16) = LUCF(XR)
      XR = 2.
      LUCV(17) = LUCF(PLTS12)
      PLTS12 = 1.
      LUCV(18) = LUCV(13) + 1CMP
      X1A = (.46,.02)
      LUCV(19) = LUCV(18) + 1CMP
      X1B = (-.1,-.19)
      LUCV(20) = LUCV(19) + 1CMP
      X1C = (-.12,.20)
      LUCV(21) = LUCF(ANGLI)
      ANGLI = -15.
      LUCV(22) = LUCF(MTAIL)
      MTAIL = 0.
      LUCV(23) = LUCF(RC)
      RC = .007
      LUCV(24) = LUCF(ANGLN)
      ANGLN = 20.
      LUCV(25) = LUCF(GAMMA)
      GAMMA = 1.4
      LUCV(26) = LUCF(BPR)
      BP(1) = (.05+.54)
      LUCV(27) = LUCF(MACH)
      MACH = .63
      LUCV(28) = -LUCF(NRN)
      LUCV(29) = LUCF(ANGLB)
      ANGLB = 7.
      LUCV(30) = LUCF(ANGLA)
      ANGLA = -16.
      LUCV(31) = LUCF(AA)
      AA = .08
      LUCV(32) = LUCF(PCHU)
      PCHJ = .05
      LUCV(33) = LUCF(PCHL)
      PCHL = .10
      LUCV(34) = LUCF(MACHB)
      MACHB = 0.
      LUCV(35) = LUCF(MACHA)
      MACHA = 0.
      KZ = LUCF(LOGS)
      KR = 0
4  NCRJ = NCRJ+1
      UU 3 L = 1.7
5  VARNAM(L) = 1H
      SAVE = DATA(81)

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DATA (81) = 1H$
DO 300 L = 1,81
  IGNORE BLANKS
  IF (DATA(L).EQ.1H ) GO TO 300
C  RESET ON ENCOUNTERING A DOLLAR SIGN
  IF ((DATA(L).EQ.1H$.OR.(DATA(L).EQ.1H)) GO TO 60
  IF (NX.LT.0) GO TO 300
  IF (DATA(L).EQ.1H= ) GO TO 150
C  FIND OUT WHICH CHARACTER WE HAVE
  DO 10 J = 1,39
  IF (DATA(L).EQ. CHAR(J)) GO TO 20
10  CONTINUE
  J = 40
20  IF (NX.EQ.0) GO TO 190
  IF (J.GT.26) GO TO 270
  VARNAM(NX) = JATA(L)
  NX = NX+1
  IF (NX.GT.8) GO TO 260
  GO TO 300
C  CHECK FOR END OF DATA
60  IF (NX.LE.1) GO TO 70
  PRINT 410,EL,VARNAM
  ENCODE (10,410,VNAME) VARNAM
  IF (VARS(1).EQ.VNAME) GO TO 310
C  SET VARNAM BACK TO BLANK
70  DO 80 J = 1,7
80  VARNAM(J) = 1H
  J = NX
  NX = 1
  IF ( J.NE.0) GO TO 300
90  IF (J.EQ.0) NX = 1
  LOCV(K) = ISIGV(IABS(LOCV(K))+1,LOCV(K))
  IF (KX.EQ.1) GO TO 299
  IF (KX.GT.20) GO TO 110
C  PUT NUMBER INTO VVAL RIGHT JUSTIFIED
  ENCODE (20,410,VVAL) (BL,J = KX,20),(VALUE(J+1),J = 2,KX)
  KX = 1
  IF (MODE.GT.2) GO TO 110
  KA = IABS(LOCV(K))-LOCV(KARRAY)
  IF (MODE.EQ.2) GO TO 100
C  INTEGER CONVERSION
  DECODE (20,420,VVAL) IARRAY(KA)
  IF (LOCV(K).GT.0) ARRAY(KA) = IARRAY(KA)
  GO TO 300
C  CONVERT TO REAL
100  DECODE (20,430,VVAL) ARRAY(KA)
  IF (LOCV(K).LT.0) IARRAY(KA) = ARRAY(KA)+.5
  MODE = 1
  GO TO 300
110  KY = LOCV(K)-KX
  MODE = 1
  IF (KY.LE.0).OR.(KY.GT.64)) GO TO 120
C  AUTOMATED PARAMETER PUT ADDRESS ON LIST
  NK = NK+1
  LC(NK+1) = KY

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      GO TO 300
120 PRINT 470,VNAME,VVAL
      GO TO 280
150 NX = 0
      ENCODE (10,410,VNAME) VARNAM
C      LOOK FOR THE VARIABLE ON THE LIST
      DO 160 K = 1,NLS1
      IF (VARLS1(K).EQ.VNAME) GO TO 300
160 CONTINUE
      PRINT 450, VNAME
      GO TO 280
190 IF((J.LE.25).OR.(J.EQ.40)) GO TO 200
C      CHANGE THE MODE UPON ENCOUNTERING A DECIMAL POINT
      IF (DATA(L).EQ.1H.) MODE = MODE+1
C      SAVE THE DIGITS TO FORM A NUMBER
      VALUE(KX) = DATA(L)
      KX = KX+1
      GO TO 300
C      CHECK FOR A DECIMAL POINT
C      CHECK FOR A COMMA
200 IF (DATA(L).EQ.1H.) GO TO 90
      MODE = 3
      KX = KX+1
      GO TO 300
270 PRINT 460
280 PRINT 440, NCRD,(DATA(J),J = 1,80)
      LP = L+35
      PRINT 410, (BL, J = 1,LP),STAR
C      SET ERROR FLAG AND LOOK FOR NEXT DOLLAR SIGN
      NX = -1
299 MODE = 1
300 CONTINUE
310 DATA(B1) = SAVE
      INCODE = K-1
      IF (INCODE.NE.0) RETURN
C      RESTORE LINE COUNTER
      NCRD = 0
      NBP5 = (LUCV(26)-LUCF(HPR))/2
      NLOGS = (LCCV(8)-LCCF(LOGS))/4
      LC(1) = LC(2)
      RETURN
410 FORMAT (80A1)
420 FORMAT (120)
430 FORMAT (L20,0)
440 FORMAT (19H0***ERROR IN CARD (13,5H ***), 9X,80A1)
450 FORMAT (*0VARIABLE NAMED *,A8, * WAS NOT FOUND*)
460 FORMAT(*0NON-ALPHABETIC CHARACTERS NOT ALLOWED IN VARIABLE NAMES*)
470 FORMAT (*0ILLEGAL STATEMENT *A7,2H= (2A10)
      END

```

```

SUBROUTINE INIT
  DO INITIALIZATION
  REAL MACH
  COMMON /A/ GAMMA,MACH,ROU1,ROU11
  COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG,IPT2
  COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMUAP,LAMUAM,XI,EIA
  COMMON X1(200),WBHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMJAP(200),LAMJAM(200)
  COMMON /D/ P1,AA,MNP,NKN,NX,NCR,LBM,IPLT,MODE,NB,YC,MJ,II,JJ,KK
  COMMON /F/ XKIG,YURIG,SCALE,PSIC,UOLD,VOLD,XOLD(30),YOLD(30)
1 PSIOLD(30)
  COMPLEX XITAIL,BP,POLE,XIA,XIB,XIC
  COMMON /H/ BP(10),POLE,XIA,XIB,XIC,XITAIL,PLTSIZ,NBPS
  REAL MACHA,MACHB,MIAIL
  COMMON /K/ RN,PCHJ,PCHL,MACHA,ANGLA,MIAIL,AVGL1,MACHS,ANGL3,AL,
1 AVGLN,IR
  COMPLEX I,S, H ,SOFX1,XIDFM,ROU1,ROU11
  DATA I /10.,1./
  SCALE = 1.
  XURIG = 0.
  YURIG = 0.
  PSIC = 0.
  ROU1 = 10.,1.
  ROU11 = (1.,0.)
C LAY DOWN PATH FROM XIA TO XIB TO XIC IN EIA-PLANE
  IF (MACHA.GT.0.) XIA = XIDFM(MACHA,ANGLA,XIA)
  IF (MACHB.GT.0.) XIB = XIDFM(MACHB,ANGLB,XIB)
  XI(1) = XIA
C COMPUTE THE NUMBER OF POINTS FROM XIA TO XIB
  MM = LABS(XIB-XIA)/AA+.9
  MM = MAXU(1,MM*MRP)
  NB = MM+1
  H = (XIB-XIA)/FLOAT(MM)
C LAY DOWN GRID TO XIB
  DO 10 L = 2,NB
10 XI(L) = XI(L-1)+H
C COMPUTE THE NUMBER OF POINTS FROM XIB TO XIC
  MM = LABS(XIC-XIB)/AA+.999999
  MM = MM*MRP
  NC = MM+NB
  H = (XIC-XIB)/FLOAT(MM)
C LAY DOWN GRID FROM XIB TO XIC
  NBPS = NB+1
  DO 20 L = NBPS,NC
20 XI(L) = XI(L-1)+H
C LAY DOWN REFLECTED GRID IN THE XI-PLANE
  DO 30 L = 1,NC
30 EIA(L) = CONJG(XI(L))
  RAD = P1/180.
  GAM = (GAMMA-1.)/2.
  COSG = 1./((MACH*MACH)+GAM)
  IF (MACHB.GT.0.) GO TO 40
C FIND MACH NUMBER AND ANGLE AT INLET
  S = SOFX1(XIB)
  U(NB) = 1.

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```

      V(NB) = 0.
      CALL GETUV (S,CONJG(S),U(VB),V(NB))
      UB = REAL(U(NB))
      VB = REAL(V(NB))
      USB = UB*UB+VB*VB
      MACHB = -SQRT(USB/(COSQ-GAM*QSB))
      ANGLB = ATAN2(VB,UB)/RAD
      GO TO 45
40  USB = COSQ*MACHB*MACHB/(1.+GAM*MACHB*MACHB)
      JB = SQRT(QSB)*COS(RAU*ANGLB)
      VB = SQRT(QSB)*SIN(RAU*ANGLB)
      U(NB) = UB
      V(NB) = VB
45  IF (MACHA.GT.0.) GO TO 50
C   FIND MACH NUMBER AND ANGLE AT EXIT
      U(1) = 1.
      V(1) = 0.
      S = SOFX1(X1A)
      CALL GETUV (S,CONJG(S),U(1),V(1))
      JA = REAL(U(1))
      VA = REAL(V(1))
      USA = UA*UA+VA*VA
      MACHA = -SQRT(USA/(COSQ-GAM*QSA))
      ANGLA = ATAN2(VA,JA)/RAD
      GO TO 55
50  USA = COSQ*MACHA*MACHA/(1.+GAM*MACHA*MACHA)
      UA = SQRT(QSA)*COS(RAU*ANGLA)
      VA = SQRT(QSA)*SIN(RAU*ANGLA)
      U(1) = UA
      V(1) = VA
55  RHOB = RHO(QSB)
      RHOA = RHO(QSA)
      IF (MTAIL.GT.0.) XITAIL = XIOFM(MTAIL,ANGLA+ANGLB,X1A)
      CALL LAMDA(U(1),V(1),LAMUAP(1),LAMDAH(1))
      X1ABS = 1./CABS(X1B-X1A)
      FAC1 = (1.-TR)*RHOA*VA-RHOB*VB
      FAC2 = (1.-TR)*RHOA*UA-RHOB*UB
      YAREAL = -FAC2-FAC1*REAL(LAMDAM(1))
      IF (FAC1.NE.0.) YAREAL = YAREAL/(FAC1*AIMAG(LAMDAM(1)))
      Y1(1) = CMPLX(YAREAL,1.)/SQRT(1.+YAREAL*YAREAL)
      Y1(1) = (X1ABS/CABS(LAMUAP(1)))*(Y1(1)/CABS(Y1(1)))
      X1(1) = -LAMDAH(1)*Y1(1)
      IF (REAL(X1(1)).LT.0.) GO TO 60
      X1(1) = -X1(1)
      Y1(1) = -Y1(1)
60  CONTINUE
      XAREAL = REAL(X1(1))
      YAREAL = REAL(Y1(1))
      XAIMG = AIMAG(X1(1))
      YAIMG = AIMAG(Y1(1))
      XBIMG = -XAIMG/(1.-TR)
      YBIMG = -YAIMG/(1.-TR)
      IPTR = 2.*PI*IX
      RETURN
      END

```

```

SUBROUTINE AUTO1 (N2,KBM)
  COMPUTE NOSE PATH, TAIL PATH, AND K1 AUTOMATED PATHS
  K1 AUTOMATED PATHS FOR EACH OF THE NK AUTOMATED PARAMETERS
  COMPLEX X1
  COMMON X1(400)
  COMMON /D/ P1,AA,MRP,NKV,NX,NCR,LBM,IPLT,MODE,NB,NC,NN,II,JJ,KK
  COMMON /E/ PARAM(56),XR,NLOGS,NK,NP,NJ,LC(32)
  C  MODE=0 FOR NON-AUTOMATED PATHS
  MODE = 0
  IF (NK,EG,6) GO TO 50
  C  SET AUTOMATED PARAMETERS TO ZERO
  DO 10 J = 1,NK
    L = LC(J+1)
  10  PARAM(L) = 0.
  50  K2 = 2+MAX0(NP,0)
  DO 20 MODE = 1,K2
    NX = MIN0(KBM,NK+1)
    NJ = 0
    CALL GTPATH (NC+1,NN,1)
    II = JJ
    IF (MODE,GI,2) GO TO 30
    II = NN-1
    IF (MODE,EG,2) WRITE (N2,100)
  C  EXTEND THE PATH ONE POINT
    X1(NN+1) = X1(NV)+(X1(NV)-X1(NN-1))
    NN = NN+1
  30  CONTINUE
    CALL MAIN (-1)
    IF (NK,LI,KBM) GO TO 20
    DO 40 J = KBM,NK,KBM
      NJ = J
      NX = MIN0(KBM,NK+1-J)
      CALL MAIN (-2)
  40  CONTINUE
  20  CONTINUE
    CALL AUTO2 (KBM)
  C  SET THE MODE TO ZERO SINCE AUTOMATION IS COMPLETE
    MODE = 0
    NJ = 0
    NX = 1
    RETURN
  100 FORMAT (25H NOSE AUTOMATION COMPLETE )
  END

```

```

SUBROUTINE AUTO2 (KBM)
  C  SETS UP AND SOLVES THE EQUATIONS FOR THE AUTOMATED PARAMETERS
  COMMON /D/ P1,AA,MRP,NKV,NX,NCR,LBM,IPLT,MODE,NB,NC,NN,II,JJ,KK
  COMMON /E/ PARAM(56),XR,NLOGS,NK,NP,NJ,LC(32)
  COMMON /F/ XORG,YORG,SCALE,PSIC,UOLD,VOLD,XOLD(30),YOLD(30),
  1  PSIOLD(30)
  COMMON /G/ N1,N2,N6,N7,N3,N4,M1
  COMPLEX X1AIL,BP,POLE,X1A,X1B,X1C

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COMMON /H/ BP(10),POLE,X1A,X1B,X1C,X1TAIL,PLISIZ,NBPS
REAL MACHA,MACHB,MTAIL
COMMON /K/ RN,PCHU,PCHL,MACHA,ANGLA,MTAIL,ANGLT,MACHB,AVGLEB,RC,
1  AVGLEB,IR
COMMON SKP(2000),ARRAY(40,41),ARRAT2(30,80),KGM(80),X1A(80)
COMPLEX X1V,X1P,XINOS,XIX,USZOWS,UOW,UJZ,UZOW,UUZJ(30),JZOW,UW
DIMENSION PSINOS(30),PSIAL(30),PSIP1(30),PSIM1(30),XNOSL(30),XPI
1 (30),XM1(30),XTAIL(30),YNOSE(30),YP1(30),YM1(30),YTAIL(30),XX(30)
DATA XU,XV/0.,1./
RAD = 180./PI
DELTA = AA/FLOAT(NKP)
C COMPUTE THE NUMBER OF ROWS AND COLUMNS OF THE MATRIX
C THE RIGHT HAND SIDE OF THE SYSTEM OF EQUATIONS IS STORED IN
L COLUMN NSIZP
NSIZ = NK+NCR+2
NSIZP = NSIZ+1
NSIZPO = NSIZP+1
C SET THE LEFT AND RIGHT HAND SIDE OF THE MATRIX TO ZERO
DO 10 J = 1,NSIZ
DO 10 K = 1,NSIZPO
10 ARRAY(J,K) = 0.
ARRAY(NK+2,NSIZP) = 1.
ARRAT(NK+2,NSIZPO) = 1.
IF (NCR.LE.3) GO TO 15
ANGL = 2.*(ANGLN+ANGLB)/RAD+PI
XU = COS(ANGL)
XV = SIN(ANGL)
15 ARRAY(NK+7,NSIZP) = 1.
C READ IN THE DATA FOR NOSE AUTOMATION
REWIND N1
NKP = NK+1
DO 20 JJ = 1,NKP,4BM
NX = MIN0(KBM,NK+2-JJ)
NJ = JJ+NX-1
READ (N1,200) K1,K2
READ (N1,200) UM1,VM1,(XM1(J),YM1(J),PSIM1(J) * J = 1,NX),XIM1
READ (N1,200) U,V,(XNOSE(J),YNOSE(J),PSINOS(J) * J = JJ+VJ),XVNOSE
READ (N1,200) UP1,VP1,(XP1(J),YP1(J),PSIP1(J) * J = 1,NX),XIP1
DO 20 K = 1,NX
J = JJ+K-1
ARRAY(NK+2,J) = 1.
C COMPUTE XU AND XV
JZOW = CMPLX(XP1(K)-XM1(K),YP1(K)-YM1(K))/CMPLX(OP1-UM1,VM1-VP1)
ARRAY(NK+6,J) = XV*REAL(UZOW)-XU*AIMAG(UZOW)
ARRAY(NK+7,J) = XU*REAL(UZOW)+XV*AIMAG(UZOW)
UZZJ(J)=CMPLX(XP1(K)+XM1(K)-2.*XNOSE(J),YP1(K)+YM1(K)-2.*YNOSE(J))
20 CONTINUE
UW = CMPLX(OP1-UM1,VM1-VP1)
UOW = CMPLX(OP1+UM1,VP1+VM1)
C READ IN DATA FOR TAIL AUTOMATION
DO 30 JJ = 1,NKP,4BM
NX = MIN0(KBM,NK+2-JJ)
NJ = JJ+NX-1
READ (N1,200) K1,K2
READ (N1,200) UM1,VM1,(XM1(J),YM1(J),PSIM1(J) * J = 1,NX),XIM1

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      READ (N1,200) U,V,(XTAIL(J),YTAIL(J),PSITAL(J), J = JU,VU),XTAIL
      READ (N1,200) UP1,VP1,(XP1(J),YP1(J),PSIP1(J), J = 1,NX),XIP1
      DO 30 K = 1,NX
      J = JU+K-1
      ARRAY(NK+3,J) = PSITAL(J)-PSINOS(J)
      ARRAY(NK+4,J) = (XP1(K)-XV1(K))/DELTA
      ARRAY(NK+5,J) = (YP1(K)-YV1(K))/DELTA
      ARRAY(NK+8,J) = (XP1(K)+XV1(K)-2.*XTAIL(J))/(DELTA*DELTA)
      ARRAY(NK+9,J) = (YP1(K)+YV1(K)-2.*YTAIL(J))/(DELTA*DELTA)
30  CONTINUE
      NPTS = 0
      IF (NP.LE.0) GO TO 95
C     READ IN LEAST SQUARE RESULTS
      DO 55 KP = 1,NP
      DO 50 JJ = 1,NKP,KBM
      IX = *ING(KBM,VK+2-JJ)
      READ (N1,200) K1,K2
      DO 50 K = 1,K2
      READ (N1,200) (XX(J), J = 1,NX),WGHT(K),XIX(K)
      DO 50 JX = 1,NX
      J = JU+JX-1
      ARRAY2(J,K) = XX(JX)-PSINOS(J)
50  CONTINUE
C     NORMALIZE AND WEIGHT ROWS
      DO 65 L = 1,K2
      SUM = 0.
      DO 60 J = 1,NKP
      SUM = SUM + ARRAY2(J,L)*ARRAY2(J,L)
      WGHT(L) = LGHT(L)/SUM
65  CONTINUE
      DO 80 K = 1,NKP
      DO 80 J = K,NKP
      DO 80 L = 1,K2
      ARRAY(J,K) = ARRAY(J,K)+WGHT(L)*ARRAY2(J,L)*ARRAY2(K,L)
80  CONTINUE
      NPTS = NPTS+K2
55  CONTINUE
      DO 70 K = 1,NKP
      FACT = 4.*XR/FLJAT(NKP)
      DO 70 J = K,NKP
      ARRAY(J,K) = FACT*ARRAY(J,K)
70  CONTINUE
95  *WRITE (N2,250) NPTS
      DO 96 J = 1,NSIZ
      DO 96 K = J,NSIZ
96  ARRAY(J,K) = ARRAY(K,J)
      DO 40 J = 1,NK
      ONE = 1.
40  ARRAY(J+1,J+1) = ARRAY(J+1,J+1) + ONE
      CALL LEQ(ARRAY,ARRAY(1,NSIZP),NSIZ,2,40,40,DET)
      WRITE (N2,240) DET
      XTL = 0.
      YTL = 0.
      DDZ = (0.,0.)
C     THE SUFFIX 0 REPRESENTS THE VALUES FOR ABSDZDW=0.

