A Quasi-Steady Model of Blade/Vortex Interaction

by

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ABSTRACT

A steady state transonic airfoil analysis code has been modified to include the presence of a vortex near the airfoil. The objective was to provide quasi-steady analysis of blade/vortex interaction for studying or predicting impulsive rotor noise. Results of BVI in low speed flows compare well with the results of incompressible methods in both lift coefficients and pressure distributions. In high speed flows, the code breaks down in the fine grid near the center of the vortex because the program does not model a compressible vortex. The code must be altered to correctly model the flow near the center of the vortex before it will be useful in the study of impulsive rotor noise.

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NOMENCLATURE

a	local speed of sound or circle radius (App. D)
c	chord
c_l	lift coefficient
c_p	pressure coefficient
F	complex potential function
k	constant
l	panel length
M	Mach number
q	speed
R	complex variable
r	radius or distance
s	surface coordinate
T	vortex position angle
u	horizontal velocity
V	velocity
v	vertical velocity
W	complex variable
w	relaxation coefficient
x	horizontal flowfield coordinate
y	vertical flowfield coordinate
Z	complex variable
α	angle of attack
β	panel orientation angle
Γ	vortex circulation
γ	circulation density
ϵ	damping coefficient
η	vertical coordinate in computational grid
θ	angle measured from branch cut
λ	source strength
ξ	horizontal coordinate in computational grid
ϕ	potential

Superscripts:

$*$	old value or critical (Fig. 3)
$-$	complex conjugate
$'$	modified

Subscripts:

c	circulatory
i	counter
j	counter
L	lower
n	normal
o	zero-lift
s	streamwise
U	upper
v	vortex
∞	freestream

INTRODUCTION

To produce lift, helicopter blades must have a high pressure region beneath the blade and a region of lower pressure above the blade. This pressure difference causes air to be sucked around the tip of the blade, forming a vortex. The vortices from the blade tips of a forward-moving helicopter form an approximate epicycloid pattern, due to the combination of forward speed and blade rotation, when viewed from above[1]. The vortices convect downward from the disc plane and distort from the epicycloid pattern under the influence of self-induced velocities.

During some flight regimes, a particular blade may pass near the vortex trailing from a previous blade or its own vortex from a previous passage. Such an occurrence of blade/vortex interaction, BVI, is governed by the advance ratio of the rotor and the helicopter's rate of descent[1]. This interaction is negligible if the vortex center is more than 1.5 blade chords from the rotor plane[2]. BVI typically occurs in low-power descending flight and in maneuvers[3].

Surendraiah[2] measured tangential velocities in a straight line vortex and found magnitudes as high as 47% of the freestream velocity. The tangential velocity in the core increases outward exponentially from the center and then decreases inversely proportional to the distance from the vortex center.

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*Style from AIAA Journal.

The vortex passage causes strong, unsteady velocity disturbances which rapidly alter local blade aerodynamics[1]. The disturbances are generally irregular. The induced velocities of the vortex may generate regions of transonic flow on the blade. Transonic flow is characterized by shock waves, strong pressure gradients that decelerate the flow from supersonic to subsonic, that cause acoustic problems due to their motion relative to an observer.

The aerodynamic phenomenon is strongly dependent on the orientation and proximity of the vortex to the blade[3]. The aerodynamic loads fluctuate rapidly, building up faster than they decay. The magnitude of the change in lift coefficient, a nondimensional expression of the lift force, is greatest when the vortex axis is parallel to the blade chord. The rate of change of the lift coefficient is a maximum with the vortex axis about 70 degrees from the chord line of the rotor blade. The rate of change of the lift coefficient is about 75% of its maximum value when the vortex axis is parallel to the blade span[2]. The rate of change of the lift coefficient increases as the blade passes closer to the center of the vortex. After BVI, an azimuth travel of about 50 degrees is required for the flow to return to a normal condition.

BVI is known to be a cause of impulsive rotor noise, or blade slap. This noise is characterized by a distinctive low-frequency nature, high intensity, and crispness and is annoying and undesirable for both military and civilian helicopters[1]. The total sound energy per unit time varies with the square of the time rate of change of the blade loading[2], and the intensity can approach 90 dB[1]. The sharpness of the disturbance increases the annoyance[4]. The acoustic radiation is usually a maximum ahead of the rotor at approximately 30 degrees below the rotor plane[1].

The impulsive rotor noise is similar to a sonic boom. The mechanism responsible has not yet been determined. George[5] suggests that the increased flow velocities during BVI cause shocks to form on the blade. As the vortex passes on by, the shocks move forward on the blade, eventually propagating off the front end of the blade. Schlieren techniques on small, Mach number scaled rotors have shown discrete bow shock waves during BVI[1]. Isom[6] suggests that the disturbances caused by the unsteady loading of the blade are so large that as they propagate, they steepen and break, forming shocks.

To investigate the aerodynamic cause of blade slap, an existing transonic airfoil analysis code, TRANDES[7], has been modified to determine the flow field of blade/vortex interaction. TRANDES incorporates a finite difference solution to the full perturbation potential equation for irrotational, inviscid transonic flow. Second-order central differences are used in regions of subsonic flow and first-order backwards (upwind) differences are used in regions of supersonic flow to reflect the hyperbolic character of the equation for supersonic flow. A rotated finite difference scheme introduced by South and Jameson[8] is used to simulate a local rotation to coordinates along and normal to the local velocity vector. This scheme not only has the correct zone of dependence for the upwind differencing used in regions of supersonic flow, but it also does not require alignment of the computational grid with the flow. In TRANDES, a coordinate transformation maps an infinite flowfield onto a finite computational grid described by Cartesian coordinates[9].

TRANVOR, the modified version of TRANDES, has two primary limitations. First, as in TRANDES, the flow is two-dimensional, so that the axis of the vortex is assumed to be parallel with the blade span. Secondly, the BVI is analyzed with a quasi-steady approach. A series of steady-state solutions for several positions of the vortex along a path are produced. This method may show the build-up of a shock, but it will probably not show the decay.

LTRAN2[10] is an unsteady code that will solve the unsteady aerodynamic problem of BVI. It is a small disturbance code with a correction for flow at the leading edge of the airfoil. The primary drawback of LTRAN2 is the computer time required for a run.

The objective of the development of TRANVOR is to provide a quick, inexpensive method to approximately model BVI and determine if impulsive rotor noise is likely to result for any blade/vortex orientation. If the existence of a BVI problem is determined, the quasi-steady results of TRANVOR might suffice for further analysis, or an appeal to LTRAN2 might be necessary. In any case, the existence of the problem can be signalled cheaply by TRANVOR.

METHOD

The finite difference scheme and the formulation of the boundary conditions in TRANDES were examined to determine the alterations necessary to represent a vortex in the flow field.

The full potential equation in TRANDES is valid for the flow about a vortex, so the form of the finite difference scheme was not altered. The finite difference formulation incorporates a mixture of old and new values for the perturbation potential, providing a tridiagonal system of equations that can be implicitly solved for one column of new potential values at a time as the computational grid is traversed. Additional terms ensure stability and hasten convergence of the system of equations. The various forms of the finite difference equations are given in Appendix A.

The presence of the vortex in the flowfield does not alter the surface boundary condition of the airfoil; the flow must still be tangent to the airfoil surface.

The infinity boundary condition of the vortex is treated identically to the infinity boundary condition of the airfoil. The potential at infinity due to the circulation of the vortex is superimposed onto the potential at infinity due to the circulation of the airfoil. This is depicted for a general case in Figure 1.

The perturbation potential for a vortex is:

$$\phi = \frac{-\Gamma_v \theta}{2\pi} \qquad (1)$$

For the perturbation potential of the flow to satisfy this equation, a branch cut in the potential field is necessary. A difference of potential equal to the strength of the vortex must exist across the branch cut which extends from the vortex center to infinity. The branch cut extends upward from the vortex center if the vortex is above the chordline of the airfoil and downward if the vortex is below the chordline. An example of this cut can be seen in Figure 1. To establish a vortex in the flowfield, this discontinuity of the potential across the cut must be established and maintained in the computational grid. To accomplish this, programming segments were added to TRANDES performing the following tasks:

(1) Input the position and strength of the vortex.
(2) Locate the center of the vortex in the computational grid.
(3) At the infinity boundary, add the potential specified by the boundary conditions of the vortex to the potentials resulting from the airfoil's circulation.
(4) Alter the horizontal difference in potential across the cut so that the velocities and other derivatives of the potential are continuous.
(5) Correct the interpolated values of the potential near the cut when the grid mesh size is halved.

Changes in the program are referenced to the card numbers that occupy columns 73-80 of the original TRANDES code[7]. Line numbers refer to the listing of TRANVOR in Appendix E.

Task 1:

The strength and position of the vortex are entered as nondimensional values through the namelist for real variables. The vortex strength is divided by the freestream velocity and the chord length to nondimensionalize it. A positive vortex strength (VORCIR) will induce clockwise rotation in the flowfield. The position of the vortex is described by a horizontal (XV) and a vertical (YV) distance from the midchord of the airfoil, as shown in Figure 2a. These distances are normalized by the airfoil chord since TRANDES assumes a unit chord. The addition of the variables VORCIR, XV, and YV to the namelist FINP follows card 31. These three variables are placed in a new common block, titled VORTEX, that contains only variables associated with the vortex. This addition follows card 28. The default value of the vortex strength is zero, specified following card 88.

Task 2:

The vortex position in the computational grid is determined in lines 144-154 following card 110. Line 144 checks for the existence of a vortex. Lines 145-148 and 149-152 determine the horizontal and vertical position of the vortex in the computational grid. IVOR is the number of horizontal grid lines below the vortex and JVOR is the number of vertical grid lines to the left of the vortex. The value of the variable IVLOC is determined in lines 153-154. Values of positive or negative one indicate the vortex is located above or below the chordline, respectively. The default vortex strength of zero indicates no vortex is present in the flowfield. Lines 180-181 print the vortex location in the computational grid and its strength.

Task 3:

The boundary conditions at infinity are altered for the circulation of the vortex in the subroutine VORBCI, placed in the code following the original TRANDES subroutines. This subroutine is called in line 299 following card 208. The increment of potential is calculated just like the original values for the airfoil alone, except the circulation is the vortex strength and the potential discontinuity does not extend horizontally from the trailing edge to infinity. The angle in the vortex potential equation is referenced to a line extending from the center of the vortex to infinity.

The potential at the corners of the computational grid are calculated in lines 3174-3177 and lines 3179-3182 for vortices located below and above the airfoil chordline, respectively. The values of the corner potentials are calculated to fall between the potentials on the adjacent sides, though the specific values are not critical to the numerical scheme.

TRANVOR handles angles of attack by rotating the freestream relative to the x-axis, keeping the airfoil chord on the x-axis. the freestream is rotated through the boundary condition at infinity. Since the vortex is located with respect to the airfoil chordline, the angle of attack affects the infinity boundary condition of the vortex in the same manner it affects the infinity boundary conditions of the airfoil. Therefore, the value of the potential at infinity for the vortex is given by equation (2).

$$\emptyset = \frac{-\Gamma_v}{2\pi} \mathrm{Tan}^{-1}\left[\beta \tan(\theta - \alpha)\right] \qquad (2)$$

Lines 3217-3223 and lines 3225-3231 adjust the infinity boundary potentials for vortices below or above the airfoil chordline, respectively, when the angle of attack is zero. In this case, it is easy to see that the boundary at infinity is treated like four sides of a rectangle. At infinity, four positions relative to the airfoil are considered: behind, above, in front of, and below the airfoil. Each of these positions is represented by the corresponding side of a rectangle. The values of the potential at infinity may be assigned by substituting the angle of the direction perpendicular to each side into equation (2). For example, all points on the top side of the rectangle are considered to be an infinite distance above the airfoil and their potential is calculated using 90 degrees as the directional angle. Thus the potential is constant along a side of the rectangle, though each side has a different value. A side intersected by a branch cut is an exception--the potential will have one value before the cut, and another value after the cut. The difference between the segments is the circulation about the airfoil or vortex that is connected to the infinity boundary by the cut.

The cases of positive and negative angles of attack must be treated separately because of the properties of the arctangent function. For a vortex below the chordline, the potentials at infinity are adjusted in lines 3186-3199. Lines 3201-3214 do the same for a vortex above the chordline.

Task4:

In TRANDES, the potential is incremented by the circulation of the airfoil when the branch cut of the airfoil is crossed in a counter-clockwise manner. This convention was repeated in TRANVOR for the potential increment across a cut used to establish a vortex; so that when sweeping from left to right, the vortex circulation is added across the cut for a vortex below the chordline and subtracted across the cut for a vortex above the chordline. This change of sign is the reason the variable IVLOC, which indicates the vortex position relative to the chordline, has a value of positive or negative unity. When horizontal velocities are calculated near the cut, the vortex circulation must either be added to or subtracted from difference equations involving two grid points on opposite sides of the cut to maintain continuity of the horizontal velocity component.

The velocity field is calculated in the main program for the Mach chart and in subroutine SOLVE to determine the flow type and for use in the system of finite difference equations. The velocity correction, found in lines 432-433, 462-463, 482-483, and 1807-1808, is preceded by two statements that determine the necessity of the adjustment. This correction removes the circulation from the potential difference between two points on opposite sides of the cut.

Second derivatives of the potential should also be continuous. The tridiagonal matrix representing the finite difference equations of Appendix A is set up in subroutine SOLVE. On the right-hand side of the equations, differences between the values of the potential at various grid locations are calculated repeatedly. Each time a difference is calculated between potentials on opposite sides of a cut, the increment of potential across the cut (the circulation of the vortex) must be removed from the difference. Table 1 shows the various conditions for which the right side (RS) terms need adjustment and the proper adjustment for each case. Most of the adjustments have opposite signs for vortices above and below the chordline, so the variable IVLOC is used to provide the proper sign. Lines 1905-1932 of TRANVOR, inserted in the subroutine SOLVE following card 1679, represent the conditions and statements listed in Table 1.

Table 1: Adjustments to the Finite Difference Scheme

Subsonic Points

IF	AND IF	THEN
i=IVOR	IVLOC=1 and j>JVOR or IVLOC=-1 and j≤JVOR	$RS' = RS - IVLOC\left(1-\frac{u^2}{a^2}\right)\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}}\frac{\Gamma_v}{(\Delta\xi)^2}$
i=IVOR	j=JVOR or j=JVOR+1	$RS' = RS + \frac{uv}{a^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{\Gamma_v}{2\Delta\xi\Delta\eta}$
i=IVOR+1	IVLOC=1 and j>JVOR or IVLOC=-1 and j≤JVOR	$RS' = RS + IVLOC\left(1-\frac{u^2}{a^2}\right)\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{\Gamma_v}{(\Delta\xi)^2}$
i=IVOR+1	j=JVOR or j=JVOR+1	$RS' = RS + \frac{uv}{a^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{\Gamma_v}{2\Delta\xi\Delta\eta}$

Table 1 (cont.)

Supersonic Points

IF	AND IF	THEN
i=IVOR	IVLOC=1 and j>JVOR or IVLOC=-1 and j≤JVOR	$RS' = RS - IVLOC \frac{v^2}{q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}} \frac{\Gamma_v}{(\Delta\xi)^2}$
i=IVOR	j=JVOR or j=JVOR+1	$RS' = RS + \frac{uv}{2q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\eta}{dy}\right)_j \frac{\Gamma_v}{\Delta\xi\Delta\eta}$
i=IVOR+1	IVLOC=1 and j>JVOR or IVLOC=-1 and j≤JVOR	$RS' = RS - IVLOC\left(1 - \frac{q^2}{a^2}\right) \frac{u^2}{q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}} \frac{\Gamma_v}{\Delta\xi\Delta\eta}$
i=IVOR+1	j=JVOR+1 and v≥0.0 or j=JVOR and v<0.0	$RS' = RS - \left(1 - \frac{q^2}{a^2}\right) \frac{2uv}{q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\eta}{dy}\right)_j \frac{\Gamma_v}{\Delta\xi\Delta\eta}$
i=IVOR+1	IVLOC=1 and j>JVOR or IVLOC=-1 and j≤JVOR+1	$RS' = RS + IVLOC \frac{v^2}{q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}} \frac{\Gamma_v}{(\Delta\xi)^2}$
i=IVOR+1	j=JVOR or j=JVOR+1	$RS' = RS + \frac{uv}{2q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\eta}{dy}\right)_j \frac{\Gamma_v}{\Delta\xi\Delta\eta}$
i=IVOR+2	IVLOC=1 and j>JVOR or IVLOC=-1 and j≤JVOR	$RS' = RS + IVLOC\left(1 - \frac{q^2}{a^2}\right) \frac{u^2}{q^2} \left(\frac{d\xi}{dx}\right)_i \left(\frac{d\xi}{dx}\right)_{i-\frac{3}{2}} \frac{\Gamma_v}{(\Delta\xi)^2}$

Task 5:

Lines 155-179 restore the proper increment of potential across the cut when the grid spacing is halved by subroutine HALVE to increase the detail of the solution. In this subroutine, each new grid point is assigned the average potential of adjacent grid points. When a new grid point is located beside the cut, it should be assigned the average potential of adjacent grid points as if they were both on the same side of the cut as the new grid point. To make the interpolation for the potential values of new grid points correct, the potential increment across the cut must be removed from the average of the potentials of adjacent grid points.

RESULTS

Six minutes of CPU time is typically required for TRANVOR to run on the AMDAHL 360.

Initially TRANVOR was tested to discover limitations on its use. Results were obtained for various positions of the vortex in the flow. Vortex positions very near the airfoil surface (less than .1c) have not been tested. The modifications did not hinder the viscous boundary layer analysis. The effect of vortices with strengths up to .6 has been analyzed successfully. Analysis with higher strengths has not been attempted.

High freestream velocities cause problems. For example, one case with a freestream Mach number of .6 broke down in the last grid because the square of the local speed of sound was calculated to be negative. This was the result of very high velocities encountered near the center of the vortex. Since the vortex is place midway between grid lines, the maximum velocity measured near the vortex center increases as the grid becomes finer, doubling each time the mesh size is halved.

TRANVOR does not model the vortex correctly for compressible flow. The tangential velocity does not continually increase towards the center of a vortex in compressible flow. Rather, as shown in Figure 3, the Mach number becomes infinite at a certain radius, r_{min}. The region within r_{min} must be empty of flow or else contain a solid core.

Three incompressible methods for analyzing BVI were used to check the accuracy of TRANVOR for low speed flows. A flat plate approximation, a source-panel method, and a conformal mapping technique are discussed in Appendices B, C, and D, respectively. Results at any subsonic flow speed may be scaled by the Prandtl-Glauert rule[10] for comparison with results at another subsonic speed.

Each method was applied to the ten cases shown in Figure 4 with a zero angle of attack. TRANVOR and the source-panel method solved the flowfield around a NACA 0012 airfoil. The conformal mapping technique produced results for a Joukowski airfoil of comparable thickness. The airfoils are compared in Figure 5.

Lift coefficients were calculated in two ways: (1) directly from the circulation about the airfoil using the Kutta-Joukowski theorem[11] or (2) by integrating the pressure distribution on the surface of the airfoil. The lift coefficients obtained by both approaches are listed in Table 2 and compared in Figure 6.

Table 2: A Comparison of Results for Low Speed Flows

	c_l from circulation			c_l from pressure		
Case	TRANVOR	Flat Plate	Conformal Mapping	TRANVOR	Source Panel	Conformal Mapping
1	.3318	.3392	.3528	.2838	.3133	.2796
2	-.3332	-.3392	-.3528	-.3200	-.3651	-.3318
3	.3333	.3392	.3528	.3314	.3651	.3318
4	-.3319	-.3992	-.3528	-.2727	-.3133	-.2796
5	.1681	.1615	.1666	.1366	.1433	.1270
6	.6637	.6785	.7056	.5314	.5747	.5069
7	-.4134	-.3952	-.4149	-.5448	-.5359	-.4954
8	.4095	.3952	.4149	.3659	.3652	.3252
9	.5984	.6133	.6394	.5943	.6446	.5797
10	-.5991	-.6133	-.6394	-.5830	-.6446	-.5797

The lift coefficients calculated from the airfoil circulation differ by less than 7% in all cases. The maximum difference for the lift coefficients found by integration was 14.9%. Part of the significant disagreement is probably due to the inaccuracy of the numerical integration of the pressure distribution. Disagreement between the two groups of lift coefficients was largest when the vortex was near the airfoil surface or had a large strength.

Cases 1&4, 2&3, and 9&10 were symmetrical--the results for each pair should have been mirror images. The non-iterative codes showed exact symmetry. The lift coefficients of TRANVOR were within 4% of being symmetrical.

Pressure distributions obtained for three cases are compared in Figures 7, 8, and 9. The close agreement between TRANVOR and the source-panel method indicate that the conformal mapping technique is probably in error. The difference in the airfoil shapes is not really significant between the leading edge and about midchord, so the pressure distributions should be more similar. With the cusped trailing edge, the flow should not slow down as much on the Joukowski airfoil as on the NACA 0012. To determine if the conformal mapping technique was indeed wrong, the coordinates of the Joukowski airfoil were entered into TRANVOR and Case 1 was repeated. Figure 10 compares the results of TRANVOR and the comformal mapping technique with the same airfoil. The fairly proportional relationship between the pressure distributions suggests that the tangential velocities are too low in the conformal mapping technique. The results of TRANVOR with the Joukowski airfoil are believed to be valid because they agree with results with the NACA 0012 airfoil for this case until around the midchord.

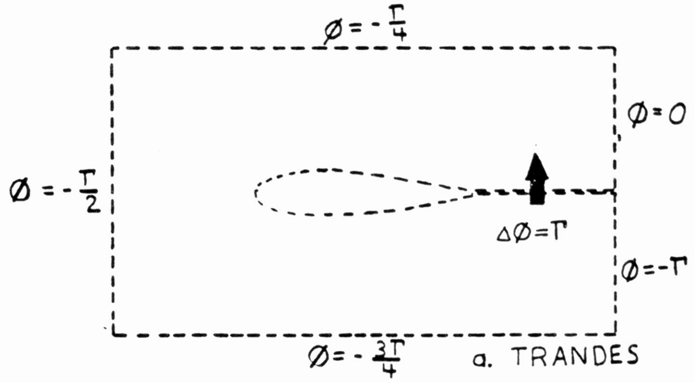
The pressure distribution of Case 8 (see Figure 8) exhibits the influence of the vortex particularly well. The counter-clockwise flow of the vortex retards the velocity on the lower surface of the airfoil, while the flow on the upper surface is hardly affected. The increased pressure on the lower surface generates lift even though the airfoil is not inclined to the freestream flow.

CONCLUSIONS

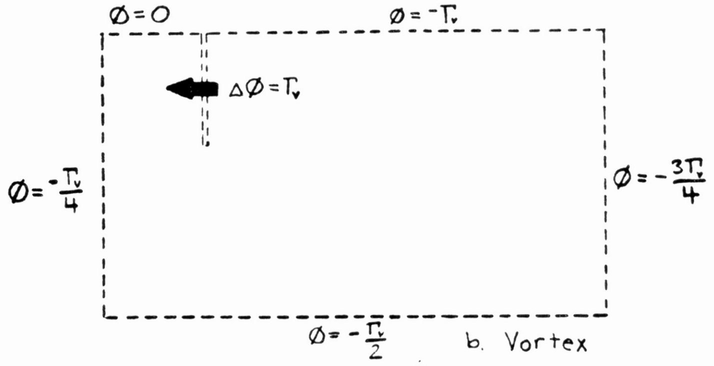
The modifications made to TRANDES to model a vortex in the flowfield produce valid solutions for BVI in low speed flows and do not interfere with boundary layer calculations.

The code is not useful for indicating or analyzing the aerodynamic mechanism responsible for impulsive rotor noise because it will not iterate on the final computational grid with high speed flows. The flow around the center of the vortex must be modelled differently before accurate solutions will be obtained for high speed flows.