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```

XURGU = 0.
YURGU = 0.
XILG = 0.
YILG = 0.
PSICG = 0.
DOZG = (0.,0.)
IF (NCR.GT.3) GO TO 120
XU = 0.
XV = 0.
120 DO 100 J = 1,NKP
  PSIC = PSIC-ARRAY(J,NSIZP)*PSINOS(J)
  XURIG = XURIG+ARRAY(J,NSIZP)*XNOSE(J)
  YURIG = YURIG+ARRAY(J,NSIZP)*YNOSE(J)
  XIL = XIL + ARRAY(J,NSIZP)*XIAIL(J)
  YIL = YIL + ARRAY(J,NSIZP)*YIAIL(J)
  JOZ = DOZ+ARRAY(J,NSIZP)*DOZJ(J)
  IF (NCR.GT.3) GO TO 105
  XU = XU-ARRAY(J,NSIZP)*ARRAY(NK+6,J)
  XV = XV-ARRAY(J,NSIZP)*ARRAY(NK+7,J)
  GO TO 100
105 PSICG = PSICG-ARRAY(J,NSIZPG)*PSINOS(J)
  XURGU = XURGU+ARRAY(J,NSIZPG)*XNOSE(J)
  YURGU = YURGU+ARRAY(J,NSIZPG)*YNOSE(J)
  XILG = XILG + ARRAY(J,NSIZPG)*XIAIL(J)
  YILG = YILG + ARRAY(J,NSIZPG)*YIAIL(J)
  DOZG = DOZG+ARRAY(J,NSIZPG)*DOZJ(J)
100 CONTINUE
C COMPUTE SLOPE OF CENTRAL STREAMLINE AT STAGNATION
  ANGL = .5*(ATAN2(-XV,-XU)+PI)
  ANGLN = RAD*ANGL-ANGLB-90.
  UN = 1.E-10*COS(ANGL)
  VN = 1.E-10*SIN(ANGL)
  CNX = COS(3.*ANGL)
  SNX = SIN(3.*ANGL)
  UZDW = CMPLX(XU,XV)
  USZDWS = 4.*(DOZ-DZDW*DW)/(DW*DW)
  BQ = REAL(USZDWS)*SNX-AIMAG(USZDWS)*CNX
  CHORD = XIL-XURIG
  IF (NCR.GT.3) GO TO 115
  RC = 3.*(XU*XU+XV*XV)/(8*CHORD)
  ABZDW = SQRT(XU*XU+XV*XV)
  GO TO 125
C FIND MAGNITUDE OF OZDW TO SATISFY RIGHT NOSE CURVATURE
115 LU = XILG-XURGU
  DELC = CHORD-LU
  USZDWS = 4.*DOZG/(LU*LU)
  BQ = REAL(USZDWS)*SNX-AIMAG(USZDWS)*CNX
  DELB = BQ-BQ
  DISCR = (RC*(DELC*30-DELB*30))**2+12.*RC*CU*30
  IF (DISCR.GE.0.) GO TO 125
  RC = -12.*BQ*CU/(DELC*BQ-DELB*CU)**2
  WRITE (N2,190) RC
  DISCR = 0.
125 ABZDW = (RC*(DELC*BQ+DELB*CU)+SQRT(DISCR))/(6.-2.*RC*DELB+DELC)
  XURIG = XURGU+ABZDW*(XURIG-XURGU)

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YORIG = YORGO+ABDZDW*(YORIG-YORGO)
YIL = YILO+ABDZDW*(YIL-YILO)
PSIC = PSIC0+ABDZDW*(PSIC-PSIC0)
CHORD = CO+ABDZDW*DELC
SCALE = 1./CHORD
PSIC = PSIC/CHORD
YIL = (YIL-YORIG)/CHORD
C STORE THE VALUES OF THE AUTOMATED PARAMETERS
DO 110 J = 1,NK
L = LC(J+1)
110 PARAM(L) = ABDZDW*ARRAY(J+1,NSIZP)+(1.-ABDZDW)*ARRAY(J+1,NSIZP0)
REWIND N1
WRITE (N1,200) (PARAM(L), L = 1,56)
WRITE (V1,200) J,V ,YIL
WRITE (V1,200) UN,VN,X1VUSE
RETURN
190 FORMAT (50H0**THIS VALUE OF RC CANNOT BE ACHIEVED** USING XC=F6.3)
200 FORMAT (4020)
240 FORMAT (14H DETERMINANT = ,E12.5)
250 FORMAT (110H THERE ARE ,14,30H POINTS USED FOR LEAST SQUARES )
END

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SUBROUTINE MAIN(I1YP)
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMDAP,LAMDAN,X1,E1A
COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMDAP(200),LAMDAN(200)
COMMON /D/ PI,AA,MKP,NKN,NX,NCR,LBM,1PLT,MODE,NB,NC,NN,11,JJ,KK
COMMON/G/ N1,N2,N6,N7,N3,N4,M1
COMMON /L/ XAREAL,XAIMG,YAREAL,YAIMG
COMMON /F/ XORIG,YORIG,SCALE,PSIC,UOLO,VULO,XJLO(30),YJLO(30),
1 PSILO(30)
COMPLEX UNN,VNN,X1NN,Y1NN,TEMP
LOGICAL ISW
DATA ISW /,FALSE./
IF (ISW) GO TO 10
ISW = ,TRUE,
UA = REAL(U(1))
VA = REAL(V(1))
CALL SAVE(1,1,1)
C READ IN THE NEXT PATH
10 IF (I1YP.GE.0) CALL GETPATH(NL+1,NN,1)
IF (MODE.EQ.99) RETURN
C GET U,V,X1,X2,LAMDAP,LAMDAN, AND ETA ON X1 = CONJUG(X1A)
J(1) = UA
V(1) = VA
X1(1) = XAREAL
Y1(1) = YAREAL
CALL GETXYO (2,NN)
IF (I1YP.GE.0) 11 = JJ
DO 40 LX = 1,NX
40 PSILO(LX) = PSIC
C CHECK FOR SUPERSONIC PATH

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      IF (KK.EQ.1) GO TO 50
C     SUBSONIC PATH, COMPUTE SOLUTION IN THE TRIANGLE
      IF (KK.EQ.0) GO TO 60
C     SAVE U,V,X1, AND Y1 AT END OF PATH SO THAT WE MAY ADD FORKS
      UMN = U(NN)
      VMN = V(NN)
      X1NN = X1(NN)
      Y1NN = Y1(NN)
60    CALL TRIANG(2,VN)
C     CHECK TO SEE IF THERE ARE ANY FORKS
      IF (KK.EQ.0) RETURN
      NFORKS = -KK
C     SAVE REAL U,V,X,Y AND PSI AT ETA(NN)
      URNN = UOLD
      VRNN = VOLD
      XRNN = XOLD(1)
      YRNN = YOLD(1)
      PSINN = PSIOLD(1)
C     COMPUTE SOLUTION ALONG EACH FORK
      DO 30 K = 1,NFORKS
      VNP = NN+1
C     READ IN THE FORK
      CALL GTPATH (NNP,VF,1)
      IF (MODE.EQ.99) RETURN
C     GET U,V,X1,X2,LAMDA+,LAMDA-, AND ETA ON X1 = CONJG(X2A)
      U(NN) = UMN
      V(NN) = VMN
      X1(NN) = X1NN
      Y1(NN) = Y1NN
      UOLD = URNN
      VOLD = VRNN
      XOLD(1) = XRNN
      YOLD(1) = YRNN
      PSIOLD(1) = PSINN
      CALL GETXYD (NNP,VF)
      CALL RECTAN (2,VN,NNP,NF)
      M = NF+1-NN
      WRITE (N1,56) KK,M
      WRITE (N1,56) UOLD,VOLD,XOLD(1),YOLD(1),PSIOLD(1),X1(NN)
      CALL TRIANG (NN+1,NF)
30    CONTINUE
      RETURN
C     SUPERSONIC PATH, READ IN THE OTHER PATH
50    IF (ITYP.GE.-1) CALL GTPATH(NC+1,MM,1)
      IF (MODE.EQ.99) RETURN
      CALL RECTAN (2,UJ,2,NN)
C     COMPUTE THE COMPLEX STREAM FUNCTION ON X1(UJ)
      DO 20 L = NC,11
      CALL GETPSI (L,UJ)
20    CONTINUE
      PSII = PSIOLD(1)
      J = UJ
      NNX = NN
70    M = NNX+1-11
      IF ((N1.EQ.3).AND.(MOD(M,2).EQ.0))GO TO 75

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WRITE (N1,90) KK,M
TEMP = CMPLX(REAL(XI(J)),REAL(ETA(1))+SIGN(100.,AIMAG(XI(J)))
WRITE (N1,90) JOLD,VOLD,XOLD(1),YOLD(1),PSIOLD(1),TEMP
IF (J.EQ.MN) GO TO 80
CALL SAVE(11+1+NNX,J)
75 NNX = NNX-1
J = J+1
CALL RECTAN (J,J,2+NNX)
PSIOLD(1) = PSI1
CALL GEIPSI (11,J)
PSI1 = PSIOLD(1)
GO TO 70
80 CONTINUE
90 FORMAT (402G)
RETURN
END

```

```

SUBROUTINE TRIANG (K1,K2)
C COMPUTE THE SOLUTION IN THE TRIANGLE XI XI(K1), XI ETA,
C ETA(K1) ETA ETA(K2)
COMMON /A/ SKP(2),ROOT
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMDA+,LAMDA-,XI,ETA
COMMON XI(200),JG+1(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMDA+(200),LAMDA-(200)
COMMON /D/ PI,AA,MRP,NRN,NX,NCR,LBM,IPLT,MDOE,NB,NC,NI,11,JJ,KK
COMPLEX TEMP , ROOT
DO 30 J = K1,K2
C SET THE BRANCH FOR THE SQUARE ROOT IN LAMDA+ AND LAMDA-
ROOT = (0.,1.)
C GET VALUES OF U,V,X1,X2,LAMDA+,LAMDA- AT XI(J),ETA(J-1) BY
C REFLECTION OF THESE QUANTITIES AT XI(J-1),ETA(J)
U(J-1) = CONJG(U(J))
V(J-1) = CONJG(V(J))
X1(J-1) = CONJG(X1(J))
Y1(J-1) = CONJG(Y1(J))
TEMP = CONJG(LAMDA+(J))
LAMDA+(J-1) = CONJG(LAMDA+(J))
LAMDA-(J-1) = TEMP
C CHECK TO SEE IF WE ARE PAST XI(NB)
IF (J.LE.NB) GO TO 10
C GET X2 AND Y2 BY REFLECTION
X2(J-1) = CONJG(X2(J))
Y2(J-1) = CONJG(Y2(J))
C CHECK TO SEE IF WE ARE PAST XI(NC)
10 IF (J.LE.NC) GO TO 20
C GET X3 AND Y3 BY REFLECTION
DO 15 LX = 1,NX
X3(LX,J-1) = CONJG(X3(LX,J))
Y3(LX,J-1) = CONJG(Y3(LX,J))
15 CONTINUE
C GET SOLUTION AT XI(J) FROM ETA(J) TO ETA(K2)
20 CALL LINEJ(J,J,K2)

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      IF (J.GE.NC) CALL SAVE (J,J,J)
C     CHECK TO SEE IF WE ARE ON A PATH OR FORK
      IF (K1.NE.2) GO TO 30
C     WE ARE ON A PATH. SAVE VALUES AT X1(J),ETA(K2) SO THAT WE CAN
C     LATER EXTEND THIS PATH WITH FORKS
      U(J-1) = U(K2)
      V(J-1) = V(K2)
      X1(J-1) = X1(K2)
      Y1(J-1) = Y1(K2)
      LAMJAP(J-1) = LAMJAP(K2)
      LAMJAM(J-1) = LAMJAM(K2)
      IF (J.GT.NB) GO TO 40
      IF (J.LT.NB) GO TO 30
      CALL GETX2(J+1,K2)
40    X2(J-1) = X2(K2)
      Y2(J-1) = Y2(K2)
      IF (J.LT.NC) GO TO 50
50    DO 60 LX = 1,NX
      X3(LX,J-1) = X3(LX,K2)
      Y3(LX,J-1) = Y3(LX,K2)
60    CONTINUE
30    CONTINUE
      END

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      SUBROUTINE RECIAN (K1,K2,K3,K4)
C     SOLVE IN THE RECTANGLE X1(K1) X1 X1(K2) , ETA(K3) ETA ETA(K4)
      COMMON /A/ SKP(2),ROOT
      COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMJAP,LAMJAM,XI,ETA
      COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMJAP(200),LAMJAM(200)
      COMMON /U/ PI,AA,MKP,NKV,VX,NCR,LBM,IPLT,MJDE,NB,NC,MN,11,JJ,KK
      COMPLEX ROOT2 = ROOT
      DO 10 J = K1,K2
C     GET THE VALUE OF THE SOLUTION AT X1(J),ETA(K3)
      IF (KK.LE.0) GO TO 20
C     A SUPERSONIC PATH GET U,V,X1,X2,LAMJAP,LAMJAM ON ETA = X1A
      CALL GETXY1 (J)
      GO TO 30
20    U(K3-1) = U(J-1)
      V(K3-1) = V(J-1)
      X1(K3-1) = X1(J-1)
      Y1(K3-1) = Y1(J-1)
      LAMJAP(K3-1) = LAMJAP(J-1)
      LAMJAM(K3-1) = LAMJAM(J-1)
      X2(K3-1) = X2(J-1)
      Y2(K3-1) = Y2(J-1)
      DO 25 LX = 1,NX
      X3(LX,K3-1) = X3(LX,J-1)
      Y3(LX,K3-1) = Y3(LX,J-1)
25    CONTINUE
C     KEEP TRACK OF THE BRANCH OF THE SQUARE ROOT FOR LAMJAP,LAMJAM-
30    ROOT2 = ROOT

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CALL LINEJ (J,K3,K4)
IF (J.EQ.NB) CALL GETX2(MAX0(NB+1,K3),K4)
K001 = K002
SUPERSONIC PATH, COMPUTE PSI ON ETA = CONJG(XIA)
IF ((K.KE.D).OR.(J.LI.VC).OR.(J.GE.JJ)) GO TO 10
IF (J.GI.NC) GO TO 40
CALL GETPSI (I=VC,J)
GO TO 10
40 CALL GETPSI(NC,J)
10 CONTINUE
RETURN
END

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SUBROUTINE LINEJ(J1,K1,K2)
C SOLVE THE EQUATIONS ALONG THE CHARACTERISTIC XI(J) FROM ETA(K1)
C TO ETA(K2)
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG,IPR
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMUAP,LAMDAM,XI,ETA
COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMBAP(200),LAMDAM(200)
COMMON /D/ PI,AA,BKP,NRN,NX,NCR,LBM,IPLT,MODE,NB,NC,NN,II,JJ,KK
COMPLEX UX1,EF,GE,RH1,RH2,RH3,RH4,LAMBPH,LAMBH,LAMBPH,LAMBH,U3,V3
1 + 1,XIH,ETAH,X3NC(30),JLAMI,DY,EIGE
DATA I / (0.,1.) /
J = J1
IF ((J.NE.NC).OR.(K1.GT.NC)) GO TO 5
DO 2 LX= 1,NX
CALL INITFN(ETA(NC),X3NC(LX),LX)
Y3(LX,NC) = (0.,0.)
X3(LX,NC) = X3NC(LX)
IF (KK.GT.0) GO TO 2
X3(LX,NC) = REAL(X3NC(LX))
2 CONTINUE
5 UX1 = XI(J)-XI(J-1)
XIH = .5*(XI(J)+XI(J-1))
DO 80 L = K1,K2
C SOLVE FOR U AND V TO FIRST ORDER ACCURACY
RH1 = V(L)-LAMUAP(L)*U(L)
RH2 = V(L-1)-LAMDAM(L-1)*U(L-1)
U3 = (RH1-RH2)/(LAMDAM(L-1)-LAMUAP(L))
V3 = RH1+LAMUAP(L)*U3
C COMPUTE LAMDA+,LAMDA- TO FIRST ORDER ACCURACY AT XI(J),ETA(L)
CALL LAMDA(U3,V3,LAMBPH,LAMBH)
C COMPUTE MIDPOINT VALUES OF LAMDA+ AND LAMDA-
LAMBPH = .5*(LAMBPH+LAMDAM(L))
LAMBHM = .5*(LAMBH+LAMDAM(L-1))
C SOLVE FOR U AND V TO SECOND ORDER ACCURACY
RH1 = V(L)-LAMBPH*U(L)
RH2 = V(L-1)-LAMBHM*U(L-1)
U(L) = (RH1-RH2)/(LAMBHM-LAMBPH)
V(L) = RH1+LAMBPH*U(L)
C FIND LAMDA+ AND LAMDA- AT XI(J),ETA(L)

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CALL LAMBDA (U(L),V(L),LAMBAP,LAMBAM)
C COMPUTE MIDPOINT VALUES OF LAMBDA+ AND LAMBDA-
LAMBPH = .5*(LAMBAP+LAMBAP(L-1))
LAMBMH = .5*(LAMBAP+LAMBAM(L))
C STORE THE NEW VALUES OF LAMBDA+ AND LAMBDA-
LAMBAP(L) = LAMBPH
LAMBAM(L) = LAMBMH
C COMPUTE X1 AND Y1 AT XI(J),ETA(L)
RH1 = X1(L)+LAMBMH*Y1(L)
RH2 = X1(L-1)+LAMBPH*Y1(L-1)
Y1(L) = (RH1-RH2)/(LAMBMH-LAMBPH)
X1(L) = RH1-LAMBMH*Y1(L)
C CHECK TO SEE IF WE HAVE REACHED XIB
IF((J.LE.NB).OR.(L.LT.NB)) GO TO 90
C COMPUTE X2 AND Y2 AT XI(J),ETA(L)
RH3 = X2(L)+LAMBMH*Y2(L)
IF (L.GT.NB) GO TO 20
C COMPUTE X2,Y2 ON ETA = XIB,X1 = XI(J)
RH4 = 1*(XB1MG+LAMBAP(L)*YB1MG)
Y2(L) = (RH3-RH4)/(LAMBMH-LAMBAP(L))
X2(L) = RH3-LAMBMH*Y2(L)
GO TO 90
20 RH4 = X2(L-1)+LAMBPH*Y2(L-1)
Y2(L) = (RH3-RH4)/(LAMBMH-LAMBPH)
X2(L) = RH3-LAMBMH*Y2(L)
IF((J.LT.NC).OR.(L.LI.NC)) GO TO 90
C COMPUTE THE INHOMOGENEOUS TERM
EF = (RH1+1*(XA1MG+LAMBMH*YA1MG))/(X1(I)-X1H)+(RH3+1*(XB1MG+LAMBMH
1 *YB1MG))/(X1(VB)-X1H)
IF (L.EQ.NC) GO TO 40
GE = (0.,0.)
C CHECK FOR SUBSONIC PATH
IF (KK.GE.0) GO TO 10
C PATH IS SUBSONIC, GET SYMMETRIC EF AND GE
EF = .5*EF
ETAH = .5*(ETA(L)+ETA(L-1))
GE = .5*((RH2-1*(XA1MG+LAMBPH*YA1MG))/(ETA(1)-ETAH) + (RH4-1*
1 (XB1MG+LAMBPH*YB1MG))/(ETA(NB)-ETAH))
10 IF (J.NE.NC) GO TO 30
C GET X3,Y3 ON INITIAL CHARACTERISTIC X1 = XIC
ETGE = (ETA(L)-ETA(L-1))*GE
DO 50 LX = 1,NX
CALL INIFN(ETA(L),X3(LX,L),LX)
IF (KK.LE.0) X3(LX,L) = .5*(X3(LX,L)+CUVUG(X3NC(LX)))
Y3(LX,L) = Y3(LX,L-1) + (ETGE-(X3(LX,L)-X3(LX,L-1)))/LAMBPH
50 CONTINUE
GO TO 90
40 IF((KK.LE.0).OR.(J.EQ.NC)) GO TO 90
DY = (DX1*EF)/LAMBMH
DO 60 LX = 1,NX
Y3(LX,L) = Y3(LX,L) + DY
60 CONTINUE
GO TO 90
C COMPUTE X3 AND Y3 AT XI(J),ETA(L)
30 DY = DX1*EF

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EIGE = (ETA(L)-ETA(L-1))*GE
OLAM1 = 1./(LAMBHH-LAMBPH)
DO 70 LX = 1,NX
RH1 = X3(LX,L)+LAMBHH*Y3(LX,L) + DY
RH2 = X3(LX,L-1)+LAMBPH*Y3(LX,L-1) + EIGE
Y3(LX,L) = (RH1-RH2)*OLAM1
X3(LX,L) = RH1-LAMBHH*Y3(LX,L)
70 CONTINUE
90 CONTINUE
80 CONTINUE
RETURN
END

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C SUBROUTINE SAVE (K1,K2,K3)
C SAVE THE SOLUTION IN THE REAL HODOGRAPH PLANE FROM ETA(K1) TO
C ETA(K2) ALONG XI(K3) ON TAPE
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG,PIR
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMOP,LAMOPM,XI,ETA
COMMON X1(200),WGT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMPJAP(200),LAMOPM(200)
COMMON /D/ PI,AA,MRP,NRN,NX,NCR,LBM,IPLT,MODE,NB,NC,NW,II,JJ,KK
COMMON /F/ XURIG,YURIG,SCALE,PSIL,UOLD,VOLD,XOLD(30),YOLD(30),
1 PSIOLD(30)
COMMON/G/ N1,N2,N6,N7,N3,V4,M1
COMPLEX XITAIL,BP,POLE,XIA,XIB,XIC
COMMON /H/ BP(10),POLE,XIA,XIB,XIC,XITAIL,PLTSIZ,NBPS
REAL LOG1,LOG2
COMPLEX TEMP
LOGICAL ISW
DATA ISW/.FALSE./ , TOL /1.E-6/
IF (ISW) GO TO 2
ISW = .TRUE.
UB = REAL(UINB)
VB = REAL(VINB)
DPSI = RHO(UB*UB+VB*VB)*(UB*YBIMG-VB*XBIMG)
RETURN
2 IF (ABS(XI(K3)-XITAIL).LT. TOL) GO TO 4
TEMP = CLOG((XI(K3)-XITAIL)/(XI(K3)-XIA))
ALPH = AIMAG(TEMP)
4 CONTINUE
TEMP = CLOG((XI(K3)-XIB)/(XI(K3)-XIA))
LOG1 = REAL(TEMP)
THEIA = AIMAG(TEMP)
IF (K1.EQ.NC) THEIA2 = 0.
TEMP = CLOG((XI(K3)-XIA)*CMPLXCOS(THEIA2)+-SIN(THEIA2)))
LOG2 = REAL(TEMP)
THEIA2 = AIMAG(TEMP)+THEIA2
DO 10 L = K1,K2
UNEW = REAL(U(L))
VNEW = REAL(V(L))
XXT = SCALE*(REAL(X2(L))*LOG1+(REAL(X1(L))+REAL(X2(L)))*LOG2
1 -XBIMG+THEIA - (XAIMG+XBIMG)*THEIA2-XURIG)

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      Y1T = SCALE*(REAL(Y2(L))*LOG1+(REAL(Y1(L))+REAL(Y2(L)))*COS2
1  -YBIMG*THETA - (YAIMG+YBIMG)*THETA2-YORIG)
      DO 50 LX = 1,NX
      XNEW = X1T + SCALE*REAL(X3(LX,L))
      YNEW = Y1T+SCALE*REAL(Y3(LX,L))
      IF (L.EQ.NC) GO TO 20
      UH = .5*(UNEW+UOLD)
      VH = .5*(VNEW+VOLD)
      UX = XNEW-XOLD(LX)
      UY = YNEW-YOLD(LX)
      RHOU = RHO(UH*UH+VH*VH)
      PSIOLD(LX) = PSIOLD(LX)+RHOU*(UH*UY-VH*UX)
      IF (ABS(ALPH-ALP+P).LT.PI) GO TO 15
C  WE HAVE JUST CROSSED LINE JOINING EXIT VELOCITY TO TRAILING EDGE
      PRINT 98,X1(K3)
      98 FORMAT (* CROSSING CUT AT *2E15.4)
      FAC = TPIR* SIGN(SCALE,ALPH)
      GO TO 5
      15 IF (ABS(THETA-THETAP).LT.PI) GO TO 20
C  WE HAVE JUST CROSSED THE CUT, ADJUST PSI
      FAC = SIGN(2.*PI*SCALE,THETAP)
      5 PSIOLD(LX)=PSIOLD(LX)+FAC*(OPSI-RHOU*(UH*YBIMG-VH*XBIMG))
      20 XOLD(LX) = XNEW
      YOLD(LX) = YNEW
      50 CONTINUE
      UOLD = UNEW
      VOLD = VNEW
      IF (L.LI.II) GO TO 10
      TEMP = X1(K3)
      IF (KK.GT.0) TEMP = CMPLX(REAL(X1(K3)),REAL(ETA(L))+SIGN(100.,
1  AIMAG(X1(K3))))
      M = NN+1-11
      IF (L.EQ.II) WRITE (N1,40) KK,M
      IF (MODE.GT.2) GO TO 30
      WRITE (N1,40) UOLD,VOLD,(XOLD(J),YOLD(J),PSIOLD(J),J=1,NX),TEMP
      GO TO 10
      30 WRITE (N1,40) (PSIOLD(J),J = 1,NX),WGHT(L),TEMP
      10 CONTINUE
      ALP+P = ALPH
      THETAP = THETA
      RETURN
      40 FORMAT (4020)
      END

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SUBROUTINE GETPSI(LSIGN,J)
REAL MACH
COMMON /A/ GAMMA,MACH
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG
COMMON U,V,X1,X2,X3,Y1,Y2,Y3,LAMUAP,LAMUAP,X1,ETA
COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMUAP(200),LAMUAP(200)
COMMON /D/ P1,AA,MKP,NRN,NX,NCR,LDM,IPLT,MODE,NB,NC,NM,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392,393,394,395,396,397,398,399,400,401,402,403,404,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,422,423,424,425,426,427,428,429,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,448,449,450,451,452,453,454,455,456,457,458,459,460,461,462,463,464,465,466,467,468,469,470,471,472,473,474,475,476,477,478,479,480,481,482,483,484,485,486,487,488,489,490,491,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,507,508,509,510,511,512,513,514,515,516,517,518,519,520,521,522,523,524,525,526,527,528,529,530,531,532,533,534,535,536,537,538,539,540,541,542,543,544,545,546,547,548,549,550,551,552,553,554,555,556,557,558,559,560,561,562,563,564,565,566,567,568,569,570,571,572,573,574,575,576,577,578,579,580,581,582,583,584,585,586,587,588,589,590,591,592,593,594,595,596,597,598,599,600,601,602,603,604,605,606,607,608,609,610,611,612,613,614,615,616,617,618,619,620,621,622,623,624,625,626,627,628,629,630,631,632,633,634,635,636,637,638,639,640,641,642,643,644,645,646,647,648,649,650,651,652,653,654,655,656,657,658,659,660,661,662,663,664,665,666,667,668,669,670,671,672,673,674,675,676,677,678,679,680,681,682,683,684,685,686,687,688,689,690,691,692,693,694,695,696,697,698,699,700,701,702,703,704,705,706,707,708,709,710,711,712,713,714,715,716,717,718,719,720,721,722,723,724,725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,756,757,758,759,760,761,762,763,764,765,766,767,768,769,770,771,772,773,774,775,776,777,778,779,780,781,782,783,784,785,786,787,788,789,790,791,792,793,794,795,796,797,798,799,800,801,802,803,804,805,806,807,808,809,810,811,812,813,814,815,816,817,818,819,820,821,822,823,824,825,826,827,828,829,830,831,832,833,834,835,836,837,838,839,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,855,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886,887,888,889,890,891,892,893,894,895,896,897,898,899,900,901,902,903,904,905,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,921,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,968,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,984,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,1000
COMMON /D/ P1,AA,MKP,NRN,NX,NCR,LDM,IPLT,MODE,NB,NC,NM,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392,393,394,395,396,397,398,399,400,401,402,403,404,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,422,423,424,425,426,427,428,429,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,448,449,450,451,452,453,454,455,456,457,458,459,460,461,462,463,464,465,466,467,468,469,470,471,472,473,474,475,476,477,478,479,480,481,482,483,484,485,486,487,488,489,490,491,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,507,508,509,510,511,512,513,514,515,516,517,518,519,520,521,522,523,524,525,526,527,528,529,530,531,532,533,534,535,536,537,538,539,540,541,542,543,544,545,546,547,548,549,550,551,552,553,554,555,556,557,558,559,560,561,562,563,564,565,566,567,568,569,570,571,572,573,574,575,576,577,578,579,580,581,582,583,584,585,586,587,588,589,590,591,592,593,594,595,596,597,598,599,600,601,602,603,604,605,606,607,608,609,610,611,612,613,614,615,616,617,618,619,620,621,622,623,624,625,626,627,628,629,630,631,632,633,634,635,636,637,638,639,640,641,642,643,644,645,646,647,648,649,650,651,652,653,654,655,656,657,658,659,660,661,662,663,664,665,666,667,668,669,670,671,672,673,674,675,676,677,678,679,680,681,682,683,684,685,686,687,688,689,690,691,692,693,694,695,696,697,698,699,700,701,702,703,704,705,706,707,708,709,710,711,712,713,714,715,716,717,718,719,720,721,722,723,724,725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,756,757,758,759,760,761,762,763,764,765,766,767,768,769,770,771,772,773,774,775,776,777,778,779,780,781,782,783,784,785,786,787,788,789,790,791,792,793,794,795,796,797,798,799,800,801,802,803,804,805,806,807,808,809,810,811,812,813,814,815,816,817,818,819,820,821,822,823,824,825,826,827,828,829,830,831,832,833,834,835,836,837,838,839,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,855,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886,887,888,889,890,891,892,893,894,895,896,897,898,899,900,901,902,903,904,905,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,921,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,968,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,984,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,1000

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COMMON /F/ XORG,YORG,SCALE,PSIG,UOLD,VOLD,XOLD(30),YOLD(30),
1 PSIGOLD(30)
COMPLEX XITAIL,BP,POLE,XIA,XIB,XIC,XITAIL,PLTSIZ,NBPS
COMMON /H/ BP(10),POLE,XIA,XIB,XIC,XITAIL,PLTSIZ,NBPS
COMPLEX CUNEW,CVNEW,CXNEW,CYNEW,UX,DY,UH,VH,CS,C4HU,CLOG2,1,2,CLO
1 ,CUOLD,CVOLD,CXOLD,CYOLD,LOG1,LOG2
DATA 1 /10.,1.)/ , ISW /0/
C COMPUTE THE COMPLEX LOG OF 2 AND CHOOSE THE BRANCH WHOSE ARGUMENT
C IS CLOSEST TO TH
CLOG2(Z,TH) = CMPLX(0.,TH)+CLOG(Z*CMPLX(COS(TH),-SIN(TH)))
IF (ISW.NE.0) GO TO 10
ISW = 1
GAM = (GAMMA-1.)/2.
COSW = 1./((MACH*MACH) + GAM
GAMI = 1./(GAMMA-1.)
RHOINF = (MACH*MACH)**GAMI
10 IF (LSIGN.GT.0) GO TO 15
LOG1 = (0.,0.)
LOG2 = (0.,0.)
15 L = IABS(LSIGN)
CUNEW = U(L)
CVNEW = V(L)
LOG1 = CLOG2(X1(J)-X1(1),AIMAG(LOG1))
LOG2 = CLOG2(X1(J)-X1(N3),AIMAG(LOG2))
CXNEW= SCALE*((X1(L)+I*XAIMG)*LOG1+(X2(L)+I*XBIMG)*LOG2+X3(1,L)
1 -XORG)
CYNEW= SCALE*((Y1(L)+I*YAIMG)*LOG1+(Y2(L)+I*YBIMG)*LOG2+Y3(1,L)
1 -YORG)
IF (LSIGN.LT.0) GO TO 20
UH = .5*(CUOLD+CUNEW)
VH = .5*(CVOLD+CVNEW)
UX = CXNEW-CXOLD
DY = CYNEW-CYOLD
CS = COSW - GAM*(UH*UH+VH*VH)
CRHO = RHOINF*LEXP(GAMI*CLOG(CS))
PSIGOLD(1) = PSIGOLD(1)+CRHO*(UH*DY-VH*DX)
20 CUOLD = CUNEW
CVOLD = CVNEW
CXOLD = CXNEW
CYOLD = CYNEW
IF ((J,LI,JJ).OR.(L,LI,1)) RETURN
UOLD = REAL(CUOLD)
VOLD = REAL(CVOLD)
XOLD(1) = REAL(CXOLD)
YOLD(1) = REAL(CYOLD)
RETURN
END

```

FUNCTION RHO(QS)

COMPUTE DENSITY RHO AS A FUNCTION OF THE SQUARE OF THE SPEED, QS
REAL MACH
COMMON /A/ GAMMA,MACH

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LOGICAL ISW
DATA ISW /,FALSE./
IF (ISW) GO TO 10
ISW = ,TRUE.
GAM = (GAMMA-1.)/2.
COSQ = 1./((MACH*MACH) + GAM
GAMI = 1./((GAMMA-1.)
RHOINF = (MACH*MACH)**GAMI
10 LS = COSQ-GAM*QS
RHO = RHOINF*CS**GAMI
RETURN
END

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SUBROUTINE GETXY0 (K1,K2)
C GET U,V,X1 AND Y1 ON X1=XIA FROM ETA(K1) TO ETA(K2)
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMUAP,LAMDA7,XI,ETA
COMMON X1(200),UG41(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMUAP(200),LAMDA7(200)
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG
COMPLEX I,S,I,LAMBPH,RH1,RH2,SOFX1
DATA I /10.,1./
C COMPUTE S AT X1 = XIA
S = SOFX1(XI(1))
CALL LAMBDA(U(K1-1),V(K1-1),LAMUAP(K1-1),LAMDA7(K1-1))
DO 100 L = K1,K2
C COMPUTE I(ETA(L))
I = CONJG(SOFX1(XI(L)))
ETA(L) = CONJG(XI(L))
J(L) = U(L-1)
V(L) = V(L-1)
CALL GETUV(S,I,J(L),V(L))
CALL LAMBDA(U(L),V(L),LAMUAP(L),LAMDA7(L))
C FIND X1 AND Y1 ALONG X1=XIA AT ETA(L)
C COMPUTE LAMDA= AT MIDPOINT
LAMBPH = .5*(LAMDA7(L)+LAMDA7(L-1))
RH1 = X1(L-1)+LAMBPH*Y1(L-1)
RH2 = -I*(XAIMG+LAMDA7(L)*YAIMG)
Y1(L) = (RH1-RH2)/(LAMBPH-LAMDA7(L))
X1(L) = RH1 - LAMBPH*Y1(L)
100 CONTINUE
RETURN
END

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```

SUBROUTINE GETXY1 (K1)
C GET U,V,LAMDA+, LAMDA-,X1 AND X2 AT XI(K1),CONJG(XIA) AND STORE
C THE RESULTS IN THE FIRST ELEMENT OF THE RESPECTIVE ARRAYS
C THE FIRST ELEMENT OF THE RESPECTIVE ARRAYS WILL CONTAIN THEIR
C VALUES AT XI(K1-1),CONJG(XIA)
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMUAP,LAMDA7,XI,ETA

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COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMBDA(200),LAMBDA*(200)
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG
COMPLEX I,S,1,RH1,RH2,LAMBH,LAMBH*,SOFX1
DATA 1/(0.,1.)/
C COMPUTE S AND XI(K1)
S = SOFX1(XI(K1))
C COMPUTE T AT ETA = CONJG(X1A)
T = CONJG(SOFX1(XI(1)))
CALL GETUV(S,T,U(1),V(1))
CALL LAMBDA(U(1),V(1),LAMBDA(1),LAMBH)
C FIND X1 AND Y1 AT ETA = CONJG(X1A) AT XI(K1)
C COMPUTE LAMBDA+ AT MIDPOINT
LAMBH* = .5*(LAMBDA(1)+LAMBH)
RH1 = X1(1)+LAMBH*Y1(1)
RH2 = I*(XAIMG+LAMBDA(1)*YAIMG)
Y1(1) = (RH1-RH2)/(LAMBH*-LAMBDA(1))
X1(1) = RH1 - LAMBH*Y1(1)
C STORE NEW LAMBDA+
LAMBDA(1) = LAMBH
RETURN
END

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SUBROUTINE GETX2(K1,K2)
C FIND X2 AND Y2 ALONG X1 = X1B FROM ETA(K1) TO ETA(K2)
COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMBDA,LAMBDA*,XI,ETA
COMMON XI(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMBDA(200),LAMBDA*(200)
COMMON /D/ PI,AA,MKP,NKN,NX,NCR,LBM,IPLT,MODE,NB,NC,MN,II,JJ,KK
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG,IPTR
COMPLEX RH1,RH2,LAMBPH,I
DATA 1/(0.,1.)/
C CHECK TO SEE IF WE ARE AT X1B
IF (K1.GI.(NB+1)) GO TO 5
C FIND X2 AND Y2 AT ETA = CONJG(X1B)
RH1 = 1./LAMBDA*(NB)
X2(NB) = -(YBIMG+REAL(RH1)*XBIMG)/AIMAG(RH1)
Y2(NB) = -RH1*(X2(NB)+I*XBIMG)-I*YBIMG
5 CONTINUE
DO 10 L = K1,K2
C COMPUTE LAMBDA- AT MIDPOINT
LAMBPH = .5*(LAMBDA(L)+LAMBDA(L-1))
RH1 = X2(L-1)+LAMBPH*Y2(L-1)
RH2 = -I*(XBIMG+LAMBDA(L)*YAIMG)
Y2(L) = (RH1-RH2)/(LAMBPH-LAMBDA(L))
X2(L) = RH1 - LAMBPH*Y2(L)
10 CONTINUE
RETURN
END

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```

SUBROUTINE GETUV (S,T,U,V)
C   GIVEN S AND T FIND U AND V
COMMON/6/ N1,N2,N6,N7,N3,N4,M1
COMPLEX S,T,U,V,GS,W,WSTR,I,HSQ,HSQPR,GSNEW,ST,CSQR1
EXTERNAL CSQR1
DATA I /(0.,1.)/ , TOL /(1.E+10/
GS = U*U+V*V
W = S
WSTR = T
ST = S*T
IF (CABS(ST).GE.TOL) GO TO 25
CALL GETHSQ(10.,0.,)HSQ,HSQPR)
W = W/CSQR1(REAL(HSQPR))
WSTR = WSTR/CSQR1(REAL(HSQPR))
GO TO 100
C   DO AT MOST 20 NEWTON ITERATIONS
25 DO 30 L = 1,20
C   COMPUTE H(GS)**2 AND ITS DERIVATIVE WITH RESPECT TO GS, HSQPR
C   CALL GETHSQ(GS,HSQ,HSQPR)
GSNEW = GS-(HSQ-ST)/HSQPR
IF (CABS(GSNEW-GS).LT.TOL) GO TO 90
80 GS = GSNEW
WRITE (N2,110) SI
CALL EXIT
90 GS = GSNEW
W = CSQR1(GS*(S/T),W)
WSTR = W*(T/S)
100 U = .5*(W+WSTR)
V = .5*I*(W-WSTR)
RETURN
110 FORMAT(42H NEWTON ITERATION DID NOT CONVERGE AT SI =,2F12.4)
END

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SUBROUTINE GETHSQ(GS,HSQ,HSQPR)
C   COMPUTE H(GS)**2 AND ITS DERIVATIVE WITH RESPECT TO GS, HSQPR
REAL MACH
COMMON /A/ GAMMA,MACH,RR,ROOT
COMPLEX GS,HSQ,HSQPR,BPH11,BPH12,CSQRT,ROOT2,TEMP,GSY,CS,ROOT1,RR
EXTERNAL CSQRT
LOGICAL ISW
DATA ISW /,FALSE./ , CONST /1./
IF (ISW) GO TO 10
GAM = (GAMMA-1.)/2.
COSQ = 1./(MACH*MACH) + GAM
WSTRSQ = (2./(GAMMA+1.))*COSQ
EMU = SQRT((GAMMA-1.)/(GAMMA+1.))
FAC = EMU/WSTRSQ
GSX = GS
WS = (1.,0.)
10 CS = COSQ-GAM*WS
BPH11 = (CS+CS)/WSTRSQ-1.
BPH12 = (CS+CS)-GS

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      RUOT2 = CSGR1((CS+CS)*(BPH12-QS),RUOT1)
      RUOT1 = FAC*RUOT2
      TEMP = CEXP(LLJG(BPH11-RUOT1)/LNU)
      TEMP = CONST/(TEMP*(BPH12+RUOT2))
C      TEMP IS H**2/MS
      HSO = QS*TEMP
      IF (ISW) GO TO 20
      ISW = .TRUE.
C      SET CONST SO THAT H(1) = 1
      CONST = 1./REAL(HSQ)
      QS = QSX
      GO TO 10
C      COMPUTE THE DERIVATIVE OF HSO WITH RESPECT TO QS
20 HSOBK = TEMP*RUOT2/(LS+CS)
      RETURN
      END