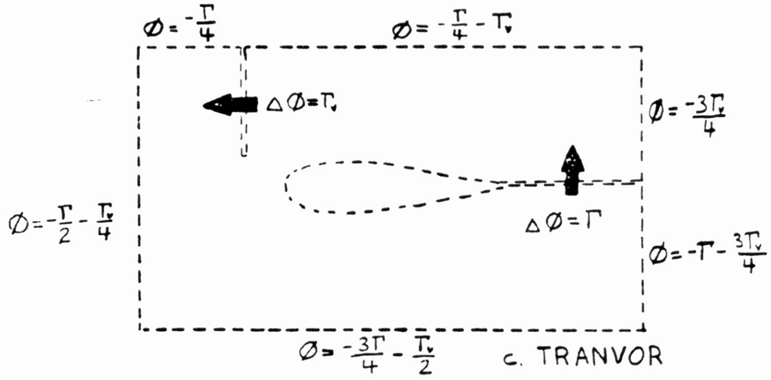
Fig. 1 Infinity Boundary Conditions



a. TRANDES

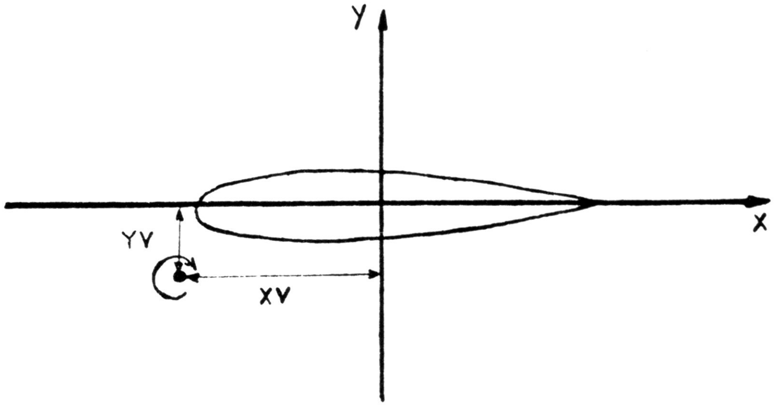


b. Vortex

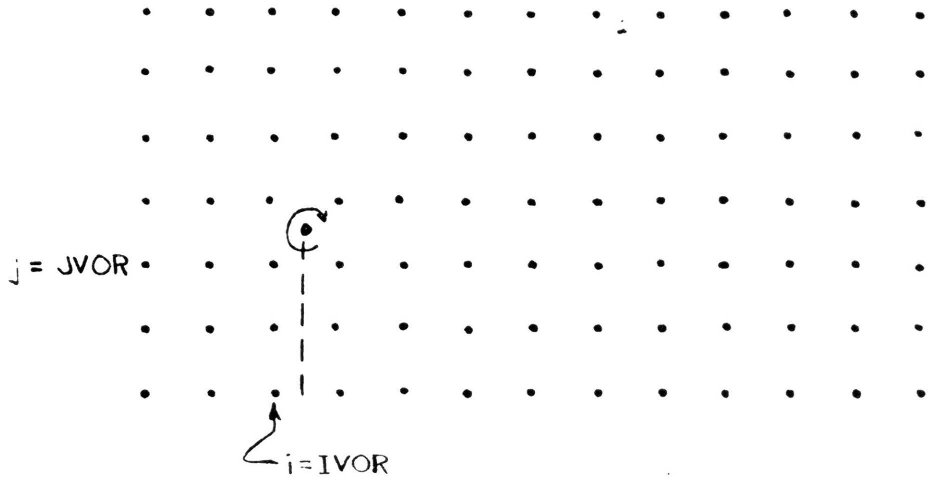


c. TRANVOR

Fig 2. Vortex Position

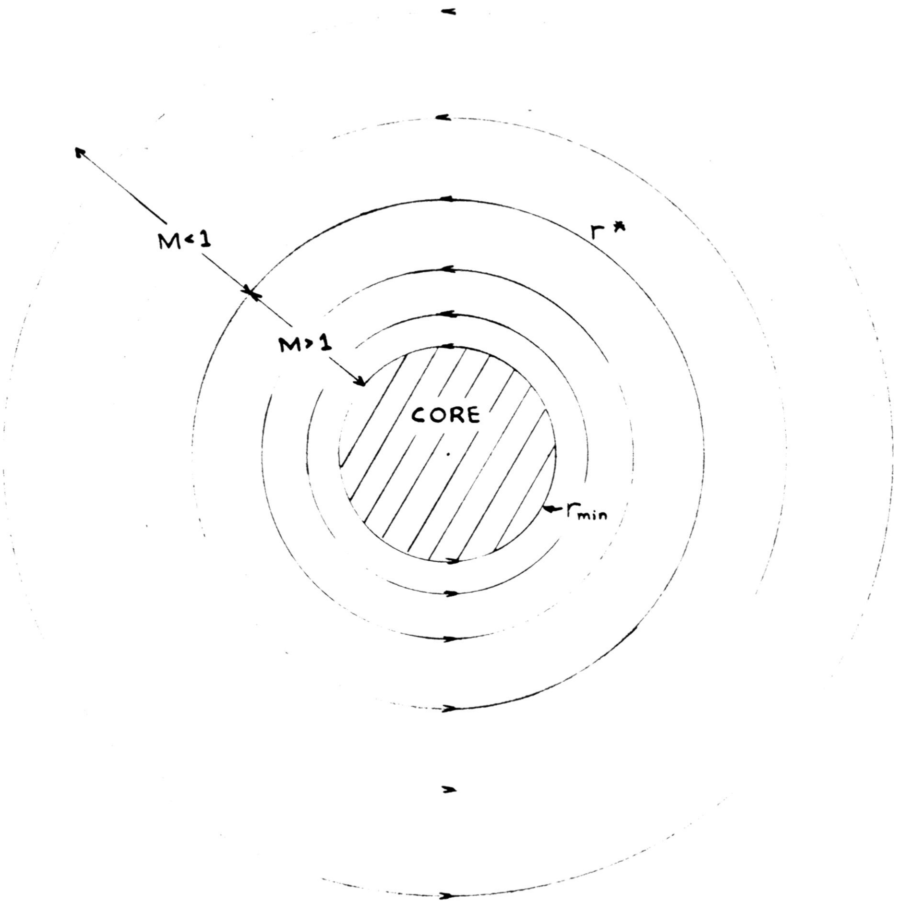


a. Flowfield



b. Computational Grid

Figure 3 Compressible Vortex



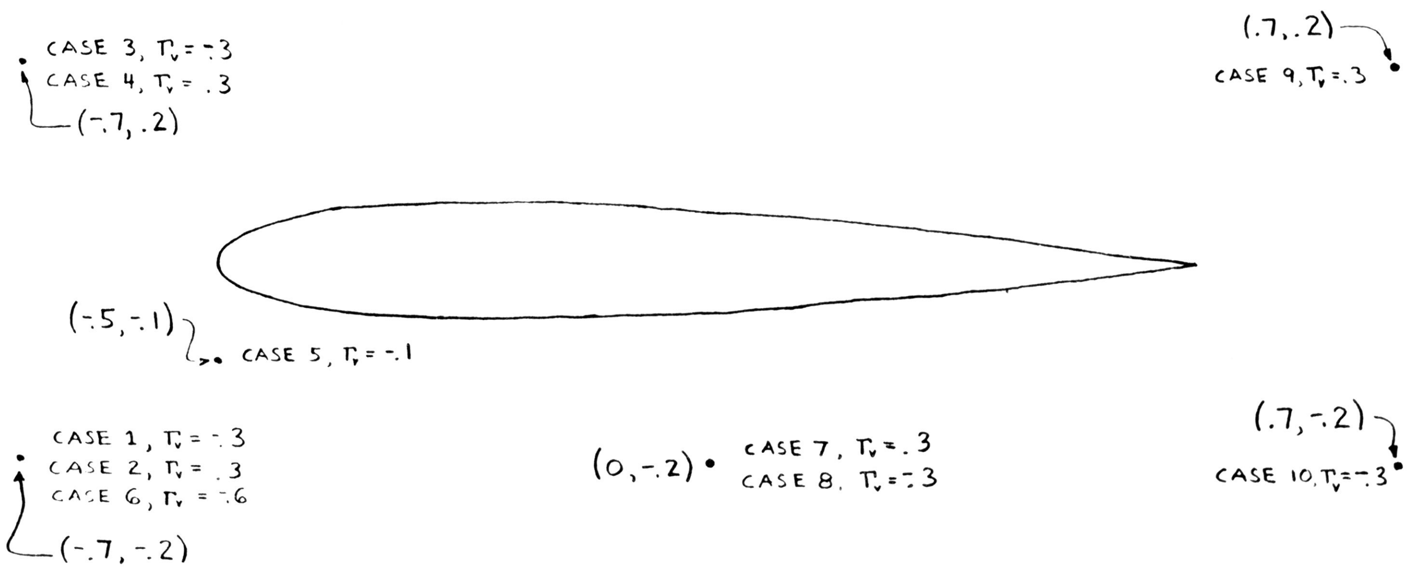


Figure 4 Test Cases

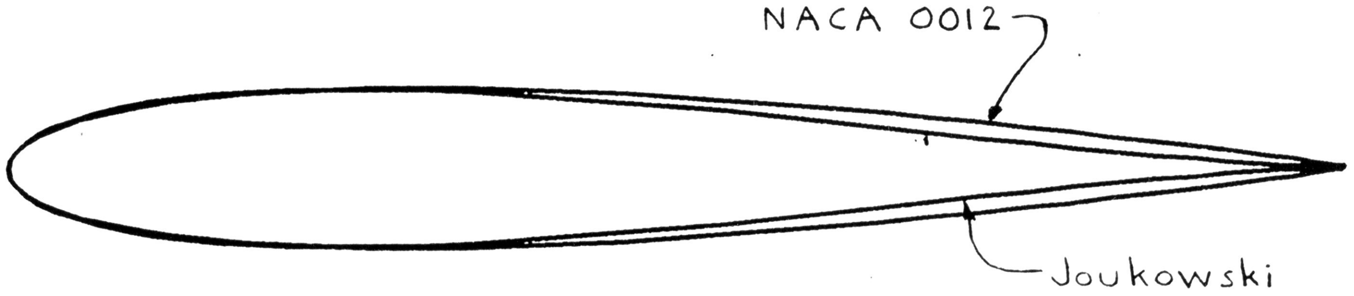


Figure 5 Airfoil Shape Comparison

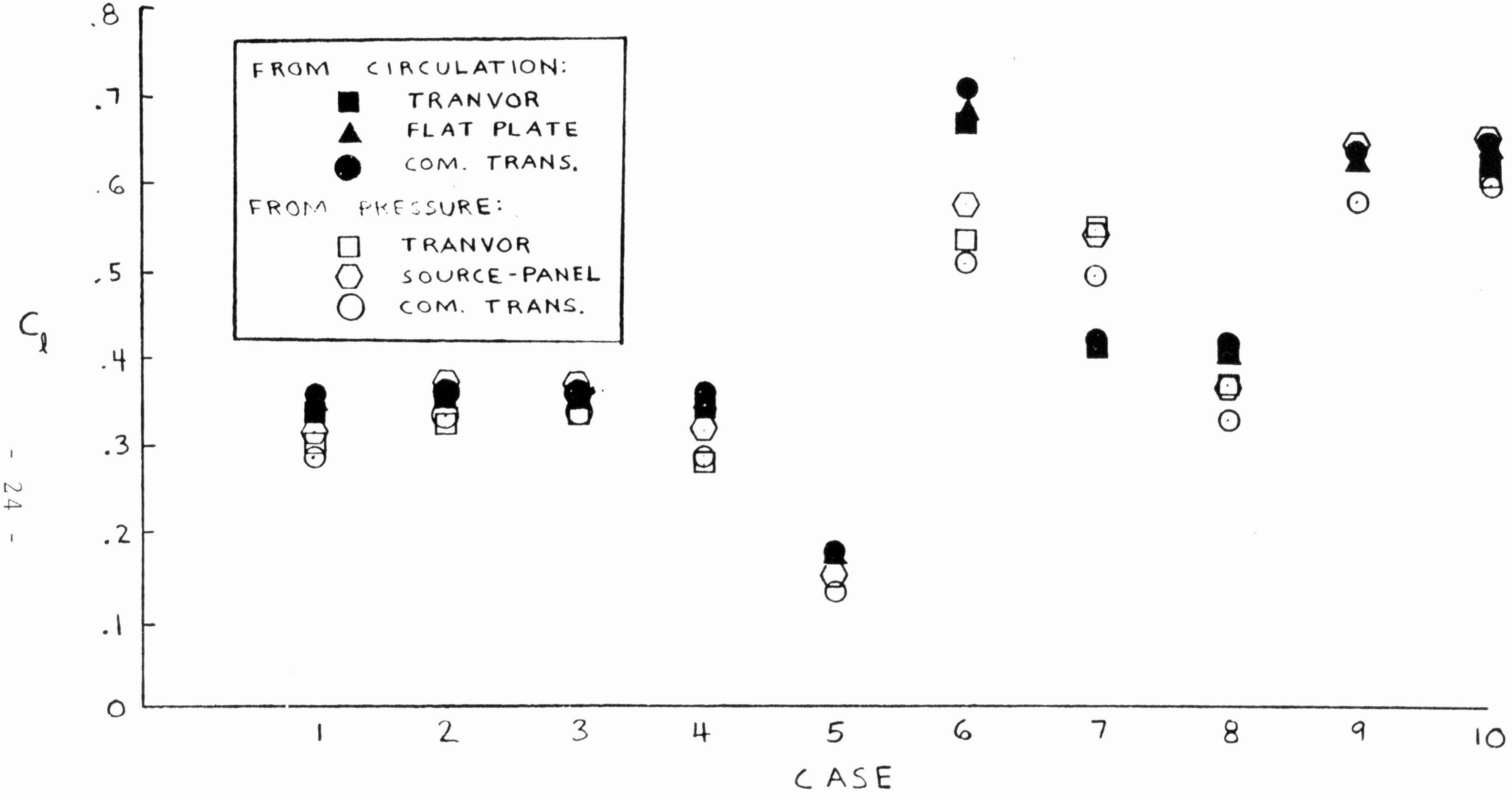


Figure 6 Comparison of Lift Coefficients

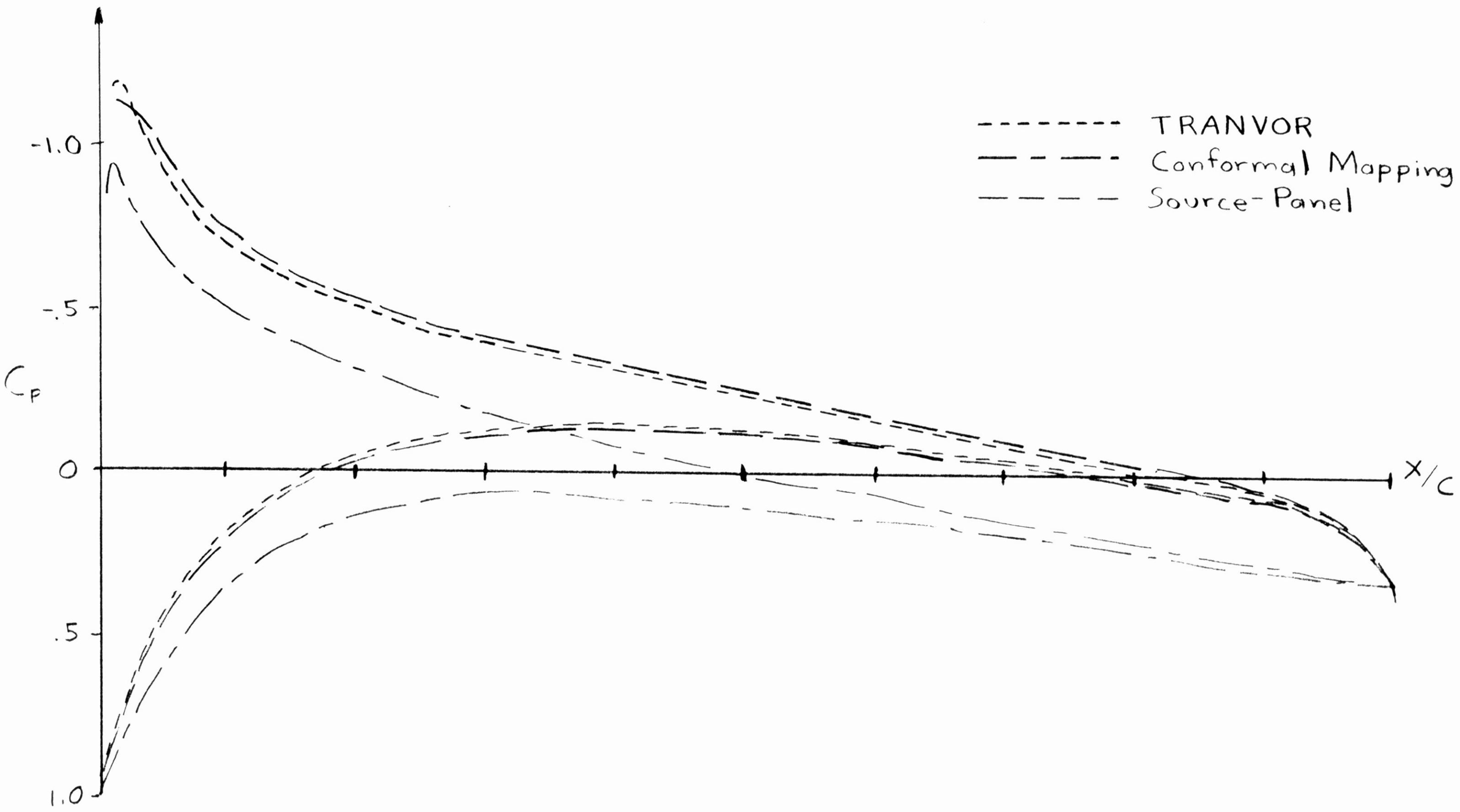


Figure 7 Case 1 Pressure Distribution

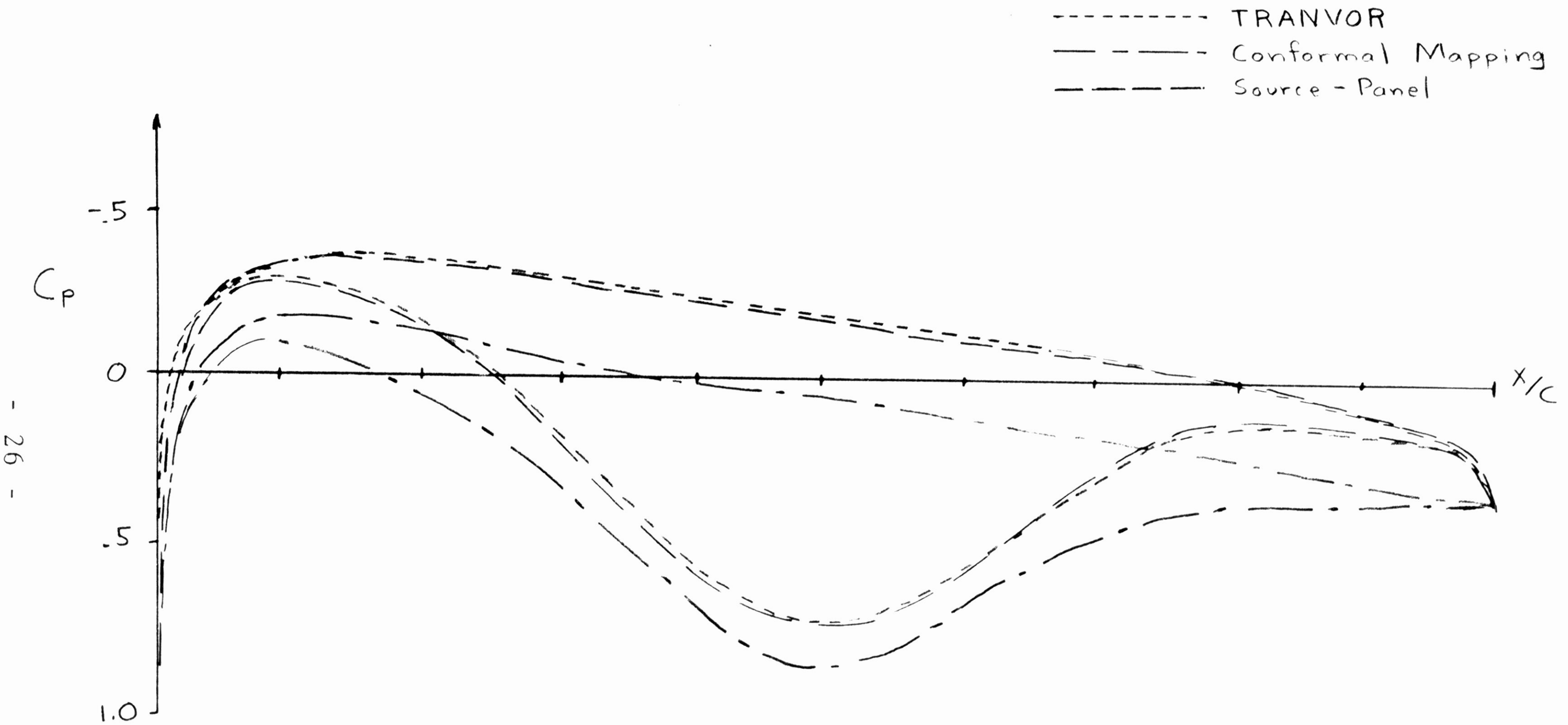


Figure 8 Case 8 Pressure Distribution

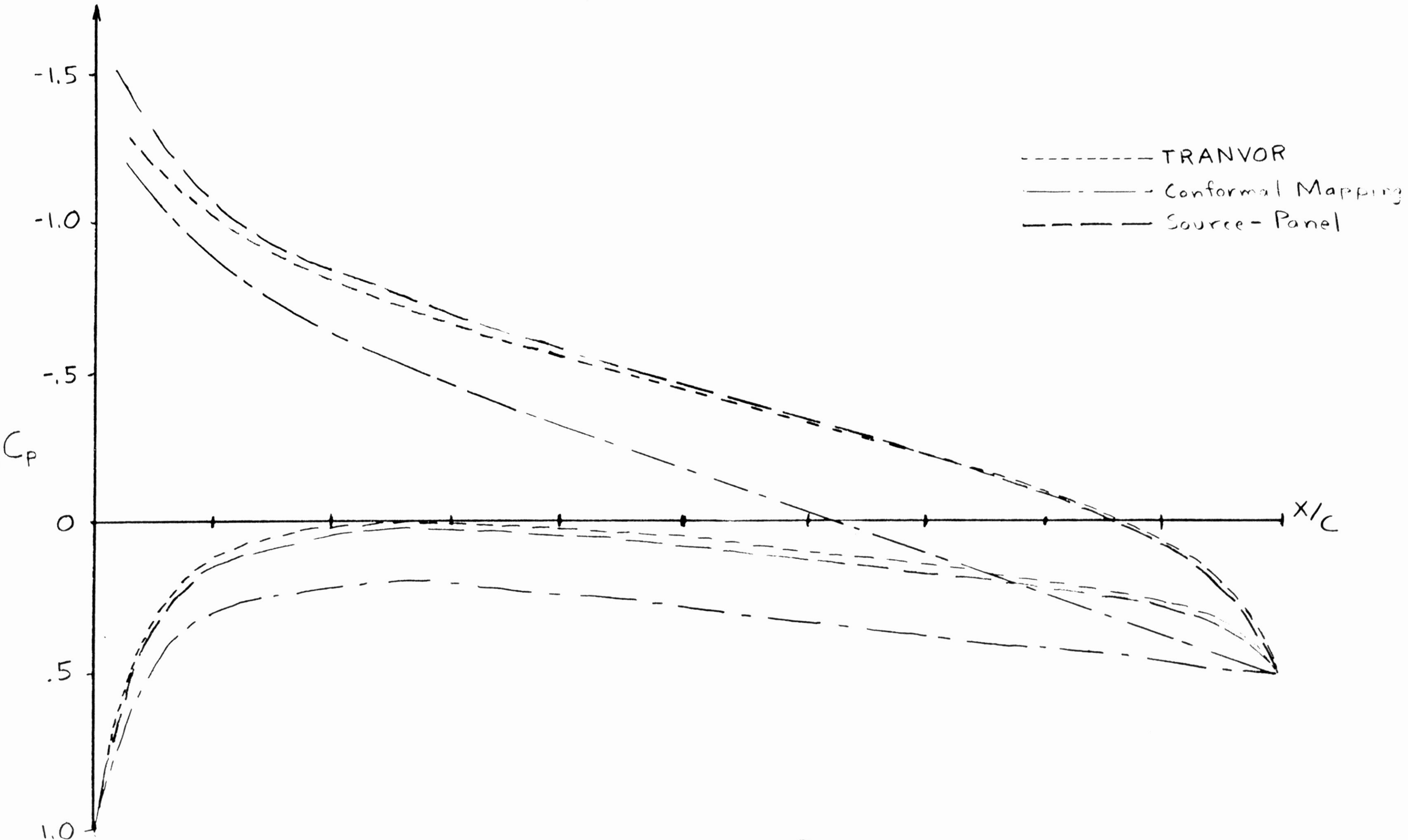


Figure 9 Case 10 Pressure Distribution

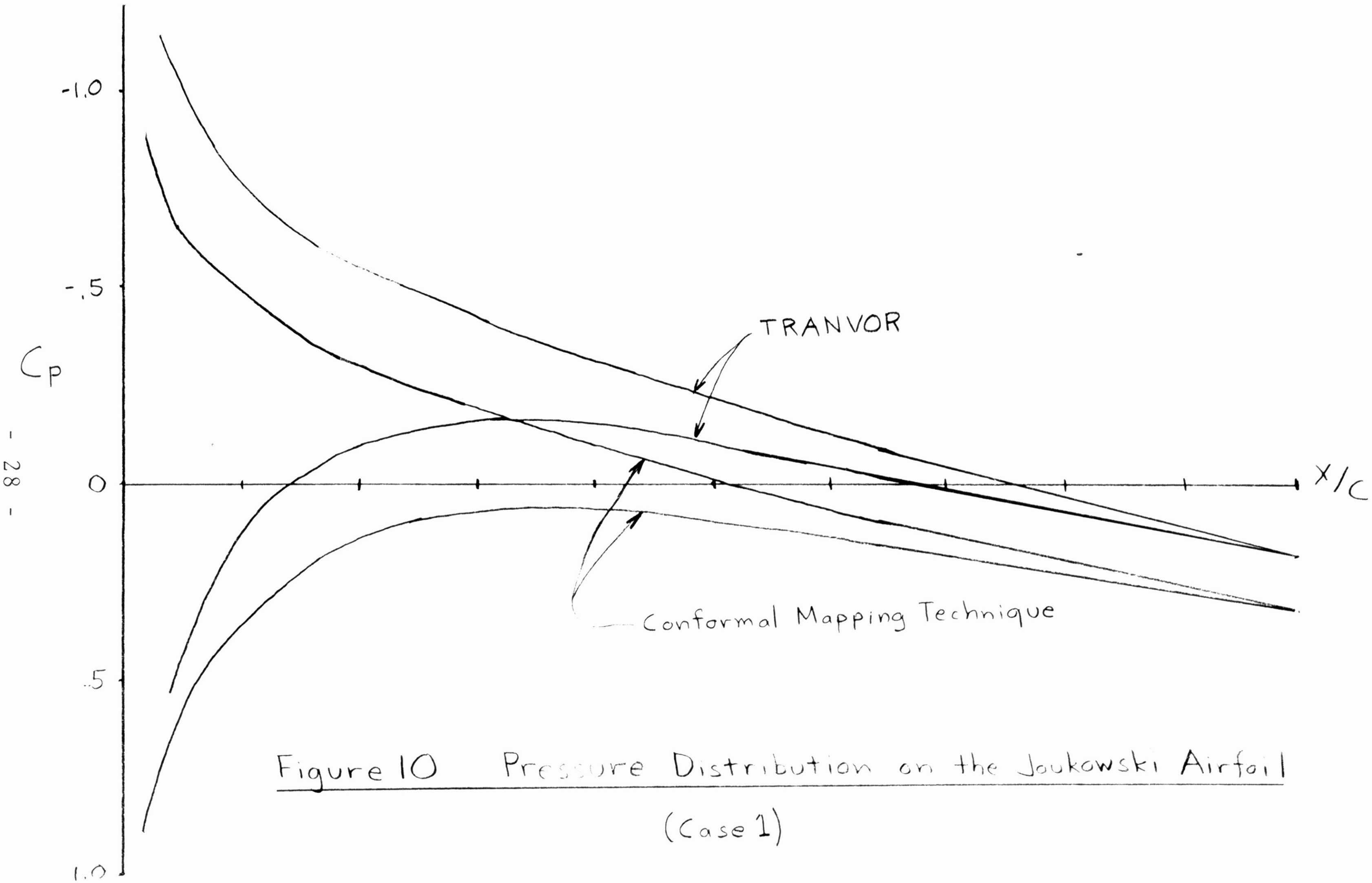


Figure 10 Pressure Distribution on the Joukowski Airfoil

(Case 1)

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APPENDIX A:

Finite Difference Scheme

$$\left[\frac{u^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\frac{1}{(\Delta\eta)^2}+\epsilon\frac{v}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\frac{1}{\Delta\xi\Delta\eta}\right]\phi_{i,j-1}$$

$$+\left[-\frac{v^2}{q^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{(\Delta\xi)^2}-\frac{u^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\left(\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}+\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\right)\frac{1}{(\Delta\eta)^2}-\epsilon\left(\frac{d\xi}{dx}\right)_i\frac{1}{\Delta\xi}\left(\frac{u}{q}\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{\Delta\xi}+\frac{v}{q}\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\frac{1}{\Delta\eta}\right]\phi_{i,j}$$

$$+\left[\frac{u^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{(\Delta\eta)^2}\right]\phi_{i,j+1}$$

$$= -\left(1-\frac{q^2}{a^2}\right)\left\{\frac{u^2}{q^2}\left(\frac{d\xi}{dx}\right)_i\frac{1}{(\Delta\xi)^2}\left[\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\left(\phi_{i,j}-\phi^*_{i-1,j}\right)-\left(\frac{d\xi}{dx}\right)_{i-\frac{3}{2}}\left(\phi^*_{i-1,j}-\phi^*_{i-2,j}\right)\right]+2\frac{uv}{q^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{1}{\Delta\xi\Delta\eta}\left(\phi_{i,j}-\phi^*_{i-1,j}\right.\right.$$

$$\left.-\phi_{i,j-1}+\phi^*_{i-1,j-1}\right)+\frac{v^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\frac{1}{(\Delta\eta)^2}\left[\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\left(\phi_{i,j}-\phi_{i,j-1}\right)-\left(\frac{d\eta}{dy}\right)_{j-\frac{3}{2}}\left(\phi_{i,j-1}-\phi_{i,j-2}\right)\right]\Bigg\}-\frac{v^2}{q^2}\left(\frac{d\xi}{dx}\right)_i\frac{1}{(\Delta\xi)^2}\left[\left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}}\left(\phi_{i+1,j}\right.\right.$$

$$\left.\left.-\phi_{i,j}\right)+\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\phi_{i-1,j}\right]+\frac{uv}{2q^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{1}{\Delta\xi\Delta\eta}\left[\phi_{i-1,j-1}-\phi_{i-1,j+1}-\phi_{i+1,j-1}+\phi_{i+1,j+1}\right]+\epsilon\left(\frac{d\xi}{dx}\right)_i\frac{1}{\Delta\xi\Delta\eta}\left[\frac{u}{q}\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\left(-\phi_{i,j}\right.\right.$$

$$\left.\left.-\phi_{i-1,j}+\phi^*_{i-1,j}\right)+\frac{v}{q}\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\left(\phi_{i,j-1}-\phi_{i,j}\right)\right]$$

<u>Case 1a: Subsonic Flow, Positive Vertical Velocity</u>

* denotes a potential value from the previous sweep

$$\left[\frac{u^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\frac{1}{(\Delta\eta)^2}\right]\emptyset_{i,j-1}$$

$$+\left[-\frac{v^2}{q^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{(\Delta\xi)^2}-\frac{u^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\left(\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}+\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\right)\frac{1}{(\Delta\eta)^2}-\epsilon\left(\frac{d\xi}{dx}\right)_i\frac{1}{\Delta\xi}\left(\frac{u}{q}\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{\Delta\xi}-\frac{v}{q}\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{\Delta\eta}\right)\right]\emptyset_{i,j}$$

$$+\left[\frac{u^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{(\Delta\eta)^2}-\epsilon\frac{v}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_{i+\frac{1}{2}}\frac{1}{\Delta\xi\Delta\eta}\right]\emptyset_{i,j+1}$$

$$=-\left(1-\frac{q^2}{a^2}\right)\left\{\frac{u^2}{q^2}\left(\frac{d\xi}{dx}\right)_i\frac{1}{(\Delta\xi)^2}\left[\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\left(\emptyset_{i,j}-\emptyset^*_{i-1,j}\right)-\left(\frac{d\xi}{dx}\right)_{i-\frac{3}{2}}\left(\emptyset^*_{i-1,j}-\emptyset_{i-2,j}\right)\right]+\frac{2UV}{q^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{1}{\Delta\xi\Delta\eta}\left(-\emptyset_{i,j}+\emptyset^*_{i-1,j}\right.\right.$$

$$\left.\left.+\emptyset_{i,j+1}-\emptyset_{i-1,j+1}\right)+\frac{v^2}{q^2}\left(\frac{d\eta}{dy}\right)_j\frac{1}{(\Delta\eta)^2}\left[\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\left(\emptyset_{i,j}-\emptyset_{i,j+1}\right)-\left(\frac{d\eta}{dy}\right)_{j+\frac{3}{2}}\left(\emptyset_{i,j+1}-\emptyset_{i,j+2}\right)\right]\right\}-\frac{v^2}{q^2}\left(\frac{d\xi}{dx}\right)_i\frac{1}{(\Delta\xi)^2}\left[\left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}}\left(\emptyset_{i+1,j}\right.\right.$$

$$\left.\left.-\emptyset_{i,j}\right)+\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\emptyset_{i-1,j}\right]+\frac{UV}{2q^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{1}{\Delta\xi\Delta\eta}\left[\emptyset_{i-1,j-1}-\emptyset_{i-1,j+1}-\emptyset_{i+1,j-1}+\emptyset_{i+1,j+1}\right]$$

$$+\epsilon\left(\frac{d\xi}{dx}\right)_i\frac{1}{\Delta\xi\Delta\eta}\left[\frac{u}{q}\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{(\Delta\xi)^2}\left(-\emptyset_{i,j}-\emptyset_{i-1,j}+\emptyset^*_{i-1,j}\right)+\frac{v}{q}\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\left(\emptyset_{i,j}-\emptyset_{i,j+1}\right)\right]$$

Case 1b: Subsonic Flow, Negative Vertical Velocity

* denotes a potential value from the previous sweep

$$\left\{\left(1-\frac{v^2}{a^2}\right)\left(\frac{d\eta}{dy}\right)_j\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\frac{1}{(\Delta\eta)^2}\right\}\varnothing_{i,j-1}$$

$$+\left\{-\frac{2}{w}\left(1-\frac{u^2}{a^2}\right)\left(\frac{d\xi}{dx}\right)_i\frac{1}{2}\left[\left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}}-\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\right]\frac{1}{(\Delta\xi)^2}-\left(1-\frac{v^2}{a^2}\right)\left(\frac{d\eta}{dy}\right)_j\left[\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}+\left(\frac{d\eta}{dy}\right)_{j-\frac{1}{2}}\right]\frac{1}{(\Delta\eta)^2}-\epsilon\frac{u}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{(\Delta\xi)^2}\right.$$

$$\left.+\epsilon\frac{v}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{\Delta\xi\,\Delta\eta}\right\}\varnothing_{i,j}$$

$$+\left\{\left(1-\frac{v^2}{a^2}\right)\left(\frac{d\eta}{dy}\right)_j\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{(\Delta\eta)^2}-\epsilon\frac{v}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{\Delta\xi\,\Delta\eta}\right\}\varnothing_{i,j+1}$$

$$=\left(1-\frac{u^2}{a^2}\right)\left(\frac{d\xi}{dx}\right)_i\left\{-\left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}}\frac{1}{(\Delta\xi)^2}\varnothing_{i+1,j}+\left[\left(\frac{d\xi}{dx}\right)_{i+\frac{1}{2}}+\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\right]\frac{1}{(\Delta\xi)^2}\left(1-\frac{1}{w}\right)\varnothing_{i,j}-\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{(\Delta\xi)^2}\varnothing_{i-1,j}\right\}$$

$$+\frac{uv}{a^2}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_j\frac{1}{2\,\Delta\xi\,\Delta\eta}\left(\varnothing_{i-1,j-1}-\varnothing_{i-1,j+1}-\varnothing_{i+1,j-1}+\varnothing_{i+1,j+1}\right)+\epsilon\frac{u}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\xi}{dx}\right)_{i-\frac{1}{2}}\frac{1}{(\Delta\xi)^2}\left(-\varnothing_{i,j}\right.$$

$$\left.-\varnothing_{i-1,j}+\varnothing^{*}_{i-1,j}\right)+\epsilon\frac{v}{q}\left(\frac{d\xi}{dx}\right)_i\left(\frac{d\eta}{dy}\right)_{j+\frac{1}{2}}\frac{1}{\Delta\xi\,\Delta\eta}\left(\varnothing_{i,j}-\varnothing_{i,j+1}\right)$$

Case 2: Supersonic Flow

* denotes a potential value from the previous sweep

APPENDIX B:

The Flat Plate Approximation[11]

The airfoil is modelled as a flat plate. The flat plate is represented by a finite number of panels. A bound vortex is located at the quarter chord of each panel. At the three-quarters chord of each panel is a control point as shown in Figure A1.

A unique vorticity distribution is determined by applying the tangent flow boundary condition at the control point of each panel. Each bound vortex with circulation density γ_j at x_j will induce a velocity normal to a control point at x_i.

$$V_{\gamma_{n_{ij}}} = \frac{\gamma_j \, \Delta X}{2\pi (X_i - X_j)}$$

A component of the freestream flow may be normal to each panel, depending on the angle of attack.

$$V_{\infty_{n_i}} = V_\infty \sin \alpha$$

The free vortex in the flowfield will also induce a velocity at each control point normal to the plate.

$$V_{v_{n_i}} = \frac{\Gamma_v}{2\pi r_{v_i}} \cos T_i$$

The sum of the normal velocities induced by each bound vortex, the normal component of the freestream, and the normal velocity induced by the free vortex must equal zero at each control point if the flow is tangent.

$$\sum_{j=1}^{np} V_{\gamma_{n_{ij}}} + V_{\infty_{n_i}} + V_{v_{n_i}} = 0$$

This equation can be rearranged and a system of np simultaneous equations solved for the circulation density of each panel, where np is the number of panels.

$$\sum_{j=1}^{np} \gamma_j \left[\frac{\Delta X}{2\pi (X_i - X_j)}\right] = -V_\infty \sin\alpha - \frac{\Gamma}{2\pi r_{v_i}} \cos T_i \qquad \text{for } i=1, np$$

The Kutta-Joukowski theorem provides a simple relationship between the lift coefficient of the airfoil and the total circulation of the bound vortex distribution.

$$C_\ell = 2\Gamma = 2 \sum_{i=1}^{np} \gamma_i \, \Delta X_i$$

A theoretical correction factor[12] for the thickness of the airfoil is applied to the results of this method.

$$C_\ell' = \left(1 + \frac{4}{3\sqrt{3}} (t/c)\right) C_\ell$$

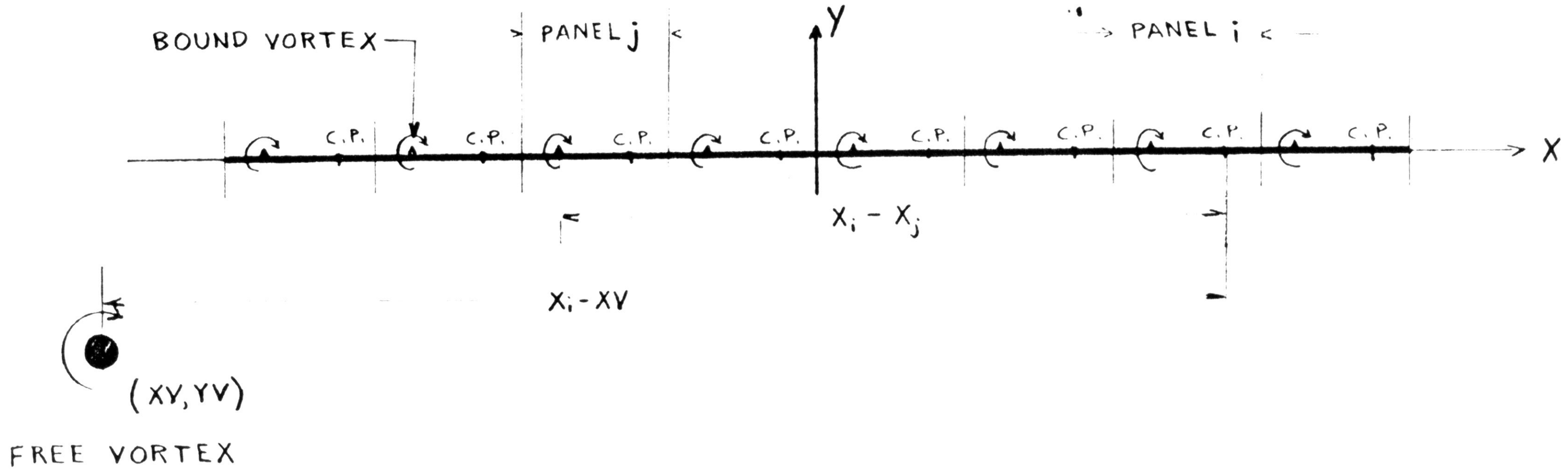

Figure B1 Flat Plate Approximation

APPENDIX C:
The Source-Panel Method[11]

The airfoil surface is represented by a finite number of panels. The tangent flow boundary condition is satisfied at a control point on the midpoint of each panel. The tangent flow is achieved by placing a source sheet of constant strength on each panel. To generate lift, the Kutta condition must be satisfied. A vortex sheet of constant circulation density is placed on each panel to provide the circulation required to satisfy the Kutta condition of smooth flow at the trailing edge. See Figure C1.

The source strength and circulation density of each panel must be determined so that the flow is tangent to the surface at each control point and the smooth at the trailing edge. Since the partial differential equation governing incompressible potential flow is linear, this problem can be solved in parts and the final solution realized by superimposing the flow of each part.