```

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C      SUBROUTINE LAMBDA (UL,VL,LAMBDA+,LAMBDA-)
      COMPUTES LAMBDA+ AND LAMBDA- GIVEN U AND V
      REAL MACH
      COMMON /A/ GAMMA,MACH,ROOT
      COMPLEX UL,VL,LAMBDA+,LAMBDA-,V,CS,QS,U,CSGR1,ROOT
      EXTERNAL CSGR1
      LOGICAL ISW
      DATA ISW /.FALSE./
      IF (ISW) GO TO 10
      ISW = .TRUE.
      GAM = (GAMMA-1.)/2.
      LUSQ = 1./((MACH*MACH) + GAM
10 U = UL
      V = VL
      QS = U*U+V*V
      LS = COSQ - GAM*QS
      ROOT = CSGR1(CS*(QS-CS),ROOT)
      LAMBDA+ = (U*V+ROOT)/(CS-V*V)
      LAMBDA- = (U*V-ROOT)/(CS-V*V)
      RETURN
      END

```

```

C      SUBROUTINE GTPATH (K1,K2,K3)
C      READS IN THE PATHS ON THE COMPLEX CHARACTERISTICS AND SETS UP THE
C      INITIAL GRID
C      PATHS ARE PRESCRIBED ON THE PLANE X1=CONJG(X1A) AND THE
C      GRID IS SET UP IN THE PLANE ETA=X1A
      COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMBDA+,LAMBDA-,X1,E1A
      COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMBDA+(200),LAMBDA-(200)
      COMMON /D/ PI,AA,MKP,NKN,NX,NCR,LBM,IPLT,MDOE,NB,NC,NM,IJ,KK
      COMMON /G/ N1,N2,N6,N7,N3,N4,M1

```



```

COMPLEX XITAIL,GP,POLE,XIA,XIB,XIL
COMMON /H/ GP(10),POLE,XIA,XIB,XIC,XITAIL,PLTSIZ,NBPS
REAL MACHA,MACHB,MTAIL
COMMON /K/ RN,PCHJ,PCHL,MACHA,ANGLA,MTAIL,ANGLT,MACHB,ANGLB,RC,

```

```

1  ANGLN,IR

```

```

COMPLEX POINT,H,XIOFS

```

```

DATA KA1 / .01/ , 42MAX /U/

```

```

READ (N6,100) NCARDS,KK

```

```

C ****CHECK FOR END OF FILE****

```

```

IF (EOF(N6).NE.0) GO TO 80

```

```

NCARDS = IABS(NCARDS)

```

```

IF ((K3.EQ.2).AND.(MODE.GT.0)) WRITE (N4,140) NCARDS,KK

```

```

KSWTCH = KK

```

```

K = K1-1

```

```

JJ = K

```

```

ISWICH = 0

```

```

LSW = MODE

```

```

IF ((MODE.EQ.2).AND.(MTAIL.LE.0)) LSW = 0

```

```

DO 60 L = 1,NCARDS

```

```

READ (N6,110) POINT,WGHTX

```

```

LL = WGHTX

```

```

C USE XITAIL IF MTAIL HAS BEEN READ IN

```

```

IF ((LSW.EQ.2).AND.(L.EQ.NCARDS)) POINT = XITAIL

```

```

IF ((K3.EQ.2).AND.(MODE.GT.0)) WRITE (N4,150) POINT,LL

```

```

C ADJUST PATH TO THE NOSE SO THAT IT ENDS AT A STAGNATION POINT

```

```

IF ((MODE.EQ.1).AND.(L.EQ.NCARDS)) POINT = XIOFS(10,0),POINT

```

```

IF (KSWTCH.GT.0) GO TO 20

```

```

10 IX = 1

```

```

CALL ADJUST(IX,IX,POINT)

```

```

IF (IX.EQ.1) GO TO 20

```

```

POINT = POINT + KA1*(XI(K)-POINT)

```

```

GO TO 10

```

```

20 M7 = CABS(POINT-XI(K))/AA+.999

```

```

KN = K+1

```

```

IF (LL.EQ.0) LL = 1

```

```

MM = MM*MRP

```

```

IF (ISWICH.LT.3) MM = MM*IABS(LL)

```

```

IF (LL.GT.0) GO TO 50

```

```

JJ = K+MM

```

```

ISWICH = MODE

```

```

KSWTCH = -1

```

```

LL = -LL

```

```

IF (KK.GT.0) CALL ADJUST(1,1,POINT)

```

```

50 H = (POINT-XI(K))/FLOAT(M7)

```

```

K = K+MM

```

```

DO 60 J = KN,K

```

```

WGHT(J) = FLOAT(LL)*FLOAT(LL)

```

```

60 XI(J) = XI(J-1)+H

```

```

IF (ISWICH.LT.3) GO TO 60

```

```

IF (K.LE.JJ) GO TO 65

```

```

KN = JJ+2

```

```

IF (KN.GE.K) GO TO 64

```

```

DO 62 J = KN,K

```

```

IF (WGHT(J).EQ.WGHT(J-1)) GO TO 62

```

```

WGHT(J-1) = .5*(WGHT(J-1)+WGHT(J))

```

```

62 CONTINUE
64 WGH1(JJ) = .5*WGHT(JJ+1)
   WGH1(K) = .5*WGHT(K)
65 K2 = K
   CALL ADJUST (JJ,K2,X1)
   K2MAX = MAX0(K2MAX,K2)
   IF (LBM.GE.K2MAX) RETURN
   WRITE (N2,120) K2,LBM
   CALL EXIT
80 MODE = 99
   JJ = K2MAX
   RETURN
100 FORMAT (13I3)
110 FORMAT (2E20,12,F10,5)
120 FORMAT (/35H THE GRID IS TOO LARGE FOR PROGRAM,15,3H K=14)
140 FORMAT (/31X,2I3)
150 FORMAT (51X,2F8,3,14)
END

```

```

SUBROUTINE ADJUST (K1,K2,X1)
REAL MACH
COMMON /A/ GAMMA,MACH
COMMON /U/ PI,AA,MRP,NRV,NX,NCR,LBM,IPLT,MODE,ND,NC,MV,II,JJ,KK
COMPLEX X1(1),S,SCRIT,X1OFS,SOFX1
LOGICAL ISW
DATA ISW /,FALSE./
IF (ISW) GO TO 5
ISW = .TRUE.
JCRIT = (GAMMA-1.)/(GAMMA+1.) + 2./((GAMMA+1.)*MACH*MACH)
CALL GETHSQ (CMPLX(OLRIT,0.),SCRIT,S)
CONST = REAL(SCRIT)
5 DO 10 J = K1,K2
  S = SOFX1(X1(J))
  ABSW = S*CONJG(S)
  IF (KK.LE.0) GO TO 20
C SUPERSONIC PATH, PLACE POINT OF THE SONIC LOCUS
  SCRIT = S*SQRT(CONST/ABSW)
  X1(J) = X1OFS(SCRIT,X1(J))
  GO TO 10
C MAKE SURE THAT THE PATH REMAINS SUBSONIC
20 IF (ABSW.GT.CONST) GO TO 30
10 CONTINUE
  RETURN
30 K2 = J+1
  RETURN
END

```

```

SUBROUTINE INITFN (ETA,Z,LJ)
C COMPUTES THE INITIAL CHARACTERISTIC DATA ON XI = XIC
C THIS ROUTINE CAN BE REPLACED BY ANY OTHER ANALYTICAL FUNCTION
C ETA IS THE VALUE OF ETA
C Z IS THE VALUE OF THE INITIAL FUNCTION, G(ETA)
COMPLEX ETA,Z,XIP,I,TEMP,ETJ
REAL LOGS
COMMON /E/ LOGS(4,12),ETJ(4),XR,NLOGS,NK,VP,NJ,LC(32)
DIMENSION PARAM(56)
EQUIVALENCE (PARAM(1),LOGS(1,1))
DATA 1 /10.,1./
LX = LJ+NJ
IF (LX.EQ.1) GO TO 5
KX = LC(LX)
PARAM(KX) = 1.
5 XIP = CONJG(ETA)
SUM UP THE POLYNOMIAL TERMS
J = 4
Z = G1J(J)
20 J = J-1
Z = Z*XIP+G1J(J)
IF (J.GT.1) GO TO 20
Z = Z*XIP
C LOG TERMS
DO 10 J = 1,NLOGS
IF((LOGS(1,J).EQ.0.).AND.(LOGS(2,J).EQ.0.)) GO TO 10
TEMP = 1. - XIP/CMPLX(LOGS(3,J),LOGS(4,J))
Z = Z+CMPLX(LOGS(1,J),LOGS(2,J))*CLOG(TEMP)
10 CONTINUE
Z = CONJG(Z)
IF (LX.EQ.1) RETURN
PARAM(KX) = 0.
RETURN
END

```

```

COMPLEX FUNCTION XIQFS(S,XIPAST)
COMPLEX XIPAST,XIOLD,XINEW,SOFXI,SOFXIP,S
DATA TOL /1.E-10/
XIOLD = XIPAST
C DO AT MOST 20 NEWTON ITERATIONS
DO 40 K = 1,20
XINEW = XIOLD-(SOFXI(XIOLD)-S)/SOFXIP(XIOLD)
IF (ABS(XINEW-XIOLD).LE.TOL) GO TO 50
XIOLD = XINEW
40 CONTINUE
PRINT 99
99 FORMAT (* NO CONVERGENCE*)
50 XIQFS = XINEW
RETURN
END

```

```

COMPLEX FUNCTION SUFFIX1 (X1)
COMPLEX X1,TEMP,POL1,C(12)
COMPLEX X1TAIL,BP,POLE,X1A,X1B,X1C
COMMON /H/ BP(10),POLE,X1A,X1B,X1C,X1TAIL,PL1S12,NBPS
LOGICAL ISW,NPOLE
DATA ISW /,FALSE./ , NPOLE/,FALSE./
IF (ISW) GO TO 10
ISW = ,TRUE.
IF ((REAL(POLE).NE.0.).OR.(AIMAG(POLE).NE.0.)) NPOLE = ,TRUE.
POL1 = 0.
NDEG = NBPS + 1
IF (.NOT.NPOLE) GO TO 30
NDEG = NBPS
POL1 = 1./POLE
30 C(1) = 1.
C(2) = BP(1)+BP(1)
C(3) = -2.
IF (NBPS.LE.1) GO TO 55
DO 50 J = 2,NBPS
TEMP = -1./BP(J)
C(J+2) = TEMP*C(J+1)
K = J
40 C(K+1) = C(K)*TEMP+C(K+1)
K = K+1
IF (K.GT.1) GO TO 40
50 CONTINUE
55 C(2) = C(2)-POL1
DO 60 J = 2,NDEG
60 C(J+1) = (C(J+1)+FLOAT(J-2)*C(J)*POL1)/FLOAT(J)
10 TEMP = C(NDEG+1)
DO 20 J = 1,NDEG
20 TEMP = X1+TEMP+C(NDEG+1-J)
SUFFIX1 = TEMP
IF (NPOLE) SUFFIX1 = SUFFIX1/(1.-POL1*X1)
RETURN
END

```

```

COMPLEX FUNCTION SUFFIXIP(X1)
COMPLEX X1TAIL,BP,POLE,X1A,X1B,X1C
COMMON /H/ BP(10),POLE,X1A,X1B,X1C,X1TAIL,PL1S12,NBPS
COMPLEX X1,TEMP,POL1
LOGICAL ISW,NPOLE
DATA ISW /,FALSE./ , NPOLE/,FALSE./
IF (ISW) GO TO 10
ISW = ,TRUE.
IF ((REAL(POLE).NE.0.).OR.(AIMAG(POLE).NE.0.)) NPOLE = ,TRUE.
IF (NPOLE) POL1 = 1./POLE
NDEG = NBPS
10 TEMP = 2.*(BP(1)-X1)
IF (NDEG.LE.1) GO TO 30
DO 20 J = 2,NDEG
20 TEMP = TEMP*(1.-X1/BP(J))

```

```

30 SUFXIP = TEMP
   IF (NPOLE) SUFXIP = TEMP / (1. - POLI * XI * (2. - POLI * XI))
   RETURN
END

```

```

C      COMPLEX FUNCTION XIOFM(M,ANG,XIOLD)
      COMPUTE XI CLOSEST TO XIOLD WHICH HAS MACH NUMBER M AND ANGLE ANG
      COMMON /A/ GAMMA,MACH
      REAL M,MACH
      COMPLEX HSW,HSWPR,S,XIOFS,XIOLD
      LOGICAL ISW
      DATA PI /3.14159265358979/, ISW /.FALSE./
      IF (ISW) GO TO 10
      ISW = .TRUE.
      RAD = PI/180.
      GAM = (GAMMA-1.)/2.
      COSW = 1./((MACH*MACH) + GAM
10 EMSQ = M*M
      ANGL = ANG*RAD
      WS = COSW*EMSQ/(1.+GAM*EMSQ)
      CALL GETHSG(CMPLX(WS,0.)*HSW,HSWPR)
      S = SQRT(REAL(HSW))*CMPLX(COS(ANGL),-SIN(ANGL))
      XIOFM = XIOFS(S,XIOLD)
      RETURN
END

```