The first flow considered is that of the freestream past the airfoil and the vortex in the flowfield without considering the Kutta condition, so there is no circulation about the airfoil. A source strength distribution that makes the flow tangent is calculated. The normal component of the flow at control point (x_i, y_i) induced by the source sheet on panel j with strength λ_j is found by integrating along panel j.

$$V_{\lambda n_{ij}} = \frac{\lambda_i}{2\pi} \int_j \frac{\partial}{\partial n_i} (\ln r_{ij})\, ds_j$$

The free vortex also induces a flow normal to each panel.

$$V_{v n_i} = \frac{\Gamma_v}{2\pi r_{v_i}} \sin(T_i - \beta_i)$$

A component of the freestream may also be normal to the panel.

$$V_{\infty n_i} = \cos(\beta_i - \alpha)$$

The sum of the normal velocities induced by each source sheet and the free vortex and the normal component of the freestream velocity will equal zero if the flow is tangent.

$$\sum_{j=1}^{np} V_{\lambda n_{ij}} + V_{v n_i} + V_{\infty n_i} = 0$$

This equation is rearranged and a system of np simultaneous equations is solved for the source strength of each panel, where np is the number of panels.

$$\sum_{j=1}^{np} \lambda_j \left[\frac{1}{2\pi} \int_j \frac{\partial}{\partial n_i} (\ln r_{ij})\, ds_j \right] = -\cos(\beta_i - \alpha) - \frac{\Gamma_v}{2\pi r_{v_i}} \sin(T_i - \beta_i)$$

This system of equations is solved twice with a uniform flow of unit velocity, at zero and ninety degree angles of attack. The speed of the tangential flow on the surface of the airfoil is calculated separately for each angle of attack by summing the tangential components of the flow induced by each of the source sheets and adding the tangential component of the freestream velocity.

$$V_{s_i} = \sum_{j=1}^{np} \frac{\lambda_j}{2\pi} \int_j \frac{\partial}{\partial s_i} (\ln r_{ij})\, ds_j + \sin(\beta_i - \alpha) + \frac{\Gamma_v}{2\pi r_{v_i}} \cos(T_i - \beta_i)$$

Now the tangential velocity distribution for any angle of attack and magnitude of the freestream velocity is found by using the appropriate superposition of the known velocity distributions.

$$V_{o_i} = V_\infty \left(\underset{(\alpha=0^\circ)}{V_{s_i}} \cos\alpha + \underset{(\alpha=90^\circ)}{V_{s_i}} \sin\alpha \right)$$

The second flow considered is purely circulatory about the airfoil. Each panel is assigned a unit vortex density. A source strength distribution is found to make this circulatory flow tangent to the airfoil surface. The normal component of the flow induced at the control point of panel i by the vortex sheet on panel j with circulation density $_j$ is found by integrating along panel j.

$$V_{n_{\gamma_{ij}}} = \frac{1}{2\pi} \int_j \frac{\partial}{\partial n_i} \left(\tan^{-1} \frac{y_i - y_j}{x_i - x_j} \right) ds_j$$

The sum of the normal velocities induced by each vortex sheet and source sheet must equal zero at each control point if the flow is tangent.

$$\sum_{j=1}^{np} V_{n_{\lambda_{ij}}} + \sum_{j=1}^{np} V_{n_{\gamma_{ij}}} = 0$$

This equation is rearranged and a system of np simultaneous equations is solved for the source strength of each panel.

$$\sum_{j=1}^{np} \lambda_j \left[\frac{1}{2\pi} \int_j \frac{\partial}{\partial n} (\ln r_{ij})\, ds_j \right] = - \sum_{j=1}^{np} \frac{1}{2\pi} \int_j \frac{\partial}{\partial n} \left(\tan^{-1} \frac{y_i - y_j}{x_i - x_j} \right) ds_j \qquad \text{for } i = 1, np$$

From the resulting distribution of source strengths and the unit circulation density distribution, the tangential speed of this circulatory flow is calculated at each control point.

$$V_{c_i} = \sum_{j=1}^{np} \frac{\lambda_j}{2\pi} \int_j \frac{\partial}{\partial s_i} (\ln r_{ij})\, ds_j + \sum_{j=1}^{np} \frac{1}{2\pi} \int_j \frac{\partial}{\partial s_i} \left(\tan^{-1} \frac{y_i - y_j}{x_i - x_j} \right) ds_j$$

The final solution is found by superimposing enough of the circulatory flow on the zero-lift flow to satisfy the Kutta condition. The flow at the trailing edge will be smooth if the tangential velocity at the last panel on the upper and lower surfaces is equal. A constant is calculated from the zero-lift and circulation velocities of these panels.

$$k = \frac{V_{o_L} - V_{o_u}}{V_{c_u} - V_{c_L}}$$

Now the velocity distribution of the circulatory flow is multiplied by this constant and superimposed on the velocity distribution of the zero-lift flow.

$$V_i = V_{o_i} + k\, V_{c_i}$$

The resulting flow satisfies the tangent flow boundary condition at each control point and is smooth at the trailing edge.

Pressure coefficients are calculated on each panel.

$$c_p = 1 - \left(\frac{V_i}{V_\infty} \right)^2$$

The lift coefficient of the airfoil is calculated by integrating the vertical component of the pressure force on the surface.

$$C_l = \sum_{i=1}^{np} C_{p_i} l_i \sin\beta_i$$

NOTE:

All of the integrals involved have a similar form after the integrands are differentiated.

$$I_{ij} = \int_0^l \frac{b - c s_j}{s_j^2 - e s_j + f} \, ds_j$$

Only two sets of integrals need to be calculated to use this method. The coefficients of the integrand are identical for the normal velocity induced by a source sheet and the tangential velocity induced by a vortex sheet. The coefficients of the numerator have opposite signs for the tangential velocity induced by a source sheet and the normal velocity induced by a vortex sheet. The best approach is to solve the two sets of integrals and store the results rather than solving the integrals each time they are encountered.

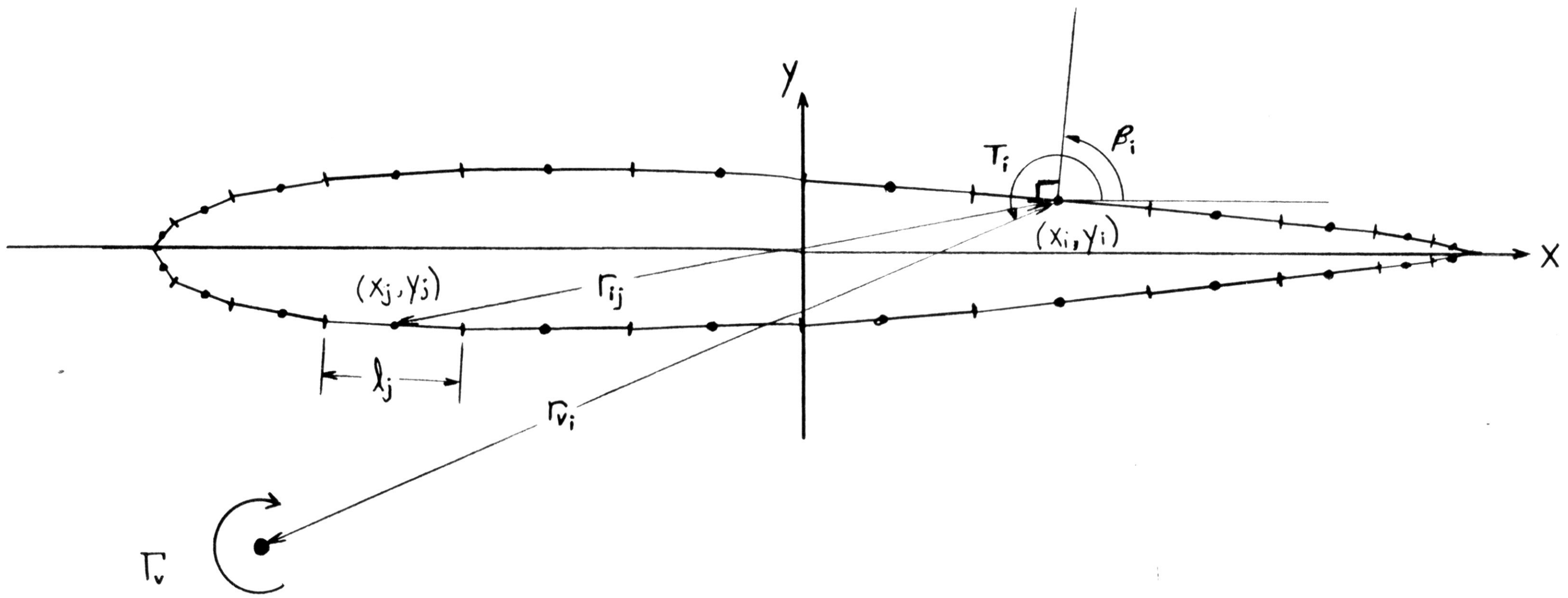

Figure C1 Source-Panel Method

APPENDIX D:
The Conformal Mapping Technique[13]

Two-dimensional incompressible, irrotational, inviscid flow can be described by a complex potential function. The velocity field is the conjugate of the gradient of the potential function. The potential functions for various flows given in Table D1 may be added to superimpose flows since the governing equation is linear.

Table D1: Potential functions

Uniform flow:	$F_1(W) = V_\infty W$
Vortex at W_v:	$F_2(W) = \frac{i\Gamma_v}{2\pi} \ln(W - W_v)$
Uniform flow past a vortex at W_v:	$F_3(W) = F_1(W) + F_2(W)$

The circle theorem[14] determines the potential function for a flow is a circle of radius **a** is introduced into the flowfield.

$$F_4(W) = F_3(W) + \overline{F}_3\left(\frac{a^2}{W}\right) = V_\infty\left(W + \frac{a^2}{W}\right) + \frac{i\Gamma_v}{2\pi} \ln\left(\frac{W^2 - W_v W}{a^2 - \overline{W}_v W}\right)$$

The circle theorem is applicable to a flow if there are no rigid boundaries in the flow and the singularities of the potential function are all at a distance greater than **a**, the radius of the circle, from the origin.

A circulatory flow about the circle is superimposed by adding another term to the potential function.

$$F_5(W) = V_\infty\left(W + \frac{a^2}{W}\right) + \frac{i\Gamma_v}{2\pi} \ln\left(\frac{W^2 - W_v W}{a^2 - \overline{W}_v W}\right) + \frac{i\Gamma}{2\pi} \ln \frac{W}{a}$$

Now the potential function describes a uniform flow passing a circle with circulatory flow and a free vortex somewhere in the flowfield.

If an analytic function R(W) is used to map the circle to another shape in the R-plane, the potential function F(R) will describe the flow about the new shape. The objective is to map the circle into a shape resembling an airfoil.

Two consecutive transformations are used as shown in Figure D1. First the circle is shifted horizontally and the radius is increased. The second transformation results in a shape called a Joukowski airfoil.

The potential function $F_5(Z)$ describes a uniform flow past a Joukowski airfoil with a vortex present in the flowfield. Since the velocity is the conjugate of the gradient of the potential function, their magnitudes are equal.

$$\left|V(Z)\right| = \left|\frac{dF_5(Z)}{dZ}\right|$$

Rather than stumbling through the tedious algebra required to determine the potential function F(Z) and differentiate it, the chain rule is used to expand the derivative.

$$\left|V(Z)\right| = \left|\frac{dF(W)}{dW} \frac{dW}{dR} \frac{dR}{dZ}\right|$$

The pressure distribution is calculated from the velocities and integrated to determine the lift coefficient of the airfoil due to the presence of the vortex in the flowfield.

The derivative dR/dZ approaches infinity at the trailing edge, implying an infinite velocity. The Kutta condition[12] requires smooth flow at the trailing edge. The flow will have a finite velocity at the trailing edge only if one of the first two derivatives goes to zero at the trailing edge. The derivative dW/dR is constant, so the derivative dF/dW should equal zero for the value of W corresponding to the trailing edge.

$$\left(\frac{dF}{dW}\right)_{W=a} = 0$$

The constraint of the Kutta condition provides a relationship between the circulation of the free vortex and the circulation of the airfoil.

$$\Gamma = \left[\frac{-2a(a-u_v)}{(a-u_v)^2 + v_v^2}\right] \Gamma_v$$

The Kutta-Joukowski theorem[11] relates the lift of an airfoil to its circulation, so the lift coefficient can be calculated as a function of the position and circulation of the vortex in the flowfield.

$$c_\ell = 2\Gamma$$

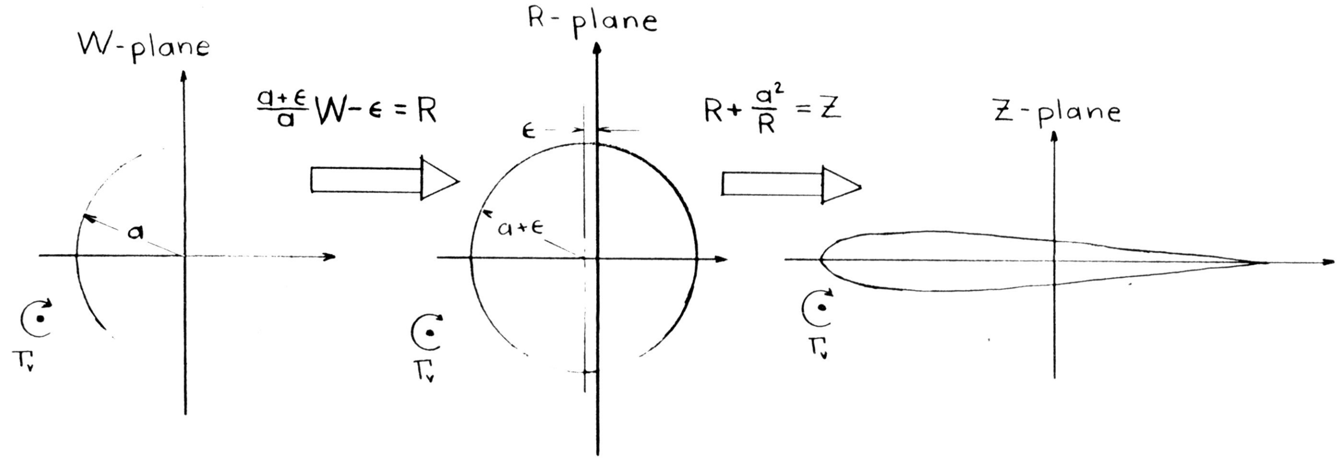

Figure D1 Transformation of a Circle to a Joukowski Airfoil

APPENDIX E:

TRANVOR Program Listing

```
//TRANVOR JOB (T177,010A,010,010,DC),'FLOW1 B'
//*MAIN SYSTEM=ANY,ORG=TCC
//*TAMU P=0
// EXEC FORTXCG,PARM.FORT='OPT(2),NOSOURCE',PARM.GO='SIZE=320K',
//       REGION.GO=320K,FXLNSPC='3120,(100,10)'
//FORT.SYSIN DD *
C ****************************  T R A N V O R  *************************
C **********************************************************************
C ***** A FORTRAN PROGRAM FOR COMPUTING THE FLOW ABOUT AIRFOILS ********
C ***** AT LOW SPEEDS WITH A VORTEX IN THE FLOWFIELD.           ********
C *****              TRANVOR IS A MODIFIED VERSION OF TRANDES   ********
C ***** DISCUSSED IN NASA CR-2821.  THUS, IT CAN ALSO BE USED   ********
C ***** FOR TRANSONIC AIRFOIL ANALYSIS AND/OR DESIGN.           ********
C ***** LELAND A. CARLSON, AEROSPACE ENGINEERING DEPARTMENT     ********
C ***** TEXAS A&M UNIVERSITY, COLLEGE STATION, TEXAS, 77843     ********
C ***** APRIL 1984 *****************************************************
C **********************************************************************
C                                                                       00000004
      REAL M                                                            00000005
      DIMENSION UVEL(99),VVEL(99)
      DIMENSION NTITLE(20),AA(500),IONIC(99)                            00000006
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00000007
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00000008
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900000009
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00000010
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00000011
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100000012
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00000013
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00000014
     1JMAX,JCON,JMAX1,NSSP,IW                                           00000015
      COMMON/JS/GG(99),GGP12(99),GGM12(99),GGM32(99),GGP32(99),A3       00000016
      COMMON/FIX/MHALF                                                  00000017
      COMMON/DELTA/ITER                                                 00000018
      COMMON/TAMU/DELTAY                                                00000019
      COMMON/RED/ITERP                                                  00000020
      COMMON/FIPUT/IREAD                                                00000021
      COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER00000022
     1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF                            00000023
      COMMON/IPT1/XIBDLY,RDEL,RDELFN,RCPB,SP,XSEP,CONV,CPB,XMON,XLSEP,  00000024
     1 MITER,LP,ITEUPC,ITELWC,XPC                                       00000025
     2,LBDLY,XLBDLY                                                     00000026
      COMMON/IPT2/IMASS                                                 00000027
      COMMON/SETCPS/CPSPO,RLAX                                          00000028
      COMMON/IPT3/ISIDE,ILAM,RADUS
C*********************************** ADDITION ***********************
      COMMON/SEPTRP/LSEP,LSEP1
      COMMON/VORTEX/VORCIR,IVLOC,XV,YV,IVOR,JVOR
C********************************************************************
      NAMELIST/FINP/M,W,X1,X2,ALP,EPS,EPSS,X4,S4,CONV,A1,A2,A3,RN,      00000029
     1 XIBDLY,CIR,CDCORR,RDEL,RDELFN,SP,XSEP,RCPB,CPB,XMON,XLSEP,XPC    00000030
     3,XLBDLY,RLAX,RADUS                                                00000031
     4,CLALP,VORCIR,XV,YV
      NAMELIST/IINP/IMAX,JMAX,IKASE,INV,MITER,NHALF,ITACT,ISKP2,ISKP3,  00000032
     1 ISKP4,ITERP,IREAD,LP,ITEUPC,ITELWC                               00000033
     2,IMASS,ILAM                                                       00000034
     2    ,IPRT1,IPRT2
      DELTAY=0.0                                                        00000035
      CPSPO=0.0                                                         00000036
      CDF=0.                                                            00000037
      CDCORR=0.0                                                        00000038
```

```
      DPM=0.0                                                           00000039
      ITER=0                                                            00000040
      MHALF=1                                                           00000041
      IW=0                                                              00000042
      CIR=0.0                                                           00000043
      DPMSUM=0.0                                                        00000044
      IDPM=1                                                            00000045
      DPOLD=0.0                                                         00000046
      M=0.5                                                             00000047
      W=1.7                                                             00000048
      X1=0.5                                                            00000049
      X2=10000.0                                                        00000050
      IPRT1=0
      IPRT2=0
      ILAM=0
      RADUS=0.035
      ALP=0.0                                                           00000051
      EPS=0.0                                                           00000052
      EPSS=0.4                                                          00000053
      X4=0.49                                                           00000054
      S4=2.0                                                            00000055
      A1=0.246                                                          00000056
      A2=0.15                                                           00000057
      A3=3.87                                                           00000058
      RN=20.0E+06                                                       00000059
      XIBDLY=-.44                                                       00000060
      XLBDLY=-.44                                                       00000061
      CPB=0.4                                                           00000062
      RDEL=0.25                                                         00000063
      RDELFN=0.125                                                      00000064
      RLAX=1.0                                                          00000065
      SP=0.004                                                          00000066
      CLALP=.10966
      XSEP=0.44                                                         00000067
      XLSEP=0.50                                                        00000068
      RCPB=0.2                                                          00000069
      XMON=0.47                                                         00000070
      CONV=1.E-05                                                       00000071
      IMAX=13                                                           00000072
      JMAX=7                                                            00000073
      IKASE=100                                                         00000074
      INV=0                                                             00000075
      MITER=800                                                         00000076
      NHALF=0                                                           00000077
      ITACT=0                                                           00000078
      IMASS=0                                                           00000079
      ISKP2=0                                                           00000080
      ISKP3=0                                                           00000081
      ISKP4=0                                                           00000082
      ITERP=0                                                           00000083
      IREAD=0                                                           00000084
      LP=1000                                                           00000085
      ITEUPC=0                                                          00000086
      ITELWC=0                                                          00000087
      XPC=0.10                                                          00000088
      VORCIR=0.0
      IVLOC=0
C*********************************** ADDITION **************************
      DO 50 I=1,99
50    CPU(I)=0.0
C***********************************************************************
```

```
      READ(5,1)(NTITLE(I),I=1,20)                                       00000089
    1 FORMAT(20A4)                                                      00000090
      PRINT 2                                                           00000091
    2 FORMAT(1H1)                                                       00000092
      READ(5,FINP)                                                      00000093
      EPSS0=EPSS                                                        00000094
      EPS0=EPS                                                          00000095
      BETA=SQRT(1.-M*M)                                                 00000096
      READ(5,IINP)                                                      00000097
      ICASE=IKASE                                                       00000098
 8001 CONTINUE                                                          00000099
      ALPDEG=ALP                                                        00000100
      CPSTAR=1.428/(M*M)*(((1.+0.2*M*M)/1.2)**3.5-1.)                   00000101
      PI=4.*ATAN(1.0)                                                   00000102
      PI2=0.5*PI                                                        00000103
      ALP=ALP*PI/180.                                                   00000104
      A22=2./(PI*A2)                                                    00000105
      A11=2./(PI*A1)                                                    00000106
      CALL VALUE                                                        00000107
  101 PRINT 3,(NTITLE(I),I=1,20)                                        00000108
    3 FORMAT(20A4)                                                      00000109
      CALL COORD                                                        00000110
      IF (ABS(VORCIR).LT.0.001) GO TO 630
  605 DO 610 I=2,IMAX1
        IF (XV.LT.X(I)) GO TO 615
  610   CONTINUE
  615 IVOR=I-1
      DO 620 J=2,JMAX1
        IF (YV.LT.Y(J)) GO TO 625
  620   CONTINUE
  625 JVOR=J-1
      IVLOC=1
      IF (YV.LT.0.0) IVLOC=-1
      IVORP1=IVOR+1
      JVORP1=JVOR+1
      IF (MHALF.EQ.1) GO TO 750
      IF (IVLOC.EQ.-1) GO TO 730
      IF ((IVOR/2-IVOR/2.+.1).GT.0.0) GO TO 722
      DO 714 J=JVORP1,JMAX
  714 P(IVORP1,J)=P(IVORP1,J)-VORCIR/2.
      IF ((JVOR/2-JVOR/2.+.1).GT.0.0) P(IVORP1,JVOR)=P(IVORP1,JVOR)
     1-VORCIR/4.
      GO TO 750
  722 DO 724 J=JVORP1,JMAX
  724 P(IVOR,J)=P(IVOR,J)+VORCIR/2.
      IF ((JVOR/2-JVOR/2.+.1).GT.0.0) P(IVOR,JVOR)=P(IVOR,JVOR)
     1+VORCIR/4.
      GO TO 750
  730 IF ((IVOR/2-IVOR/2.+.1).GT.0.0) GO TO 742
      DO 734 J=1,JVOR
  734 P(IVORP1,J)=P(IVORP1,J)+VORCIR/2.
      IF ((JVOR/2-JVOR/2.+.1).LT.0.0) P(IVORP1,JVORP1)=
     1P(IVORP1,JVORP1)+VORCIR/4.
      GO TO 750
  742 DO 744 J=1,JVOR
  744 P(IVOR,J)=P(IVOR,J)-VORCIR/2.
      IF ((JVOR/2-JVOR/2.+.1).LT.0.0) P(IVOR,JVORP1)=P(IVOR,JVORP1)
     1-VORCIR/4.
  750 PRINT 617,IVOR,JVOR,VORCIR
  617 FORMAT(1H,'IVOR=',I2,5X,'JVOR=',I2,5X,'VORCIR=',F10.6)
  630 PRINT 6,M,ALPDEG,X1,ICASE
```

```
    6 FORMAT(1HO,3X,'MACH NO. IS ',F5.3,' ANGLE OF ATTACK IS ',F9.3,' DE00000112
     1GREES',/,10X,' DIRECT SOLUTION TO ',F8.2,                          /.   00000113
     225X,'CASE NUMBER',I6)                                                   00000114
      IF(INV.EQ.O)PRINT 6001                                                  00000115
 6001 FORMAT(1HO,3X,'INVISCID ANALYSIS CASE')                                 00000116
      IF(ITACT.EQ.1)PRINT 6002                                                00000117
 6002 FORMAT(1H ,3X,'WITH VISCOUS INTERACTION')                               00000118
      IF(INV.EQ.1)PRINT 6003                                                  00000119
 6003 FORMAT(1HO,3X,'INVERSE DESIGN CASE')                                    00000120
      IF(IMASS.EQ.1) PRINT 6005                                               00000121
 6005 FORMAT(1H ,3X,'AND MASSIVE SEPARATION')                                 00000122
      IF(IMASS.EQ.O)GO TO 6000
      SPP=0.0
      ALPNU=0.0
      ALPT=ALPDEG
      IF(ALPDEG.LE.15.3) GO TO 6006
      ALPNU=ALPT-15.3
      ALPT=15.3
 6006 SP=-7.14352E-05*ALPT+(0.0142857*CLALP+0.004714337)
      IF(ALPDEG.LE.15.3) GO TO 6008
      SPP=(-8.4074E-11*RN+2.1707E-04)*ALPNU
      SP=SP+SPP
 6008 CONTINUE
      IF(SP.GT.0.0055) SP=0.0055
      IF(SP.LT.0.004) SP=0.004
      PRINT 6007,SP
 6007 FORMAT(1H ,3X,'SP PARAMETER VALUE IS CALCULATED TO BE ',F10.5)
 6000 CONTINUE
      WRITE(6,FINP)                                                           00000123
      WRITE(6,IINP)                                                           00000124
      IF(MHALF.EQ.1)GO TO 102                                                 00000125
      JB=JMAX/2+1                                                             00000126
      DO 104 I=ILE,IMAX                                                       00000127
  104 P(I,JB-1)=0.5*(P(I,JB-2)+PB(I))                                         00000128
      P(IMAX,JMAX-1)=P(IMAX,JMAX-2)                                           00000129
      P(IMAX-1,JMAX)=P(IMAX-2,JMAX)                                           00000130
      P(2,JMAX)=P(3,JMAX)                                                     00000131
      P(1,JMAX-1)=P(1,JMAX-2)                                                 00000132
      P(1,2)=P(1,3)                                                           00000133
      P(2,1)=P(3,1)                                                           00000134
      P(IMAX-1,1)=P(IMAX-2,1)                                                 00000135
      P(IMAX,2)=P(IMAX,3)                                                     00000136
  102 CONTINUE                                                                00000137
      ILE1=ILE-1                                                              00000138
      I11=I1-1                                                                00000139
      ITE=IMAX-ILE1                                                           00000140
      ITE1=ITE+1                                                              00000141
      CALL FOIL                                                               00000142
      IF(IREAD.EQ.1.AND.MHALF.EQ.1)MHALF=MHALF+1                              00000143
    7 DO 8 J=1,JMAX                                                           00000144
    8 P1(J)=P(1,J)                                                            00000145
      CALL FLOW1                                                              00000146
      CALL FLOW2                                                              00000147
      IF(MHALF.EQ.1) GO TO 9                                                  00000148
      IF(IMASS.EQ.1)GO TO 5001                                                00000149
      IF(INV.EQ.O) GO TO 9                                                    00000150
      GO TO 5002                                                              00000151
 5001 IF(MHALF.GT.2.OR.ITER.GT.50)GO TO 5002                                  00000152
      GO TO 9                                                                 00000153
 5002 IF(I1.GT.ITE) GO TO 9                                                   00000154
      CALL FLOW3                                                              00000155
```

```
      IF(X2.GT.1000.0)GO TO 10                                          00000156
    9 CALL WAKE                                                         00000157
   10 STE=S4+2./PI*ATAN((0.5-X4)/A2)                                    00000158
      CIR=-(STE-S(ITE+1))/DS*(P(ITE,JB)-PB(ITE))+(STE-S(ITE))/DS*       00000159
     1(P(ITE+1,JB)-PB(ITE+1))                                           00000160
      IF(IMASS.EQ.0)GO TO 1441                                          00000161
      JB2=JB-1                                                          00000162
      DO 1442 J=JB2,JMAX1                                               00000163
      IF(YU(ITE).GT.E(J).AND.YU(ITE).LE.E(J+1))GO TO 1443               00000164
 1442 CONTINUE                                                          00000165
 1443 JA=J+1                                                            00000166
      IF(JA.LE.JB)JA=JB+1                                               00000167
      PHITE=P(ITE,JA-1)+(P(ITE,JA)-P(ITE,JA-1))*(YU(ITE)-E(JA-1))/DE    00000168
 1441 CONTINUE                                                          00000169
      QUAN1=-.5*CIR/PI                                                  00000170
      QUAN2=ATAN(BETA*A1/A2*DS/DE)                                      00000171
      QUAN3=ATAN(BETA*TAN(ALP))                                         00000172
      IF(M.GT.1.)GO TO 11                                               00000173
      IF(ALP.GT.0.0)GO TO 108                                           00000174
      IF(ALP.LT.0.0)GO TO 1081                                          00000175
      P(IMAX,JMAX)=QUAN1*QUAN2                                          00000176
      DO 12 I=2,IMAX1                                                   00000177
      P(I,JMAX)=- CIR/4.0                                               00000178
   12 P(I,1)=-0.75*CIR                                                  00000179
      P(1,JMAX)=QUAN1*(PI-QUAN2)                                        00000180
      P(1,1)=QUAN1*(PI+QUAN2)                                           00000181
      P(IMAX,1)=QUAN1*(2.*PI-QUAN2)                                     00000182
      DO 13 J=2,JMAX1                                                   00000183
   13 P(1,J)=-0.5*CIR                                                   00000184
      JBM1=JB-1                                                         00000185
      DO 14 J=2,JBM1                                                    00000186
   14 P(IMAX,J)=-CIR                                                    00000187
      DO 1414 J=JB,JMAX1
 1414 P(IMAX,J)=0.0
      GO TO 109                                                         00000188
 1081 DO 1083 I=2,IMAX1                                                 00000189
      P(I,JMAX)=QUAN1*(PI+ATAN(BETA/TAN(ALP)))                          00000190
 1083 P(I,1)=QUAN1*PI+P(I,JMAX)                                         00000191
      GO TO 1082                                                        00000192
  108 DO 110 I=2,IMAX1                                                  00000193
      P(I,JMAX)=QUAN1*ATAN(BETA/TAN(ALP))                               00000194
  110 P(I,1)=QUAN1*PI+P(I,JMAX)                                         00000195
 1082 CONTINUE                                                          00000196
      DO 111 J=2,JMAX1                                                  00000197
  111 P(1,J)=QUAN1*(PI-QUAN3)                                           00000198
      JBM1=JB-1                                                         00000199
      DO 112 J=2,JBM1                                                   00000200
  112 P(IMAX,J)=QUAN1*(2.*PI-QUAN3)                                     00000201
      DO 113 J=JB,JMAX1                                                 00000202
  113 P(IMAX,J)=QUAN1*(-QUAN3)                                          00000203
      P(IMAX,JMAX)=QUAN1*QUAN2                                          00000204
      P(1,JMAX)=QUAN1*(PI-QUAN2)                                        00000205
      P(1,1)=QUAN1*(PI+QUAN2)                                           00000206
      P(IMAX,1)=QUAN1*(2.*PI-QUAN2)                                     00000207
  109 CONTINUE                                                          00000208
      IF (IVLOC.NE.0) CALL VORBCI(BETA,QUAN2,QUAN3)
      PB(IMAX)=-CIR+P(IMAX,JB)                                          00000209
   11 ITER=ITER+1                                                       00000210
      DPMSUM=DPMSUM+DPM                                                 00000211
      IDPM=IDPM+1                                                       00000212
      IF(IDPM.LE.10)GO TO 512                                           00000213
```

```
      DPOLD=DPMSUM                                                      00000214
      DPMSUM=0.0                                                        00000215
      IDPM=1                                                            00000216
  512 CONTINUE                                                          00000217
      IF(IMASS.EQ.1)DELTAY=YU(ITE)-YUORIG(ITE)                          00000218
      IF(IMASS.EQ.1) GO TO 5003                                         00000219
      IF(ITACT.EQ.1)DELTAY=DUPOLD(ITE)                                  00000220
 5003 IF(ITER/10*10.EQ.ITER)                                            00000221
     1PRINT 15,ITER,CIR,DPM,ICON,JCON,NSSP,DELTAY                       00000222
   15 FORMAT(1H ,'ITERATION',I4,' CIR = ',F8.5,' DPM = ',F11.8,' AT',   00000223
     12I3,' NSSP = ',I4,' DELTAY OR DELSTAR = ',F7.4)                   00000224
      IF(M.LE.1.0)GO TO 16                                              00000225
C  ADD P(IMAX,J) CARD HERE FOR M GT 1.0 CASE                            00000226
   16 IF(INV.EQ.0.AND.ITACT.EQ.0)GO TO 24                               00000227
      IF(MHALF.EQ.1)GO TO 24                                            00000228
      IF(IREAD.EQ.1.AND.ITACT.EQ.1)GO TO 9005                           00000229
      IF(ITER.LT.50)GO TO 24                                            00000230
      IF(ITACT.EQ.1)GO TO 9005                                          00000231
      IF(MHALF.EQ.2.AND.ISKP2.EQ.1)GO TO 24                             00000232
      IF(MHALF.EQ.3.AND.ISKP3.EQ.1)GO TO 24                             00000233
      IF(MHALF.EQ.4.AND.ISKP4.EQ.1)GO TO 24                             00000234
      IF(ITER/10*10.EQ.ITER)CALL SHAPE                                  00000235
      GO TO 9006                                                        00000236
 9005 IF(ITER/10*10.EQ.ITER)CALL VISACT                                 00000237
C***************************************** ADDITION *****************
      IF(ITER/10*10.EQ.ITER.AND.IMASS.EQ.1) LSEP1=LSEP
C********************************************************************
      IF(MHALF.EQ.2.AND.ITER.LE.50)GO TO 9006                           00000238
      IF(ITER/10*10.EQ.ITER.AND.IMASS.EQ.1)CALL SHAPE                   00000239
      IF(IMASS.EQ.0)GO TO 9006                                          00000240
      DO 9112 I=I1,ITE                                                  00000241
      IF(YU(I).GE.0.0)GO TO 9112                                        00000242
      YU(I)=YU(I-1)                                                     00000243
      SLU(I)=0.0                                                        00000244
 9112 CONTINUE                                                          00000245
 9006 IF(ITER/LP*LP.EQ.ITER)PRINT22,(X(I),YU(I),YL(I),I=ILE,IMAX1)       00000246
      IF(ITER/LP*LP.EQ.ITER)PRINT 22,(X(I),SLU(I),SLL(I),I=ILE,IMAX1)    00000247
   24 CONTINUE                                                          00000248
      IF(ITER.GE.MITER)GO TO 17                                         00000249
      IF(INV.EQ.0.AND.ITACT.EQ.0)GO TO 106                              00000250
      IF(MHALF.GT.1)GO TO 106                                           00000251
      IF(MHALF.EQ.1.AND.ITER.LT.50)GO TO 106                            00000252
      DPM=0.                                                            00000253
  106 CONTINUE                                                          00000254
      IF(DPM.LT.CONV)GO TO 17                                           00000255
   21 DPM=0.0                                                           00000256
      GO TO 7                                                           00000257
   17 CONTINUE                                                          00000258
C     *** THE FOLLOWING CAN BE USED TO PRINT OUT THE *******            00000259
C     ******PERTURBATION POTENTIAL FLOWFIELD SOLUTION IF DESIRED******* 00000260
      IF(IPRT1.EQ.0) GO TO 3776
      DO 18 JJ=1,JMAX                                                   00000261
      J=JMAX+1-JJ                                                       00000262
      PRINT 19,J                                                        00000263
   19 FORMAT(1H ,'ROW  ',I5)                                            00000264
      PRINT 20,(P(I,J),I=1,IMAX)                                        00000265
   20 FORMAT(1H ,10E11.3)                                               00000266
   18 CONTINUE                                                          00000267
      PRINT 19,JB                                                       00000268
      PRINT 20,(PB(I),I=1,IMAX)                                         00000269
 3776 CONTINUE
```

```
      IF(MHALF.LE.NHALF)GO TO 8007
C     ***** THE FOLLOWING CA BE USED TO PUNCH OUTPUT IF DESIRED******
C     DO 8005 JJ=1,JMAX
C8006 FORMAT(5E15.7)
C     J=JMAX-JJ+1
C8005 CONTINUE
 8007 CONTINUE
C   PRINTE SHAPE HERE IF REQUIRED
      IF(MHALF.EQ.1)GO TO 26
      IF(INV.EQ.1)CALL SHAPE
      IF(ITACT.EQ.0)GO TO 26
      IF(ITER.GE.MITER)GO TO 7501
      CALL VISACT
C************************************* ADDITION ******************
      IF(IMASS.EQ.1)LSEP1=LSEP
C*****************************************************************
      IF(IMASS.EQ.1)CALL SHAPE
 7501 PRINT 9008,RN
 9008 FORMAT('0','BOUNDARY LAYER ANALYSIS FOR REYNOLDS NUMBER OF',E12.3,
     *//,5X,'X',9X,'YUORIG',4X,'DU',8X,'SLU',7X,'YLORIG',4X,'DL',8X,'SLL
     *')
      PRINT 9009,(X(I),YUORIG(I),DUPOLD(I),SLU(I),YLORIG(I),DLWOLD(I),
     *SLL(I),I=ILE,ITE)
 9009 FORMAT(5X,7F10.5)
      GO TO 9007
   26 CALL PRESS
 9007 DO 25 I=ILE,IMAX1
      YU(I)=A1*TAN(PI/2.*YU(I))
   25 YL(I)=A1*TAN(PI/2.*YL(I))
      PRINT 6004
 6004 FORMAT(1H ,' CP BY CENTRAL DIFFERENCES')
      PRINT 9010
 9010 FORMAT(1H ,'X',10X,'CPU',10X,'CPL')
      PRINT 9011,(X(I),CPU(I),CPL(I),I=ILE,IMAX1)
 9011 FORMAT(1H ,3F10.3)
      IMAX2=IMAX-2
      PRINT 221
  221 FORMAT(1H ,'X',10X,'YU',10X,'YL',10X,'SLU',8X,'SLL')
   22 FORMAT(3(' X= ',F7.4,' YU= ',F7.4,' YL= ',F7.4))
      PRINT 220,(X(I),YU(I),YL(I),SLU(I),SLL(I),I=ILE,ITE)
  220 FORMAT(1H ,5F10.5)
      IF(MHALF.LE.NHALF)GO TO 8014
 8014 CONTINUE
      DO 9002 I=ILE,ITE
      YU(I)=ATAN(YU(I)/A1)/PI2
 9002 YL(I)=ATAN(YL(I)/A1)/PI2
      NMACH=2
      JL=2
      JU=JMAX1
      JDUM=JMAX-2
      IF(JDUM.LE.43)GO TO 513
      NMACH=1
      JU=JB
  513 CONTINUE
      PRINT 514
  514 FORMAT(//,38X,'MACH CHART IN COMPUTATIONALTIONAL
     1PLANE-FREE STREAM FROM TOP',/)
      PRINT 515,IMAX1
  515 FORMAT(3X,'I=2,',I2,' TOP TO BOTTOM',/)
      PRINT 516,JL,JU
  516 FORMAT(3X,'J=',I2,1H,,I2,' LEFT TO RIGHT'/)
```

```
      DO 500 I=2,ILE1                                                   00000313
      DO 501 J=2,JMAX1                                                  00000314
      U=QI*(COS(ALP)+FF(I)*(P(I+1,J)-P(I-1,J))/(2.*DS))                 00000315
      IF (IVLOC.EQ.0) GO TO 691
      IF (I.NE.IVOR.AND.I.NE.(IVOR+1)) GO TO 691
      IF (IVLOC.EQ.1.AND.J.GT.JVOR.OR.IVLOC.EQ.-1.AND.J.LE.JVOR)
     1U=U+IVLOC*QI*FF(I)*VORCIR/2./DS
  691 V=QI*(SIN(ALP)+GG(J)*(P(I,J+1)-P(I,J-1))/(2.*DE))
      UU=U*U                                                            00000317
      VV=V*V                                                            00000318
      AD=AI2-0.2*(UU+VV-QI2)                                            00000319
      UVEL(J)=U
      VVEL(J)=V
  501 IONIC(J)=100.0*SQRT((UU+VV)/AD)                                   00000320
      PRINT 28,(IONIC(J),J=JL,JU)                                       00000321
      IF(IPRT2.EQ.0) GO TO 500
      PRINT 2878,(UVEL(J),J=2,JMAX1)
      PRINT 2878,(VVEL(J),J=2,JMAX1)
 2878 FORMAT(1H ,15F8.1)
  500 CONTINUE                                                          00000322
      DO 502 I=ILE,ITE                                                  00000323
      DO 503 J=2,JMAX1                                                  00000324
      UVEL(J)=0.0
      VVEL(J)=0.0
  503 IONIC(J)=0                                                        00000325
      JB2=JB-2                                                          00000326
      DO 504 J=JB2,JMAX1                                                00000327
      IF(YU(I).GT.E(J).AND.YU(I).LE.E(J+1))GO TO 505                    00000328
  504 CONTINUE                                                          00000329
  505 JA=J+1                                                            00000330
      IF(JA.LE.JB)JA=JB+1                                               00000331
      DO 506 J=JA,JMAX1                                                 00000332
      U=QI*(COS(ALP)+FF(I)*(P(I+1,J)-P(I-1,J))/(2.*DS))                 00000333
      IF (IVLOC.EQ.0) GO TO 692
      IF (I.NE.IVOR.AND.I.NE.(IVOR+1)) GO TO 692
      IF (IVLOC.EQ.1.AND.J.GT.JVOR.OR.IVLOC.EQ.-1.AND.J.LE.JVOR)
     1U=U+IVLOC*QI*FF(I)*VORCIR/2./DS
  692 V=QI*(SIN(ALP)+GG(J)*(P(I,J+1)-P(I,J-1))/(2.*DE))                 00000334
      UU=U*U                                                            00000335
      VV=V*V                                                            00000336
      AD=AI2-0.2*(UU+VV-QI2)                                            00000337
      UVEL(J)=U
      VVEL(J)=V
  506 IONIC(J)=100.0*SQRT((UU+VV)/AD)                                   00000338
      JB2=JB+2                                                          00000339
      DO 507 JJ=1,JMAX1                                                 00000340
      J=JB2-JJ                                                          00000341
      IF(YL(I).GE.E(J).AND.YL(I).LT.E(J+1))GO TO 508                    00000342
  507 CONTINUE                                                          00000343
  508 JA=J                                                              00000344
      IF(JA.GE.JB)JA=JB-1                                               00000345
      DO 509 J=2,JA                                                     00000346
      U=QI*(COS(ALP)+FF(I)*(P(I+1,J)-P(I-1,J))/(2.*DS))                 00000347
      IF (IVLOC.EQ.0) GO TO 693
      IF (I.NE.IVOR.AND.I.NE.(IVOR+1)) GO TO 693
      IF (IVLOC.EQ.1.AND.J.GT.JVOR.OR.IVLOC.EQ.-1.AND.J.LE.JVOR)
     1U=U+IVLOC*QI*FF(I)*VORCIR/2./DS
  693 V=QI*(SIN(ALP)+GG(J)*(P(I,J+1)-P(I,J-1))/(2.*DE))                 00000348
      IF(J.EQ.(JB-1))V=QI*(SIN(ALP)+GG(J)*(PB(I)-P(I,J-1))/(2.*DE))     00000349
      UU=U*U                                                            00000350
      VV=V*V                                                            00000351
```

```
      AD=AI2-0.2*(UU+VV-QI2)                                            00000352
      UVEL(J)=U
      VVEL(J)=V
  509 IONIC(J)=100.0*SQRT((UU+VV)/AD)                                   00000353
      PRINT 28,(IONIC(J),J=JL,JU)                                       00000354
      IF(IPRT2.EQ.0) GO TO 502
      PRINT 2878,(UVEL(J),J=2,JMAX1)
      PRINT 2878,(VVEL(J),J=2,JMAX1)
  502 CONTINUE                                                          00000355
      DO 510 I=ITE1,IMAX1                                               00000356
      DO 511 J=2,JMAX1                                                  00000357
      U=QI*(COS(ALP)+FF(I)*(P(I+1,J)-P(I-1,J))/(2.*DS))                 00000358
      IF (IVLOC.EQ.0) GO TO 694
      IF (I.NE.IVOR.AND.I.NE.(IVOR+1)) GO TO 694
      IF (IVLOC.EQ.1.AND.J.GT.JVOR.OR.IVLOC.EQ.-1.AND.J.LE.JVOR)
     1U=U+IVLOC*QI*FF(I)*VORCIR/2./DS
  694 V=QI*(SIN(ALP)+GG(J)*(P(I,J+1)-P(I,J-1))/(2.*DE))
      IF(J.EQ.JB)V=V-QI*(GG(J)*(CIR/(2.*DE)))                           00000360
      IF(J.EQ.JB-1)V=V-QI*(GG(J)*(CIR/(2.*DE)))                         00000361
      UU=U*U                                                            00000362
      VV=V*V                                                            00000363
      AD=AI2-0.2*(UU+VV-QI2)                                            00000364
      UVEL(J)=U
      VVEL(J)=V
  511 IONIC(J)=100.0*SQRT((UU+VV)/AD)                                   00000365
      PRINT 28,(IONIC(J),J=JL,JU)                                       00000366
      IF(IPRT2.EQ.0) GO TO 510
      PRINT 2878,(UVEL(J),J=2,JMAX1)
      PRINT 2878,(VVEL(J),J=2,JMAX1)
  510 CONTINUE                                                          00000367
   28 FORMAT(1H ,40I3)                                                  00000368
      IF(NMACH.EQ.2)GO TO 519
      NMACH=NMACH+1
      JL=JB
      JU=JMAX1
      JDUM=JU-JL-42
      IF(JDUM.GT.0)JU=JL+42
      GO TO 513
 519  CONTINUE
      DO 9003 I=ILE,ITE                                                 00000369
      YU(I)=A1*TAN(PI/2.*YU(I))                                         00000370
 9003 YL(I)=A1*TAN(PI/2.*YL(I))                                         00000371
      CL=0.5*(CPL(ILE)-CPU(ILE))*(X(ILE)+0.5)                           00000372
      CPSTAG=2./(1.4*M*M)*((1.+0.2*M*M)**3.5-1.)                        00000373
      CD=(CPSTAG+CPU(ILE))*(YU(ILE))*0.5-(CPSTAG+CPL(ILE))*(YL(ILE))*0.500000374
      CMLE=0.5*(CPU(ILE)-CPL(ILE))*(X(ILE)+0.5)**2                      00000375
      IEND=ITE-1                                                        00000376
      DO 9000 I=ILE,IEND                                                00000377
      T1=CPL(I)-CPU(I)                                                  00000378
      T2=CPL(I+1)-CPU(I+1)                                              00000379
      T3=(X(I+1)-X(I))*0.5                                              00000380
      CL=CL+(T1+T2)*T3                                                  00000381
      IF(ITACT.EQ.1)GO TO 8010                                          00000382
      CD=CD+(CPU(I)+CPU(I+1))*0.5*(YU(I+1)-YU(I))-(CPL(I)+CPL(I+1))*0.5 00000383
     1*(YL(I+1)-YL(I))                                                  00000384
      GO TO 8011                                                        00000385
 8010 CD=CD+(CPU(I)+CPU(I+1))*.5*(YUORIG(I+1)-YUORIG(I))-(CPL(I)+CPL(I+100000386
     *))*.5*(YLORIG(I+1)-YLORIG(I))                                     00000387
 8011 CONTINUE                                                          00000388
      T6=-T1*(X(I)+0.5)                                                 00000389
      T7=-T2*(X(I+1)+0.5)                                               00000390
```

```fortran
 9000 CMLE=CMLE+(T6+T7)*T3                                                00000391
      CL=CL+0.5*(CPL(ITE)-CPU(ITE))*(0.5-X(ITE))                          00000392
      CMLE=CMLE+0.5*(CPU(ITE)-CPL(ITE))*(X(ITE)+0.5)*(0.5-X(ITE))         00000393
      IF(ITACT.EQ.1)GO TO 8012                                            00000394
      CD=CD-(CPU(ITE)+CPL(ITE))*0.5*(YU(ITE)-YL(ITE))                     00000395
      GO TO 8013                                                          00000396
 8012 CD=CD-CDCORR                                                        00000397
 8013 CONTINUE                                                            00000398
      FN=CL*COS(ALP)-CD*SIN(ALP)                                          00000399
      FT=CL*SIN(ALP)+CD*COS(ALP)                                          00000400
      CL=FN                                                               00000401
      CD=FT                                                               00000402
      CMC4=CMLE+CL/4.                                                     00000403
      CDWAV=CD                                                            00000404
      CD=CDWAV+CDF                                                        00000405
      PRINT 9012,CDWAV                                                    00000406
 9012 FORMAT(1H0,20X,'WAVE CD = ',F10.6)                                  00000407
      NOV=ITE-ILE+1                                                       00000408
      DO 114 I=ILE,ITE                                                    00000409
      J=I-ILE1                                                            00000410
      J1=J+NOV                                                            00000411
      J2=J+2*NOV                                                          00000412
      J3=J+3*NOV                                                          00000413
      J4=J+4*NOV                                                          00000414
      AA(J)=X(I)                                                          00000415
      AA(J1)=CPU(I)                                                       00000416
      AA(J2)=CPL(I)                                                       00000417
      AA(J3)=-YU(I)                                                       00000418
  114 AA(J4)=-YL(I)                                                       00000419
      NL=50                                                               00000420
      IF(NOV.GT.45)NL=100                                                 00000421
      CALL PLOT(ICASE,AA,NOV,5,NL,0)                                      00000422
      CLCIR=2.*CIR                                                        00000423
      PRINT 8002,CPSTAR,CLCIR                                             00000424
 8002 FORMAT(1H ,40X,'PRESSURE COEFFICIENT',//,41X,'CPSTAR = ',F10.4,    00000425
     1 5X,'CLCIR = ',F10.4)                                               00000426
      PRINT 9001,CL,CD,CMLE,CDF,CMC4                                      00000427
 9001 FORMAT(1H0,20X,'CL = ',F10.4,' CD = ',F10.6,' CMLE = ',F10.4,      00000428
     *' CDF = ',F10.6,' CMC4 = ',F10.4)                                   00000429
C************************************ ADDITION ********************
      XUSEP=X(ITE)
      IF(MHALF.EQ.1)GO TO 9051
      IF(INV.EQ.1)GO TO 9051
      IF(ITACT.EQ.0)GO TO 9051
      IF(IMASS.EQ.0)LSEP=LSEP1
      IF(MHALF.GT.1.AND.ITACT.NE.0)XUSEP=X(LSEP)
      PRINT 9050,XUSEP
9050  FORMAT('0XUSEP =',F10.5)
C******************************************************************
9051  PRINT 8003                                                          00000430
 8003 FORMAT(1H1)                                                         00000431
      IF(MHALF.GT.NHALF)GO TO 100                                         00000432
      MHALF=MHALF+1                                                       00000433
      MITER=MITER/2                                                       00000434
      CALL HALVE                                                          00000435
C                                                                         00000436
      IF(INV.EQ.1.AND.MHALF.EQ.3)MITER=400                                00000437
      IF(IMASS.EQ.1.AND.MHALF.EQ.3)MITER=400                              00000438
      IF(MHALF.EQ.4)MITER=400                                             00000439
C                                                                         00000440
      DPM=0.0                                                             00000441
```

```
      DPOLD=0.0                                                         00000442
      IDPM=1                                                            00000443
      DPMSUM=0.0                                                        00000444
      EPSS=EPSS0                                                        00000445
      EPS=EPS0                                                          00000446
      ITER=0                                                            00000447
      DELTAY=0.0                                                        00000448
      GO TO 101                                                         00000449
  100 CONTINUE                                                          00000450
      IF(INV.EQ.1)CALL BDLY                                             00000451
      IF(ITACT.EQ.1)GO TO 9014                                          00000452
      WRITE(7,9015)(X(I),YU(I),YL(I),CPU(I),CPL(I),I=ILE,ITE)           00000453
 9015 FORMAT(5F10.5)                                                    00000454
      STOP                                                              00000455
 9014 WRITE(7,9015)(X(I),YUORIG(I),YLORIG(I),CPU(I),CPL(I),I=ILE,ITE)   00000456
      STOP                                                              00000457
      END                                                               00000458
      SUBROUTINE FOIL                                                   00000459
CC  **********  READS IN INITIAL AIRFOIL SHAPE AND DETERMINES ORDINATES 00000460
C **********  AND SLOPES AT COMPUTATIONAL GRID POINTS ************       00000461
      REAL M                                                            00000462
      DIMENSION XI(99),YI(99),XO(99),YO(99),SI(99),SO(99),XP(99),YP(99),00000463
     1D1Y(99),D2Y(99),D3Y(99),XIB(99),YIB(99)                           00000464
      DIMENSION XOR(99)                                                 00000465
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00000466
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00000467
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900000468
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00000469
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00000470
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100000471
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00000472
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00000473
     1JMAX,JCON,JMAX1,NSSP,IW                                           00000474
      COMMON/FIX/MHALF                                                  00000475
      COMMON/RED/ITERP                                                  00000476
      COMMON/FIPUT/IREAD                                                00000477
      COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER00000478
     1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF                            00000479
      COMMON/IPT1/XIBDLY,RDEL,RDELFN,RCPB,SP,XSEP,CONV,CPB,XMON,XLSEP,  00000480
     1 MITER,LP,ITEUPC,ITELWC,XPC                                       00000481
     2,LBDLY,XLBDLY                                                     00000482
C     THIS PROGRAM DEPENDS UPON AIRFOIL BEING BEING STUDIED             00000483
      PRINT 2                                                           00000484
    2 FORMAT(1H0,20X,'AIRFOIL COORDINATES',/,5X,'X       YU         YL  00000485
     1   UPPER SLOPE LOWER SLOPE')                                      00000486
      IBDLY=ILE-1                                                       00000487
  215 IBDLY=IBDLY+1                                                     00000488
      IF(X(IBDLY).LT.XIBDLY)GO TO 215                                   00000489
      LBDLY=ILE-1                                                       00000490
  218 LBDLY=LBDLY+1                                                     00000491
      IF(X(LBDLY).LT.XLBDLY)GO TO 218                                   00000492
      IF(ITACT.EQ.1)GO TO 35                                            00000493
      IF(INV.EQ.0)GO TO 7                                               00000494
   35 IF(MHALF.LE.2)GO TO 7                                             00000495
      I=IMAX1/2                                                         00000496
      II=IMAX-2                                                         00000497
      ISTOR=I11                                                         00000498
      IF(ITACT.EQ.1)I11=IBDLY-1                                         00000499
    8 CPU(II)=CPU(I)                                                    00000500
      CPL(II)=CPL(I)                                                    00000501
      SLU(II)=SLU(I)                                                    00000502
```

```
      SLL(II)=SLL(I)                                                    00000503
      DUPOLD(II)=DUPOLD(I)                                              00000504
      DLWOLD(II)=DLWOLD(I)                                              00000505
      YU(II)=YU(I)                                                      00000506
      YL(II)=YL(I)                                                      00000507
      I=I-1                                                             00000508
      II=II-2                                                           00000509
      IF(II.GE.I11)GO TO 8                                              00000510
      IMAX2=IMAX-2                                                      00000511
      IS=II+3                                                           00000512
      DO 9 I=IS,IMAX2,2                                                 00000513
      DUPOLD(I)=.5*(DUPOLD(I+1)+DUPOLD(I-1))                            00000514
      DLWOLD(I)=.5*(DLWOLD(I+1)+DLWOLD(I-1))                            00000515
      CPU(I)=0.5*(CPU(I+1)+CPU(I-1))                                    00000516
      CPL(I)=0.5*(CPL(I+1)+CPL(I-1))                                    00000517
      SLU(I)=0.5*(SLU(I+1)+SLU(I-1))                                    00000518
      SLL(I)=0.5*(SLL(I+1)+SLL(I-1))                                    00000519
      YU(I)=0.5*(YU(I+1)+YU(I-1))                                       00000520
    9 YL(I)=0.5*(YL(I+1)+YL(I-1))                                       00000521
      YU(IMAX1)=0.0001                                                  00000522
      YL(IMAX1)=-0.0001                                                 00000523
      SLU(IMAX1)=0.0                                                    00000524
      SLL(IMAX1)=0.0                                                    00000525
      DUPOLD(IMAX1)=0.                                                  00000526
      DLWOLD(IMAX1)=0.                                                  00000527
      I11=ISTOR                                                         00000528
      GO TO 10                                                          00000529
    7 CONTINUE                                                          00000530
      DO 6 I=ITE1,IMAX                                                  00000531
      YUORIG(I)=.0001                                                   00000532
      YLORIG(I)=-0.0001                                                 00000533
      DUPOLD(I)=0.                                                      00000534
      DLWOLD(I)=0.                                                      00000535
      YU(I)=0.0001                                                      00000536
      YL(I)=-0.0001                                                     00000537
      SLU(I)=0.0                                                        00000538
    6 SLL(I)=0.0                                                        00000539
   10 IF(INV.EQ.1)IEND=I11                                              00000540
      IF(INV.EQ.0)IEND=ITE                                              00000541
      IF(MHALF.LT.3)IEND=ITE                                            00000542
C     UPPER SURFACE,XI IN PERCENT CHORD                                 00000543
      IF(MHALF.GT.1)GO TO 21                                            00000544
      READ 14, NI                                                       00000545
      READ 15,(XI(I),YI(I),I=1,NI)                                      00000546
      READ15,DERIX,DERIY,DERFX,DERFY                                    00000547
   14 FORMAT(I5)                                                        00000548
      DO 18 I=1,NI                                                      00000549
   18 XI(I)=XI(I)-0.5                                                   00000550
   21 DO 16 I=ILE,IEND                                                  00000551
      II=I-ILE+1                                                        00000552
   15 FORMAT(8F10.4)                                                    00000553
C  15 FORMAT(2F10.4)                                                    00000554
   16 XO(II)=X(I)                                                       00000555
      NO=IEND-ILE+1                                                     00000556
      CALL ARC(XI,YI,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,DERIX,DERFX,DERIY,   00000557
     1DERFY,NI,NO,1)                                                    00000558
      IF(ITACT.EQ.1)GO TO 23                                            00000559
      DO 17 I=ILE,IEND                                                  00000560
      II=I-ILE+1                                                        00000561
      DUPOLD(I)=0.                                                      00000562
      YU(I)=YO(II)                                                      00000563
```

```
      YUORIG(I)=YO(II)
   17 SLU(I)=YP(II)/XP(II)
      GO TO 25
   23 DO 24 I=ILE,IEND
      II=I-ILE+1
      IF(I.LT.IBDLY)GO TO 36
      IF(MHALF.GT.2)GO TO 26
   36 YU(I)=YO(II)
      YUORIG(I)=YO(II)
      DUPOLD(I)=0.
      SUPPER(I)=SO(II)
      SLU(I)=YP(II)/XP(II)
      GO TO 24
   26 YUORIG(I)=YO(II)
      SUPPER(I)=SO(II)
   24 CONTINUE
C     LOWER SURFACE, XI IN PERCENT CHORD
   25 IF(MHALF.GT.1)GO TO 22
      READ14,NIB
      READ15,(XIB(I),YIB(I),I=1,NIB)
      READ15,DERIXB,DERIYB,DERFXB,DERFYB
      DO 19 I=1,NIB
   19 XIB(I)=XIB(I)-0.5
   22 CALL ARC(XIB,YIB,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,DERIXB,DERFXB,
     1DERIYB,DERFYB,NIB,NO,1)
      IF(ITACT.EQ.1)GO TO 27
      DO 20 I=ILE,IEND
      II=I-ILE+1
      DLWOLD(I)=0.
      YL(I)=YO(II)
      YLORIG(I)=YO(II)
   20 SLL(I)=YP(II)/XP(II)
      GO TO 28
   27 DO 29 I=ILE,IEND
      II=I-ILE+1
      IF(I.LT.LBDLY)GO TO 37
      IF(MHALF.GT.2)GO TO 30
   37 YL(I)=YO(II)
      YLORIG(I)=YO(II)
      DLWOLD(I)=0.
      SLOWER(I)=SO(II)
      SLL(I)=YP(II)/XP(II)
      GO TO 29
   30 YLORIG(I)=YO(II)
      SLOWER(I)=SO(II)
   29 CONTINUE
      IF(IREAD.EQ.0)GO TO 28
      READ 217,(YU(I),YL(I),SLU(I),SLL(I),I=ILE,ITE)
      READ 217,(DUPOLD(I),DLWOLD(I),I=ILE,ITE)
  217 FORMAT(5E15.7)
   28 DO 1 I=ILE,IEND
C     NACA 00XX AIRFOIL CASE
C     T=0.12
C     XX=X(I)+0.5
C     YU(I)=(T/0.2)*(0.2969*SQRT(XX)-0.126*XX-0.3516*XX**2+0.2843*XX**3
C    1-0.1015*XX**4)
C       SLU(I)=T/0.2*(0.14845/SQRT(XX)-0.126-0.7032*XX+0.8529*XX**2
C    1-0.406*XX**3)
C     YL(I)=-YU(I)
C     SLL(I)=-SLU(I)
C     YLORIG(I)=YL(I)
```

```
C     YUORIG(I)=YU(I)
      PRINT 3, X(I),YU(I),YL(I),SLU(I),SLL(I)                           00000615
    3 FORMAT(5F10.5)                                                    00000616
    1 CONTINUE                                                          00000617
C     FINDING COORDS IN ETA-PSI SYSTEM                                  00000618
      DO 4 I=ILE,IMAX1                                                  00000619
      YU(I)=ATAN(YU(I)/A1)/PI2                                          00000620
    4 YL(I)=ATAN(YL(I)/A1)/PI2                                          00000621
      IF(INV.EQ.0)RETURN                                                00000622
      IF(IREAD.EQ.1.AND.MHALF.EQ.1)GO TO 103                            00000623
      IF(MHALF.EQ.1)RETURN                                              00000624
      IF(MHALF.GT.3.AND.ITERP.EQ.1)GO TO 100                            00000625
  103 CONTINUE                                                          00000626
      READ(5,5)(CPU(I),I=I1 ,ITE)                                       00000627
      CPU(I11)=0.0                                                      00000628
      READ(5,5)(CPL(I),I=I1 ,ITE)                                       00000629
      CPL(I11)=0.0                                                      00000630
      ITEP1=ITE+1                                                       00000631
      DO 339 I=ITEP1,IMAX                                               00000632
      CPU(I)=0.                                                         00000633
  339 CPL(I)=0.                                                         00000634
    5 FORMAT(8F10.3)                                                    00000635
  100 CONTINUE                                                          00000636
      PRINT 101                                                         00000637
  101 FORMAT(1H0,20X,'UPPER CP INPUT')                                  00000638
      PRINT 5,(CPU(I),I=I1 ,ITE)                                        00000639
      PRINT 102                                                         00000640
  102 FORMAT(1H0,20X,'LOWER CP INPUT')                                  00000641
      PRINT 5,(CPL(I),I=I1 ,ITE)                                        00000642
      RETURN                                                            00000643
      END                                                               00000644
      SUBROUTINE VISACT                                                 00000645
C                                                                       00000646
C  *********  COMPUTES BOUNDARY LAYER WHEN VISCOUS INTERACTION INCLUDED 00000647
C**********   IN THE ANALYSIS CASE    **************                    00000648
C                                                                       00000649
      REAL M,NEW                                                        00000650
      INTEGER SEPMK                                                     00000651
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00000652
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00000653
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900000654
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00000655
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00000656
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100000657
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00000658
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00000659
     1JMAX,JCON,JMAX1,NSSP,IW                                           00000660
      COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER00000661
     1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF                            00000662
      COMMON/DELTA/ITER                                                 00000663
      COMMON/IPT1/XIBDLY,RDEL,RDELFN,RCPB,SP,XSEP,CONV,CPB,XMON,XLSEP,  00000664
     1 MITER,LP,ITEUPC,ITELWC,XPC                                       00000665
     2,LBDLY,XLBDLY                                                     00000666
      COMMON/IPT2/IMASS                                                 00000667
      COMMON/FIX/MHALF                                                  00000668
      COMMON/SETCPS/CPSPO,RLAX                                          00000669
      COMMON/IPT3/ISIDE,ILAM,RADUS                                      00000670
C************************************ ADDITION ********************
      COMMON/SEPTRP/LSEP,LSEP1
C******************************************************************
      DIMENSION UE(99),DSS(99),DUDS(99),YUN(99),YLN(99),EM(99)          00000671
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      DIMENSION XI(99),YI(99),XO(99),YO(99),SI(99),SO(99),XP(99),YP(99),00000672
     1D1Y(99),D2Y(99),D3Y(99),XIB(99),YIB(99)                           00000673
      DIMENSION HS(99),XOR(99)                                          00000674
      DIMENSION CPUT(99),CPLT(99)                                       00000675
      IF(MHALF.EQ.2.AND.ITER.LE.50)LSPOLD=ITE                           00000676
      IF(MHALF.GT.2.AND.ITER.LE.50)LSPOLD=LSPOLD*2-1                    00000677
      SEPMK=0                                                           00000678
C*************************************** ADDITION *******************
      LSEP1=ITE
C********************************************************************
      IF(IMAX.GT.55)RDEL=RDELFN                                         00000679
      ISIDE=0                                                           00000680
      ICYCLE=1                                                          00000681
      ICYBOT=1                                                          00000682
      CALL PRESS                                                        00000683
      IF(DPM.LE.CONV)GO TO 5009                                         00000684
      IF(ITER.GE.(MITER-1))GO TO 5009                                   00000685
      GO TO 5005                                                        00000686
 5009 DO 5006 J=ILE,IMAX1                                               00000687
      CPUT(J)=CPU(J)                                                    00000688
 5006 CPLT(J)=CPL(J)                                                    00000689
 5005 CONTINUE                                                          00000690
      JB2=JB-2                                                          00000691
      DO 3010 J=JB2,JMAX1                                               00000692
      IF(YU(ITE).GT.E(J).AND.YU(ITE).LE.E(J+1))GO TO 3011               00000693
 3010 CONTINUE                                                          00000694
 3011 JA=J+1                                                            00000695
      IF(JA.LE.JB)JA=JB+1                                               00000696
      PHITE=P(ITE,JA-1)+(P(ITE,JA)-P(ITE,JA-1))*(YU(ITE)-E(JA-1))/DE    00000697
      DO 500 J=ILE,ITE                                                  00000698
      YU(J)=A1*TAN(PI/2.*YU(J))                                         00000699
  500 YL(J)=A1*TAN(PI/2.*YL(J))                                         00000700
 5061 CONTINUE                                                          00000701
      TR=0.3424                                                         00000702
      TE1=5.E-03                                                        00000703
      TE2=5.E-05                                                        00000704
      LMON=IMAX1/2+1                                                    00000705
 4001 LMON=LMON+1                                                       00000706
      IF(X(LMON).LT.XMON)GO TO 4001                                     00000707
      LSEP=IMAX1/2+1                                                    00000708
 4002 LSEP=LSEP+1                                                       00000709
      IF(X(LSEP).LT.XLSEP)GO TO 4002                                    00000710
      IF(IMASS.EQ.1)LSEP=ITE                                            00000711
      CM=1.+.2*M**2                                                     00000712
 1000 ISIDE=ISIDE+1                                                     00000713
      SEPMK=0                                                           00000714
      DO 2 J=ILE,ITE                                                    00000715
      DEL(J)=0.                                                         00000716
      IF(ISIDE.EQ.2)GO TO 3                                             00000717
      CP=CPU(J)                                                         00000718
    4 TEST=(5.*(CM/(1.+.7*CP*M**2)**(.2857143)-1.))                     00000719
      EM(J)=0.001                                                       00000720
      IF(TEST.GT.0.)EM(J)=SQRT(TEST)                                    00000721
      DD=1.+.2*EM(J)**2                                                 00000722
      T=CM/DD                                                           00000723
      UE(J)=EM(J)/M*SQRT(T)                                             00000724
      GO TO 2                                                           00000725
    3 CP=CPL(J)                                                         00000726
      GO TO 4                                                           00000727
    2 CONTINUE                                                          00000728
      IF(ISIDE.EQ.1)USTR=UE(ITE)                                        00000729
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      ILEP1=ILE+1                                                       00000730
      DSS(ILE)=SLOWER(ILE)                                              00000731
      IF(ISIDE.EQ.1)DSS(ILE)=SUPPER(ILE)                                00000732
      DO 5 J=ILEP1,ITE                                                  00000733
      IF(ISIDE.EQ.2)GO TO 6                                             00000734
      DSS(J)=SUPPER(J)-SUPPER(J-1)                                      00000735
      GO TO 5                                                           00000736
    6 DSS(J)=SLOWER(J)-SLOWER(J-1)                                      00000737
    5 DUDS(J)=(UE(J)-UE(J-1))/DSS(J)                                    00000738
      DT=1.                                                             00000739
      SEPR=0.                                                           00000740
      HH=0.                                                             00000741
      IBDS=ITE-1                                                        00000742
      IF(ISIDE.EQ.1)ISTART=IBDLY                                        00000743
      IF(ISIDE.EQ.2)ISTART=LBDLY                                        00000744
C     ILAM=1                                                            00000745
      IF(ILAM.EQ.0)GO TO 5060                                           00000746
      CALL THWAIT(THETA,HH,UE,DSS,DUDS,ISTART)                          00000747
      IF(ISIDE.EQ.1)IBDLY=ISTART                                        00000752
      IF(ISIDE.EQ.2)LBDLY=ISTART                                        00000753
      IF(ISTART.GE.ITE)THET2=THETA                                      00000754
      IF(ISTART.GE.ITE)GO TO 202                                        00000755
 5060 CONTINUE                                                          00000756
      IF(ITER/LP*LP.EQ.ITER)PRINT 1,RN                                  00000748
    1 FORMAT(1HO,10X,'BOUNDARY LAYER ANALYSIS FOR REYNOLDS NO. OF ',E10.00000749
     13,//,5X,'X',9X,                 'M',8X,'DELs',4X,'THETA',3X,'SEP',00000750
     210X,'H',9X,'PI',5X,'TAU')                                         00000751
      DO 200 J=ISTART,IBDS                                              00000757
      EMT=(EM(J+1)+EM(J))/2.                                            00000758
      UESA=(UE(J+1)+UE(J))/2.                                           00000759
      VM=1.+.2*EMT**2                                                   00000760
      T=CM/VM                                                           00000761
      RFT=UESA*(T+TR)*T/(1.+TR)*RN                                      00000762
      IF(J.NE.ISTART)GO TO 30                                           00000763
      THET1=320./RFT                                                    00000764
      IF(ILAM.EQ.1)THET1=THETA                                          00000765
      THET2=THET1                                                       00000766
      GE=6.5                                                            00000767
   30 FC=1.+.066*EMT**2-.008*EMT**3                                     00000768
      FR=1.-.134*EMT**2+.027*EMT**3                                     00000769
      IND=0                                                             00000770
   40 IND=IND+1                                                         00000771
      IF(THET1.LT.1.E-06)THET1=1.E-06                                   00000772
      IF(FR.LT.0.)FR=ABS(FR)                                            00000773
      IF(RFT.LT.0.)RFT=ABS(RFT)                                         00000774
      TAU=     (FC*(2.4711*ALOG(FR*RFT*THET1)+4.75)+1.5*GE+1724./(GE**2+00000775
     1200.)-16.87)                                                      00000776
      IF(TAU.LT.0.)TAU=-TAU                                             00000777
      TAU=1./TAU**2                                                     00000778
      IF(TAU.LT.1.E-06)TAU=1.E-06                                       00000779
      HB=1./(1.-GE*SQRT(TAU))                                           00000780
      H=(HB+1.)*(1.+.178*EMT**2)-1.                                     00000781
      SEP=-THET1*DUDS(J+1)/UESA                                         00000782
      IF(SEP.GT.1.0)SEP=1.0                                             00000783
      IF(SEP.LT.SP)GO TO 41                                             00000784
      IF(ISIDE.EQ.1.AND.IMASS.EQ.1) GO TO 3005                          00000785
      IF(X(J+1).LT.XSEP)SEP=SP                                          00000786
      GO TO 3006                                                        00000787
 3005 IF(X(J+1).LT.XLSEP)SEP=SP                                         00000788
 3006 CONTINUE                                                          00000789
   41 PII=H*SEP/TAU                                                     00000790
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      IF(PII.LT.-1.5)PII=-1.5                                           00000791
      IF(PII.GT.1.E4)PII=1.E4                                           00000792
   50 CONTINUE                                                          00000793
      G=6.1*SQRT(PII+1.81)-1.7                                          00000794
      T2=ABS((G-GE)/GE)                                                 00000795
      GE=G                                                              00000796
      DT2=DT                                                            00000797
      DT=(H+2.-EMT**2)*SEP+TAU                                          00000798
      IF(IND.GT.1)GO TO 100                                             00000799
      THT=THET2                                                         00000800
      THET1=DT*DSS(J+1)+THT                                             00000801
      THET1=.5*(THET1+THT)                                              00000802
      GO TO 40                                                          00000803
  100 DT=(DT2+DT)/2.                                                    00000804
      TI=ABS((DT-DT2)/DT)                                               00000805
      IF(TI.LT.TE2)GO TO 120                                            00000806
  110 THET1=DT*DSS(J+1)+THT                                             00000807
      THET1=.5*(THET1+THT)                                              00000808
      IF(IND.LE.500)GO TO 40                                            00000809
      IF(PII.EQ.-1.5)GO TO 130                                          00000810
      GO TO 130                                                         00000811
  120 IF(T2.GE.TE1)GO TO 110                                            00000812
  130 THET2=DT*DSS(J+1)+THT                                             00000813
      THET1=.5*(THET2+THT)                                              00000814
      SEP=-THET1*DUDS(J+1)/UESA                                         00000815
      SEPR=(SEPR*DSS(J+1)+SEP*DSS(J))/(DSS(J)+DSS(J+1))                 00000816
      HH=(HH*DSS(J+1)+H*DSS(J))/(DSS(J)+DSS(J+1))                       00000817
      DELS=HH*THT                                                       00000818
      DEL(J)=DELS                                                       00000819
      HS(J)=HH                                                          00000820
      IF(DEL(J).GT.0.1)DEL(J)=0.1                                       00000821
      IF(IMASS.EQ.1) GO TO 3001                                         00000822
      GO TO 3004                                                        00000823
 3001 IF(ISIDE.EQ.2)GO TO 3004                                          00000824
      IF(J.NE.LSPOLD)GO TO 3015
      EMSTR=EM(LSPOLD)
      USTR=UE(LSPOLD)
      HSTR=HH
      TSTR=THT/(X(LSPOLD)+0.50)
 3015 CONTINUE
      IF(SEPMK.EQ.1) GO TO 3004                                         00000825
      IF(SEPR.GT.SP)LSEP=J                                              00000826
      IF(LSEP.LT.ITE)SEPMK=1                                            00000827
 3004 CONTINUE                                                          00000828
      IF(ITER/LP*LP.EQ.ITER)PRINT 10,X(J),EM(J),DELS,THT,SEPR,HH,PII,TAU00000829
   10 FORMAT(9F10.5,I10,F10.5)                                          00000830
C*********************************** ADDITION **********************
      IF(IMASS.EQ.1)GOTO 205
      IF(ISIDE.EQ.2)GOTO 205
      IF(SEPMK.EQ.1)GOTO 205
      IF(SEPR.GT.SP)LSEP1=J
      IF(LSEP1.LT.ITE)SEPMK=1
C*******************************************************************
  205 CONTINUE                                                          00000831
    9 CONTINUE                                                          00000832
      IF(J.EQ.IBDS)GO TO 200                                            00000833
      SEPR=SEP                                                          00000834
      HH=H                                                              00000835
  200 CONTINUE                                                          00000836
      SEPR=-SEPR+2.*SEP                                                 00000837
      HH=HS(ITE-1)+(DSS(ITE)/DSS(ITE-1))*(HS(ITE-1)-HS(ITE-2))          00000838
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```
      HS(ITE)=HH                                                        00000839
      DELS=HH*THET2                                                     00000840
      DEL(ITE)=DELS                                                     00000841
      IF(DEL(ITE).GT.0.1)DEL(ITE)=0.1                                   00000842
      IF(IMASS.EQ.1)GO TO 3002                                          00000843
 3002 CONTINUE                                                          00000844
      IF(ITER/LP*LP.EQ.ITER)PRINT10,X(ITE),EM(ITE),DELS,THET2,SEPR,     00000845
     *HH,PII,TAU                                                        00000846
  202 IF(ISIDE.EQ.2)GO TO 203                                           00000847
C********************************** ADDITION **********************
      IF(LSPOLD.EQ.ITE) GOTO 72
      IF(IMASS.EQ.1)GO TO 440
   72 EMSTR=EM(ITE)                                                     00000848
      USTR=UE(ITE)
C*****************************************************************
      HSTR=HH                                                           00000849
      TSTR=THET2                                                        00000850
  440 CONTINUE
      DO 170 J=ILE,IBDS                                                 00000851
  170 IF(DEL(J+1).LT.DEL(J))DEL(J+1)=DEL(J)                             00000852
  203 CONTINUE                                                          00000853
      IF(ISIDE.EQ.1)GO TO 2200                                          00000854
      J=ILE                                                             00000855
 2180 J=J+1                                                             00000856
      IF(DEL(J+1).LT.DEL(J))GO TO 2185                                  00000857
      IF(J.LT.IBDS)GO TO 2180                                           00000858
      GO TO 2200                                                        00000859
 2185 IF(X(J).GT.XPC)GO TO 2190                                         00000860
      DEL(J+1)=DEL(J)                                                   00000861
      GO TO 2180                                                        00000862
 2190 J=J+1                                                             00000863
      IF(J.GT.IBDS)GO TO 2200                                           00000864
      IF(DEL(J+1).GT.DEL(J))DEL(J+1)=DEL(J)                             00000865
      IF(J.LT.IBDS)GO TO 2190                                           00000866
 2200 CONTINUE                                                          00000867
      ISMOTH=2                                                          00000868
      IF(IMAX.GT.55)ISMOTH=4                                            00000869
      DO 171 JJ=1,ISMOTH                                                00000870
      OLD=DEL(ILE)                                                      00000871
      ILEP2=ILE+2                                                       00000872
      DO 171 J=ILEP2,ITE                                                00000873
      NEW=DEL(J-1)                                                      00000874
      DEL(J-1)=.25*(OLD+NEW+NEW+DEL(J))                                 00000875
  171 OLD=NEW                                                           00000876
      FAC=-DSS(ITE)/DSS(ITE-1)                                          00000877
      DEL(ITE)=FAC*DEL(ITE-2)+(1.-FAC)*DEL(ITE-1)                       00000878
      DO 172 J=ILEP1,IBDS                                               00000879
      SLOPE=SLU(J)                                                      00000880
      IF(ISIDE.EQ.2)SLOPE=SLL(J)                                        00000881
      CO=ABS(ATAN(SLOPE))                                               00000882
      CO=COS(CO)                                                        00000883
      IF(ISIDE.EQ.2)GO TO 173                                           00000884
      DY=DUPOLD(J)+RDEL*(DEL(J)-DUPOLD(J))                              00000885
      YU(J)=YUORIG(J)+DY/CO                                             00000886
      DUPOLD(J)=DY                                                      00000887
      GO TO 172                                                         00000888
  173 DY=DLWOLD(J)+RDEL*(DEL(J)-DLWOLD(J))                              00000889
      YL(J)=YLORIG(J)-DY/CO                                             00000890
      DLWOLD(J)=DY                                                      00000891
      GO TO 172                                                         00000892
  172 CONTINUE                                                          00000893
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        SLOPE=SLU(ITE)
       IF(ISIDE.EQ.2)SLOPE=SLL(ITE)
       CO=ABS(ATAN(SLOPE))
       CO=COS(CO)
       IF(ISIDE.EQ.2)GO TO 175
       DY=DUPOLD(ITE)+RDEL*(DEL(ITE)-DUPOLD(ITE))
       YU(ITE)=YUORIG(ITE)+DY/CO
       DUPOLD(ITE)=DY
       GO TO 204
  175  DY=DLWOLD(ITE)+RDEL*(DEL(ITE)-DLWOLD(ITE))
       YL(ITE)=YLORIG(ITE)-DY/CO
       DLWOLD(ITE)=DY
  204  CONTINUE
       IF(ITEUPC.EQ.0)GO TO 5003
C      **INSERT SEPERATED CORRECTION HERE IF DESIRED**
C      ** SEPERATED COORECTION**
       IF(ISIDE.EQ.2)GO TO 5003
       IF(ICYCLE.GT.1)GO TO 300
       LMON=IMAX/2+1
       CPB=0.
       DO 5001 J=LMON,IBDS
       CPN=CPL(J)
       CPB=AMAX1(CPB,CPN)
 5001  CONTINUE
       CPB=0.6
       PRINT 5002,CPB
 5002  FORMAT(' ','BASE PRESSURE COEFFICIENT = ',F10.3)
       IF(LSEP.EQ.ITE)LSEP=ITE-1
       LSEP1=LSEP+1
       SLOP=(CPB-CPU(LSEP))/(.5-X(LSEP))
       DO 501 J=LSEP1,ITE
  501  CPU(J)=SLOP*(X(J)-X(LSEP))+CPU(LSEP)
       ICYCLE=ICYCLE+1
       ISIDE=0
       GO TO 1000
 5003  CONTINUE
       IF(ITELWC.EQ.0)GO TO 300
       IF(ISIDE.EQ.1)GO TO 300
C      ** LOWER SURFACE CORRECTION, IF DESIRED**
       IF(ICYBOT.GT.1)GO TO 300
       IF(LSEP.EQ.ITE)LSEP=ITE-1
       SLOP=(CPB-CPL(LSEP))/(.5-X(LSEP))
       LSEP1=LSEP+1
       DO 5004 J=LSEP1,ITE
 5004  CPL(J)=SLOP*(X(J)-X(LSEP))+CPL(LSEP)
       ICYBOT=ICYBOT+1
       ISIDE=1
       GO TO 1000
C      ** END SEPERATED REGION CORRECTION **
  300  CONTINUE
       IF(ISIDE.LT.2)GO TO 1000
       XO(1)=-.5
       XI(1)=-.5
       YI(1)=0.
       NI=ITE-ILE+2
       DO 210 I=ILE,ITE
       II=I-ILE+2
       XI(II)=X(I)
       XO(II)=X(I)
  210  YI(II)=YU(I)
       NO=NI
```