```

C      SUBROUTINE TITLE
      PRINTS THE TITLE PAGE OF THE OUTPUT
      REAL MACH,LOGS
      COMMON /A/ GAMMA,MACH
      COMPLEX U,V,X1,X2,X3,Y1,Y2,Y3,LAMDAP,LAMDAH,XI,EIA
      COMMON X1(200),WGHT(200),ETA(200),U(200),V(200),X1(200),Y1(200),
1 X2(200),Y2(200),X3(10,200),Y3(10,200),LAMDAP(200),LAMDAH(200)
      COMMON /D/ PI,AA,RRP,NRV,VX,NCR,LBM,IPLT,MJJE,NB,NC,MN,II,JJ,KK
      COMMON /E/ PARAM(56),XR,NLOGS,NK,NP,NJ,LC(32)
      COMMON/G/ N1,N2,N6,N7,N3,N4,M1
      COMPLEX XI1AIL,BP,POLE,X1A,X1B,X1C
      COMMON /H/ BP(10),POLE,X1A,X1B,X1C,XI1AIL,PLTSIZ,NBPS
      REAL MACHA,MACH3,XI1AIL
      COMMON /K/ RN,PCHJ,PCHL,MACHA,ANGLA,M1AIL,AVGL1,MACH3,AVGL3,RC,
1 ANGLN,IR
      DIMENSION P1(56),CX(56),LOGS(4,12)
      EQUIVALENCE (PARAM(1),LOGS(1,1))
      REWIND N1
      IF (IPLT,LT,0) GO TO 7
      READ (N1,50) (PARAM(L), L = 1,56)
      IF (N1,EW,M1) GO TO 7
      REWIND M1
      READ (N1,50) (P1(L), L = 1,56)

```

```

    DO 5 L = 1,56
5  PARAM(L) = (4.*PARAM(L)-P1(L))/3.
    DATE IS A CDC ROUTINE WHICH GIVES THE MONTH, DAY, AND YEAR
7  CALL DATE(IGATE)
    NRUV = IABS(NRV)
    WRITE (N4,60) NRUV,IOATE
    VM1 = 8H    RUN =
    NM2 = 8H    NRP =
    *WRITE (N4,60) NM1,NRN,NM2,NRP
    NM1 = 8H    NP =
    VM2 = 8H    NCR =
    WRITE (N4,60) NM1,NP,NM2,NCR
    NM1 = 8HPLISIZ =
    NM2 = 8H    IPLI =
    *WRITE (N4,100) VM1,PLTSIZ,NM2,IPLI
    VM1 = 8H    MACH =
    VM2 = 8H    RN =
    E6 = 2HE6
    IF (RNX.EQ.0.) E6 = 1H
    RVX = 1.E-6*RN
    WRITE (N4,90) VM1,MACH,VM2,RNX,E6
    IF (RM.EQ.0.) GO TO 10
    VM1 = 8H    IRANU =
    VM2 = 8H    TRANL =
    *WRITE (N4,90) NM1,PCHU,VM2,PCHL
10  VM1 = 8H    RC =
    VM2 = 8HANGNUSE =
    *WRITE (N4,90) VM1,RC,NM2,ANGLN
    VM1 = 8H    MTAIL =
    VM2 = 8HANGTAIL =
    *WRITE (N4,90) NM1,MTAIL,NM2,ANGLI
    VM1 = 8H    IR =
    VM2 = 8H    WLS =
    *WRITE (N4,90) NM1,IR,NM2,XR
    VM1 = 8H    GAMMA =
    NM2 = 8H    GRID =
    *WRITE (N4,90) VM1,GAMMA,VM2,AA
    IF (MACHB.LT.0) GO TO 12
    VM1 = 8HMINLET =
    VM2 = 8H    ANGLIN =
    *WRITE (N4,90) NM1,MACHB,NM2,ANGLB
12  IF (MACHA.LT.0) GO TO 14
    VM1 = 8HMEEXIT =
    NM2 = 8HANGEXIT =
    *WRITE (N4,90) VM1,MACHA,NM2,ANGLA
14  *WRITE (N4,70)
    VM1 = 8H    XIA =
    NM2 = 8H    XIB =
    *WRITE (N4,130) NM1,XIA,VM2,XIB
    NM1 = 8H    XIC =
    VM2 = 8H    BP =
    K = 2
    IF ((REAL(POLE).EQ.0.).AND.(AIMAG(POLE).EQ.0.)) GO TO 16
    K = 1
    VM3 = 8H    POLE =

```

```

      WRITE (N4,130) NM1,XIC,VM3,PUL
      GO TO 18
16  WRITE (N4,130) VM1,XIC,VM2,BP(1)
18  IF (NBPS.GE,K) WRITE (N4,130) (NM2,BP(J),J = K,NBPS)
      WRITE (N4,70)
      DO 20 L = 1,56
20  LX(L) = 4H *
      DO 30 L = 1,NK
      J = LC(L+1)
30  LX(J) = 4H *
C    WRITE OUT POLYNOMIAL COEFFICIENTS
      NM1 = BH      EI =
      VM2 = BH      ETSQ =
      WRITE (N4,110) NM1,PARAM(49),LX(49),PARAM(50),LX(50),NM2,PARAM(51)
1    ,LX(51),PARAM(52),LX(52)
      NM1 = BH      ETCU =
      NM2 = BH      ETCU =
      WRITE (N4,110) VM1,PARAM(53),LX(53),PARAM(54),LX(54),NM2,PARAM(55)
1    ,LX(55),PARAM(56),LX(56)
C    PRINT OUT LOG COEFFICIENTS AND LOCATIONS
      IF (NLOGS.EQ.0) GO TO 45
      DO 40 J = 1,NLOGS
      WRITE (N4,140) LOGS(1,J),LX(4*J-3),LOGS(2,J),LX(4*J-2),LOGS(3,J),
1    LX(4*J-1),LOGS(4,J)
40  CONTINUE
45  WRITE (N4,150)
      CALL PLPA1H(2+MAXD(0,NP),2)
      IF (IPLT.NE.0) CALL GOPLUT(NRN)
      RETURN
60  FURMAI (/17X,A8,I4,13X1H:9XA8,I4)
70  FURMAI (1H0)
80  FURMAI (1H1 /15X,28HIRANSJONIC CASCADE DESIGN RUN IS,17XA10///39X,
1    6HIAPE 7 /)
90  FURMAI (/17X,A8,F7.3,10X1H:9X,A8,F7.3,A2)
100 FURMAI (/17X,A8,F7.3,10X1H:9X,A8,I4 )
110 FURMAI ( 6XA8,F7.3,A4,F7.3,A2, 6X1H: 4XA8,F7.3,A4,F7.3,A2/)
120 FURMAI ( 6XA8,F7.3,3X1H,F7.3,8X1H: 4X,A8,F7.3,3X1H,,F7.3/)
130 FURMAI (/11X5HLOG =F7.3,A4,F7.3,A2,6X1H,12XF7.3,A4,F7.3)
140 FURMAI (/30X25H* AUTOMATED PARAMETERS )
150 FURMAI (4020)
      END

```

```

C    SUBROUTINE BODYPT(MX)
      READS TAPE1 DATA FINDS BODY POINTS AND CONSTRUCTS P-N DIAGRAMS
      COMPLEX XI,XIBODY,CHAR
      REAL MACHN,KAPPA
      COMMON XI(200),UREAL(200),VREAL(200),AREAL(200),YREAL(200),PS1(
1    200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2    CHAR(41,10),ILINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3    ,THETA(200),H(200)
      COMMON /L/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG,IPTR
      COMMON /D/ P1,AA,MKP,NRV,VX,NCR,LBM,IPLT,MUDE,NB,NC,NN,I1,JJ,KK

```

```

COMMON/G/ N1,N2,N3,N7,N3,N4,M1
COMMON /J/ PG(405),XMIN,TMIN,XFAC,YFAC,NCH,LSZ,NCLN,IWU,JLV,KCH
COMPLEX ROTATE
INTEGER HP,HN
DATA HP,HN,NKOW/14P,1HN,1/
ANGROT = ATAN2(-XBIMG,-YBIMG)
ROTATE = CMPLX(COS(ANGROT),SIN(ANGROT))
C SET UP AXES FOR THE P-N DIAGRAM
CALL PNAXIS(10.,0.)
C SET UP PLOT PAGE
IPL = MOD(IPLT/10,10)
IF (IPL.EQ.0) GO TO 5
CALL ORIGIN (3.5,1.5)
5 WRITE (N4,200)
IF (N4.NE.N2) WRITE (N2,200)
XBODY(1) = 1.
XBODY(2) = 0.
YBODY(2) = 0.
READ (N1,210) UBODY(1),VBODY(1),YBODY(1)
IF (EOF(N1).NE.0) RETURN
READ (N1,210) UBODY(2),VBODY(2),XBODY(2)
IF (N1.NE.N3) GO TO 7
READ (M1,210) UR2,VR2,YR2
UBODY(1) = (4.*UBODY(1)-UR2)/3.
VBODY(1) = (4.*VBODY(1)-VR2)/3.
YBODY(1) = (4.*YBODY(1)-YR2)/3.
READ (M1,210) UR2,VR2,XBODY(2)
UBODY(2) = (4.*UBODY(2)-UR2)/3.
VBODY(2) = (4.*VBODY(2)-VR2)/3.
7 NX = 3
YIL = YBODY(1)*REAL(ROTATE)+AIMAG(ROTATE)
IF (YIL.LI.0.) CALL CPL31 (CMPLX(0.,-YIL),-3)
C READ DATA FOR A PATH OR FURK
10 READ (N1,210) KK,NPTS
C ***CHECK FOR END OF FILE***
IF (EOF(N1).NE.0) GO TO 160
DO 15 L = 1,NPTS
READ (N1,210) UREAL(L),VREAL(L),XREAL(L),YREAL(L),PS1(L),X1(L)
15 CONTINUE
IF (N1.NE.N3) GO TO 20
READ (M1,210) KK,NPTS
J = 1
DO 25 L = 1,NPTS
READ (M1,210) UR2,VR2,XR2,YR2,PSIR2,X1(L)
UREAL(L) = (4.*JREAL(J)-UR2)/3.
VREAL(L) = (4.*JREAL(J)-VR2)/3.
XREAL(L) = (4.*XREAL(J)-XR2)/3.
YREAL(L) = (4.*YREAL(J)-YR2)/3.
PS1(L) = (4.*PS1(J)-PSIR2)/3.
J = J+2
25 CONTINUE
20 LN = NPTS-2
C CHECK FOR A SUPERSONIC PATH
IF (KK.GI.0) GO TO 40
C WE ARE ON A SUBSONIC PATH OR FURK

```



```

C      PUT SYMBOL P AT POINTS ON PATH OR FORK WHERE PSI IS POSITIVE
C      PUT SYMBOL V AT POINTS ON PATH OR FORK WHERE PSI IS NEGATIVE
      DO 30 J = 1,NPTS
      L = HP
      IF (PSI(J),LT,0.) L = HV
30    CALL PNT (XI(J),L)
      IF (KK,LT,0) GO TO 10
C      WE ARE ON A FORK, LOOK FOR BODY POINTS
40    IF (LN,LT,1) GO TO 100
      DO 90 J = 1,LN
      CALL INTERP(J,MX,ICLK)
      IF (ICLK,EG,0) GO TO 90
C      A BODY POINT HAS BEEN FOUND IN THE INTERVAL
      CALL BDDPTS(MX)
C      CHECK FOR ERRONEOUS POINTS
      IF (KK,GT,0) GO TO 110
      90    CONTINUE
100   IF (KK,LE,0) GO TO 10
C      SUPERSONIC PATH WITH NO BODY POINTS
130   IF (NROW,NE,1) GO TO 60
      MRQ = NPTS/65+1
      IF (N2,LE,N4) GO TO 60
C      PREPARE FOR 11Y PAGE OUTPUT
      MNT = NPTS/36+1
      IVC = 1
      IF (MRQ,NE,MNT) INC = 2
60    IF (MOD(NROW-1,MRQ),NE,0) GO TO 150
C      CONSTRUCT P-N TRIANGLE FOR SUPERSONIC PATH
      NCOUNT = 0
      DO 140 J = 1,NPTS,MRQ
      NCOUNT = NCOUNT+1
      L = HP
      IF (PSI(J),LT,0) L = HV
140   ILINE(NCOUNT) = L
      WRITE (N4,180) (ILINE(J),J = 1,NCOUNT)
      IF ((N2,LE,N4).OR.(MOD(NROW-1,MNT),NE,0)) GO TO 150
      WRITE (N2,180) (ILINE(J),J = 1,NCOUNT,INC)
150   IF (IPL,GT,2) CALL PLINK (NROW,NPTS)
      NROW = NROW+1
      IF (NPTS,GT,1) GO TO 10
C      TRIANGLE IS COMPLETE
      WRITE (N4,200)
      IF (N4,NE,N2) WRITE (N2,200)
      NROW = 1
      GO TO 10
C      PLOT EVERY MRP CHARACTERISTIC FROM THE BODY TO THE SONIC LINE
110   IF ((IPL,LE,2).OR.(MOD(NROW-1,MRQ),NE,0)) GO TO 130
      CALL LPLU1(ROATE*CMPLX(XBODY(MX-1),YBODY(MX-1)),3)
      DO 120 L = J,LN
120   CALL LPLU1(ROATE*CMPLX(XREAL(L+2),YREAL(L+2)),2)
      GO TO 130
160   MX = MX-1
      WRITE (N4,290) PG
      IF (IPL,NE,0) CALL ORIGIN (3.5,1.5)
      IF (N2,EQ,N4) RETURN

```

```

      DO 310 J = 2,403,13
      JP = J+6
310  WRITE (N2,320) (PG(L),L = J,JP)
320  FORMAT (1X,B10)
      RETURN
180  FORMAT(65(1X,A1))
200  FORMAT (1H1)
C    ***CHANGE (4020) TO (20A4) ON IBM 360***
210  FORMAT (4D20)
290  FORMAT (  ///////////(1X,13A10))
      END

SUBROUTINE PLIML(K1,K2)
C    PLOTS CHARACTERISTICS IN THE SUPERSONIC REGION
COMMON /L/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG
COMPLEX XI,XIBODY,CHAR
REAL MACHN,KAPPA
COMMON XI(200),UREAL(200),VREAL(200),XREAL(200),YREAL(200),PSI(
1  200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2  CHAR(41,10),LLINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3  ,THEIA(200),N(200)
COMMON /O/ PI,AA,MRP,MKN,VX,NCR,LBM,IPLT,MODE,NB,NC,NH,II,JJ,KK
COMMON/G/ N1,N2,N6,N7,N3,V4,M1
COMPLEX ROTATE
DIMENSION MPOINT(41),PSIMP(41)
LOGICAL ISW
DATA ISW /,FALSE./ , NAR /41/ , MAR /10/
IF (ISW) GO TO 5
ISW = ,TRUE,
ANGROT = ATAN2(-XBIMG,-YBIMG)
ROTATE = CMPLX(COS(ANGROT),SIN(ANGROT))
5  L = 0
C    CHECK FOR FIRST ROW OF TRIANGLE
IF (K1.GT.1) GO TO 30
FAC = -PSI(1)/ABS(PSI(1))
MRQ = MRP
10  DO 20 J = 1,K2,MRQ
    L = L+1
    CHAR(L,1) = ROTATE*CMPLX(XREAL(J),YREAL(J))
    PSIMP(L) = PSI(J)
20  MPOINT(L) = 1
    LL = L-1
C    CHECK TO SEE IF WE HAVE EXCEEDED THE DIMENSION OF CHAR
IF (L.LE.NAR) RETURN
WRITE (N4,100)
MRQ = MRQ+MRQ
L = 0
GO TO 10
30  DO 70 J = 1,K2,MRQ
    L = L+1
    IF (FAC*PSI(J).LE.0.) GO TO 60
    POINT IS OUTSIDE THE BODY

```

```

      MPOINT(L) = MPOINT(L)+1
      IF (MPOINT(L).EQ.2) GO TO 50
C     CHECK FOR DIMENSION OF CHAR
      IF (MPOINT(L).LE.MAR) GO TO 60
      MPOINT(L) = 2
      CALL CPLOT(CHAR(L,1),3)
      DO 40 K = 2,MAR
40    CALL CPLOT (CHAR(L,K),2)
      CHAR(L,1) = CHAR(L,MAR)
      GO TO 60
C     FIND A POINT ON THE BODY BY LINEAR INTERPOLATION
50    R2 = PSI(J)-PSITMP(L)
      R1 = PSI(J)/R2
      R2 = -PSITMP(L)/R2
      CHAR(L,1) = R1*CHAR(L,1)+ROTATE*R2*CMPLX(XREAL(J),YREAL(J))
C     STORE THE POINT FOR PLOTTING
60    K = MPOINT(L)
      CHAR(L,K) = ROTATE*CMPLX(XREAL(J),YREAL(J))
70    PSITMP(L) = PSI(J)
      IF (K2.GT.1) RETURN
C     WE HAVE FINISHED THIS SUPERSONIC PATH
C     FINISH PLOTTING THE CHARACTERISTICS
      DO 90 J = 1,LL
      L = MPOINT(J)
      IF (L.LE.1) GO TO 90
      CALL CPLOT(CHAR(J,1),3)
      DO 80 K = 2,L
80    CALL CPLOT(CHAR(J,K),2)
90    CONTINUE
      RETURN
100  FORMAT(2/H 100 MANY SUPERSONIC POINTS )
      END

```

```

      SUBROUTINE INTERP(K1,K2,K3)
C     COMPUTES POINTS ON THE BODY BY QUADRATIC INTERPOLATION
C     THE BODY IS THE STREAMLINE PSI = 0.
C     K1,K2 AND K3 ARE 3 CONSECUTIVE POINTS
C     K3 IS ZERO WHEN THERE IS NO BODY POINT IN THIS INTERVAL
      COMPLEX X1,X1BODY,CHAR
      REAL MACHN,KAPPA
      COMMON X1(200),UREAL(200),YREAL(200),XREAL(200),YREAL(200),PSI(
1    200),X1BODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2    CHAR(41,1),ILINE(200),SI(200),MACHN(200),KAPPA(200),ANGL(200)
3    ,THETA(200),H(200)
      COMPLEX X113,X123
      K3 = 0
      XB = PSI(K1+1)
      XC = PSI(K1+2)
C     CHECK FOR A SIGN CHANGE BETWEEN THE SECOND AND THIRD INTERVAL
      IF (XB*XC.LT.0.) GO TO 20
      IF (XB*XC.GT.0.) RETURN
C     CHECK TO SEE IF BOTH XB AND XC ARE ZERO

```

```

1* (XB+XL*EW.0.) RETURN
20 K3 = 1
XA = PSI(K1)
EA = XC-XB
EB = XC-XA
EC = XB-XA
C DO LINEAR INTERPOLATION BETWEEN POINTS 2 AND 3
U23 = (UREAL(K1+1)*XC-UREAL(K1+2)*XB)/EA
V23 = (VREAL(K1+1)*XC-VREAL(K1+2)*XB)/EA
X23 = (XREAL(K1+1)*XC-XREAL(K1+2)*XB)/EA
Y23 = (YREAL(K1+1)*XC-YREAL(K1+2)*XB)/EA
X123 = (XI(K1+1)*XC-XI(K1+2)*XB)/EA
C DO LINEAR INTERPOLATION BETWEEN POINTS 1 AND 3
U13 = (UREAL(K1) *XC-UREAL(K1+2)*XA)/EB
V13 = (VREAL(K1) *XC-VREAL(K1+2)*XA)/EB
X13 = (XREAL(K1) *XC-XREAL(K1+2)*XA)/EB
Y13 = (YREAL(K1) *XC-YREAL(K1+2)*XA)/EB
X113 = (XI(K1)*XC-XI(K1+2)*XA)/EB
C IF PSI IS NOT MONOTONIC USE LINEAR INTERPOLATION
IF (EA*EC.GT.0.) GO TO 30
K3 = -1
UBODY(K2) = U23
VBODY(K2) = V23
XBODY(K2) = X23
YBODY(K2) = Y23
XIBODY(K2) = X123
RETURN
C DO QUADRATIC INTERPOLATION
30 UBODY(K2) = (U13*XB-U23*XA)/EC
VBODY(K2) = (V13*XB-V23*XA)/EC
XBODY(K2) = (X13*XB-X23*XA)/EC
YBODY(K2) = (Y13*XB-Y23*XA)/EC
XIBODY(K2) = (X113*XB-X123*XA)/EC
RETURN
END