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      CALL ARC(XI,YI,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,0.0,0.0,1.0,0.0,NI,  00000955
     1NO,1)                                                             00000956
      DO 211 I=ILE,ITE                                                  00000957
      II=I-ILE+2                                                        00000958
      YI(II)=YL(I)                                                      00000959
      IF(I.LT.IBDLY)GO TO 211                                           00000960
      SLU(I)=YP(II)/XP(II)                                              00000961
  211 CONTINUE                                                          00000962
      IF(ITEUPC.EQ.0)GO TO 5025                                         00000963
      LSEP1=LSEP+1                                                      00000964
      IF(XPC.LT.0.495)GO TO 5029                                        00000965
      DO 5030 J=LSEP1,ITE                                               00000966
      IF(SLU(J).GT.0.0)GO TO 5031                                       00000967
 5030 CONTINUE                                                          00000968
      GO TO 5025                                                        00000969
 5031 DO 5032 I=J,ITE                                                   00000970
      YU(I)=YU(J-1)                                                     00000971
 5032 SLU(I)=0.0                                                        00000972
      GO TO 5025                                                        00000973
 5029 CONTINUE                                                          00000974
      DO 5026 I=LSEP1,ITE                                               00000975
      YU(I)=YU(LSEP)+SLU(LSEP)*(X(I)-X(LSEP))                           00000976
 5026 SLU(I)=SLU(LSEP)                                                  00000977
 5025 CONTINUE                                                          00000978
      CALL ARC(XI,YI,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,0.0,0.0,-1.0,0.0,    00000979
     1NI,NO,1)                                                          00000980
      DO 212 I=ILE,ITE                                                  00000981
      II=I-ILE+2                                                        00000982
      YU(I)=ATAN(YU(I)/A1)/PI2                                          00000983
      YL(I)=ATAN(YL(I)/A1)/PI2                                          00000984
      IF(I.LT.LBDLY)GO TO 212                                           00000985
      SLL(I)=YP(II)/XP(II)                                              00000986
  212 CONTINUE                                                          00000987
      IF(ITELWC.EQ.0)GO TO 5027                                         00000988
      LSEP1=LSEP+1                                                      00000989
      IF(XPC.LT.0.495)GO TO 5036                                        00000990
      DO 5033 J=LSEP1,ITE                                               00000991
      IF(SLL(J).LT.0.0)GO TO 5034                                       00000992
 5033 CONTINUE                                                          00000993
      GO TO 5027                                                        00000994
 5034 DO 5035 I=J,ITE                                                   00000995
      YL(I)=YL(J-1)                                                     00000996
 5035 SLL(I)=0.0                                                        00000997
      GO TO 5027                                                        00000998
 5036 CONTINUE                                                          00000999
      DO 5028 I=LSEP1,ITE                                               00001000
      YL(I)=YL(LSEP)+SLL(LSEP)*(X(I)-X(LSEP))                           00001001
 5028 SLL(I)=SLL(LSEP)                                                  00001002
 5027 CONTINUE                                                          00001003
      HBT=(HSTR+1.)/(1.+.178*EMSTR**2)-1.                               00001004
      HBB=(HH+1.)/(1.+.178*EM(ITE)**2)-1.                               00001005
      CDF=TSTR*(USTR**(2.5+.5*HBT))+THET2*(UE(ITE)**(2.5+.5*HBB))       00001006
      CDF=2.*CDF                                                        00001007
      IF(DPM.LE.CONV) GO TO 5010                                        00001008
      IF(ITER.GE.(MITER-1))GO TO 5010                                   00001009
      GO TO 5008                                                        00001010
 5010 DO 5007 J=ILE,IMAX1                                               00001011
      CPU(J)=CPUT(J)                                                    00001012
 5007 CPL(J)=CPLT(J)                                                    00001013
 5008 CONTINUE                                                          00001014
      IF(IMASS.EQ.0)GO TO 3007                                          00001015
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      IF(MHALF.EQ.4)LSEP=LSPOLD                                         00001016
      IF(LSEP.GT.LSPOLD)LSEP=LSPOLD                                     00001017
      IF(LSEP.GE.(ITE-1))GO TO 3008                                     00001018
      I1=LSEP                                                           00001019
      I11=I1-1                                                          00001020
      X1=X(I1)-0.001                                                    00001021
      X2=0.5                                                            00001022
      JB2=JB-2                                                          00001023
      DO 3012 J=JB2,JMAX1                                               00001024
      IF(YU(I1).GT.E(J).AND.YU(I1).LE.E(J+1))GO TO 3013                 00001025
 3012 CONTINUE                                                          00001026
 3013 JA=J+1                                                            00001027
      IF(JA.LE.JB)JA=JB+1                                               00001028
      PHSEP=P(I1,JA-1)+(P(I1,JA)-P(I1,JA-1))*(YU(I1)-E(JA-1))/DE        00001029
      CPU(LSEP)=-2.*(PHITE-PHSEP)/(X(ITE)-X(LSEP))                      00001030
      CPU(LSEP)=CPSPO+RLAX*(CPU(LSEP)-CPSPO)                            00001031
      CPSPO=CPU(LSEP)                                                   00001032
      DO 3009 J=LSEP,ITE                                                00001033
 3009 CPU(J)=CPU(LSEP)                                                  00001034
      PRINT 6152,X(LSEP),CPU(LSEP)                                      00001035
 6152 FORMAT(' ',2X,'SEPARATION AT ',F10.5,5X,'SEPARATED CP IS ',F10.5) 00001036
      LSPOLD=LSEP                                                       00001037
      RETURN                                                            00001038
 3008 I1=ITE+1                                                          00001039
      I11=I1-1                                                          00001040
      X1=0.5                                                            00001041
      X2=10000.0                                                        00001042
 3007 CONTINUE                                                          00001043
C******************************** ADDITION *************************
      IF(X(LSEP1).GE.X(ITE))GOTO 3091
      PRINT 3092,X(LSEP1)
3092  FORMAT(' UPPER SURFACE SEPARATION AT 'G15.9)
      RETURN
3091  PRINT 3093,X(ITE)
3093  FORMAT(' NO UPPER SURFACE SEPARATION BEFORE ',F10.5)
C*****************************************************************
      RETURN                                                            00001044
      END                                                               00001045
      SUBROUTINE THWAIT(THETA,HH,UE,DSS,DUDS,ISTART)                    00001046
C ***** THIS SUBROUTINE IS BASED UPON A NASA LANGLEY   *****************
C ***** PROGRAM ORIGINALLY DEVELOPED BY THE GRUMMAN    *****************
C ***** AEROSPACE CORPORATION  ******************************************
      REAL M                                                            00001047
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001048
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001049
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001050
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001051
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001052
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001053
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00001054
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001055
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001056
      COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER00001057
     1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF                            00001058
      COMMON/DELTA/ITER                                                 00001059
      COMMON/IPT1/XIBDLY,RDEL,RDELFN,RCPB,SP,XSEP,CONV,CPB,XMON,XLSEP,  00001060
     1 MITER,LP,ITEUPC,ITELWC,XPC                                       00001061
     2,LBDLY,XLBDLY                                                     00001062
      COMMON/IPT2/IMASS                                                 00001063
      COMMON/FIX/MHALF                                                  00001064
      COMMON/SETCPS/CPSPO,RLAX                                          00001065
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      COMMON/IPT3/ISIDE,ILAM,RADUS                                      00001066
      DIMENSION UE(99),DSS(99),DUDS(99)                                 00001067
      DIMENSION TWM(29),TWL(29),TWH(29),UBAR(500)                       00001068
      DIMENSION HP(29),HPP(29),HPPP(29),PL(29),PPL(29),PPPL(29)         00001069
      F1(YY,Y1,Y2,Y3,DB)=YY+DB*(Y1+.5*DB*(Y2+DB*Y3/3.))                 00001070
      F2(A1,A2,DS)=.5*DS*(A1+A2)                                        00001071
      DATA TWL/0.500.0.463,0.404,0.382,0.359,0.333,0.313,               00001072
     1        0.291,0.268,0.244,0.220,0.208,0.195,0.182,0.168,          00001073
     2        0.153,0.138,0.130,0.122,0.113,0.104,0.095,0.085,          00001074
     3        0.072,0.056,0.038,0.027,0.015,0.000/                      00001075
      DATA TWH/2.00,2.07,2.18,2.23,2.28,2.34,2.39,2.44,2.49,            00001076
     1   2.55,2.61,2.64,2.67,2.71,2.75,2.81,2.87,2.90,2.94,2.99,        00001077
     2   3.04,3.09,3.15,3.22,3.30,3.39,3.44,3.49,3.55/                  00001078
      DATA TWM/-0.25,-0.20,-0.14,-0.12,-0.10,-0.080,-0.064,             00001079
     1   -0.048,-0.032,-0.016,0.0,0.008,0.016,0.024,0.032,0.040,        00001080
     2   0.048,0.052,0.056,0.060,0.064,0.068,0.072,                     00001081
     3   0.076,0.080,0.084,0.086,0.088.0.090/                           00001082
      DATA MM /0/                                                       00001083
      IBUB=0                                                            00001084
      IF(MM.NE.0) GO TO 2                                               00001085
      CALL FIT2 (29,TWM,TWH,HP,HPP,HPPP,3,3,0.,0.)                      00001086
      CALL FIT2 (29,TWM,TWL,PL,PPL,PPPL,3,3,0.,0:)                      00001087
      MM      = 1                                                       00001088
      RE=RN                                                             00001089
      AMACH=M                                                           00001090
      R=1.0                                                             00001091
      OMEG=1.0                                                          00001092
      RCVF=0.89                                                         00001093
C     RADUS=0.035                                                       00001094
    2 CONTINUE                                                          00001095
      KTRAN= 0                                                          00001096
      SINT= 0.                                                          00001097
      VAL     = .2                                                      00001098
      UBAR5B= 0.                                                        00001099
      IF(ITER/LP*LP.EQ.ITER)PRINT 100                                   00001100
      TRAT    = SQRT(.5*RADUS/RE)*(1.+.2*AMACH**2)**(-.75)              00001101
      DELTA1= 0.64474*TRAT                                              00001102
      DELTA2= 0.29478*TRAT                                              00001103
      H= 2.187                                                          00001104
      TM= -0.08695                                                      00001105
      RD1= 0.                                                           00001106
      RD2= 0.                                                           00001107
      CFV=1.E+10                                                        00001108
      N=ILE-1                                                           00001109
      T1      = 0.                                                      00001110
      R1      = 1.                                                      00001111
      XSURF=-0.50                                                       00001112
      DUDS(ILE)=UE(ILE)/DSS(ILE)                                        00001113
      SLG=DSS(ILE)                                                      00001114
      IF(ISIDE.EQ.1)GO TO 1001                                          00001115
      DO 1002 J=ILE,ITE                                                 00001116
      IF(CPL(J+1).LT:CPL(J))GO TO 1003                                  00001117
 1002 CONTINUE                                                          00001118
 1003 IF(J.EQ.ILE)GO TO 1001                                            00001119
      N=J                                                               00001120
      XSURF=X(N)                                                        00001121
      SLG=DSS(N+1)                                                      00001122
 1001 CONTINUE                                                          00001123
      IF(ITER/LP*LP.EQ.ITER)PRINT 101,XSURF,CFV,DELTA1,DELTA2,H,RD2,    00001124
     1 RD1,TM                                                           00001125
    5 DELTP1= DELTA1                                                    00001126
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      DELTP2= DELTA2                                                    00001127
      U=UE(N+1)                                                         00001128
      UP=DUDS(N+1)                                                      00001129
      T2      = U**2*((1.+.2*AMACH**2*(U**2-1)))**2.5                   00001130
      UBAR(N+1)= U                                                      00001131
      TMO     = TM                                                      00001132
      UBAR5A= UBAR5B                                                    00001133
      QQQ= SQRT(1.+VAL*AMACH**2*(1.-UBAR(N+1)**2))                      00001134
      FMACH= AMACH*UBAR(N+1)/QQQ                                        00001135
      TRAT= 1.+VAL*FMACH**2                                             00001136
      UBAR5B= UBAR(N+1)**5/TRAT**(1.5)*R**2                             00001137
      SINT=SINT+F2(UBAR5A,UBAR5B,DSS(N+1))                              00001138
      TTT= 0.45*SINT/UBAR(N+1)**6*TRAT**3/R**2                          00001139
      TM      = -UP*TTT/SQRT(TRAT)                                      00001140
      IF(TM.GT.0.090) GO TO 19                                          00001141
      DO 6 J=1,28                                                       00001142
      IF(TWM(J+1).GT.TM) GO TO 60                                       00001143
    6 CONTINUE                                                          00001144
   60 DB=TM-TWM(J)                                                      00001145
      TL=F1       (TWL(J),PL(J),PPL(J),PPPL(J),DB)                      00001146
      HINC=F1     (TWH(J),HP(J),HPP(J),HPPP(J),DB)                      00001147
      IF(HINC.LT.1.0) HINC= 1.0                                         00001148
      IF(TL.LT.0.) TL= 0.                                               00001149
      H= TRAT*(HINC+1.)-1.                                              00001150
      DELTA2  = SQRT(TTT/RE)*(1.+.2*AMACH**2)**(-.75)                   00001151
      DELTA1= H *DELTA2                                                 00001152
      RD2     = RE*UBAR(N+1)*DELTA2*QQQ**3.                             00001153
      RD1= H *RD2                                                       00001154
      CFV=2.*TL/RD2                                                     00001155
      DEL(N+1)=DELTA1                                                   00001156
      N= N+1                                                            00001157
      SM=SLG                                                            00001158
C***************************************** ADDITION *****************
      IF(N.EQ.ITE) GO TO 30
C********************************************************************
      SLG=SLG+DSS(N+1)                                                  00001159
C*********************************** MODIFY *********************
30    IF(ITER/LP*LP.EQ.ITER)PRINT 101,X(N),CFV,DELTA1,DELTA2,H,RD2,RD1, 00001160
     1 TM                                                               00001161
   14 IF(KTRAN.GT.0) GO TO 15                                           00001162
      RD2TR= 217.-11787.*TM+366762*TM**2-4380632.*TM**3                 00001163
     1   +10453860.*TM**4                                               00001164
      IF(RD2.LT.RD2TR) GO TO 21                                         00001165
      KTRAN= 1                                                          00001166
      KT=1                                                              00001167
      IF(ITER/LP*LP.EQ.ITER)PRINT 33,X(N)                               00001168
   33 FORMAT(3X,'INSTABILITY DETECTED AT X=',F10.5)                     00001169
      UNSTM= -TM                                                        00001170
      RD2UNS= RD2                                                       00001171
      SSHF= 0.                                                          00001172
      SUNST= SM                                                         00001173
      GO TO 21                                                          00001174
   15 SSHF=SSHF-F2(TMO,TM,DSS(N))/(SM-SUNST)                            00001175
      RD2TR= RD2UNS+914.+27250.*SSHF+328333*SSHF**2                     00001176
      IF(RD2.GT.RD2TR) GO TO 25                                         00001177
      GO TO 21                                                          00001178
   19 IBUB=1                                                            00001179
      IF(ITER/LP*LP.NE.ITER)GO TO 27                                    00001180
      WRITE(6,102)X(N)                                                  00001181
      IF(RD2.GT.135.)WRITE(6,107)X(N)                                   00001182
      IF(RD2.LT.135.)WRITE(6,108)X(N)                                   00001183
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      GO TO 27
   21 IF(N-ITE)5,28,28
   25 IF(ITER/LP*LP.EQ.ITER)PRINT 106,X(N)
   27 THETA=DELTA2
      HH=H
      ISTART=N
      IF(IBUB.EQ.1)ISTART=N+1
      RETURN
   28 IF(ITER/LP*LP.EQ.ITER)PRINT 109
      THETA=DELTA2
      HH=H
      ISTART=N
      RETURN
  100 FORMAT(12X,'X',13X,'CF',11X,'D-STAR',9X,'D-THETA',10X,'H',12X,
     1        'RE-THETA',7X,'RE-STAR',10X,'TM'/)
  101 FORMAT(4X,8E15.4)
  102 FORMAT(/10X,'SEPARATION OCCURRED AT X= ',F10.5)
C 103 FORMAT(/10X,*FINAL LAMINAR BOUNDARY LAYER PROFILES*/)
C 104 FORMAT(/10X,*Y*,19X,*VEL. RATIO*,10X,*STRESS*/)
C 105 FORMAT(3(10X,F10.5))
  106 FORMAT(/10X,'TRANSITION OCCURS AT X= ',F10.5)
  107 FORMAT( 10X,'SHORT BUBBLE FORMED?',
     1 'TRANSITION TO TURBULENT FLOW IS ASSUMED, X=',F10.5/)
  108 FORMAT( 10X,'LONG BUBBLE? LAMINAR STALL MAY OCCUR, X=',F10.5,
     1 /10X,'BOUNDARY LAYER CALCULATION WILL BE CONTINUED ',
     2 'AS TURBULENT BUT ACCURACY OF RESULTS IS QUESTIONABLE'/)
  109 FORMAT(//10X,'BOUNDARY LAYER CALCULATION COMPLETED?',
     1  /10X,'NEITHER SEPARATION NOR TRANSITION WAS DETECTED'/)
C 110 FORMAT(//10X,*SPECIFIED SEPARATION POINT REACHED, X=*,F10.5,
C    1  /10X,*NO TURBULENT CALCULATION WILL BE PERFORMED*)
      END
      SUBROUTINE FIT2(N,X,F,FP,FPP,FPPP,K1,KN,END1,ENDN)
C     IMPLICIT REAL*4 (A-H,O-Z)
      DIMENSION X(1),F(1),FP(1),FPP(1),FPPP(1)
      NM1=N-1
      IF (N.LT.3) X(N+1)=X(N)+1.0
      IF (N.LT.3) F(N+1)=F(N)
      DX2=X(2)-X(1)
      GO TO (1,2,3),K1
    1 FP(1)=0.5
      FPPP(1)=3.*((F(2)-F(1))/DX2-END1)/DX2
      GO TO 4
    2 FP(1)=0.0
      FPPP(1)=END1
      GO TO 4
    3 FP(1)=-1.0
      FPPP(1)=-DX2*END1
    4 DO 5 I=2,NM1
      IP      = I+1
      IM      = I-1
      DX1=X(I)-X(IM )
      DX2=X(IP )-X(I)
      FP(I)=.5*DX2/(DX1+DX2-.5*DX1*FP(IM ))
    5 FPPP(I)=(6.*(F(IP )-F(I))/DX2-6.*(F(I)-F(IM ))/DX1-DX1*FPPP(IM ))
     1*FP(I)/DX2
      DX1=X(N)-X(NM1)
      FP(N)=0.0
      GO TO (6,7,8),KN
    6 FPPP(N)=(6.*(ENDN-(F(N)-F(NM1))/DX1)/DX1-FPPP(NM1))/(2.-FP(NM1))
      GO TO 9
    7 FPPP(N)=ENDN
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      GO TO 9                                                           00001245
    8 FPPP(N)=(ENDN*DX1+FPPP(NM1))/(1.+FP(NM1))                         00001246
    9 FPP(N)=FPPP(N)                                                    00001247
      DO 10 II=1,NM1                                                    00001248
      I=N-II                                                            00001249
      IP      = I+1                                                     00001250
      DX2=X(IP )-X(I)                                                   00001251
      FPP(I)=FPPP(I)-FP(I)*FPP(IP )                                     00001252
      FPPP(I)=(FPP(IP )-FPP(I))/DX2                                     00001253
   10 FP(I)=(F(IP )-F(I))/DX2-DX2*(FPP(IP )+2.*FPP(I))/6.               00001254
      FPPP(N)=FPPP(NM1)                                                 00001255
      DX1=X(N)-X(NM1)                                                   00001256
      FP(N)=(F(N)-F(NM1))/DX1+DX1*(FPP(NM1)+2.*FPP(N))/6.               00001257
      RETURN                                                            00001258
      END                                                               00001259
      SUBROUTINE BDLY                                                   00001260
C                                                                       00001261
C    *********** COMPUTES BOUNDARY LAYER IN THE DESIGN CASE   *****     00001262
C                                                                       00001263
      REAL M,NEW                                                        00001264
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001265
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001266
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001267
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001268
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001269
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001270
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00001271
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001272
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001273
      COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER00001274
     1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF                            00001275
      COMMON/DELTA/ITER                                                 00001276
      COMMON/IPT1/XIBDLY,RDEL,RDELFN,RCPB,SP,XSEP,CONV,CPB,XMON,XLSEP,  00001277
     1 MITER,LP,ITEUPC,ITELWC,XPC                                       00001278
     2,LBDLY,XLBDLY                                                     00001279
      DIMENSION UE(99),DSS(99),DUDS(99),YUN(99),YLN(99),EM(99)          00001280
      DIMENSION HS(99)                                                  00001281
      DIMENSION XI(99),YI(99),XO(99),YO(99),SI(99),XP(99),D1Y(99),      00001282
     1D2Y(99),D3Y(99),XIB(99),YIB(99),SO(99) ,YP(99)                    00001283
      ISIDE=0                                                           00001284
      LSEP=ITE                                                          00001285
      SEPMK=0                                                           00001286
      ICYCLE=1                                                          00001287
      DO 500 J=ILE,ITE                                                  00001288
      YUN(J)=YU(J)                                                      00001289
  500 YLN(J)=YL(J)                                                      00001290
      TR=0.3424                                                         00001291
      TE1=5.E-03                                                        00001292
      TE2=5.E-05                                                        00001293
      CM=1.+.2*M**2                                                     00001294
    1 FORMAT(1H1,10X,'BOUNDARY LAYER ANALYSIS FOR REYNOLDS NO. OF ',E10.00001295
     13,//,5X,'X',9X,'Y',9X,'YNEW',8X,'M',8X,'DELS',4X,'THETA',3X,'SEP',00001296
     210X,'H',9X,'PI',5X,'TAU')                                         00001297
 1000 ISIDE=ISIDE+1                                                     00001298
      PRINT 1,RN                                                        00001299
      DO 2 J=ILE,ITE                                                    00001300
      DEL(J)=0.                                                         00001301
      IF(ISIDE.EQ.2)GO TO 3                                             00001302
      CP=CPU(J)                                                         00001303
    4 TEST=(5.*(CM/(1.+.7*CP*M**2)**(.2857143)-1.))                     00001304
      EM(J)=0.                                                          00001305
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      IF(TEST.GT.0.)EM(J)=SQRT(TEST)                                    00001306
      DD=1.+.2*EM(J)**2                                                 00001307
      T=CM/DD                                                           00001308
      UE(J)=EM(J)/M*SQRT(T)                                             00001309
      GO TO 2                                                           00001310
    3 CP=CPL(J)                                                         00001311
      GO TO 4                                                           00001312
    2 CONTINUE                                                          00001313
      IF(ISIDE.EQ.1)USTR=UE(ITE)                                        00001314
      ILEP1=ILE+1                                                       00001315
      XO(1)=-.5                                                         00001316
      XI(1)=-.5                                                         00001317
      YI(1)=0.                                                          00001318
      NI=ITE-ILE+2                                                      00001319
      DO 210 I=ILE,ITE                                                  00001320
      II=I-ILE+2                                                        00001321
      XI(II)=X(I)                                                       00001322
      XO(II)=X(I)                                                       00001323
  210 YI(II)=YU(I)                                                      00001324
      NO=NI                                                             00001325
      CALL ARC(XI,YI,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,0.0,0.0,1.0,0.0,NI,  00001326
     1NO,1)                                                             00001327
      DO 211 I=ILE,ITE                                                  00001328
      II=I-ILE+2                                                        00001329
      YI(II)=YL(I)                                                      00001330
      SLU(I)=YP(II)/XP(II)                                              00001331
  211 SUPPER(I)=SO(II)                                                  00001332
      CALL ARC(XI,YI,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,0.0,0.0,-1.0,0.0,    00001333
     1NI,NO,1)                                                          00001334
      DO 212 I=ILE,ITE                                                  00001335
      II=I-ILE+2                                                        00001336
      SLL(I)=YP(II)/XP(II)                                              00001337
  212 SLOWER(I)=SO(II)                                                  00001338
      DO 5 J=ILEP1,ITE                                                  00001339
      IF(ISIDE.EQ.2)GO TO 6                                             00001340
      DSS(J)=SUPPER(J)-SUPPER(J-1)                                      00001341
      GO TO 5                                                           00001342
    6 DSS(J)=SLOWER(J)-SLOWER(J-1)                                      00001343
    5 DUDS(J)=(UE(J)-UE(J-1))/DSS(J)                                    00001344
      DT=1.                                                             00001345
      SEPR=0.                                                           00001346
      HH=0.                                                             00001347
      IBDS=ITE-1                                                        00001348
      DO 200 J=IBDLY,IBDS                                               00001349
      EMT=(EM(J+1)+EM(J))/2.                                            00001350
      UESA=(UE(J+1)+UE(J))/2.                                           00001351
      VM=1.+.2*EMT**2                                                   00001352
      T=CM/VM                                                           00001353
      RFT=UESA*(T+TR)*T/(1.+TR)*RN                                      00001354
      IF(J.NE.IBDLY)GO TO 30                                            00001355
      THET1=320./RFT                                                    00001356
      THET2=THET1                                                       00001357
      GE=6.5                                                            00001358
   30 FC=1.+.066*EMT**2-.008*EMT**3                                     00001359
      FR=1.-.134*EMT**2+.027*EMT**3                                     00001360
      IND=0                                                             00001361
   40 IND=IND+1                                                         00001362
      TAU=1./(FC*(2.4711*ALOG(FR*RFT*THET1)+4.75)+1.5*GE+1724./(GE**2+  00001363
     1200.)-16.87)**2                                                   00001364
      HB=1./(1.-GE*SQRT(TAU))                                           00001365
      H=(HB+1.)*(1.+.178*EMT**2)-1.                                     00001366
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      SEP=-THET1*DUDS(J+1)/UESA                                         00001367
      IF(SEP.LT.SP)GO TO 41                                             00001368
      IF(X(J+1).LT.XSEP)SEP=SP                                          00001369
   41 PII=H*SEP/TAU                                                     00001370
      IF(PII.LT.-1.5)PII=-1.5                                           00001371
      IF(PII.GT.1.E4)PII=1.E4                                           00001372
   50 CONTINUE                                                          00001373
      G=6.1*SQRT(PII+1.81)-1.7                                          00001374
      T2=ABS((G-GE)/GE)                                                 00001375
      GE=G                                                              00001376
      DT2=DT                                                            00001377
      DT=(H+2.-EMT**2)*SEP+TAU                                          00001378
      IF(IND.GT.1)GO TO 100                                             00001379
      THT=THET2                                                         00001380
      THET1=DT*DSS(J+1)+THT                                             00001381
      THET1=.5*(THET1+THT)                                              00001382
      GO TO 40                                                          00001383
  100 DT=(DT2+DT)/2.                                                    00001384
      TI=ABS((DT-DT2)/DT)                                               00001385
      IF(TI.LT.TE2)GO TO 120                                            00001386
  110 THET1=DT*DSS(J+1)+THT                                             00001387
      THET1=.5*(THET1+THT)                                              00001388
      IF(IND.LE.500)GO TO 40                                            00001389
      IF(PII.EQ.-1.5)GO TO 130                                          00001390
      PRINT 160                                                         00001391
  160 FORMAT(' PROBLEMS')                                               00001392
      GO TO 130                                                         00001393
  120 IF(T2.GE.TE1)GO TO 110                                            00001394
  130 THET2=DT*DSS(J+1)+THT                                             00001395
      THET1=.5*(THET2+THT)                                              00001396
      SEP=-THET1*DUDS(J+1)/UESA                                         00001397
      SEPR=(SEPR*DSS(J+1)+SEP*DSS(J))/(DSS(J)+DSS(J+1))                 00001398
      HH=(HH*DSS(J+1)+H*DSS(J))/(DSS(J)+DSS(J+1))                       00001399
      DELS=HH*THT                                                       00001400
      DEL(J)=DELS                                                       00001401
      IF(DEL(J).GT.0.1)DEL(J)=0.1                                       00001402
      HS(J)=HH                                                          00001403
      IF(ISIDE.EQ.2)GO TO 8                                             00001404
      SLOPE=SLU(J)                                                      00001405
      CO=ABS(ATAN(SLOPE))                                               00001406
      CO=COS(CO)                                                        00001407
      YUN(J)=YU(J)-DELS/CO                                              00001408
      PRINT 10,X(J),YU(J),YUN(J),EM(J),DELS,THT,SEPR,HH,PII,            00001409
     1IND,TAU                                                           00001410
   10 FORMAT(9F10.5,I10,F10.5)                                          00001411
      IF(SEPMK.EQ.1)GO TO 205                                           00001412
      IF(SEPR.GT.SP)LSEP=J                                              00001413
      IF(LSEP.NE.ITE)SEPMK=1                                            00001414
  205 CONTINUE                                                          00001415
      GO TO 9                                                           00001416
    8 SLOPE=SLL(J)                                                      00001417
      CO=ABS(ATAN(SLOPE))                                               00001418
      CO=COS(CO)                                                        00001419
      YLN(J)=YL(J)+DELS/CO                                              00001420
      PRINT 10,X(J),YL(J),YLN(J),EM(J),DELS,THT,SEPR,HH,PII,            00001421
     1IND,TAU                                                           00001422
    9 CONTINUE                                                          00001423
      IF(J.EQ.IBDS)GO TO 200                                            00001424
      SEPR=SEP                                                          00001425
      HH=H                                                              00001426
  200 CONTINUE                                                          00001427
```