SUBROUTINE BLADE(K1)
C REORDER THE K1 BODY POINTS, PRINT AND PLOT THE RESULTS
REAL MACH
COMMON /A/ GAMMA,MACH
COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG
COMMON /F/ XORIG,YORIG,SCALE
COMPLEX XI,XIBODY,CHAR
REAL MACHN,KAPPA
COMMON XI(200),UREAL(200),VREAL(200),XREAL(200),YREAL(200),PSI(
1 200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2 CHAR(41,10),ILINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3 ,THETA(200),H(200)
COMMON /O/ PI,AA,AKP,NRV,NX,NCR,LBM,IPLOT,MODE,NB,NC,NH,II,JJ,KK
COMMON /G/ A1,N2,N6,N7,N3,N4,M1
COMPLEX XI1AIL,BP,POLE,X1A,X1B,X1C
COMMON /H/ BP(10),POLE,X1A,X1B,X1C,X1TAIL,PLTSIZ,NBPS

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```

      REAL MACHA,MACHB,MTAIL
      COMMON /K/ RN,PCHU,PCHL,MACHA,ANGLA,MTAIL,ANGLI,MACHB,ANGLB,KC,
1  ANGLN,IK
      COMMON /I/ SF,SIZE,ANG,XMAX,YMAX,XUR,YUR,PSSIZ
      COMPLEX EINT(3),BASE(3)
      COMMON /II/ IITLE(2)
      CMACHQS) = SQRT(QS/ICDSC-((GAMMA-1.)/2.)*QS)
      GAM = (GAMMA-1.)/2.
      CUSQ = GAM + 1./(MACH*MACH)
      RAD = 180./PI
      IPL = MOD(IPLI/10,10)
      SM = 5./SF
      ANGROT = ATAN2(-XBIMG,-YBIMG)
      COSA = COS(ANGROT)
      SINA = SIN(ANGROT)
      SOL = 2.*PI*SM*SQRT(XBIMG*XBIMG+YBIMG*YBIMG)
      IF (K1.LE.1) GO TO 25
C      CREATE A POINTER LIST
      DO 10 J = 1,K1
C 10 ILINE(J) = J
C      ORDER THE POINTS AROUND THE BODY AND FIND THE THICKNESS/CHORD
      IC = 0.
      LMAX = 1
      XIBODY(1) = XITAIL
      DO 20 J = 2,K1
      K = ILINE(J-1)
      LMAXP = LMAX
      XMX = XBODY(K)
      LMAX = J-1
      DO 30 L = J,K1
      LL = ILINE(L)
      IF (XBODY(LL).LE.XMX) GO TO 30
      XMX = XBODY(LL)
      LMAX = L
30 CONTINUE
      IC = AMAX1(IC,ABS(YBODY(LMAX)-YBODY(LMAXP)))
      IF (LMAX.EQ.(J-1)) GO TO 20
      ILINE(J-1) = ILINE(LMAX)
      ILINE(LMAX) = K
20 CONTINUE
      SIZE = .07
      SOL = SOL*SCALE
25 WRITE (N4,110) IC,SOL
      IHA = 90.-ANGLA - RAD*ANGROT
      IHB = 90.-ANGLB - RAD*ANGROT
      TURN = IHA-IHB
      WRITE (N4,120) MACHB,IHB,MACHA,IHA,TURN
      IF (K1.LE.1) RETURN
      LL = ILINE(K1)
      BASE(1) = XIB
      EINT(1) = CONJG(XIBODY(LL)-XIB)
      BASE(2) = XIA
      EINT(2) = CONJG(XIB-XIA)
      BASE(3) = XITAIL - 1.E-6
      EINT(3) = CONJG(XIA-XITAIL)

```

```

      FACT = 1.
      ANG = 45.
      L1 = K1+1
      I1 = -1
50  DO 40 L = 1,K1
      J = ILINE(L)
      L2 = 1
      IF (REAL(XIBODY(J)).GT.REAL(XIB)) L2 = 2
      IF (REAL(XIBODY(J)).GT.REAL(XIA)) L2 = 3
      IF (FACT*AIMAG((XIBODY(J)-BASE(L2))*EIV(L2)),L1,0.) GO TO 40
      L1 = L1+I1
      XREAL(L1) = XBODY(J)*COSA-YBODY(J)*SINA
      YREAL(L1) = XBODY(J)*SINA+YBODY(J)*COSA
      WS = UBODY(J)*UBODY(J)+VBODY(J)*VBODY(J)
      EMN = EMACH(WS)
      MACHN(L1) = EMN
      ANGL(L1) = ATAN2(JBODY(J)*SINA+VBODY(J)*COSA,UBODY(J)*COSA-
1  VBODY(J)*SINA)
      IF (IPL.EQ.0) GO TO 40
      CALL CSYMBL (CMPLX(XREAL(L1),SM*(.50+EMN)),3,-1)
40  CONTINUE
      IF (FACT.EQ.-1) GO TO 60
      ANG = 0.
      L1 = 0
      I1 = 1
      FACT = -1.
      GO TO 50
60  KP = K1+1
C  PLOT MACH NUMBER AT THE TAIL POINT
      ANG = 45.
      EMN = SM*(MACHN(1)+.50)
      CALL CSYMBL(CMPLX(XREAL(1),EMN),3,-1)
      ANG = 0.
      XREAL(KP) = XREAL(1)
      YREAL(KP) = YREAL(1)+TR*SOL
      ANGL(KP) = ANGL(1)
      MACHN(KP) = MACHN(1)
      IF (YREAL(1).LT.0.) CALL CPLOT (CMPLX(0.,-YREAL(1)),.5)
      CALL OUTPT(KP)
      IF (IPL .EQ.0) RETURN
      CALL ORIGIN (3.5,1.5)
      ANG = 0.
      SIZE = .14
      SP = 1.
      CALL CSYMBL ((-,.80,8.0) ,1MM,1)
      EMA = ABS(MACHA)
      EMB = ABS(MACHB)
      ENCODE (60,140,TITLE) EMB ,EMA ,TURN,SOL
      CALL CSYMBL((0.,-.5),TITLE,60)
      CALL XYAXES ((-1.0,2.5),0.,6.0,.20,90.)
      CALL FRAMEX
      RETURN
110 FORMAT(1H1/35X,16H1THICKNESS/CHORD=,F6.4//39X,10H4AP/CHORD=,F6.3/)
120 FORMAT (13X ,18HINLET MACH NUMBER=,F6.3,15X,17HINLET FLOW ANGLE=,
1  F7.2//13X, 18H EXIT MACH NUMBER=,F6.3,15X, 17H EXIT FLOW ANGLE=,

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```

2 F7.2//35X,14HTURNING ANGLE=F7.2//)
140 FOR 441 (4H M1=F4.3,5X3H%2=F4.3,5X7HDEL TH=F6.2,5X4HG/C=F4.2)
END

```

```

C SUBROUTINE BADPTS(K1)
  ELIMINATE MOST ERRONEOUS POINTS
  COMPLEX XI,XIBODY,CHAR
  REAL MACHN,KAPPA
  COMMON XI(200),UREAL(200),VREAL(200),XREAL(200),YREAL(200),PSI(
1 200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2 CHAR(41,10),ILINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3 ,THETA(200),H(200)
  COMMON /C/ XAREAL,XAIMG,YAREAL,YAIMG,XBIMG,YBIMG
  COMMON /D/ PI,AA,MKP,NRN,NX,NCR,LBM,IPLT,MDEL,NB,NC,NN,II,JJ,KK
  XI = XBODY(1)+(YBODY(K1)-YBODY(1))*(XBIMG/YBIMG)
  IF (UBODY(K1).LT.-.2) RETURN
C LOOK FOR POINTS ON THE CENTRAL STREAMLINE
  IF (XBODY(K1).LT.0.) GO TO 10
  IF (XBODY(K1).GT.XI) RETURN
C SAVE THIS POINT
20 K1 = MIN0(K1+1,LBM)
  RETURN
10 IF (ABS(UBODY(K1)).LE.ABS(VBODY(K1))) GO TO 20
  RETURN
END

```

```

SUBROUTINE HUGRF(K1)
  COMPLEX X01
  COMPLEX XI,XIBODY,CHAR
  REAL MACHN,KAPPA
  COMMON XI(200),UREAL(200),VREAL(200),XREAL(200),YREAL(200),PSI(
1 200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2 CHAR(41,10),ILINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3 ,THETA(200),H(200)
  COMMON /D/ PI,AA,MKP,NRN,NX,NCR,LBM,IPLT,MDEL,NB,NC,NN,II,JJ,KK
  COMPLEX XITAIL,JP,POLE,XIA,XIB,XIC
  COMMON /H/ BP(10),POLE,XIA,XIB,XIC,XITAIL,PLTSIZ,NBPS
  COMMON /I/ SF,SIZE,ANG,XMAX,YMAX,XUR,YUR,PGSIZ
  IPL = MOD (IPLT,10)
  IF (IPL.EQ.0) RETURN
  XI(NC) = XIC
  XI(NC-1) = XIC
  CALL LOCUS (IPL)
  IF (K1.LE.1) RETURN
  K = 0
  DO 10 J = 1,K1
C CHECK FOR SUPERSONIC POINTS
  IF (ABS(AIMAG(XIBODY(J))).GT.10.) GO TO 10
  K = K+1
10

```

```

      CALL CSYMBL(XIBODY(J),3,-1)
10  CONTINUE
      IPL = IPLT/100
15  IF (IPL.EQ.0) RETURN
      IF (IPL.EQ.2) GO TO 30
      IPL = IPL-1
      IF (K.GE.K1) GO TO 15
C   PLOT THE SUPERSONIC TRIANGLE
      CALL FRAMEK
      CALL ORIGIN (7.5,7.5)
      SF = 10.
      DO 20 J = 1,K1
      IF (ABS(AIMAG(XIBODY(J))).LT.10.) GO TO 20
      TEMP = AIMAG(XIBODY(J))
      TEMP = TEMP* SIGN(100.,TEMP)
      XIBODY(J) = CMPLX(REAL(XIBODY(J)),TEMP)
      CALL CSYMBL(XIBODY(J),3,-1)
20  CONTINUE
      CALL XYAXES((0.,0.),7.,3.,.1,0.)
      CALL XYAXES((0.,0.),7.,3.,.1,90.)
      CALL (PLOT ((-7,-7),3)
      CALL CPLOT ((1.3,3),2)
      IF (IPL.EQ.1) RETURN
30  CALL FRAMEK
      CALL ORIGIN (2.0,5.0)
      XMAX = 60.
      SF = 50.
      KP = K1+1
      ROT = CMPLX(XREAL(KP),-YREAL(KP))
      ROT = ROT/CABS(ROT)
      IPEN = 3
      DO 40 L = 1,KP
      CALL CPLOT (ROT*CMPLX(XREAL(L),YREAL(L)),IPEN)
40  IPEN = 2
      IPEN = 3
      DO 50 L = 1,KP
      OELS = THETA(L)*H(L)
      XS = XREAL(L) + OELS*SIN(ANGL (L))
      YS = YREAL(L) + OELS*COS(ANGL(L))
      CALL CPLOT (ROT*CMPLX(XS,YS),IPEN)
50  IPEN = 2
      RETURN
      END

```

```

SUBROUTINE LOCUS(IPL)
COMPLEX S,XIOFS,XI,XIO,CSQRT,XIMIN,XIMAX,HSQPR,EIJ
REAL MACH,LOGS
COMMON /A/ GAMMA,MACH
COMMON /D/ PI,AA,MRP,NRN,VX,NCR,LBM,IPLT,MODE,NB,NC,MN,II,JJ,KK
COMMON /E/ LOGS(4,12),EIJ(4),XH,NLOGS,NK,NP,NJ,LL(32)
COMPLEX XITAIL,BP,POLE,XIA,XIB,XIC
COMMON /H/ BP(10),POLE,XIA,XIB,XIC,XITAIL,PLTS12,NBPS

```



```

C   FIND POINT ON BOUNDARY AND DRAW LINE TO IT
    IPENL = -2
    IF (IPENL.EQ.3) GO TO 20
    XP = XMAX
    IF (XX.LE.0.) XP = 0.
40  YP = YY+((YL-YY)/(XL-XX))*(XP-XX)
    IF (ABS(YP-YP-YP-YP).GT.YMAX) GO TO 110
50  CALL PLOT (XP,YP,IABS(IPENL))
    IF (IPENL.EQ.3) GO TO 10
    GO TO 20
60  IPENL = IABS(IPENL)
    IF (IPENL.EQ.2) GO TO 20
C   FIND POINT ON BOUNDARY AND DRAW LINE TO IT
    IPENL = 2
    IF (IPENL.EQ.3) GO TO 20
    YP = YMAX
    IF (YY.LE.0.) YP = 0.
70  XP = XX+((XL-XX)/(YL-YY))*(YP-YY)
    GO TO 50
80  IF (IABS(IPENL).EQ.3) GO TO 10
    IPENL = IPENL+1
    IF (IPENL.EQ.3) GO TO 70
    IPENL = 3
    GO TO 40
90  CALL FRAMEK
    XL = 0.
    YL = 0.
    IPEVL = 0
    RETURN
100 XOR = XP
    YOR = YP
    RETURN
110 IF (IPENL.EQ.3) GO TO 70
    GO TO 60
END

```

```

SUBROUTINE CSYMBL (X,N,L)
COMMON /1/ SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PGSIZ
DIMENSION X(2)

```

```

C   CHANGE RELATIVE MOVEMENTS TO ABSOLUTE INCHES

```

```

    XX = XOR+SF*X(1)

```

```

    YY = YOR+SF*X(2)

```

```

C   CHECK TO SEE IF WE ARE WITHIN THE PAGE

```

```

    IF ((XX.LT.0.).OR.(YY.LT.0.).OR.(XX.GT.XMAX).OR.(YY.GT.YMAX))

```

```

1)RETURN

```

```

    CALL SYMBOL (XX,YY,SIZE,N,ANG,L)

```

```

    RETURN

```

```

END

```

```

      PI(2) = YMIN+FLOAT(NLIN-J)*H1
      CALL PN (PI,HP)
30  CONTINUE
      RETURN
      END

```

```

      SUBROUTINE GUPLOT(NRN)
      INITIATE PLOT
      *****
      THIS SUBROUTINE SHOULD BE REPLACED BY ANY ROUTINE WHICH INSTRUCTS
      THE SYSTEM TO INITIATE A PLOT
      *****
      DIMENSION IO(3)
      IO(3) = 0
      NRUN = IABS(NRN)
      ENCODE (20,30+IO) NRUN
      IF (NRN.LT.0) GO TO 25
      CALL PLOTS (120,IO+11.,11.)
      RETURN
25  CALL PLOTSL (120,IO+11.,11.)
      RETURN
30  FORMAT ( 5X,3NRUN , 15)
      END

```

```

      SUBROUTINE CPLOT (X,IPEN)
      MOVE PEN TO THE POSITION DEFINED BY X WHEN X IS ON THE PAGE
      COMMON /1/ SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PBSIZ
      DIMENSION X(2)
      DATA XL,YL,IPENL /0.,0.,0/
      CHANGE RELATIVE MOVEMENTS TO ABSOLUTE INCHES
      XX = XOR+SF*X(1)
      YY = YOR+SF*X(2)
      CHECK TO SEE IF WE ARE WITHIN THE PAGE
      IF (ABS(XX+XX-XMAX).GT.XMAX) GO TO 30
      IF (ABS(YY+YY-YMAX).GT.YMAX) GO TO 60
      IF (IPENL.NE.0) GO TO 80
10  CALL PLOT (XX+YY,IABS(IPEN))
      IPENL = 0
20  XL = XX
      YL = YY
      IF (IPEN.GT.0) RETURN
      IF (IPENL.NE.0) GO TO 100
      XOR = XX
      YOR = YY
      RETURN
30  IPENL = -IABS(IPENL)
      IF ((XX.GT.XMAX).AND.(IPENL.LT.0.)) GO TO 90
      CHECK TO SEE IF PEN IS ALREADY OUT OF BOUNDS
      IF (IPENL.NE.0) GO TO 20

```

```

C      COMPUTE THE CHARACTER NUMBER
      IWD = (P(1)-XMIN)*XFAC+1.5
C      COMPUTE THE LINE NUMBER - ONE
      JLN = FLOAT((NLIN-IFIX((P(2)-YMIN)*YFAC)))/.5
C      CHECK TO SEE IF WE ARE WITHIN PRESCRIBED LIMITS
      IF ((IWD.LE.0).OR.(JLN.LT.0).OR.(IWD.GT.LSZ).OR.(JLN.GT.NLIN)) RET
10RN
C      COMPUTE THE WORD NUMBER
      J = 1+(IWD+JLN*LSZ)/NCH
C      COMPUTE THE CHARACTER NUMBER
      KCH = 1+MOD(IWD,NCH)
C      REPLACE THE CHARACTER BY L
C      ****NON-ANSI - SEE WRITEUP AT END****
      UNCODE (NCH,10,PG(J)) (IJ(K),K = 1,NCH)
      IJ(KCH) = L
C      ****NON-ANSI - SEE WRITEUP AT END****
      ENCODE (NCH,10,PG(J)) (IJ(K),K = 1,NCH)
      RETURN
10  FORMAT (10A1)
      END

```

```

      SUBROUTINE PNAXIS (P)
C      DRAW AXES THROUGH THE POINT P
C      THE X-AXIS WILL CONSIST OF ---+-- WHERE THE + APPEARS EVERY 10
C      CHARACTERS ON THE LINE
C      THE Y-AXIS CONSISTS OF + EVERY FIVE LINES FROM THE POINT P
      INTEGER HP,H5
      DIMENSION P(2), PT(2)
      COMMON /J/ PG(403),XMIN,YMIN,XFAC,YFAC,NCH,LSZ,NLIN,IWD,JLV,KCH
C      SEE SUBROUTINE PN FOR THE MEANING OF THE ELEMENTS IN THIS BLOCK
C      SET THE GRAPH TO ALL BLANKS
      DATA HB,HP,HM/1M,1M+.1M+/
      II = NLIN*LSZ/NCH
      DO 10 J = 1,II
10  PG(J) = HB
      H1 = 1./XFAC
      CALL PN (P,HP)
      II = IWD
      PT(2) = P(2)
C      DO X-AXIS
      LS = LSZ-1
      DO 20 J = 1,LS
      PT(1) = XMIN+FLOAT(J-1)*H1
      L = H5
      IF (MOD(J-II,10).EQ.0) L = HP
20  CALL PN (PT,L)
C      DO Y-AXIS
      H1 = 1./YFAC
      II = 1+NLIN-JLV
      PT(1) = P(1)
      DO 30 J = 1,NLIN
      IF (MOD(J-II,5).NE.0) GO TO 30

```