```
      SEPR=-SEPR+2.*SEP
      HH=HS(ITE-1)+(DSS(ITE)/DSS(ITE-1))*(HS(ITE-1)-HS(ITE-2))
      HS(ITE)=HH
      DELS=HH*THET2
      DEL(ITE)=DELS
      IF(DEL(ITE).GT.0.1)DEL(ITE)=0.1
      IF(ISIDE.EQ.2)GO TO 201
      SLOPE=SLU(ITE)
      CO=ABS(ATAN(SLOPE))
      CO=COS(CO)
      YUN(ITE)=YU(ITE)-DELS/CO
      PRINT10,X(ITE),YU(ITE),YUN(ITE),EM(ITE),DELS,THET2,SEPR,HH,PII,
     1IND,TAU
      GO TO 202
  201 SLOPE=SLL(ITE)
      CO=ABS(ATAN(SLOPE))
      CO=COS(CO)
      YLN(ITE)=YL(ITE)+DELS/CO
      PRINT 10,X(ITE),YL(ITE),YLN(ITE),EM(ITE),DELS,THET2,SEPR,HH,PII,
     1IND,TAU
  202 IF(ISIDE.EQ.2)GO TO 203
      EMSTR=EM(ITE)
      HSTR=HH
      TSTR=THET2
      DO 170 J=ILE,IBDS
  170 IF(DEL(J+1).LT.DEL(J))DEL(J+1)=DEL(J)
  203 CONTINUE
      IF(ISIDE.EQ.1)GO TO 2200
      J=ILE
 2180 J=J+1
      IF(DEL(J+1).LT.DEL(J))GO TO 2185
      IF(J.LT.IBDS)GO TO 2180
      GO TO 2200
 2185 IF(X(J).GT.XPC)GO TO 2190
      DEL(J+1)=DEL(J)
      GO TO 2180
 2190 J=J+1
      IF(DEL(J+1).GT.DEL(J))DEL(J+1)=DEL(J)
      IF(J.LT.IBDS)GO TO 2190
 2200 CONTINUE
      ISMOTH=2
      IF(IMAX.GT.55)ISMOTH=4
      DO 171 JJ=1,ISMOTH
      OLD=DEL(ILE)
      ILEP2=ILE+2
      DO 171 J=ILEP2,ITE
      NEW=DEL(J-1)
      DEL(J-1)=.25*(OLD+NEW+NEW+DEL(J))
  171 OLD=NEW
      FAC=-DSS(ITE)/DSS(ITE-1)
      DEL(ITE)=FAC*DEL(ITE-2)+(1.-FAC)*DEL(ITE-1)
      PRINT 180
  180 FORMAT('   X           YOLD        YNEW        DELSTAR')
      DO 172 J=ILEP1,IBDS
      SLOPE=SLU(J)
      IF(ISIDE.EQ.2)SLOPE=SLL(J)
      CO=ABS(ATAN(SLOPE))
      CO=COS(CO)
      IF(ISIDE.EQ.2)GO TO 173
      YUN(J)=YU(J)-DEL(J)/CO
      PRINT 174,X(J),YU(J),YUN(J),DEL(J)
```

```
      GO TO 172
  173 YLN(J)=YL(J)+DEL(J)/CO
      PRINT 174,X(J),YL(J),YLN(J),DEL(J)
  174 FORMAT(4F10.5)
  172 CONTINUE
       SLOPE=SLU(ITE)
      IF(ISIDE.EQ.2)SLOPE=SLL(ITE)
      CO=ABS(ATAN(SLOPE))
      CO=COS(CO)
      IF(ISIDE.EQ.2)GO TO 175
      YUN(ITE)=YU(ITE)-DEL(ITE)/CO
      PRINT 174,X(ITE),YU(ITE),YUN(ITE),DEL(ITE)
      GO TO 204
  175 YLN(ITE)=YL(ITE)+DEL(ITE)/CO
      PRINT 174,X(ITE),YL(ITE),YLN(ITE),DEL(ITE)
  204 IF(ISIDE.LT.2)GO TO 1000
      HBT=(HSTR+1.)/(1.+.178*EMSTR**2)-1.
      HBB=(HH+1.)/(1.+.178*EM(ITE)**2)-1.
      CDF=TSTR*(USTR**(2.5+.5*HBT))+THET2*(UE(ITE)**(2.5+.5*HBB))
      CDF=2.*CDF
      PRINT 3010,CDF
 3010 FORMAT(1HO,' CDF = ',F10.6)
      IF(X(LSEP).GE.XSEP)GO TO 3011
      PRINT 3012,X(LSEP)
 3012 FORMAT(1H ,'UPPER SURFACE SEPARATION DETECTED AT ',F10.5)
      RETURN
 3011 PRINT 3013,XSEP
 3013 FORMAT(1H ,'NO UPPER SURFACE SEPARATION BEFORE',F10.5)
      RETURN
      END
      SUBROUTINE VALUE
C
C  ********   THIS DETERMINES THE INITIAL SOLUTION *****
C
      REAL M
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(99
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP1
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1,
     1JMAX,JCON,JMAX1,NSSP,IW
      COMMON/FIPUT/IREAD
C     INITIALIZES VALUES
      IF(IREAD.EQ.O)GO TO 3
      DO 4 JJ=1,JMAX
      J=JMAX-JJ+1
      READ 5,(P(I,J),I=1,IMAX)
    5 FORMAT(5E15.7)
    4 CONTINUE
      READ5,(PB(I),I=1,IMAX)
      RETURN
    3 CONTINUE
      DO 1 I=1,IMAX
      PB(I)=O.O
      DO 1 J=1,JMAX
    1 P(I,J)=O.O
      RETURN
      END
```

```
      SUBROUTINE SOLVE(JL,JU)                                           00001550
C                                                                       00001551
C   *********  THIS SUBROUTINE SETS UP THE COEFFICIENTS USED IN THE *****00001552
C                RELAXATION SOLUTION   **********                       00001553
C                                                                       00001554
      REAL M,ML                                                         00001555
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001556
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001557
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001558
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001559
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001560
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001561
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00001562
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001563
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001564
      COMMON/ADAM/VJB,VJB1,VJBP1                                        00001565
      COMMON/JS/GG(99),GGP12(99),GGM12(99),GGM32(99),GGP32(99),A3       00001566
      COMMON/VORTEX/VORCIR,IVLOC,XV,YV,IVOR,JVOR
      DST2=2.*DS                                                        00001567
      DET2=2.*DE                                                        00001568
      DEDE=DE*DE                                                        00001569
      DSDS=DS*DS                                                        00001570
      DSDE=DS*DE                                                        00001571
      FDS=F/DS                                                          00001572
      DO 30 J=JL,JU
      IF(I.NE.ILE1)GO TO 300                                            00001574
      IF(J.NE.JB-1)GO TO 300                                            00001575
      HLD=P(ILE,JB)                                                     00001576
      P(ILE,JB)=PB(ILE)                                                 00001577
  300 CONTINUE                                                          00001578
      G=GG(J)                                                           00001579
      GP12=GGP12(J)                                                     00001580
      GM12=GGM12(J)                                                     00001581
      GDE=G/DE                                                          00001582
      U=QI*(COS(ALP)+F*(P(I+1,J)-P1(J))/(2.*DS))                        00001583
      V=QI*(SIN(ALP)+G*(P(I,J+1)-P(I,J-1))/(2.*DE))                     00001584
      IF (IVLOC.EQ.0) GO TO 700
      IF (I.NE.IVOR.AND.I.NE.(IVOR+1)) GO TO 700
      IF (IVLOC.EQ.1.AND.J.GT.JVOR.OR.IVLOC.EQ.-1.AND.J.LE.JVOR)
     1U=U+IVLOC*QI*F*VORCIR/2./DS
  700 CONTINUE
      IF(IW.EQ.0)GO TO 6                                                00001585
      IF(J.EQ.JB)V=V-QI*(G*(CIR/(2.*DE)))                               00001586
      IF(J.EQ.JB-1)V=V-QI*(G*(CIR/(2.*DE)))                             00001587
    6 CONTINUE                                                          00001588
      UU=U*U                                                            00001589
      VV=V*V                                                            00001590
      Q=SQRT(UU+VV)                                                     00001591
      QQ=Q*Q                                                            00001592
      AA=AI2-0.2*(UU+VV-QI2)                                            00001593
      IF(AA.LT.0.0)PRINT 11,I,J                                         00001594
   11 FORMAT(' AA.LT.0.0   I=',I5,' J = ',I5)                           00001595
      IF(AA.LT.0.0)GO TO 21                                             00001596
      IF(IW.EQ.0)GO TO 7                                                00001597
      IF(J.NE.JB.AND.J.NE.JB-1)GO TO 9                                  00001598
      IF(J.EQ.JB-1)GO TO 8                                              00001599
      VVJB=VV                                                           00001600
      VJB=V                                                             00001601
      AAJB=AA                                                           00001602
      QQJB=QQ                                                           00001603
      UUJB=UU                                                           00001604
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```
      GO TO 7                                                           00001605
    8 VVJB1=VV                                                          00001606
      VJB1=V                                                            00001607
      AAJB1=AA                                                          00001608
      QQJB1=QQ                                                          00001609
      UUJB1=UU                                                          00001610
      GO TO 7                                                           00001611
   10 VVJBP1=VV                                                         00001612
      VJBP1=V                                                           00001613
      QQJBP1=QQ                                                         00001614
      AAJBP1=AA                                                         00001615
      GO TO 7                                                           00001616
    9 IF(J.EQ.JB+1)GO TO 10                                             00001617
    7 CONTINUE                                                          00001618
      ML=(UU+VV)/AA                                                     00001619
      IF(ML.GT.1.0)GO TO 4                                              00001620
C     SUBSONIC POINT                                                    00001621
      FAV=1.0*(FP12+FM12)                                               00001622
      FPF=0.5*F*FAV                                                     00001623
      SUB(J-1)=(1.-VV/AA)*GDE*GM12/DE                                   00001624
      D(J)=-2.*(1.-UU/AA)*FPF/DSDS/W-(1.-VV/AA)*G*(GP12+GM12)/DEDE      00001625
     1-EPS*FDS*U/Q*FM12/DS                                              00001626
      IF(D(J).EQ.0.0)GO TO 21                                           00001627
      SUP(J)=(1.-VV/AA)*GDE*GP12/DE                                     00001628
      RS(J)=(1.-UU/AA)*F*(-FP12/DSDS*P(I+1,J)+FAV/DSDS*(1.-1./W)         00001629
     1*P(I,J)-FM12/DSDS*P(I-1,J))+U*V/AA*FDS*GDE*0.5*(P(I-1,J-1)        00001630
     2-P(I-1,J+1)-P(I+1,J-1)+P(I+1,J+1))                                00001631
      RS(J)=RS(J)+EPS*FDS*(U/Q*FM12*(-P(I,J)-P(I-1,J)+P1(J))/DS)         00001632
      IF(V.LE.0.0)GO TO 200                                             00001633
      SUB(J-1)=SUB(J-1)+EPS*FDS*V/Q*GM12/DE                             00001634
      D(J)=D(J)-EPS*FDS*V/Q*GM12/DE                                     00001635
      RS(J)=RS(J)+EPS*FDS*V/Q*GM12/DE*(P(I,J-1)-P(I,J))                 00001636
      GO TO 3                                                           00001637
  200 SUP(J)=SUP(J)-EPS*FDS*V/Q*GP12/DE                                 00001638
      D(J)=D(J)+EPS*FDS*V/Q*GP12/DE                                     00001639
      RS(J)=RS(J)+EPS*FDS*V/Q*GP12/DE*(P(I,J)-P(I,J+1))                 00001640
      GO TO 3                                                           00001641
C     DAMPING COEFF IS EPSS AT SUPERSONIC POINTS                        00001642
C     SUPERSONIC CASE. V GT 0                                           00001643
    4 GM32=GGM32(J)                                                     00001644
      NSSP=NSSP+1                                                       00001645
      GP32=GGP32(J)                                                     00001646
      IF(V.LT.0.0)GO TO 5                                               00001647
      SUB(J-1)=UU/QQ*GDE*GM12/DE+EPSS*FDS*V/Q*GM12/DE                   00001648
      D(J)=-VV/QQ*FDS*FM12/DS-UU/QQ*GDE*(GP12+GM12)/DE-EPSS*FDS*        00001649
     1(U/Q*FM12/DS+V/Q*GM12/DE)                                         00001650
      SUP(J)=UU/QQ*GDE*GP12/DE                                          00001651
      RS(J)=-(1.-QQ/AA)*(UU/QQ*F DS*(FM12*(P(I,J)-P1(J))-FM32*(P1(J)-    00001652
     1P2(J)))/DS+2.*U*V/QQ*F*G*(P(I,J)-P1(J)-P(I,J-1)+P1(J-1))/DSDE     00001653
     2+VV/QQ*G*(GM12*(P(I,J)-P(I,J-1))-GM32*(P(I,J-1)-P(I,J-2)))/       00001654
     3DEDE)                                                             00001655
      RS(J)=RS(J)-VV/QQ*F*(FP12*(P(I+1,J)-P(I,J))+FM12*P(I-1,J))/DSDS   00001656
     1+U*V/QQ*F*G*(P(I-1,J-1)-P(I-1,J+1)-P(I+1,J-1)+P(I+1,J+1))/DSDE    00001657
     2*0.5                                                              00001658
     3+EPSS*F*(U/Q*FM12*(-P(I,J)-P(I-1,J)+P1(J))/DSDS+V/Q*GM12*(P(I,J-1)00001659
     4-P(I,J))/DSDE)                                                    00001660
      GO TO 3                                                           00001661
C     SUPERSONIC CASE V  LT  0                                          00001662
    5 SUB(J-1)=UU/QQ*G DE*GM12/DE                                       00001663
      D(J)=-VV/QQ*F DS*FM12/DS-UU/QQ*G DE*(GM12+GP12)/DE-EPSS*F DS*     00001664
     1(U/Q*FM12/DS-V/Q*GP12/DE)                                         00001665
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      SUP(J)=UU/QQ*GDE*GP12/DE-EPSS*FDS*V/Q*GP12/DE                     00001666
      RS(J)=-(1.-QQ/AA)*(UU/QQ*F DS*(FM12*(P(I,J)-P1(J))-FM32*(P1(J)-   00001667
     1P2(J)))/DS+2.*U*V/QQ*F*G*(-P(I,J)+P1(J)+P(I,J+1)-P1(J+1))/DSDE    00001668
     2+VV/QQ*G*(GP12*(P(I,J)-P(I,J+1))-GP32*(P(I,J+1)-P(I,J+2)))/       00001669
     3DEDE)                                                             00001670
      RS(J)=RS(J)-VV/QQ*F*(FP12*(P(I+1,J)-P(I,J))+FM12*P(I-1,J))/DSDS   00001671
     1+U*V/QQ*F*G*(P(I-1,J-1)-P(I-1,J+1)-P(I+1,J-1)+P(I+1,J+1))/DSDE    00001672
     1*0.5                                                              00001673
     2+EPSS*F*(U/Q*FM12*(-P(I,J)-P(I-1,J)+P1(J))/DSDS+V/Q*GP12*(P(I,J)- 00001674
     3P(I,J+1))/DSDE)                                                   00001675
      IF(I.NE.ILE1)GO TO 3                                              00001676
      IF(J.NE.JB-1)GO TO 3                                              00001677
      P(ILE,JB)=HLD                                                     00001678
    3 CONTINUE                                                          00001679
      IF (IVLOC.EQ.0) GO TO 30
      IF (I.NE.IVOR) GO TO 31
        IF (IVLOC.EQ.1.AND.J.LE.JVOR.OR.IVLOC.EQ.-1.AND.J.GT.JVOR)
     1     GO TO 33
          IF (ML.LE.1.) RS(J)=RS(J)-IVLOC*(1.-UU/AA)*F*FP12
     1       *VORCIR/DSDS
          IF (ML.GT.1.) RS(J)=RS(J)-IVLOC*VV/QQ*F*FP12*VORCIR/DSDS
   33   IF (J.NE.JVOR.AND.J.NE.JVOR+1) GO TO 31
          IF (ML.LE.1.) RS(J)=RS(J)+U*V/AA*F*G*VORCIR/2./DS/DE
          IF (ML.GT.1.) RS(J)=RS(J)+U*V/QQ*F*G*VORCIR/2./DS/DE
   31 IF (I.NE.IVOR+1) GO TO 32
        IF (IVLOC.EQ.1.AND.J.LE.JVOR.OR.IVLOC.EQ.-1.AND.J.GT.JVOR)
     1     GO TO 34
          IF (ML.LE.1.) RS(J)=RS(J)+IVLOC*(1.-UU/AA)*F*FM12
     1       *VORCIR/DSDS
          IF (ML.GT.1.) RS(J)=RS(J)+IVLOC*VV/QQ*F*FM12*VORCIR/DSDS-
     1       IVLOC*(1.-QQ/AA)*UU/QQ*F*FM12*VORCIR/DSDS
   34   IF (J.NE.JVOR.AND.J.NE.JVOR+1) GO TO 32
          IF (ML.LE.1.) RS(J)=RS(J)+U*V/AA*F*G*VORCIR/DS/DE/2.
          IF (ML.LE.1.) GO TO 32
          RS(J)=RS(J)+U*V/QQ*F*G*VORCIR/2./DS/DE
          IF (J.EQ.JVOR+1.AND.V.GE.0.0.OR.J.EQ.JVOR.AND.V.LT.0.0)
     1       RS(J)=RS(J)-(1.-QQ/AA)*2.*U*V/QQ*F*G*VORCIR/DS/DE
   32 IF ((I.EQ.IVOR+2.AND.ML.GT.1.).AND.(IVLOC.EQ.1.AND.
     1   J.GT.JVOR.OR.IVLOC.EQ.-1.AND.J.LE.JVOR))
     2   RS(J)=RS(J)+IVLOC*(1.-QQ/AA)*UU/QQ*F*FM32*VORCIR/DSDS
   30 CONTINUE
      RETURN
   21 DO 18 JJ=1,JMAX                                                   00001681
      J=JMAX+1-JJ                                                       00001682
      PRINT 19,J                                                        00001683
   19 FORMAT(1H ,'ROW ',I5)                                             00001684
      PRINT 20,(P(I,J),I=1,IMAX)                                        00001685
   20 FORMAT(1H ,10E11.3)                                               00001686
   18 CONTINUE                                                          00001687
      PRINT 19,JB                                                       00001688
      PRINT 20,(PB(I),I=1,IMAX)                                         00001689
      STOP                                                              00001690
      END                                                               00001691
      SUBROUTINE PRESS                                                  00001692
C                                                                       00001693
C ********      THIS COMPUTES THE CP DISTRIBUTION ON THE AIRFOIL *******00001694
C                                                                       00001695
      REAL M                                                            00001696
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001697
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001698
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001699
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     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001700
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001701
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001702
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                   00001703
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001704
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001705
      COMMON/FIX/MHALF                                                  00001706
      COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER00001707
     1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF                            00001708
C     COMPUTES CP ON AIRFOIL                                            00001709
      IPRM=0                                                            00001710
      IF(ITACT.EQ.1)IPRM=1                                              00001711
   19 IPRM=IPRM+1                                                       00001712
      IEND=IMAX1                                                        00001713
      JB2=JB-2                                                          00001714
      DO 1 I=ILE,IEND                                                   00001715
      TEMP2=YU(I)                                                       00001716
      IF(I.GT.ITE)YU(I)=0.0001                                          00001717
      DO 2 J=JB2,JMAX1                                                  00001718
      IF(YU(I).GT.E(J).AND.YU(I).LE.E(J+1))GO TO 3                      00001719
    2 CONTINUE                                                          00001720
    3 JA=J+1                                                            00001721
      IF(JA.LE.JB)JA=JB+1                                               00001722
      F=FF(I)                                                           00001723
      IF(IPRM.EQ.2)GO TO 20                                             00001724
      IF(I.GT.(ILE+1))GO TO 15                                          00001725
   20 U=0.0                                                             00001726
      U=QI*(COS(ALP)+F*((P(I+1,JA-1)-P(I-1,JA-1))/(2.*DS)+(YU(I)-E(JA-1)00001727
     1)*(P(I+1,JA)-P(I+1,JA-1)-P(I-1,JA)+P(I-1,JA-1))/(2.*DS*DE)))      00001728
      GO TO 16                                                          00001729
   15 CONTINUE                                                          00001730
C     U USING BACKWARD DIFFERENCE ON PHIX                               00001731
      U=QI*(COS(ALP)+F*((3.*P(I,JA-1)-4.*P(I-1,JA-1)+P(I-2,JA-1))/(2.*DS00001732
     1)+(YU(I)-E(JA-1)                                                  00001733
     1)*(P(I+1,JA)-P(I+1,JA-1)-P(I-1,JA)+P(I-1,JA-1))/(2.*DS*DE)))      00001734
   16 CONTINUE                                                          00001735
      UU=U*U                                                            00001736
      GB=A11/(1.+TAN(PI2*YU(I))**2)                                     00001737
  100 V=QI*(SIN(ALP)+GB*((-3.*P(I,JA-1)+4.*P(I,JA)-P(I,JA+1))/(2.*DE)   00001738
     1+(YU(I)-E(JA-1))*(P(I,JA-1)-2.*P(I,JA)+P(I,JA+1))/(DE**2)))       00001739
  101 VV=V*V                                                            00001740
      YU(I)=TEMP2                                                       00001741
    1 CPU(I)=(1./(0.7*M*M))*((1.+0.2*M*M*(1.-(UU+VV)/QI2))**3.5-1.)     00001742
      ITE1=ITE+1                                                        00001743
      DO 4 I=ILE1,IMAX                                                  00001744
      TEMP1=PB(I)                                                       00001745
      PB(I)=P(I,JB)                                                     00001746
    4 P(I,JB)=TEMP1                                                     00001747
      JB2=JB+2                                                          00001748
      DO 5 I=ILE,IEND                                                   00001749
      TEMP2=YL(I)                                                       00001750
      IF(I.GT.ITE)YL(I)=-0.0001                                         00001751
      DO 6 JJ=1,JB                                                      00001752
      J=JB2-JJ                                                          00001753
      IF(YL(I).GE.E(J).AND.YL(I).LT.E(J+1))GO TO 7                      00001754
    6 CONTINUE                                                          00001755
    7 JA=J                                                              00001756
      IF(JA.GE.JB)JA=JB-1                                               00001757
      F=FF(I)                                                           00001758
      IF(IPRM.EQ.2)GO TO 21                                             00001759
      IF(I.GT.(ILE+1))GO TO 17                                          00001760
```