```

      THETAH= RTH0/RTH
      THT = THETAH
      THETA(L) = THETAH
30  FC = 1.0+.066*THSQ-.008*TH*THSQ
      FK = 1.-.134*THSQ+.027*THSQ*TH
C    UU AT MOST 200 ITERATIONS
      UU 140 J = 1.200
      RTAU= 1./(FC*(2.4711*ALOG(FR*RTH*THETAH)+4.75)+1.5*GE+1724./
1    (GE*GE+200.))-16.87)
      IAU = RTAU*RTAU
      HB = 1./(1.+GE*RTAU)
      HH = (HB+1.)*(1+.178*THSQ)-1.
      SEP = -THETAH*UQUS
      PIE= HH*SEP/IAU
      PIE= AMAX1(PIMIN,AMIN1(PIMAX,PIE))
      G = 6.1*SQRT(PIE+1.81)-1.7
      I2 = ABS(G-GE)/GE
      GE = G
      U12 = 01
      U1 = (HH+2.-THSQ)*SEP+IAU
      IF (J.EQ.1) GO TO 110
      I1 = ABS((01-U12)/U1)
      IF ((I1.L1,TE2).AND.(I2.L1,TE1)) GO TO 130
110  THETAH= THT+.5*U1*US
140  CONTINUE
130  THETA(LP) = U1*US+THT
      THETAH = THETA(LP)
      THT = THETA(LP)
      H(L) = (H(L)*US+H4*USOLU)/(US+USOLU)
      H(LP) = HH
      USOLU = US
      L = LP
      IF (L.NE.K2) GO TO 10
      H(K2) = 2.*H(K2)-H(K2-INC)
      H(K1) = 0.
      RETURN
      END

```

```

      SUBROUTINE PN (P,L)
C    PUT CHARACTER L INTO ROW AND COLUMN DETERMINED BY POSITION P
      DIMENSION P(2), IJ(10)
      COMMON /J/ PG(403),XMIN,YMIN,XFAC,YFAC,NCH,LSZ,NLIN,IWD,JLV,KCH
C    XMIN,YMIN IS THE LOWER LEFT HAND CORNER OF THE GRAPH
C    XFAC,YFAC ARE THE SCALING INCREMENTS FOR X AND Y
C    NCH IS THE NUMBER OF CHARACTERS IN A MACHINE WORD.10 FOR CDC 6600
C    LSZ IS THE NUMBER OF CHARACTERS WHICH WILL COMPRISE A PRINT LINE
C    NLIN IS THE NUMBER OF LINES THE GRAPH WILL HAVE
C    THE CHARACTER L WILL APPEAR IN THE IWD WORD ON LINE JLV
C    KCH IS THE NUMBER OF THE CHARACTER WITHIN THE WORD WHICH WILL BE
C    REPLACED BY THE THE CHARACTER CONTAINED IN L
C    THE DIMENSION OF PG MUST BE NLIN*LSZ/NCH
C    SEE BLOCK DATA FOR THE DEFINITION OF ELEMENTS IN THIS BLOCK

```

```

      SEP = -THETA(L)*DQDS
      WRITE (N4,710) XREAL(L),YREAL(L),ANG,KAPPA(L),MACHN(L)
1   ,THETA(L),SEP,XS,YS
120 LC = LC+1
      IF (LC,LE,55) GO TO 130
      LC = 4
      WRITE (N4,200)
      WRITE (N4,700)
130 CONTINUE
      RETURN
200 FORMAT (1H1//)
690 FORMAT(13X,45HCOORDINATES FROM LOWER SURFACE TAIL TO UPPER
1,12HSURFACE TAIL /)
700 FORMAT ( 9X,1HX,8X,1HY,6X,3HANG,6X,1HX,7X,1HM,5X,5HTHETA,5X,
1 3HSEP,7X,2HXS,7X,2HYS//)
710 FORMAT (F11.5,F9.5,F9.1,F7.2,F8.4,4F9.5)
720 FORMAT (F11.5,F9.5,F9.1,F7.2,F8.4,4X,A10,4X,2F9.5)
      END

```

```

C   SUBROUTINE NASHMC (K1,K2)
      COMPUTE THE BOUNDRY LAYER FROM POINT K1 TO K2
      COMMON /A/ GAMMA,MACH
      COMPLEX X1,XIBODY,CHAR
      REAL MACHN,KAPPA
      COMMON X1(200),UREAL(200),VREAL(200),XREAL(200),YREAL(200),PSI(
1  200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2  CHAR(41,10),ICLINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3  ,THETA(200),M(200)
      REAL MACHA,MACHB,MTAIL
      COMMON /K/ RN,PCHJ,PLHL,MACHA,ANGLA,MTAIL,ANGLT,MACHB,ANGLB,RL
1  ANGLN,IC
      REAL MH,MHSG,NU,MACH
      DATA IR /,3424/, KTH0/320./, IE1/5.E-3/, IE2/5.E-3/, P1MIN
1  /-1.5/, P1MAX/1.E4/
      GAM = (GAMMA-1.)/2.
      GAM1 = 1./(GAMMA-1.)
      CSINF = 1.+GAM*MACH*MACH
      INC = ISIGN(1,K2-K1)
      GE = 6.5
      L = K1
      USOLD = ABS(S(L)-S(L-INC))
10  LP = L+INC
      MH = .5*(MACHN(L)+MACHN(LP))
      MHSG = MH*MH
      CSIH = 1.+GAM*MHSG
      US = ABS(S(LP)-S(L))
      UWDS = (MACHN(LP)-MACHN(L))/(US*MH*CSIH)
      I = CSINF/CSIH
      RHON = 1.*GAM1
      NU = I*(1.+(IR)/(RHON*(1+(IR))))
      RIH = RN*MH/(MACH*NU)
      IF (L,NE,K1) GO TO 30

```

```

      THETA(L) = 0.
      IF (MACHN(L).GT.QMAX) KQMAX = L
      IF (MACHN(L).LT.QMIN) KQMIN = L
      QMIN = AMIN1(MACHN(L),QMIN)
      QMAX = AMAX1(MACHN(L),QMAX)
      DX = XREAL(L)-XREAL(L-1)
      DY = YREAL(L)-YREAL(L-1)
      IF (ANGL(L)-ANGL(L-1).GT.PI/2.) ANGL(L) = ANGL(L)-PI
      DTH = ANGL(L)-ANGL(L-1)
      FAC = 1.
      IF (DTH.NE.0.) FAC = .5*DTH/SIN(.5*DTH)
      DS = FAC*SQRT(DX*DX+DY*DY)
      S(L) = S(L-1)+DS
      KAPPA(L-1) = -DTH/DS
70  CONTINUE
      LTRU = KP+2
      LTRL = -1
      IF (KN.LE.0.) GO TO 105
      L = KQMAX
      IF (PCHU.LT.0.) GO TO 80
      DO 75 L = KQMIN,KP
      IF (XREAL(L).GE.PCHU) GO TO 80
75  CONTINUE
      CALL ABORT
80  XTRANS = XREAL(L)
      LTRU = L
      CALL NASHMC (L,KP)
      IF (PCHL.GT.0.) XTRANS = PCHL
      DO 90 L = 1,KQMIN
      IF (XREAL(L).LE.XTRANS) GO TO 100
90  CONTINUE
      IF (KN.NE.0.) CALL ABORT
100 LTRL = L
      CALL NASHMC(LTRL,1)
105 WRITE (N4,690)
      WRITE (N4,700)
      LC = .15
      INC = 1
      DO 130 L = 1,KP
      ANG = RAD*ANGL(L)
      IF (IPL.GT.1) CALL CSYMBL(CMPLX(XREAL(L),YREAL(L)),15,-1)
      UELS = THETA(L)*H(L)
      XS = XREAL(L)+UELS*SIN(ANGL(L))
      YS = YREAL(L)+UELS*COS(ANGL(L))
      IF ((L.LT.LTRL).OR.(L.GT.LTRU)) GO TO 110
      MSG = 1H
      IF (MACHN(L).LT.TOL) MSG = 10HSTAGNATION
      IF ((L.EQ.LTRL+1).OR.(L.EQ.LTRU-1)) MSG = 10HTRANSITION
      WRITE (N4,720) XREAL(L),YREAL(L),ANG,KAPPA(L),MACHN(L),MSG,XS,YS
      INC = -1
      GO TO 120
110 CONTINUE
      LP = L+INC
      CSI = 1.+GAM*MACHN(L)*MACHN(L)
      UODS = (MACHN(L)-MACHN(LP))/(CSI*MACHN(L)*ABS(S(L)-S(LP)))

```

```

SUBROUTINE LINES (K1,K2)
COMMON ARRAY(1)
COMPLEX ARRAY
CALL CPLOT (ARRAY(K1),3)
KP = K1+1
DO 10 J = KP,K2
10 CALL CPLOT (ARRAY(J),2)
RETURN
END

```

```

SUBROUTINE POINTS (K1,K2)
COMMON ARRAY(1)
COMPLEX ARRAY
DO 20 J = K1,K2
20 CALL CSYMBL (ARRAY(J),26,-1)
RETURN
END

```

```

SUBROUTINE OUTPT (KP)
REAL MACH
COMMON /A/ GAMMA,MACH
COMPLEX XI,XIBODY,CHAR
REAL MACHN,KAPPA
COMMON XI(200),UREAL(200),VREAL(200),XREAL(200),YREAL(200),PSI(
1 200),XIBODY(200),UBODY(200),VBODY(200),XBODY(200),YBODY(200),
2 CHAR(41,10),ILINE(200),S(200),MACHN(200),KAPPA(200),ANGL(200)
3 ,THETA(200),H(200)
COMMON /D/ PI,AA,MKP,NRN,VX,NCR,LBM,IPLT,MODE,NB,NC,NA,11,JJ,KK
COMMON/G/ N1,N2,N6,N7,N3,V4,M1
COMPLEX XI1AIL,BP,POLE,X1A,X1B,X1C
COMMON /H/ BP(10),POLE,X1A,X1B,X1C,X1TAIL,PLISIZ,NBPS
COMMON /I/ SF,SIZE,ANG,XMAX,YMAX,XUR,YUR,PSSIZ
REAL MACHA,MACHB,MTAIL
COMMON /K/ RN,PCHJ,PCHL,MACHA,ANGLA,MTAIL,ANGLT,MACHB,ANGLB,KC,
1 ANGLN,IR
IPL = MOD(IPLT/10,10)
RAD = 180./PI
TOL = 1.E-5
GAM = .5*(GAMMA-1.)
KUMIN = 1
KUMAX = 1
UMIN = MACHN(1)
UMAX = GMIN
H(1) = 0.
THETA(1) = 0.
S(1) = 0.
KAPPA(KP) = 0.
DO 70 L = 2,KP
H(L) = 0.

```

```

20 CONTINUE
25 MODL = 0
   IF (K2.LE.5) RETURN
   DO 30 J = 1,99
   CALL GTPATH(NC+1,NN,K2)
   IF (MODL.EQ.99) RETURN
   IF (KK.GI.0) GO TO 50
C   SUBSONIC PATH
   CALL LINES (NC,NN)
   IF (KK.EQ.0) GO TO 30
C   THIS PATH HAS -KK FORKS
   NFORKS = -KK
   DO 40 K = 1,NFORKS
   CALL GTPATH(NN+1,VF,K2)
   CALL LINES(NN,VF)
40 CONTINUE
   GO TO 30
50 CONTINUE
   IF (KK.EQ.2) CALL XXPTS (NC,NN)
   IF (K2.NE.8) CALL LINES (NC,NN)
   CALL GTPATH(NC+1,VN,K2)
   IF (KK.EQ.2) CALL XXPTS (NC,NN)
   IF (K2.NE.8) CALL LINES (NC,NN)
30 CONTINUE
60 FORMAT(1H1/35X,14H1APE 6: PATH U /)
70 FORMAT (1H0//35X16H10FORMATION PATHS/)
   RETURN
   END

```

```

SUBROUTINE XXPTS (K1,K2)
REAL MACH
COMMON /A/ GAMMA,MACH
COMPLEX ARRAY,XIOPS,SOFX1, S,SCRIT
COMMON ARRAY(1)
LOGICAL ISW
DATA ISW /.FALSE./
IF (ISW) GO TO 5
ISW = .TRUE.
QCRIT = (GAMMA-1.)/(GAMMA+1.) + 2./((GAMMA+1.)*MACH*MACH)
CALL GETMSQ (CMPLX(QCRIT,0.),SCRIT,S)
CONST = REAL(SCRIT)
5 ARRAY(K2+1) = ARRAY(K2)
L = K2
10 ARRAY(L) = XIOPS(CONJG(CONST/SOFX1(ARRAY(L))),ARRAY(L+1))
L = L+1
IF (L.GE.K1) GO TO 10
RETURN
END

```



```

X1 = CMPLX(LOGS(3,J),LOGS(4,J))
ANG = RAD*ATAN2(AIMAG(X1),REAL(X1))
CALL CSYMBL (X1,4,-1)
X1 = X1*(1+.05/CABS(X1))
SIZE = .35
CALL CSYMBL (X1,20,-1)
SIZE = .14
40 CONTINUE
42 ANG = 0.
SCF = SF
SF = 1.
IF (NRN.GE.0) GO TO 55
CALL XYAXES ((0.,0.),3.5,3.5,SF1,0.)
CALL XYAXES ((0.,0.),2.0,3.5,SF1,90.)
CALL CSYMBL ((-3.0,-3.5),TITLE,60)
GO TO 58
55 CALL XYAXES((0.,0.),6.5,3.5,SF1,0.)
CALL XYAXES((0.,0.),4.,4.,SF1,90.)
CALL CSYMBL ((-4.0,5.5),TITLE,60)
58 SF = SCF
SIZE = .07
IF (IPL.GE.1) CALL PLPATH(2+MAX0(0,NP),IPL+2)
SIZE = .07
RETURN
END

```

```

SUBROUTINE PLPATH(K1,K2)
COMMON /D/ P1,AA,MRP,NRV,VX,NCR,LBM,IPLT,MODE,NB,NC,VN,II,JJ,KK
COMMON/G/ N1,N2,N6,N7,N3,V4,M1
REWIND N6
IF (K2.EQ.2) WRITE (N4,60)
MODE = 1
CALL GTPATH (NC+1,NN,K2)
IF (MODE.EQ.99) RETURN
IF (K2.GE.5) CALL LINES (VC,NN)
MODE = 2
CALL GTPATH (NC+1,NN,K2)
IF (MODE.EQ.99) RETURN
IF (K2.GE.5) CALL LINES (VC,NN)
IF (K2.GI.2) CALL POINTS (NN,NN)
IF (K2.EQ.3) RETURN
IF (K1.LE.2) GO TO 25
IF (K2.EQ.2) WRITE (N4,70)
DO 20 MODE = 3,41
CALL GTPATH (NC+1,NN,K2)
IF (MODE.EQ.99) RETURN
IF ((K2.EQ.4).OR.(K2.EQ.7)) CALL POINTS (JJ,NN)
IF ((K2.EQ.5).OR.(K2.GE.8)) CALL LINES (VC,NN)
IF (KK.LE.0) GO TO 20
CALL GTPATH(NC+1,VN,K2)
IF ((K2.EQ.4).OR.(K2.EQ.7)) CALL POINTS (JJ,NN)
IF ((K2.EQ.5).OR.(K2.GE.8)) CALL LINES (VC,NN)

```

```

COMMON /1/ SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PGS12
COMMON /11/ TITLE(8)
DIMENSION CONL(20),TEMP(61)
EXTERNAL CSORT,SOFXI
GAM = (GAMMA-1.)/2.
COSQ = GAM+ 1./(MACH*MACH)
COMX = AMIN1(COSQ,3.)
RAD = 180./PI
IND = 1
SF = 1.
SF1 = PLTSIZ/5.
CALL ORIGIN (0.,.5)
XIMIN = (-7.0,-4.0)*SF1
XIMAX = (4.0,5.0)*SF1
IX = 44
JX = 36
XSZ = 11.0
YSZ = 9.0
IF (NRN.GE.0) GO TO 6
CALL ORIGIN (2.25,4.0)
SF1 = SF1+SF1
XIMIN = (-3.75,-2.0)*SF1
XIMAX = (3.75,3.5)*SF1
JX = 44
IX = 60
XSZ = 7.50
YSZ = 5.5
6 IF (IPL.GE.6) IND = 20
DO 10 J = 1,IND
  EMX = FLDA1(IND+1-J)/FLDA1(IND)
  XI = COMX*EMX*EMX/(1.+GAM*EMX*EMX)
  CALL GETHSQ(XI,S,HSQPR)
10 CONL(IND+1-J) = REAL(S)
  CALL CONIUR (IX,JX,IND,XSZ,YSZ,SOFXI,CUWL,TEMP,XIMIN,XIMAX)
  SF = 1./SF1
  CALL ORIGIN (7.0,4.5)
  IF (NRN.GE.0) GO TO 5
  CALL ORIGIN (6.0,6.0)
5 CALL CSYMBL (XIA,11,-1)
  CALL CSYMBL (XIB,11,-1)
  CALL CSYMBL(XIC,12,-1)
  CALL CPLOT(XIL,3)
  CALL CPLOT(XIB,2)
  CALL CPLOT (XIA,2)
  XIO = XIOFS((0.,0.),(-1.,0.))
  CALL CSYMBL (XIO,63,-1)
  DO 30 J = 1,NBPS
30 CALL CSYMBL(OP(J),1,-1)
  IF ((REAL(POLE).EQ.0.).AND.(AIMAG(POLE).EQ.0.)) GO TO 35
  RPOLE = REAL(POLE)
  IF ((RPOLE.LE.REAL(XIMIN)).OR.(RPOLE.GE.REAL(XIMAX))) GO TO 35
C PLOT THE LOCATION OF THE POLE
  CALL SYMBOL (POLE,5,-1)
35 IF (NLOGS.EQ.0) GO TO 42
  DO 40 J = 1,NLOGS

```

```

SUBROUTINE ORIGIN(X,Y)
COMMON /1/ SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PGSIZ
XOR = X
YOR = Y
RETURN
ENTRY FRAMEA
XOR = 0.
YOR = 0.
CALL PLOT (PGSIZ,0.,-3)
RETURN
END

```