```
   21 U=0.0                                                             00001761
      U=QI*(COS(ALP)+F*((P(I+1,JA+1)-P(I-1,JA+1))/(2.*DS)+(YL(I)-E(JA+1)00001762
     1)*(P(I+1,JA+1)-P(I+1,JA)-P(I-1,JA+1)+P(I-1,JA))/(2.*DS*DE)))      00001763
      GO TO 18                                                          00001764
   17 CONTINUE                                                          00001765
C     U USING BACKWARDS DIFFERNCE SCHEME ON PHIX                        00001766
      U=QI*(COS(ALP)+F*((3.*P(I,JA+1)-4.*P(I-1,JA+1)+P(I-2,JA+1))/(2.*DS00001767
     1)+(YL(I)-E(JA+1)                                                  00001768
     1)*(P(I+1,JA+1)-P(I+1,JA)-P(I-1,JA+1)+P(I-1,JA))/(2.*DS*DE)))      00001769
   18 CONTINUE                                                          00001770
      UU=U*U                                                            00001771
      GB=A11/(1.+TAN(YL(I)*PI2)**2)                                     00001772
  102 V=QI*(SIN(ALP)+GB*((3.*P(I,JA+1)-4.*P(I,JA)+P(I,JA-1))/(2.*DE)+   00001773
     1(YL(I)-E(JA+1))*(P(I,JA+1)-2.*P(I,JA)+P(I,JA-1))/(DE**2)))        00001774
  103 VV=V*V                                                            00001775
      YL(I)=TEMP2                                                       00001776
    5 CPL(I)=(1./(0.7*M*M))*((1.+0.2*M*M*(1.-(UU+VV)/QI2))**3.5-1.)     00001777
      DO 8 I=ILE1,IMAX                                                  00001778
      TEMP1=PB(I)                                                       00001779
      PB(I)=P(I,JB)                                                     00001780
    8 P(I,JB)=TEMP1                                                     00001781
      IF(ITACT.EQ.1)RETURN                                              00001782
   11 IF(IPRM.EQ.1)PRINT 200                                            00001783
  200 FORMAT(1H ,'CP BY BACKWARD DIFFERENCES')                          00001784
      IF(IPRM.EQ.2)PRINT 201                                            00001785
  201 FORMAT(1H ,'CP BY CENTRAL DIFFERENCES')                           00001786
      PRINT 12                                                          00001787
   12 FORMAT(1H ,'X',10X,'CPU',10X,'CPL')                               00001788
      PRINT 13,(X(I),CPU(I),CPL(I),I=ILE,IMAX1)                         00001789
   13 FORMAT(1H ,3F10.3)                                                00001790
      IF(IPRM.LT.2)GO TO 19                                             00001791
      RETURN                                                            00001792
      END                                                               00001793
      SUBROUTINE FLOW1                                                  00001794
C                                                                       00001795
C  *********   SOLVES FLOW IN FRONT OF THE AIRFOIL   *****              00001796
C                                                                       00001797
      REAL M                                                            00001798
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001799
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001800
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001801
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001802
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001803
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001804
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00001805
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001806
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001807
C     RELAXES FLOW IN FRONT OF AIRFOIL                                  00001808
C************************************* ADDITION ************************
      JB=JMAX/2+1
C***********************************************************************
      NSSP=0                                                            00001809
C************************************* ADDITION ************************
      FFM32(2)=0.0
C***********************************************************************
      ISTAR=2                                                           00001810
      IF(M.LT.1.0)GO TO 1                                               00001811
      ISTAR=3                                                           00001812
      DO 2 J=1,JMAX                                                     00001813
      P1(J)=P(2,J)                                                      00001814
    2 P2(J)=P(1,J)                                                      00001815
```

```
    1 CONTINUE                                                          00001816
      AI=1117.0                                                         00001817
      AI2=AI**2                                                         00001818
      QI=M*AI                                                           00001819
      QI2=QI**2                                                         00001820
      DO 1000 I=ISTAR,ILE1                                              00001821
      F=FF(I)                                                           00001822
      FP12=FFP12(I)                                                     00001823
      FM12=FFM12(I)                                                     00001824
      FM32=FFM32(I)                                                     00001825
      CALL SOLVE(2,JMAX1)                                               00001826
      RS(2)=RS(2)-SUB(1)*P(I,1)                                         00001827
      RS(JMAX1)=RS(JMAX1)-SUP(JMAX1)*P(I,JMAX)                          00001828
      CALL TRID(2,JMAX1)                                                00001829
      DO 6 J=2,JMAX1                                                    00001830
      DP=ABS(P(I,J)-RS(J))                                              00001831
      IF(DP.GT.DPM)ICON=I                                               00001832
      IF(DP.GT.DPM)JCON=J                                               00001833
      IF(DP.GT.DPM)DPM=DP                                               00001834
      P2(J)=P1(J)                                                       00001835
      P1(J)=P(I,J)                                                      00001836
    6 P(I,J)=RS(J)                                                      00001837
      P2(1)=P1(1)                                                       00001838
      P2(JMAX)=P1(JMAX)                                                 00001839
      P1(1)=P(I,1)                                                      00001840
      P1(JMAX)=P(I,JMAX)                                                00001841
 1000 CONTINUE                                                          00001842
      RETURN                                                            00001843
      END                                                               00001844
      SUBROUTINE COORD                                                  00001845
C                                                                       00001846
C  ********    SETS UP COORDINATES IN COMPUTATIONAL AND PHYSICAL GRIDS *00001847
C                                                                       00001848
      REAL M                                                            00001849
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001850
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001851
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001852
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001853
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001854
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001855
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00001856
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001857
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001858
      COMMON/FIX/MHALF                                                  00001859
      COMMON/JS/GG(99),GGP12(99),GGM12(99),GGM32(99),GGP32(99),A3       00001860
      DE=2.0/(JMAX-1)                                                   00001861
      IF(INV.EQ.0)GO TO 999                                             00001862
      READ 997,X1,X2                                                    00001863
  997 FORMAT(2F10.5)                                                    00001864
  999 CONTINUE                                                          00001865
      DS=2.*(1.+S4)/(IMAX-1)                                            00001866
C     THIS PROGRAM DEPENDS UPON TRANSFORMATION USED                     00001867
      S(1)=-1.0-S4                                                      00001868
      E(1)=-1.0                                                         00001869
      S(IMAX)=1.0+S4                                                    00001870
      E(JMAX)=1.0                                                       00001871
      IMAX1=IMAX-1                                                      00001872
      JMAX1=JMAX-1                                                      00001873
      DO 2 I=2,IMAX1                                                    00001874
    2 S(I)=S(I-1)+DS.                                                   00001875
      S3=-S4+0.5*DS-0.01                                                00001876
```

```
      DO 11 I=1,IMAX1
      IF(S3.GE.S(I).AND.S3.LT.S(I+1))GO TO 12
   11 CONTINUE
   12 I3=I+1
      I31=I3-1
      IM=IMAX/2+1
      I4=IMAX-I31
      I41=I4+1
      DO 13 I=2,I31
   13 X(I)=-X4+A2*TAN(PI2*(S(I)+S4))+A3*TAN(PI2*(S(I)+S4)**3)
      TERM1=1.5*X4/S4-.25*PI*A2
      TERM2=(.5*PI*A2*S4-X4)/(2.*S4**3)
      DO 14 I=I3,I4
   14 X(I)=S(I)*(TERM1+TERM2*S(I)**2)
      DO 16 I=I41,IMAX1
   16 X(I)=X4+A2*TAN(PI2*(S(I)-S4))+A3*TAN(PI2*(S(I)-S4)**3)
      DG 3 J=2,JMAX1
      E(J)=E(J-1)+DE
    3 Y(J)=A1*TAN(PI2*E(J))
      PRINT 4
    4 FORMAT(//,25X,'X-Y GRID SYSTEM',//)
      PRINT 5,(I,X(I),I=2,IMAX1)
    5 FORMAT(   6(I5,E12.4))
      PRINT 5,(J,Y(J),J=2,JMAX1)
      DO 7 I=2,IMAX1
      IF(X1.GE.X(I).AND.X1.LT.X(I+1))GO TO 8
    7 CONTINUE
    8 I1=I+1
      SLE=-0.5
      DO 9 I=2,IMAX1
      IF(SLE.GE.X(I).AND.SLE.LE.X(I+1))GO TO 10
    9 CONTINUE
   10 ILE=I+1
      QUAN1=S(2)+S4
      FF(2)=   PI2*A2*(1.+TAN(PI2*QUAN1)**2)+1.5*A3*(1.+TAN(PI2*QUAN1**3
     1)**2)*(QUAN1**2)*PI
      FF(2)=1./FF(2)
      QUAN1=S(2)+0.5*DS+S4
      FFP12(2)=PI2*A2*(1.+TAN(PI2*QUAN1)**2)+1.5*A3*(1.+TAN(PI2*QUAN1**3
     1)**2)*(QUAN1**2)*PI
      FFP12(2)=1./FFP12(2)
      QUAN1=S(2)-0.5*DS+S4
      FFM12(2)=PI2*A2*(1.+TAN(PI2*QUAN1)**2)+1.5*A3*(1.+TAN(PI2*QUAN1**3
     1)**2)*(QUAN1**2)*PI
      FFM12(2)=1./FFM12(2)
      FFM1(2)=0.0
      DO 18 I=3,I31
      QUAN1=S(I)+S4
      FF(I)=   PI2*A2*(1.+TAN(PI2*QUAN1)**2)+1.5*A3*(1.+TAN(PI2*QUAN1**3
     1)**2)*(QUAN1**2)*PI
      FF(I)=1./FF(I)
      QUAN1=S(I)+0.5*DS+S4
      FFP12(I)=PI2*A2*(1.+TAN(PI2*QUAN1)**2)+1.5*A3*(1.+TAN(PI2*QUAN1**3
     1)**2)*(QUAN1**2)*PI
      FFP12(I)=1./FFP12(I)
      FFM12(I)=FFP12(I-1)
      FFM1(I)=FF(I-1)
   18 FFM32(I)=FFM12(I-1)
      FFP12(I31)=1./(TERM1+3.*TERM2*(S(I31)+0.5*DS)**2)
      IM1=IM-1
      DO 19 I=I3,IM
```

```
      FF(I)=1./(TERM1+3.*TERM2*S(I)**2)                                 00001938
      FFP12(I)=1./(TERM1+3.*TERM2*(S(I)+0.5*DS) **2)                    00001939
      FFM12(I)=FFP12(I-1)                                               00001940
      FFM1(I)=FF(I-1)                                                   00001941
   19 FFM32(I)=FFM12(I-1)                                               00001942
      FFP12(IM)=FFM12(IM)                                               00001943
      DO 800 II=2,IM1                                                   00001944
      I=IMAX-II+1                                                       00001945
      FF(I)=FF(II)                                                      00001946
      FFP12(I)=FFM12(II)                                                00001947
      FFM12(I)=FFP12(II)                                                00001948
      FFM1(I)=FF(II+1)                                                  00001949
  800 FFM32(I)=FFP12(II+1)                                              00001950
      GGP32(2)=A11*COS(PI2*(E(3)+0.5*DE))**2                            00001951
      GG(2)=A11*COS(PI2*E(2))**2                                        00001952
      GGP12(2)=A11*COS(PI2*(E(2)+0.5*DE))**2                            00001953
      GGM12(2)=A11*COS(PI2*(E(2)-0.5*DE))**2                            00001954
      GGM32(2)=0.0                                                      00001955
      DO 801 J=3,JMAX1                                                  00001956
      IF(J.EQ.JMAX1)GO TO 804                                           00001957
      GGP32(J)=A11*COS(PI2*(E(J)+1.5*DE))**2                            00001958
  804 GG(J)=A11*COS(PI2*E(J))**2                                        00001959
      GGP12(J)=A11*COS(PI2*(E(J)+0.5*DE))**2                            00001960
      GGM12(J)=GGP12(J-1)                                               00001961
  801 GGM32(J)=GGM12(J-1)                                               00001962
      GGP32(JMAX1)=0.0                                                  00001963
      RETURN                                                            00001964
      END                                                               00001965
      SUBROUTINE FLOW3                                                  00001966
C                                                                       00001967
C    *********   SOLVES FOW IN THE INVERSE REGION  *****                00001968
C                                                                       00001969
      REAL M                                                            00001970
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00001971
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00001972
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900001973
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00001974
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00001975
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100001976
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00001977
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00001978
     1JMAX,JCON,JMAX1,NSSP,IW                                           00001979
      COMMON/BAKER/TEMP3,TEMP4                                          00001980
      COMMON/DELTA/ITER                                                 00001981
      COMMON/FIX/MHALF                                                  00001982
      COMMON/IPT2/IMASS                                                 00001983
C     RELAXES FLOW IN INVERSE REGION                                    00001984
      JA=JA1                                                            00001985
      IS=I1-2                                                           00001986
      DO 14 I=IS,IMAX                                                   00001987
   14 TEMP(I)=P(I,JB-1)                                                 00001988
      DO 3000 I=I1,IMAX1                                                00001989
      IF(X(I).GE.X2)GO TO 3100                                          00001990
C     FLOW ABOVE AIRFOIL                                                00001991
      JB2=JB-2                                                          00001992
      DO 3 J=JB2,JMAX1                                                  00001993
      IF(YU(I).GT.E(J).AND.YU(I).LE.E(J+1))GO TO 4                      00001994
    3 CONTINUE                                                          00001995
    4 JA=J+1                                                            00001996
      IF(JA.LE.JB)JA=JB+1                                               00001997
      F=FF(I)                                                           00001998
```

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      FP12=FFP12(I)
      FM12=FFM12(I)
      FM1=FFM1(I)
      FM32=FFM32(I)
      GB=A11/(1.+TAN(YU(I   )*PI2)**2)
      VV=SLU(I)**2
      UU=1.0
 4000 DU1(I)=-COS(ALP)+((1./(1.+VV/UU))*(1.-((1.+0.7*M*M*CPU(I   ))**0.28
     16-1.)*5./(M*M)))**0.5-F*((-4.*P1(JA-1)+P2(JA-1))/(2.*DS))
     2-F*(YU(I)-E(JA-1))*(P(I+1,JA)-P(I+1,JA-1)-P1(JA)+P1(JA-1))/(2.
     3*DS*DE)
      DU1(I)=DU1(I)/(F*(1.5/DS))
 4001 CONTINUE
      DU2(I)=-P(I,JA)+2.0*DU1(I)
      P(I,JA-1)=DU1(I)
      P(I,JA-2)=DU2(I)
      CALL SOLVE(JA,JMAX1)
      RS(JA)=RS(JA)-SUB(JA-1)*P(I,JA-1)
      RS(JMAX1)=RS(JMAX1)-SUP(JMAX1)*P(I,JMAX)
      CALL TRID(JA,JMAX1)
      DO 1 J=JA,JMAX1
      DP=ABS(P(I,J)-RS(J))
      IF(DP.GT.DPM)ICON=I
      IF(DP.GT.DPM)JCON=J
      IF(DP.GT.DPM)DPM=DP
      P2(J)=P1(J)
      P1(J)=P(I,J)
    1 P(I,J)=RS(J)
      JAM1=JA-1
      DO 2 J=JB,JAM1
      P2(J)=P1(J)
    2 P1(J)=P(I,J)
      VV=SLU(I)**2
      UU=1.0
 4002 DU1(I)=-COS(ALP)+((1./(1.+VV/UU))*(1.-((1.+0.7*M*M*CPU(I   ))**0.28
     16-1.)*5./(M*M)))**0.5-F*((-4.*P(I-1,JA-1)+P(I-2,JA-1))/(2.*DS))
     2-F*(YU(I)-E(JA-1))*(P(I+1,JA)-P(I+1,JA-1)-P(I-1,JA)+P(I-1,JA-1))/
     3(2.*DS*DE)
      DU1(I)=DU1(I)/(F*(1.5/DS))
 4003 CONTINUE
      DU2(I)=-P(I,JA)+2.0*DU1(I)
      P(I,JA-1)=DU1(I)
      P(I,JA-2)=DU2(I)
      P2(JMAX)=P1(JMAX)
      P1(JMAX)=P(I,JMAX)
      JA1=JA
 3000 CONTINUE
 3100 JA=JB1
      DO 5 I=IS,IMAX
      P(I,JB-1)=TEMP(I)
      TEMP(I)=P(I,JB+1)
      TEMP1=PB(I)
      PB(I)=P(I,JB)
    5 P(I,JB)=TEMP1
    6 TEMP1=TEMP4
      TEMP4=P1(JB)
      P1(JB)=TEMP1
      TEMP1=TEMP3
      TEMP3=P2(JB)
      P2(JB)=TEMP1
      IF(IMASS.EQ.1)GO TO 3600
```

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      DO 3500 I=I1,IMAX1                                                00002060
C     FLOW BELOW AIRFOIL                                                00002061
      IF(X(I).GE.X2)GO TO 3600                                          00002062
      JB2=JB+2                                                          00002063
      DO 10 JJ=1,JB                                                     00002064
      J=JB2-JJ                                                          00002065
      IF(YL(I).GE.E(J).AND.YL(I).LT.E(J+1))GO TO 11                     00002066
   10 CONTINUE                                                          00002067
   11 JA=J                                                              00002068
      IF(JA.GE.JB)JA=JB-1                                               00002069
      F=FF(I)                                                           00002070
      FP12=FFP12(I)                                                     00002071
      FM12=FFM12(I)                                                     00002072
      FM1=FFM1(I)                                                       00002073
      FM32=FFM32(I)                                                     00002074
      GB=A11/(1.+TAN(YL(I   )*PI2)**2)                                  00002075
      VV=SLL(I)**2                                                      00002076
      UU=1.0                                                            00002077
 4004 DL1(I)=-COS(ALP)+((1./(1.+VV/UU))*(1.-((1.+0.7*M*M*CPL(I   ))**0.2800002078
     16-1.)*5./(M*M)))**0.5-F*((-4.*P1(JA+1)+P2(JA+1))/(2.*DS))         00002079
     2-F*(YL(I)-E(JA+1))*(P(I+1,JA+1)-P(I+1,JA)-P1(JA+1)+P1(JA))/(2.    00002080
     3*DS*DE)                                                           00002081
      DL1(I)=DL1(I)/(F*(1.5/DS))                                        00002082
 4005 CONTINUE                                                          00002083
      DL2(I)=2.*DL1(I)-P(I,JA)                                          00002084
      P(I,JA+1)=DL1(I)                                                  00002085
      P(I,JA+2)=DL2(I)                                                  00002086
      CALL SOLVE(2,JA)                                                  00002087
      RS(2)=RS(2)-SUB(1)*P(I,1)                                         00002088
      RS(JA)=RS(JA)-SUP(JA)*P(I,JA+1)                                   00002089
      CALL TRID(2,JA)                                                   00002090
      DO 7 J=2,JA                                                       00002091
      DP=ABS(P(I,J)-RS(J))                                              00002092
      IF(DP.LE.DPM)GO TO 8                                              00002093
      ICON=I                                                            00002094
      JCON=J                                                            00002095
      DPM=DP                                                            00002096
    8 P2(J)=P1(J)                                                       00002097
      P1(J)=P(I,J)                                                      00002098
    7 P(I,J)=RS(J)                                                      00002099
      JAM1=JA+1                                                         00002100
      DO 9 J=JAM1,JB                                                    00002101
      P2(J)=P1(J)                                                       00002102
    9 P1(J)=P(I,J)                                                      00002103
      VV=SLL(I)**2                                                      00002104
      UU=1.0                                                            00002105
 4006 DL1(I)=-COS(ALP)+((1./(1.+VV/UU))*(1.-((1.+0.7*M*M*CPL(I   ))**0.2800002106
     16-1.)*5./(M*M)))**0.5-F*((-4.*P(I-1,JA+1)+P(I-2,JA+1))/(2.*DS))   00002107
     2-F*(YL(I)-E(JA+1))*(P(I+1,JA+1)-P(I+1,JA)-P(I-1,JA+1)+P(I-1,JA))/ 00002108
     3(2.*DS*DE)                                                        00002109
      DL1(I)=DL1(I)/(F*(1.5/DS))                                        00002110
 4007 CONTINUE                                                          00002111
      DL2(I)=2.*DL1(I)-P(I,JA)                                          00002112
      P(I,JA+1)=DL1(I)                                                  00002113
      P(I,JA+2)=DL2(I)                                                  00002114
      P2(1)=P1(1)                                                       00002115
      P1(1)=P(I,1)                                                      00002116
      JB1=JA                                                            00002117
 3500 CONTINUE                                                          00002118
 3600 DO 12 I=IS,IMAX                                                   00002119
      P(I,JB+1)=TEMP(I)                                                 00002120
```

```
      TEMP1=PB(I)
      PB(I)=P(I,JB)
   12 P(I,JB)=TEMP1
      P1(JB)=TEMP4
      P2(JB)=TEMP3
      RETURN
      END
      SUBROUTINE FLOW2
C
C  **********   SOLVES FLOW IN THE DRIECT REGION  ******
C
      REAL M
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(99
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP1
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1,
     1JMAX,JCON,JMAX1,NSSP,IW
      COMMON/BAKER/TEMP3,TEMP4
      COMMON/IPT2/IMASS
C     RELAXES FLOW ABOVE AND BELOW AIRFOIL
      JB=JMAX/2+1
      JB1=JB-1
      JA1=JB+1
      JB2=JB-2
      TEMP5=P1(JB)
      TEMP6=P2(JB)
      DO 12 I=ILE,ITE1
   12 TEMP(I)=P(I,JB-1)
      IF(ILE.GT.I11)GO TO 2001
      DO 2000 I=ILE,I11
C     FLOW ABOVE AIRFOIL
      F=FF(I)
      FP12=FFP12(I)
      FM12=FFM12(I)
      FM32=FFM32(I)
      GB=A11/(1.+TAN(PI2*YU(I))**2)
      DO 1 J=JB2,JMAX1
      IF(YU(I).GT.E(J).AND.YU(I).LE.E(J+1))GO TO 2
    1 CONTINUE
    2 JA=J+1
      IF(JA.LE.JB)JA=JB+1
      DU1(I)=SLU(I)*(COS(ALP)+F*((P(I+1,JA-1)-P1(JA-1))/(2.*DS)
     1+(YU(I)-E(JA-1))*(P(I+1,JA)-P(I+1,JA-1)-P1(JA)+P1(JA-1))/(2.*DS*DE
     2)))-SIN(ALP)-GB*((4.*P(I,JA)-P(I,JA+1))/(2.*DE)+(YU(I)-E(JA-1))*
     3(-2.*P(I,JA)+P(I,JA+1))/(DE**2))
      DU1(I)=DU1(I)/(-1.5*GB/DE     +(YU(I)-E(JA-1))/(DE**2)*GB)
      DU2(I)=-P(I,JA)+DU1(I)*2.0
      P(I,JA-1)=DU1(I)
      P(I,JA-2)=DU2(I)
      CALL SOLVE(JA,JMAX1)
      RS(JA)=RS(JA)-SUB(JA-1)*P(I,JA-1)
      RS(JMAX1)=RS(JMAX1)-SUP(JMAX1)*P(I,JMAX)
      CALL TRID(JA,JMAX1)
      DO 4 J=JA,JMAX1
      DP=ABS(P(I,J)-RS(J))
      IF(DP.GT.DPM)ICON=I
      IF(DP.GT.DPM)JCON=J
```

```
      IF(DP.GT.DPM)DPM=DP
      P2(J)=P1(J)
      P1(J)=P(I,J)
    4 P(I,J)=RS(J)
      JAM1=JA-1
      DO 5 J=JB,JAM1
      P2(J)=P1(J)
    5 P1(J)=P(I,J)
      P2(JMAX)=P1(JMAX)
      P1(JMAX)=P(I,JMAX)
      JA1=JA
      DU1(I)=SLU(I)*(COS(ALP)+F*((P(I+1,JA-1)-P(I-1,JA-1))/(2.*DS)
     1+(YU(I)-E(JA-1))*(P(I+1,JA)-P(I+1,JA-1)-P(I-1,JA)+P(I-1,JA-1))/
     2(2.*DS*DE)))-SIN(ALP)-GB*((4.*P(I,JA)-P(I,JA+1))/(2.*DE)+
     3(YU(I)-E(JA-1))*(-2.*P(I,JA)+P(I,JA+1))/(DE**2))
      DU1(I)=DU1(I)/(-1.5*GB/DE+(YU(I)-E(JA-1))/(DE**2)*GB)
      DU2(I)=-P(I,JA)+DU1(I)*2.0
      P(I,JA-1)=DU1(I)
      P(I,JA-2)=DU2(I)
 2000 CONTINUE
 2001 CONTINUE
      TEMP3=P2(JB)
      TEMP4=P1(JB)
C     FLOW BELOW AIRFOIL
      DO 8 I=ILE,ITE1
      P(I,JB-1)=TEMP(I)
      TEMP(I)=P(I,JB+1)
      TEMP1=PB(I)
      PB(I)=P(I,JB)
      P(I,JB)=TEMP1
    8 CONTINUE
      P1(JB)=TEMP5
      P2(JB)=TEMP6
      ITMP1=I1
      ITMP11=I11
      IF(IMASS.EQ.1)I1=ITE+1
      IF(IMASS.EQ.1)I11=ITE
      IF(ILE.GT.I11)GO TO 2501
      DO 2500 I=ILE,I11
      GB=A11/(1.+TAN(PI2*YL(I))**2)
      F=FF(I)
      FP12=FFP12(I)
      FM12=FFM12(I)
      FM32=FFM32(I)
      DO 6 JJ=1,JMAX1
      J=JB-JJ+2
      IF(YL(I).GE.E(J).AND.YL(I).LT.E(J+1))GO TO 7
    6 CONTINUE
    7 JA=J
      IF(JA.GE.JB)JA=JB-1
      DL1(I)=SLL(I)*(COS(ALP)+F*((P(I+1,JA+1)-P1(JA+1))/(2.*DS)+
     1(YL(I)-E(JA+1))*(P(I+1,JA+1)-P(I+1,JA)-P1(JA+1)+P1(JA))/(2.*DS*DE)
     2))-SIN(ALP)-GB*((-4.*P(I,JA)+P(I,JA-1))/(2.*DE)+(YL(I)-E(JA+1))*
     3(-2.*P(I,JA)+P(I,JA-1))/(DE**2))
      DL1(I)=DL1(I)/(1.5*GB/DE+(YL(I)-E(JA+1))/(DE**2)*GB)
      DL2(I)=2.*DL1(I)-P(I,JA)
      P(I,JA+1)=DL1(I)
      P(I,JA+2)=DL2(I)
      CALL SOLVE(2,JA)
      RS(2)=RS(2)-SUB(1)*P(I,1)
      RS(JA)=RS(JA)-SUP(JA)*P(I,JA+1)
```

```
      CALL TRID(2,JA)                                                   00002243
      DO 9 J=2,JA                                                       00002244
      DP=ABS(P(I,J)-RS(J))                                              00002245
      IF(DP.GT.DPM)ICON=I                                               00002246
      IF(DP.GT.DPM)JCON=J                                               00002247
      IF(DP.GT.DPM)DPM=DP                                               00002248
      P2(J)=P1(J)                                                       00002249
      P1(J)=P(I,J)                                                      00002250
    9 P(I,J)=RS(J)                                                      00002251
      JAM1=JA+1                                                         00002252
      DO 10 J=JAM1,JB                                                   00002253
      P2(J)=P1(J)                                                       00002254
   10 P1(J)=P(I,J)                                                      00002255
      P2(1)=P1(1)                                                       00002256
      P1(1)=P(I,1)                                                      00002257
      JB1=JA                                                            00002258
      DL1(I)=SLL(I)*(COS(ALP)+F*((P(I+1,JA+1)-P(I-1,JA+1))/(2.*DS)+     00002259
     1(YL(I)-E(JA+1))*(P(I+1,JA+1)-P(I+1,JA)-P(I-1,JA+1)+P(I-1,JA))/(2.00002260
     2*DS*DE)))-SIN(ALP)-GB*((-4.*P(I,JA)+P(I,JA-1))/(2.*DE)+(YL(I)-E(00002261
     3JA+1))*(-2.*P(I,JA)+P(I,JA-1))/(DE**2))                           00002262
      DL1(I)=DL1(I)/(1.5*GB/DE+(YL(I)-E(JA+1))/(DE**2)*GB)              00002263
      DL2(I)=2.*DL1(I)-P(I,JA)                                          00002264
      P(I,JA+1)=DL1(I)                                                  00002265
      P(I,JA+2)=DL2(I)                                                  00002266
 2500 CONTINUE                                                          00002267
 2501 CONTINUE                                                          00002268
      DO 11 I=ILE,ITE1                                                  00002269
      P(I,JB+1)=TEMP(I)                                                 00002270
      TEMP1=PB(I)                                                       00002271
      PB(I)=P(I,JB)                                                     00002272
   11 P(I,JB)=TEMP1                                                     00002273
      TEMP1=TEMP4                                                       00002274
      TEMP4=P1(JB)                                                      00002275
      P1(JB)=TEMP1                                                      00002276
      TEMP1=TEMP3                                                       00002277
      TEMP3=P2(JB)                                                      00002278
      P2(JB)=TEMP1                                                      00002279
      PB(ILE1)=P(ILE1,JB)                                               00002280
      PB(ILE-2)=P(ILE-2,JB)                                             00002281
      I1=ITMP1                                                          00002282
      I11=ITMP11                                                        00002283
      RETURN                                                            00002284
      END                                                               00002285
      SUBROUTINE WAKE                                                   00002286
C                                                                       00002287
C   **********   SOLVES FLOW BEHIND THE AIRFOIL ******                  00002288
C                                                                       00002289
      REAL M                                                            00002290
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00002291
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00002292
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900002293
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00002294
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00002295
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100002296
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00002297
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00002298
     1JMAX,JCON,JMAX1,NSSP,IW                                           00002299
      COMMON/ADAM/VJB,VJB1,VJBP1                                        00002300
      COMMON/IPT2/IMASS                                                 00002301
C     RELAXES FLOW IN WAKE DIRECTLY                                     00002302
      DIMENSION PTEMP(99)                                               00002303
```

```
      IMARK=0
      IF(IMASS.EQ.0)GO TO 100
      JB2=JB-1
      DO 101 J=JB2,JMAX1
      IF(YU(ITE).GT.E(J).AND.YU(ITE).LE.E(J+1))GO TO 102
  101 CONTINUE
 102  JA=J+1
      IF(JA.LE.JB)JA=JB+1
      STE=S4+2./PI*ATAN((0.5-X4)/A2)
      QUAN1=STE-S4
      F=PI*A2*0.5*(1.+TAN(PI2*QUAN1)**2)
      F=1./F
      JAM1=JA-1
      DO 103 J=JB,JAM1
      IMARK=1
C     PTEMP(J)=P(ITE,J)
      P(ITE,J)=0.5/F*  CPU(I1)+(4.*P(ITE+1,J)-P(ITE+2,J))/(2.*DS)
     1 +(STE-S(ITE))*(-2.*P(ITE+1,J)+P(ITE+2,J))/(DS*DS)
      P(ITE,J)=P(ITE,J)/(1.5/DS-(STE-S(ITE))/(DS*DS))
      P1(J)=P(ITE,J)
      P2(J)=-P(ITE+1,J)+2.*P1(J)
  103 CONTINUE
  100 CONTINUE
      IW=1
      DO 4000 I=ITE1,IMAX1
      F=FF(I)
      FP12=FFP12(I)
      FM12=FFM12(I)
      FM32=FFM32(I)
      CALL SOLVE(2,JMAX1)
      RS(2)=RS(2)-SUB(1)*P(I,1)
      RS(JMAX1)=RS(JMAX1)-SUP(JMAX1)*P(I,JMAX)
      IF(QQJBP1.LE.AAJBP1)GO TO 1
      IF(VJBP1.LT.0.)GO TO 1
      G=A11/(1.+TAN(PI2*E(JB+1))**2)
      GM32=A11/(1.+TAN(PI2*(E(JB+1)-1.5*DE))**2)
      RS(JB+1)=RS(JB+1)-(1.-QQJBP1/AAJBP1)*(VVJBP1/QQJBP1*G*GM32*CIR/
     1(DE**2))
    1 IF(QQJB.LE.AAJB)GO TO 2
      IF(VJB.LT.0.0)GO TO 3
      G=A11/(1.+TAN(PI2*E(JB))**2)
      GM12=A11/(1.+TAN(PI2*(E(JB)-0.5*DE))**2)
      RS(JB)=RS(JB)+(1.-QQJB/AAJB)*(VVJB/QQJB*G*GM12*CIR/(DE**2))
     1-UUJB/QQJB*G*GM12*CIR/(DE**2)
      GO TO 4
    3 G=A11/(1.+TAN(PI2*E(JB))**2)
      GM12=A11/(1.+TAN(PI2*(E(JB)-0.5*DE))**2)
      RS(JB)=RS(JB)-UUJB/QQJB*G*GM12*CIR/(DE**2)
      GO TO 4
    2 G=A11/(1.+TAN(PI2*E(JB))**2)
      C=(1.-VVJB/AAJB)*G
      GM12=A11/(1.+TAN(PI2*(E(JB)-0.5*DE))**2)
      RS(JB)=RS(JB)-C*GM12*CIR/(DE**2)
    4 IF(QQJB1.GT.AAJB1)GO TO 5
      G=A11/(1.+TAN(PI2*E(JB-1))**2)
      C=(1.-VVJB1/AAJB1)*G
      GP12=A11/(1.+TAN(PI2*(E(JB-1)+0.5*DE))**2)
      RS(JB-1)=RS(JB-1)+C*GP12*CIR/(DE**2)
      GO TO 6
    5 IF(VJB1.LT.0.0)GO TO 7
      G=A11/(1.+TAN(PI2*E(JB-1))**2)
```