```

SUBROUTINE XAXES (X,BOT,TOP,SCF,ANGL)
C X IS THE LOCATION OF THE ORIGIN ON THE AXIS
C BOT IS THE LENGTH OF THE AXIS TO THE LEFT OF THE ORIGIN
C TOP IS THE LENGTH TO THE RIGHT OF THE ORIGIN
COMPLEX ZB,ZI,H,COR
COMMON /1/ SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PGSIZ
DIMENSION X(2), Y(2)
ANG0 = ANG
SFO = SF
SIZ0 = SIZE
Y(1) = XOR
Y(2) = YOR
ANG = 0.
SF = 1.
SIZE = .14
XOR = X(1)+XOR
YOR = X(2)+YOR
ZB = CMPLX(-BOT,0.)
ZI = CMPLX(TOP,0.)
COR = (-.25,+.3)
NC = 16
IF (ABS(ANGL).NE.90.) GO TO 10
C VERTICAL Y-AXIS
ZB = (0,+.1.)*ZB
ZI = (0,+.1.)*ZI
COR = (-.6,0.)
NC = 15
C DRAW LINE FOR THE AXIS
10 CALL LPLOT (ZI,3)
CALL CPUT (ZB,2)
L = TOP
K = BOT
N = 1+K+L
S = -FLOAT(K)*SCF
H = ZI/TOP
ZB = -FLOAT(K)*H
ZI = ZB+LOR
DO 20 I = 1,N
C DRAW HATCH MARK
CALL CSYMBL (ZB,NC,-1)

```

```

      B = S+FLOAT(I-1)*SIF
      ***NON-ANSI = SEE WRITEUP AT E40***
      ENCODE (10,30,A) B
C     LABEL AXIS
      CALL CSYMBL (Z1,A,4)
      ZB = ZB+H
20    ZI = ZI+H
      SF = SFO
      SIZE = SIZO
      ANG = ANGO
      XJR = Y(1)
      YJR = Y(2)
      RETURN
50    FORMAT (F4.1)
      END

```

```

C     SUBROUTINE CONTOUR (M,N,NC,XS,YS,FN,CONL,TEMP,XIMIN,XIMAX)
C     M IS THE NUMBER OF SUBDIVISIONS IN THE X DIRECTION
C     N IS THE NUMBER OF SUBDIVISIONS IN THE Y DIRECTION
C     XS IS THE X-JOIN OF THE PLOTTED AREA
C     YS IS THE HIGH OF THE PLOTTED AREA
C     IABS(NC) IS THE NUMBER OF CONTOUR CURVES, NC NEGATIVE DRAWS A BOX
C     AROUND THE PLOTTED AREA
C     FN IS THE COMPLEX FUNCTION WHOSE ABSOLUTE SQUARED IS TO BE PLOTTED
C     XIMIN AND XIMAX ARE VALUES OF XI AT LOWER LEFT AND UPPER RIGHT
C     CONL IS AN ARRAY OF CONTOUR LEVELS IN INCREASING ORDER
C     TEMP IS A TEMPORARY ARRY OF LENGTH M
      COMPLEX FN,M,XIMIN,XIMAX
      DIMENSION (CONL(1),TEMP(1))
      RDX1 = (REAL(XIMAX)-REAL(XIMIN))/FLOAT(M)
      ADX1 = (AIMAG(XIMAX)-AIMAG(XIMIN))/FLOAT(M)
      DX = XS/FLOAT(M)
      DY = YS/FLOAT(N)
      NCL = IABS(NC)
      MP = N+1
      DO 10 I = 1,MP
        W = FN(XIMIN+FLOAT(I-1)*RDX1)
10    TEMP(I) = REAL(W)*REAL(W) + AIMAG(W)*AIMAG(W)
        YP = 0.
        DO 400 J = 1,N
          XP = 0.
          W = FN(XIMIN+CMPLX(0.,FLOAT(J)*ADY1))
          IP = REAL(W)*REAL(W) + AIMAG(W)*AIMAG(W)
          YPP = YP+DY
          DO 360 L = 1,M
            XPP = XP+DX
            W = FN(XIMIN+CMPLX(FLOAT(L)*RDX1,FLOAT(J)*ADY1))
            LP = REAL(W)*REAL(W) + AIMAG(W)*AIMAG(W)
            IUP = AMAX1(IP,FM,TEMP(I),TEMP(I+1))
            IOT = AMIN1(IP,FM,TEMP(I),TEMP(I+1))
            IF (CONL(NCL),L1,301) GO TO 350
          DO 40 L1 = 1,NCL

```

```

      IF (CONL(L1).GT.TOP) GO TO 50
40  CONTINUE
      GO TO 350
50  DO 340 L = L1,NCL
      IF (CONL(L).GT.TOP) GO TO 350
C    A= LOWER LEFT    B=LOWER RIGHT    C=UPPER LEFT    D=UPPER RIGHT
      A = TEMP(1)-CONL(L)
      B = TEMP(1+1)-CONL(L)
      C = 14-CONL(L)
      D = 14-CONL(L)
C    FORM ITYP BY LOOKING AT THE SIGNS AT THE FOUR CORNERS
      IA = ISIGN(1,A)
      IB = ISIGN(2,B)
      IC = ISIGN(4,C)
      ID = ISIGN(8,D)
      ITYP = B+(1A+1B+1C+1D+1)/2
      GO TO (340,220,230,240,250,260,270,280,290,270,260,250,240,230,
1    220,340) ITYP
C    SIGN OF A IS DIFFERENT FROM B,C AND D
220  X1 = XP
      Y1 = YP+DY*A/(A-C)
      X2 = XP+DX*A/(A-D)
      Y2 = YP
      GO TO 300
C    SIGN OF B IS DIFFERENT FROM A,C AND D
230  X1 = XP+DX*B/(A-B)
      Y1 = YP
      X2 = XPP
      Y2 = YP+DY*B/(B-D)
      GO TO 300
C    SIGN OF A AND B IS DIFFERENT THAN SIGN OF C AND D
240  X1 = XP
      Y1 = YP+DY*A/(A-C)
      X2 = XPP
      Y2 = YP+DY*B/(B-D)
      GO TO 300
C    SIGN OF C IS DIFFERENT FROM A,B AND D
250  X1 = XP
      Y1 = YP+DY*A/(A-C)
      X2 = XP+DX*C/(C-D)
      Y2 = YPP
      GO TO 300
C    SIGN OF A AND C IS DIFFERENT THAN SIGN OF B AND D
260  X1 = XP+DX*A/(A-B)
      Y1 = YP
      X2 = XP+DX*C/(C-D)
      Y2 = YPP
      GO TO 300
270  IHD = 1
      GO TO 340
C    SIGN OF D IS DIFFERENT FROM A,B AND C
280  X1 = XP+DX*C/(C-D)
      Y1 = YPP
      X2 = XPP
      Y2 = YP+DY*B/(B-D)

```

```

300 CALL CPLOT (CMPLX(X1,Y1),3)
    CALL CPLOT (CMPLX(X2,Y2),2)
340 CONTINUE
350 TEMP(1) = TM
    XP = XPP
    IM = IP
360 CONTINUE
    TEMP(M+1) = TP
    YP = YPP
400 CONTINUE
    RETURN
END

```

```

C      COMPLEX FUNCTION CSQRT(Z,BRANCH)
C      COMPUTES THE COMPLEX SQUARE ROOT OF Z AND CHOOSES THE BRANCH
C      THE CUT OF THE SQUARE ROOT IS A STRAIGHT LINE FROM THE
C      ORIGIN PASSING THROUGH C+BRANCH
    DIMENSION Z(2),BRANCH(2)
    REAL IMAGZ
    REALZ = Z(1)
    IMAGZ = Z(2)
    R = REALZ*REALZ+IMAGZ*IMAGZ
    Q = 0.
    IF (R.EQ.0.) GO TO 40
    Q = SQRT(.5*(SQRT(R)+ABS(REALZ)))
    IF (REALZ.GE.0.) GO TO 10
    R = Q
    Q = .5+IMAGZ/R
    GO TO 20
10 R = .5+IMAGZ/Q
20 IF (Q*BRANCH(1)+R*BRANCH(2)) 30,40,40
30 CSQRT = CMPLX(-Q,-R)
    RETURN
40 CSQRT = CMPLX(Q,R)
    RETURN
END

```

```

C      SUBROUTINE LEQ (A,B,NEQS,NSOLNS,IA,IB,DET)
C      LINEAR EQUATIONS SOLUTIONS WRITTEN AT AEC COMPUTING CENTER (NYU)
C      SOLVE A SYSTEM OF LINEAR EQUATIONS OF THE FORM AX=B BY A MODIFIED
C      GAUSS ELIMINATION SCHEME
C      NEQS = NUMBER OF EQUATIONS AND UNKNOWN
C      NSOLNS = NUMBER OF VECTOR SOLUTIONS DESIRED
C      IA = NUMBER OF ROWS OF A AS DEFINED BY DIMENSION STATEMENT ENTRY
C      IB = NUMBER OF ROWS OF B AS DEFINED BY DIMENSION STATEMENT ENTRY
C      ADET = DETERMINANT OF A, AFTER EXIT FROM LEQ
    DIMENSION A(IA,IA), B(IB,IB)
    NSIZ = NEQS
    NBSIZ = NSOLNS

```

```

C      NORMALIZE EACH ROW BY ITS LARGEST ELEMENT
C      FORM PARTIAL DETERMINANT
      DET = 1.0
      DO 40 I = 1, NSIZ
      BIG = A(I,1)
      IF (NSIZ.EQ.1) GO TO 130
      DO 10 J = 2, NSIZ
      IF (ABS(BIG).GE.ABS(A(I,J))) GO TO 10
      BIG = A(I,J)
10  CONTINUE
      BG = 1.0/BIG
      DO 20 J = 1, NSIZ
20  A(I,J) = A(I,J)*BG
      DO 30 J = 1, NBSIZ
30  B(I,J) = B(I,J)*BG
      DET = DET*BIG
40  CONTINUE
C      START SYSTEM REDUCTION
      NUMSYS = NSIZ-1
      DO 120 I = 1, NUMSYS
C      SCAN FIRST COLUMN OF CURRENT SYSTEM FOR LARGEST ELEMENT
C      CALL THE ROW CONTAINING THIS ELEMENT, ROW NBGRW
      NN = I+1
      BIG = A(I,I)
      NBGRW = 1
      DO 50 J = NN, NSIZ
      IF (ABS(BIG).GE.ABS(A(J,I))) GO TO 50
      BIG = A(J,I)
      NBGRW = J
50  CONTINUE
      BG = 1.0/BIG
C      SWAP ROW I WITH ROW NBGRW UNLESS I=NBGRW
      IF (NBGRW.EQ.I) GO TO 80
C      SWAP A-MATRIX ROWS
      DO 60 J = 1, NSIZ
      TEMP = A(NBGRW,J)
      A(NBGRW,J) = A(I,J)
60  A(I,J) = TEMP
      DET = -DET
C      SWAP B-MATRIX ROWS
      DO 70 J = 1, NBSIZ
      TEMP = B(NBGRW,J)
      B(NBGRW,J) = B(I,J)
70  B(I,J) = TEMP
C      ELIMINATE UNKNOWN FROM FIRST COLUMN OF CURRENT SYSTEM
80  DO 110 K = NN, NSIZ
C      COMPUTE PIVOTAL MULTIPLIER
      PMULT = -A(K,I)*BG
      IF (PMULT.EQ.0.) GO TO 110
C      APPLY PMULT TO ALL COLUMNS OF THE CURRENT A-MATRIX ROW
      DO 90 J = NN, NSIZ
90  A(K,J) = PMULT*A(I,J)+A(K,J)
C      APPLY PMULT TO ALL COLUMNS OF MATRIX B
      DO 100 L = 1, NBSIZ
100 B(K,L) = PMULT*B(I,L)+B(K,L)

```

```

110 CONTINUE
120 CONTINUE
    DO 3ACK SUBSTITUTION WITH B-MATRIX COLUMN = NCOLB
130 DO 170 NCOLB = 1, VBSIZ
C   DO FOR ROW = NROW
    DO 160 I = 1, VSIZ
        NROW = NSIZ+1-I
        TEMP = 0.0
C   NUMBER OF PREVIOUSLY COMPUTED UNKNOWN = VXS
        NXS = NSIZ-VROW
C   ARE WE DOING THE BOTTOM ROW
        IF (NXS.EQ.0) GO TO 150
        DO 140 K = 1, NXS
            KK = NSIZ+1-K
140     TEMP = TEMP+B(KK,NCOLB)*A(NROW,KK)
150     B(NROW,NCOLB) = (B(NROW,NCOLB)-TEMP)/A(NROW,NROW)
C   HAVE WE FINISHED ALL ROWS FOR B-MATRIX COLUMN = NCOLB
160 CONTINUE
C   HAVE WE JUST FINISHED WITH B-MATRIX COLUMN NCOLB=NSIZ
170 CONTINUE
C   NOW FINISH COMPUTING THE DETERMINANT
    DO 180 I = 1, NSIZ
180     DET = DET*A(I,I)
    RETURN
END

```

BLOCK DATA

```

COMMON/6/ N1,N2,N6,N7,N3,V4,M1
COMMON /1/ SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PGSIZ
COMMON /J/ PG(403),XMIN,YMIN,XFAC,YFAC,NC1,LSZ,NLIN,INU,JLV,KCH
DATA N1,N2,N3,V4,V6,N7/1,2,3,4,6,7/
C   ***CHANGE NCH TO 4 FOR IBM360***
C   ***CHANGE LSZ TO 120 ON IBM 360***
DATA XMIN,YMIN,XFAC,YFAC,NCH,LSZ,NLIN/-1.2,-.6,50.,25.,10.,130,31/
DATA SF,SIZE,ANG,XMAX,YMAX,XOR,YOR,PGSIZ/5.0,.14,0.,11.,11.,0.,0.,
1 12.00/
END

```

```

C   *****WRITEUP FOR ENCODE-DECODE STATEMENTS*****
C   ENCODE/DECODE STATEMENTS
C   ENCODE IS SIMILAR TO A FORMATTED WRITE STATEMENT
C   DECODE IS SIMILAR TO A FORMATTED READ STATEMENT
C   NO TAPES ARE ACTUALLY INVOLVED SINCE THE TRANSFERS TAKE PLACE
C   WITHIN CORE
C   THE FIRST ARGUMENT IS THE NUMBER OF CHARACTERS TO BE READ OR

```


C WRITTEN
 C THE SECOND ARGUMENT IS THE FORMAT NUMBER
 C THE THIRD ARGUMENT IS THE ADDRESS TO WHICH OR FROM WHICH THE
 C I/O LIST WILL BE WRITTEN OR READ
 C A MORE DETAILED DESCRIPTION CAN BE FOUND IN THE FOLLOWING MANUAL
 C CONTROL DATA 6400/6500/6600 COMPUTER SYSTEMS FORTRAN REFERENCE
 C MANUAL, SECTION 10.6(ENCODE/DECODE STATEMENTS), PAGES 13-17 (1969)

C *****WRITEUP FOR CALCOMP ROUTINES*****

C SYMBOL

C SUBROUTINE TO WRITE MESSAGES AND SPECIAL CHARACTERS ON THE
 C GRAPHIC OUTPUT.

C USAGE

C CALL SYMBOL(X,Y,H,TEXT,ANGLE,NCHAR)

C WHERE

C X,Y ARE THE COORDINATES ON THE GRAPH PAPER OF THE FIRST
 C CHARACTER OF THE MESSAGE. IF NCHAR IS POSITIVE, THE
 C PEN STARTS AT THE LOWER LEFT CORNER OF THE FIRST
 C CHARACTER. IF NCHAR IS NEGATIVE, THE PEN STARTS
 C AT THE CENTER OF THE FIRST CHARACTER.

C H IS THE HEIGHT OF A CHARACTER IN (REAL NUMBER) INCHES.
 C CHARACTERS FROM THE BI-OCTAL EQUIVALENCE TABLE
 C ARE 4/7 AS WIDE AS THEY ARE HIGH. THE SPACE
 C BETWEEN CHARACTERS IS 2/7 THAT OF THEIR HEIGHT.
 C THUS, THE TOTAL SPACE REQUIRED FOR N CHARACTERS
 C EQUALS (6/7)*(H)*(N).

C AS THE CHARACTERS ARE STORED IN A 7 BY 4 MATRIX,
 C AN INTEGER MULTIPLE OF .07 INCHES GIVES THE BEST
 C RESOLUTION.

C TEXT IS THE MESSAGE USED IF NCHAR IS POSITIVE OR ZERO
 C (A HULLERITH CONSTANT -- NH MESSAGE). OR
 C IS ONE SYMBOL TAKEN FROM THE INTEGER EQUIVALENCE
 C TABLE IF NCHAR IS NEGATIVE. (SEE BELOW)

C ANGLE IS THE ANGLE AT WHICH THE LINE OF CHARACTERS IS DRAWN
 C IN DEGREES

C NCHAR > 0 GIVES THE INTEGER NUMBER OF CHARACTERS IN TEXT TO BE
 C WRITTEN

C = 0 WRITES CHARACTERS IN TEXT UNTIL A 0 CHARACTER IS
 C ENCOUNTERED

C < 0 ONLY ONE CHARACTER IS PRINTED, THE CHARACTER BEING
 C TAKEN FROM THE INTEGER EQUIVALENCE SYMBOL TABLE.

C THE FOLLOWING INTEGER EQUIVALENCES ARE USED

C INTEGER 1 DRAWS AN OCTAGON

C INTEGER 3 DRAWS A +

C INTEGER 4 DRAWS AN X

C INTEGER 5 DRAWS A DIAMOND SHAPE

C INTEGER 11 DRAWS A *

C INTEGER 12 DRAWS AN X WITH BARS ABOVE AND BELOW IT

C INTEGER 15 DRAWS A -

C INTEGER 16 DRAWS A VERTICAL LINE

C INTEGER 20 DRAWS AN ARROW POINTING TO THE RIGHT

C INTEGER 25 DRAWS AN O

```

C          INTEGER 63 DRAWS A PLUS WITH A BOX AROUND IT
C
C      PLOT
C      SUBROUTINE TO MOVE PEN ON PLOTTER.
C      PURPOSE
C      A) CREATE AN ORIGIN
C      B) POSITION THE PEN AND DO THE DRAWING
C      C) TERMINATE THE USE OF THE PLOT PACKAGE.
C      PLOT IS CALLED BY ALL ROUTINES THAT DO GRAPHIC WRITING.
C      USAGE
C      CALL PLOT(X,Y,IPEV)
C      X,Y      THE PEN IS MOVED FROM ITS PRESENT COORDINATES TO
C               THE COORDINATES (X,Y) RELATIVE TO THE CURRENT
C               ORIGIN. X AND Y ARE REAL NUMBERS MEASURED IN INCHES.
C      IPEV=1   WHILE MOVING TO (X,Y) THE PEN REMAINS ON OR OFF THE
C               PAPER, AS BEFORE BEING CALLED.
C      =2       THE PEN MARKS THE PAPER WHILE MOVING FROM ITS
C               PRESENT POSITION TO (X,Y)
C      =3       THE PEN DOES NOT MARK THE PAPER WHILE MOVING FROM
C               ITS PRESENT POSITION TO (X,Y)
C      =-1,-2,-3 THE PEN IS MOVED RESPECTIVELY AS FOR +1,+2, OR +3
C               HOWEVER, THE FINAL POSITION OF THE PEN (X,Y)
C               BECOMES THE NEW ORIGIN (0,0).
C      =999     TERMINATES THE PLOT FILE. THE USER MUST CALL THIS
C               AT THE END OF THE PROGRAM IF THE GRAPHIC OUTPUT
C               IS NOT TO BE DESTROYED.

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