```
      GP12=A11/(1.+TAN(PI2*(E(JB-1)+0.5*DE))**2)                        00002365
      RS(JB-1)=RS(JB-1)+UUJB1/QQJB1*G*GP12*CIR/(DE**2)                  00002366
      GO TO 6                                                           00002367
    7 G=A11/(1.+TAN(PI2*E(JB-1))**2)                                    00002368
      GP12=A11/(1.+TAN(PI2*(E(JB-1)+0.5*DE))**2)                        00002369
      RS(JB-1)=RS(JB-1)-(1.-QQJB1/AAJB1)*VVJB1/QQJB1*G*GP12*CIR/(DE**2) 00002370
     1+UUJB1/QQJB1*G*GP12*CIR/(DE**2)                                   00002371
    6 CALL TRID(2,JMAX1)                                                00002372
      DO 8 J=2,JMAX1                                                    00002373
      DP=ABS(P(I,J)-RS(J))                                              00002374
      IF(DP.LT.DPM)GO TO 9                                              00002375
      ICON=I                                                            00002376
      JCON=J                                                            00002377
      DPM=DP                                                            00002378
    9 P2(J)=P1(J)                                                       00002379
      P1(J)=P(I,J)                                                      00002380
    8 P(I,J)=RS(J)                                                      00002381
      P2(1)=P1(1)                                                       00002382
      P2(JMAX)=P1(JMAX)                                                 00002383
      P1(1)=P(I,1)                                                      00002384
      P1(JMAX)=P(I,JMAX)                                                00002385
 4000 CONTINUE                                                          00002386
C     IF(IMARK.EQ.0)GO TO 105                                           00002387
C     DO 104 J=JB,JAM1                                                  00002388
C 104 P(ITE,J)=PTEMP(J)                                                 00002389
C 105 CONTINUE                                                          00002390
      DO 10 I=ITE1,IMAX1                                                00002391
      PB(I)=P(I,JB)-CIR                                                 00002392
   10 CONTINUE                                                          00002393
      PB(ILE1)=P(ILE1,JB)                                               00002394
      IW=0                                                              00002395
      RETURN                                                            00002396
      END                                                               00002397
      SUBROUTINE SHAPE                                                  00002398
C                                                                       00002399
C   *********   COMPUTES SHAPE OF AIRFOIL IN INVERSE DESIGN CASE******** 00002400
C                                                                       00002401
      REAL M                                                            00002402
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00002403
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00002404
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900002405
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00002406
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00002407
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100002408
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00002409
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00002410
     1JMAX,JCON,JMAX1,NSSP,IW                                           00002411
      COMMON/TAMU/DELTAY                                                00002412
      COMMON/IPT2/IMASS                                                 00002413
      IF(I1.GE.ITE)RETURN                                               00002414
      DELTAY=0.0                                                        00002415
      IF(IMASS.EQ.1)GO TO 100                                           00002416
      IF(INV.EQ.0)I1=ILE+2                                              00002417
  100 CONTINUE                                                          00002418
      IP1=I1                                                            00002419
      DO 1 I=IP1,ITE1                                                   00002420
      YOLD=YU(I)                                                        00002421
      JB2=JB-2                                                          00002422
      DO 3 J=JB2,JMAX1                                                  00002423
      IF(YU(I-1).GT.E(J).AND.YU(I-1).LE.E(J+1))GO TO 4                  00002424
    3 CONTINUE                                                          00002425
```

```
    4 JA=J+1                                                            00002426
      L=I-1                                                             00002427
      IF(JA.LE.JB)JA=JB+1                                               00002428
      F=FF(L)                                                           00002429
      U=QI*(COS(ALP)+F*((P(I,JA-1)-P(I-2,JA-1))/(2.*DS)+(YU(L)-E(JA-1)  00002430
     1)*(P(I,JA)-P(I,JA-1)-P(I-2,JA)+P(I-2,JA-1))/(2.*DS*DE)))          00002431
      GB=A11/(1.+TAN(PI2*YU(I-1))**2)                                   00002432
      V=QI*(SIN(ALP)+GB*((-3.*P(L,JA-1)+4.*P(L,JA)-P(L,JA+1))/(2.*      00002433
     1DE)+(YU(L)-E(JA-1))*(P(L,JA-1)-2.*P(L,JA)+P(L,JA+1))/(DE**2)))    00002434
      FY=(GB/F)*V/U                                                     00002435
      IF(I.EQ.I1)GO TO 14                                               00002436
      SLU(I-1)=V/U                                                      00002437
   14 CONTINUE                                                          00002438
      FK1=DS*FY                                                         00002439
      YN=YU(L)+0.5*FK1                                                  00002440
      F=FFM12(I)                                                        00002441
      DO 20 J=JB2,JMAX1                                                 00002442
      IF(YN.GT.E(J).AND.YN.LE.E(J+1))GO TO 50                           00002443
   20 CONTINUE                                                          00002444
   50 JA=J+1                                                            00002445
      IF(JA.LE.JB)JA=JB+1                                               00002446
      U=QI*(COS(ALP)+F*((P(I,JA-1)-P(I-1,JA-1))/DS+(YN-E(JA-1))*        00002447
     1(P(I,JA)-P(I,JA-1)-P(L,JA)+P(L,JA-1))/(DS*DE)))                   00002448
      GB=A11/(1.+TAN(PI2*YN)**2)                                        00002449
      V=QI*(SIN(ALP)+GB*((-3.*(P(I,JA-1)+P(L,JA-1))+4.*(P(I,JA)+P(L,    00002450
     1JA))-P(I,JA+1)-P(L,JA+1))/(4.*DE)+(YN-E(JA-1))*0.5*(P(I,JA-1)     00002451
     2+P(I-1,JA-1)-2.*(P(I,JA)+P(L,JA))+P(I,JA+1)+P(L,JA+1))/(DE**2)))  00002452
      FK2=GB/F*DS*V/U                                                   00002453
      YN=YU(L)+0.5*FK2                                                  00002454
      DO 21 J=JB2,JMAX1                                                 00002455
      IF(YN.GT.E(J).AND.YN.LE.E(J+1))GO TO 22                           00002456
   21 CONTINUE                                                          00002457
   22 JA=J+1                                                            00002458
      IF(JA.LE.JB)JA=JB+1                                               00002459
      U=QI*(COS(ALP)+F*((P(I,JA-1)-P(I-1,JA-1))/DS+(YN-E(JA-1))*        00002460
     1(P(I,JA)-P(I,JA-1)-P(L,JA)+P(L,JA-1))/(DS*DE)))                   00002461
      GB=A11/(1.+TAN(PI2*YN)**2)                                        00002462
      V=QI*(SIN(ALP)+GB*((-3.*(P(I,JA-1)+P(L,JA-1))+4.*(P(I,JA)+P(L,    00002463
     1JA))-P(I,JA+1)-P(L,JA+1))/(4.*DE)+(YN-E(JA-1))*0.5*(P(I,JA-1)     00002464
     2+P(I-1,JA-1)-2.*(P(I,JA)+P(L,JA))+P(I,JA+1)+P(L,JA+1))/(DE**2)))  00002465
      FK3=GB/F*DS*V/U                                                   00002466
      YN=YU(L)+FK3                                                      00002467
      F=FF(I)                                                           00002468
      DO 2 J=JB2,JMAX1                                                  00002469
      IF(YN.GT.E(J).AND.YN.LE.E(J+1))GO TO 5                            00002470
    2 CONTINUE                                                          00002471
    5 JA=J+1                                                            00002472
      IF(JA.LE.JB)JA=JB+1                                               00002473
      U=QI*(COS(ALP)+F*((P(I+1,JA-1)-P(I-1,JA-1))/(2.*DS)+(YN-E(JA-1))* 00002474
     1(P(I+1,JA)-P(I+1,JA-1)-P(I-1,JA)+P(I-1,JA-1))/(2.*DS*DE)))        00002475
      GB=A11/(1.+TAN(PI2*YN)**2)                                        00002476
      V=QI*(SIN(ALP)+GB*((-3.*P(I,JA-1)+4.*P(I,JA)-P(I,JA+1))/(2.*DE)   00002477
     1+(YN-E(JA-1))*(P(I,JA-1)-2.*P(I,JA)+P(I,JA+1))/(DE**2)))          00002478
      FK4=GB/F*DS*V/U                                                   00002479
      YU(I)=YU(L)+(FK1+2.*FK2+2.*FK3+FK4)/6.                            00002480
      IF(I.GT.ITE)GO TO 1                                               00002481
      CHANGE=ABS(YU(I)-YOLD)                                            00002482
      IF(CHANGE.GT.DELTAY)DELTAY=CHANGE                                 00002483
    1 CONTINUE                                                          00002484
      IF(IMASS.EQ.0)GO TO 1000                                          00002485
      RETURN                                                            00002486
```

```
 1000 CONTINUE                                                          00002487
      DO 6 I=ILE1,IMAX                                                  00002488
      TEMP1=P(I,JB)                                                     00002489
      P(I,JB)=PB(I)                                                     00002490
    6 PB(I)=TEMP1                                                       00002491
      DO 7 I=IP1,ITE1                                                   00002492
      YOLD=YL(I)                                                        00002493
      JB2=JB+2                                                          00002494
      DO 8 JJ=1,JB                                                      00002495
      J=JB2-JJ                                                          00002496
      IF(YL(I-1).GE.E(J).AND.YL(I-1).LT.E(J+1))GO TO 9                  00002497
    8 CONTINUE                                                          00002498
    9 JA=J                                                              00002499
      IF(JA.GE.JB)JA=JB-1                                               00002500
      L=I-1                                                             00002501
      F=FF(L)                                                           00002502
      U=QI*(COS(ALP)+F*((P(I,JA+1)-P(I-2,JA+1))/(2.*DS)+(YL(L)-E(JA+1))*00002503
     1(P(I,JA+1)-P(I,JA)-P(I-2,JA+1)+P(I-2,JA))/(2.*DS*DE)))            00002504
      GB=A11/(1.+TAN(PI2*YL(L))**2)                                     00002505
      V=QI*(SIN(ALP)+GB*((3.*P(L,JA+1)-4.*P(L,JA)+P(L,JA-1))/(2.*DE)+   00002506
     1(YL(L)-E(JA+1))*(P(L,JA+1)-2.*P(L,JA)+P(L,JA-1))/(DE**2)))        00002507
      FY=GB/F*V/U                                                       00002508
      IF(I.EQ.I1)GO TO 15                                               00002509
      SLL(I-1)=V/U                                                      00002510
   15 CONTINUE                                                          00002511
      FK1=DS*FY                                                         00002512
      YN=YL(L)+0.5*FK1                                                  00002513
      F=FFM12(I)                                                        00002514
      DO 25 JJ=1,JB                                                     00002515
      J=JB2-JJ                                                          00002516
      IF(YN.GE.E(J).AND.YN.LT.E(J+1))GO TO 26                           00002517
   25 CONTINUE                                                          00002518
   26 JA=J                                                              00002519
      IF(JA.GE.JB)JA=JB-1                                               00002520
      U=QI*(COS(ALP)+F*((P(I,JA+1)-P(L,JA+1))/DS+(YN-E(JA+1))*(P(I,JA+1)00002521
     1-P(I,JA)-P(L,JA+1)+P(L,JA))/(DS*DE)))                             00002522
      GB=A11/(1.+TAN(PI2*YN)**2)                                        00002523
      V=QI*(SIN(ALP)+GB*((3.*(P(I,JA+1)+P(L,JA+1))-4.*(P(I,JA)+P(L,JA)) 00002524
     1+P(I,JA-1)+P(L,JA-1))/(4.*DE)+(YN-E(JA+1))*(P(I,JA+1)+P(L,JA+1)   00002525
     2-2.*(P(I,JA)+P(L,JA))+P(I,JA-1)+P(L,JA-1))*0.5/(DE**2)))          00002526
      FK2=GB/F*DS*V/U                                                   00002527
      YN=YL(L)+0.5*FK2                                                  00002528
      DO 27 JJ=1,JB                                                     00002529
      J=JB2-JJ                                                          00002530
      IF(YN.GE.E(J).AND.YN.LT.E(J+1))GO TO 28                           00002531
   27 CONTINUE                                                          00002532
   28 JA=J                                                              00002533
      IF(JA.GE.JB)JA=JB-1                                               00002534
      U=QI*(COS(ALP)+F*((P(I,JA+1)-P(L,JA+1))/DS+(YN-E(JA+1))*(P(I,JA+1)00002535
     1-P(I,JA)-P(L,JA+1)+P(L,JA))/(DS*DE)))                             00002536
      GB=A11/(1.+TAN(PI2*YN)**2)                                        00002537
      V=QI*(SIN(ALP)+GB*((3.*(P(I,JA+1)+P(L,JA+1))-4.*(P(I,JA)+P(L,JA)) 00002538
     1+P(I,JA-1)+P(L,JA-1))/(4.*DE)+(YN-E(JA+1))*(P(I,JA+1)+P(L,JA+1)   00002539
     2-2.*(P(I,JA)+P(L,JA))+P(I,JA-1)+P(L,JA-1))*0.5/(DE**2)))          00002540
      FK3=GB/F*DS*V/U                                                   00002541
      YN=YL(L)+FK3                                                      00002542
      F=FF(I)                                                           00002543
      DO 10 JJ=1,JB                                                     00002544
      J=JB2-JJ                                                          00002545
      IF(YN.GE.E(J).AND.YN.LT.E(J+1))GO TO 11                           00002546
   10 CONTINUE                                                          00002547
```

```
   11 JA=J                                                              00002548
      IF(JA.GE.JB)JA=JB-1                                               00002549
      U=QI*(COS(ALP)+F*((P(I+1,JA+1)-P(I-1,JA+1))/(2.*DS)+(YN-E(JA+1))* 00002550
     1(P(I+1,JA+1)-P(I+1,JA)-P(I-1,JA+1)+P(I-1,JA))/(2.*DS*DE)))        00002551
      GB=A11/(1.+TAN(PI2*YN)**2)                                        00002552
      V=QI*(SIN(ALP)+GB*((3.*P(I,JA+1)-4.*P(I,JA)+P(I,JA-1))/(2.*DE)+   00002553
     1(YN-E(JA+1))*(P(I,JA+1)-2.*P(I,JA)+P(I,JA-1))/(DE**2)))           00002554
      FK4=GB/F*DS*V/U                                                   00002555
      YL(I)=YL(L)+(FK1+2.*FK2+2.*FK3+FK4)/6.                            00002556
      IF(I.GT.ITE)GO TO 7                                               00002557
      CHANGE=ABS(YL(I)-YOLD)                                            00002558
      IF(CHANGE.GT.DELTAY)DELTAY=CHANGE                                 00002559
    7 CONTINUE                                                          00002560
      DO 12 I=ILE1,IMAX                                                 00002561
      TEMP1=P(I,JB)                                                     00002562
      P(I,JB)=PB(I)                                                     00002563
   12 PB(I)=TEMP1                                                       00002564
      RETURN                                                            00002565
      END                                                               00002566
      SUBROUTINE TRID(IL,IH)                                            00002567
C                                                                       00002568
C ******   TRIDIAGONAL EQUATION SOLVER *******                          00002569
C                                                                       00002570
      REAL M                                                            00002571
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00002572
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00002573
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900002574
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00002575
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00002576
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100002577
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00002578
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00002579
     1JMAX,JCON,JMAX1,NSSP,IW                                           00002580
      N=IH                                                              00002581
      NN=N-1                                                            00002582
      SUP(IL)=SUP(IL)/D(IL)                                             00002583
      RS(IL)=RS(IL)/D(IL)                                               00002584
      IDUM=IL+1                                                         00002585
      DO 10 L=IDUM,N                                                    00002586
      II=L-1                                                            00002587
      D(L)=D(L)-SUP(II)*SUB(II)                                         00002588
      IF(L.EQ.N)GO TO 10                                                00002589
      IF(D(L).EQ.0)PRINT 1000,IL,IH,L
 1000 FORMAT(3I5)
      SUP(L)=SUP(L)/D(L)                                                00002590
   10 RS(L)=(RS(L)-SUB(II)*RS(II))/D(L)                                 00002591
      DO 20 K=IL,NN                                                     00002592
      L=N-K+IL-1                                                        00002593
   20 RS(L)=RS(L)-SUP(L)*RS(L+1)                                        00002594
      RETURN                                                            00002595
      END                                                               00002596
      SUBROUTINE HALVE                                                  00002597
C                                                                       00002598
C    ******   THIS SUBROUTINE HALVES THE GRID SPACING ETC. ******       00002599
C                                                                       00002600
      REAL M                                                            00002601
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00002602
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00002603
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900002604
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00002605
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00002606
```

```
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100002607
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4.S4                                  00002608
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00002609
     1JMAX,JCON,JMAX1,NSSP,IW                                           00002610
      IMAX=2*IMAX-1                                                     00002611
      JMAX=2*JMAX-1                                                     00002612
      IMAX1=IMAX-1                                                      00002613
      JMAX1=JMAX-1                                                      00002614
      J=JMAX1/2+1                                                       00002615
      JJ=JMAX                                                           00002616
    1 I=IMAX1/2+1                                                       00002617
      II=IMAX                                                           00002618
    2 P(II,JJ)=P(I,J)                                                   00002619
      I=I-1                                                             00002620
      II=II-2                                                           00002621
      IF(I.GT.O)GO TO 2                                                 00002622
      J=J-1                                                             00002623
      JJ=JJ-2                                                           00002624
      IF(J.GT.O)GO TO 1                                                 00002625
      DO 3 J=1,JMAX,2                                                   00002626
      DO 3 I=2,IMAX1,2                                                  00002627
    3 P(I,J)=O.5*(P(I+1,J)+P(I-1,J))                                    00002628
      DO 4 I=1,IMAX                                                     00002629
      DO 4 J=2,JMAX1,2                                                  00002630
    4 P(I,J)=O.5*(P(I,J+1)+P(I,J-1))                                    00002631
      I=IMAX1/2+1                                                       00002632
      II=IMAX                                                           00002633
    5 PB(II)=PB(I)                                                      00002634
      I=I-1                                                             00002635
      II=II-2                                                           00002636
      IF(I.GT.O)GO TO 5                                                 00002637
      DO 6 I=2,IMAX1,2                                                  00002638
    6 PB(I)=O.5*(PB(I+1)+PB(I-1))                                       00002639
      RETURN                                                            00002640
      END                                                               00002641
      SUBROUTINE PLOT(NO,A,N,M,NL,NS)                                   00002642
C                                                                       00002643
C  ******    THIS CREATES A PLOT OF RESULTS ON THE STANDARD PRINT OUT **00002644
C                                                                       00002645
      DIMENSION OUT(101),YPR(11),ANG(9),A(500)                          00002646
    1 FORMAT(1H1,60X,7H CHART ,I3,//)                                   00002647
    2 FORMAT(1H ,F11.4,5X,101A1)                                        00002648
    3 FORMAT(1H )                                                       00002649
    7 FORMAT(1H ,16X,101H.         .         .         .         .      00002650
     1    .         .         .         .         .         .)          00002651
    8 FORMAT(1HO,9X,11F10.3)                                            00002652
      DATA BLANK/1H /,ANG/1HU,1HL,1HT,1HB,1H5,1H6,1H7,1H8,1H9/          00002653
      NLL=NL                                                            00002654
      IF(NS)  16,  16,  10                                              00002655
   10 DO 15 I=1,N                                                       00002656
      DO 14 J=I,N                                                       00002657
      IF(A(I)-A(J)) 14,  14,  11                                        00002658
   11 L=I-N                                                             00002659
      LL=J-N                                                            00002660
      DO 12 K=1,M                                                       00002661
      L=L+N                                                             00002662
      LL=LL+N                                                           00002663
      F=A(L)                                                            00002664
      A(L)=A(LL)                                                        00002665
   12 A(LL)=F                                                           00002666
   14 CONTINUE                                                          00002667
```

```
   15 CONTINUE                                                          00002668
   16 IF(NLL) 20,  18,  20                                              00002669
   18 NLL=50                                                            00002670
   20 WRITE(6,1)NO                                                      00002671
      XSCAL=(A(N)-A(1))/(FLOAT(NLL-1))                                  00002672
      M1=N+1                                                            00002673
      YMIN=A(M1)                                                        00002674
      YMAX=YMIN                                                         00002675
      M2=M*N                                                            00002676
      DO 40 J=M1,M2                                                     00002677
      IF(A(J)-YMIN)  28,26,26                                           00002678
   26 IF(A(J)-YMAX) 40,40,30                                            00002679
   28 YMIN=A(J)                                                         00002680
      GO TO 40                                                          00002681
   30 YMAX=A(J)                                                         00002682
   40 CONTINUE                                                          00002683
      YSCAL=(YMAX-YMIN)/100.0                                           00002684
      XB=A(1)                                                           00002685
      L=1                                                               00002686
      MY=M-1                                                            00002687
      I=1                                                               00002688
   45 F=I-1                                                             00002689
      XPR=XB+F*XSCAL                                                    00002690
      IF(A(L)-XPR) 50,50,70                                             00002691
   50 DO 55 IX=1,101                                                    00002692
   55 OUT(IX)=BLANK                                                     00002693
      DO 60 J=1,MY                                                      00002694
      LL=L+J*N                                                          00002695
      JP=((A(LL)-YMIN)/YSCAL)+1.0                                       00002696
      OUT(JP)=ANG(J)                                                    00002697
   60 CONTINUE                                                          00002698
      WRITE(6,2)XPR,(OUT(IZ),IZ=1,101)                                  00002699
      L=L+1                                                             00002700
      GOTO80                                                            00002701
   70 WRITE(6,3)                                                        00002702
   80 I=I+1                                                             00002703
      IF(I-NLL) 45,84,86                                                00002704
   84 XPR=A(N)                                                          00002705
      GO TO 50                                                          00002706
   86 WRITE(6,7)                                                        00002707
      YPR(1)=YMIN                                                       00002708
      DO 90 KN=1,9                                                      00002709
   90 YPR(KN+1)=YPR(KN)+YSCAL*10.0                                      00002710
      YPR(11)=YMAX                                                      00002711
      WRITE(6,8)(YPR(IP),IP=1,11)                                       00002712
      RETURN                                                            00002713
      END                                                               00002714
      SUBROUTINE ARC(XI,YI,XO,YO,SI,SO,XP,YP,D1Y,D2Y,D3Y,DERIX,DERFX,   00002715
     1DERIY,DERFY,NI,NO,INT)                                            00002716
C                                                                       00002717
C  ********    DETERMINES THE ARC LENGTH OF THE AIRFOIL POINTS *****    00002718
C                                                                       00002719
      DIMENSION XI(1),YI(1),XO(1),YO(1),SI(1),SO(1),XP(1),YP(1),D1Y(1), 00002720
     1D2Y(1),D3Y(1)                                                     00002721
C        SI - INPUT CHORD LENGTH       SO - OUTPUT CHORD LENGTH         00002722
C        COMPUTE ARC LENGTH SI USING CIRCULAR ARC SEGMENTS              00002723
C        INT=1     SPLINE XI AND YI VS SI                               00002724
      EPSI=1.E-10                                                       00002725
      N1=NI-1                                                           00002726
      SI(1)=0.                                                          00002727
                   H1=0.                                                00002728
```

```
      DX1=XI(2)-XI(1)                                                   00002729
                          DY1=YI(2)-YI(1)                               00002730
      C1=SQRT(DX1**2+DY1**2)                                            00002731
      SI(2)=C1                                                          00002732
      IF(NI.EQ.2)RETURN                                                 00002733
      DO 1 I=2,N1                                                       00002734
      DX1=XI(I)-XI(I-1)                                                 00002735
                            DY1=YI(I)-YI(I-1)                           00002736
      DX2=XI(I+1)-XI(I)                                                 00002737
                            DY2=YI(I+1)-YI(I)                           00002738
      DX=XI(I+1)-XI(I-1)                                                00002739
                             DY=YI(I+1)-YI(I-1)                         00002740
      C2=SQRT(DX2**2+DY2**2)                                            00002741
      C=SQRT(DX**2+DY**2)                                               00002742
      A=(DY1*DX-DY*DX1)/2.                                              00002743
      H=4.*A/(C*C1*C2)                                                  00002744
      HAV=(H1+H)/2.                                                     00002745
      DS=C1*(1.+(C1/2.*HAV)**2/6.)                                      00002746
      SI(I)=SI(I-1)+DS                                                  00002747
      C1=C2                                                             00002748
      H1=H                                                              00002749
    1 CONTINUE                                                          00002750
      DS=C1*(1.+(C1/2.*H)**2/6.)                                        00002751
      SI(NI)=SI(NI-1)+DS                                                00002752
      IF(INT.NE.1)RETURN                                                00002753
    2 CONTINUE                                                          00002754
C        SPLINE XI AS A FUNCTION OF SI                                  00002755
      CALL SPLINE(SI,XI,SO,XO,XP,D1Y,D2Y,D3Y,1,3,DERIX,DERFX,NI,NO,0)   00002756
    3 CONTINUE                                                          00002757
C        SPLINE YI AS A FUNCTION OF SI                                  00002758
      CALL SPLINE(SI,YI,SO,YO,YP,D1Y,D2Y,D3Y,1,3,DERIY,DERFY,NI,NO,1)   00002759
      RETURN                                                            00002760
      END                                                               00002761
      SUBROUTINE SPLINE(XIN,YIN,XOUT,YOUT,DYDX,D1Y,D2Y,D3Y,NDERI,NDERF, 00002762
     1DERIVI,DERIVF,NIN,NOUT,INTERP)                                    00002763
C     E B KLUNKER        JANUARY 1973                                   00002764
C     COMPUTE A CUBIC SPLINE THROUGH THE SET OF POINTS XIN(I),YIN(I)    00002765
C     XIN  MUST BE MONOTON1C                                            00002766
C     XIN,YIN      INPUT INDEPENDENT AND DEPENDENT VARIABLES            00002767
C     XOUT,YOUT    OUTPUT INDEPENDENT AND DEPENDENT VARIABLES           00002768
C     D1Y,D2Y,D3Y  1ST, 2ND, AND 3RD DERIVATIVE AT SPLINE POINTS XIN    00002769
C     DYDX         DERIVATIVE AT XOUT                                   00002770
C     NIN ,NOUT    NUMBER OF INPUT AND OUTPUT VALUES                    00002771
C     NDERI        ORDER OF DERIVATIVE AT INITIAL SPLINE POINT (1,2,OR 300002772
C     NDERF        ORDER OF DERIVATIVE AT FINAL SPLINE POINT (1,2,OR 3) 00002773
C     DERIVI       VALUE OF DERIVATIVE AT INITIAL SPLINE POINT          00002774
C     INTERP NE 1  INTERPOLATE FOR GIVEN  VALUES YOUT                   00002775
C     NTIMES NE 1  SPLINE COEFFICIENTS ARE NOT RECOMPUTED               00002776
      DIMENSION XIN(1),YIN(1),XOUT(1),YOUT(1),DYDX(1),D1Y(1),D2Y(1),    00002777
     1D3Y(1)                                                            00002778
      EPSI1=-1.E-10                                                     00002779
                        EPSI2=-EPSI1                                    00002780
      NIM1=NIN-1                                                        00002781
      DX=XIN(2)-XIN(1)                                                  00002782
                          I=2                                           00002783
      IF(DX.EQ.0.)GO TO 35                                              00002784
      DF=(YIN(2)-YIN(1))/DX                                             00002785
      IF(NDERI-2)1,2,3                                                  00002786
    1 C=.5                                                              00002787
               F=3.*(DF-DERIVI)/DX                                      00002788
      GO TO 4                                                           00002789
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```
    2 C=0.                                                      00002790
           F=DERIVI                                             00002791
      GO TO 4                                                   00002792
    3 C=-1.                                                     00002793
          F=-DX*DERIVI                                          00002794
C        FORWARD LOOP OF TRIDIAGONAL MATRIX COMPUTATION         00002795
    4 D1Y(1)=-C                                                 00002796
              D2Y(1)=F                                          00002797
      DO 5 I=2,NIM1                                             00002798
      DX1=XIN(I+1)-XIN(I)                                       00002799
      IF(DX1.EQ.0.)GO TO 36                                     00002800
      DF1=(YIN(I+1)-YIN(I))/DX1                                 00002801
      B=2.*(DX+DX1)                                             00002802
      F=6.*(DF1-DF)                                             00002803
      DENOM=B+DX*D1Y(I-1)                                       00002804
      D2Y(I)=(F-DX*D2Y(I-1))/DENOM                              00002805
      D1Y(I)=-DX1/DENOM                                         00002806
      DX=DX1                                                    00002807
      DF=DF1                                                    00002808
    5 CONTINUE                                                  00002809
      I=NIN                                                     00002810
      IF(NDERF-2)6,7,8                                          00002811
    6 A=.5                                                      00002812
          F=-3.*(DF1-DERIVF)/DX1                                00002813
      GO TO 9                                                   00002814
    7 A=0.                                                      00002815
          F=DERIVF                                              00002816
      GO TO 9                                                   00002817
    8 A=-1.                                                     00002818
           F=DX1*DERIVF                                         00002819
    9 DENOM=1.+A*D1Y(I-1)                                       00002820
      D2Y(I)=(F-A*D2Y(I-1))/DENOM                               00002821
      D1Y(I)=0.                                                 00002822
C        BACK SUBSTITUTION OF TRIDIAGONAL MATRIX COMPUTATION    00002823
      K=NIN                                                     00002824
      DO 11 I=1,NIM1                                            00002825
      K=K-1                                                     00002826
      D2Y(K)=D2Y(K)+D1Y(K)*D2Y(K+1)                             00002827
   10 DX1=XIN(K+1)-XIN(K)                                       00002828
      DF1=(YIN(K+1)-YIN(K))/DX1                                 00002829
      D1Y(K+1)=DF1+DX1/6.*(D2Y(K)+2.*D2Y(K+1))                  00002830
      D3Y(K+1)=(D2Y(K+1)-D2Y(K))/DX1                            00002831
   11 CONTINUE                                                  00002832
      D1Y(1)=DF1-DX1/6.*(2.*D2Y(1)+D2Y(2))                      00002833
      D3Y(1)=D3Y(2)                                             00002834
      IF(INTERP.NE.1)GO TO 16                                   00002835
C        INTERPOLATE FOR GIVEN VALUES OF XOUT                   00002836
      DO 15 J=1,NOUT                                            00002837
      DO 12 I=1,NIN                                             00002838
      DX=XIN(I)-XOUT(J)                                         00002839
      IF(DX.GE.EPSI1.AND.DX.LE.EPSI2)GO TO 13                   00002840
      IF(DX.GE.EPSI2)GO TO 14                                   00002841
   12 CONTINUE                                                  00002842
      GO TO 37                                                  00002843
   13 YOUT(J)=YIN(I)                                            00002844
      DYDX(J)=D1Y(I)                                            00002845
      GO TO 15                                                  00002846
   14 DX=XOUT(J)-XIN(I)                                         00002847
      YOUT(J)=YIN(I)+DX*(D1Y(I)+DX/2.*(D2Y(I)+DX/3.*D3Y(I)))    00002848
      DYDX(J)=D1Y(I)+DX*(D2Y(I)+DX/2.*D3Y(I))                   00002849
   15 CONTINUE                                                  00002850
```

```
      GO TO 23                                                          00002851
C        INTERPOLATION FOR GIVEN VALUES OF YOUT                         00002852
   16 DO 22 J=1,NOUT                                                    00002853
      DO 17 I=1,NIN                                                     00002854
      DY=YIN(I)-YOUT(J)                                                 00002855
      IF(DY.GE.EPSI1.AND.DY.LE.EPSI2)GO TO 18                           00002856
      IF(DY.GE.EPSI2)GO TO 19                                           00002857
   17 CONTINUE                                                          00002858
      GO TO 38                                                          00002859
   18 YOUT(J)=YIN(I)                                                    00002860
      XOUT(J)=XIN(I)                                                    00002861
      DYDX(J)=D1Y(I)                                                    00002862
      GO TO 22                                                          00002863
   19 DX=-DY/D1Y(I)                                                     00002864
   20 YO=YIN(I)+DX*(D1Y(I)+DX/2.*(D2Y(I)+DX/3.*D3Y(I)))                 00002865
      DY=YO-YOUT(J)                                                     00002866
      IF(DY.GE.EPSI1.AND.DY.LE.EPSI2)GO TO 21                           00002867
      YP=D1Y(I)+DX*(D2Y(I)+DX/2.*D3Y(I))                                00002868
      DELX=-DY/YP                                                       00002869
      DX=DX+DELX                                                        00002870
      GO TO 20                                                          00002871
   21 XOUT(J)=XIN(I)+DX                                                 00002872
      DYDX(J)=D1Y(I)+DX*(D2Y(I)+DX/2.*D3Y(I))                           00002873
   22 CONTINUE                                                          00002874
   23 RETURN                                                            00002875
   35 PRINT 100                                                         00002876
      PRINT 101,XIN(1),XIN(2)                                           00002877
      STOP                                                              00002878
   36 PRINT 100                                                         00002879
      PRINT 102,I,XIN(I),XIN(I+1)                                       00002880
      STOP                                                              00002881
   37 PRINT 100                                                         00002882
      PRINT 103,J,XOUT(J),XIN(NIN)                                      00002883
      STOP                                                              00002884
   38 PRINT 100                                                         00002885
      PRINT 104,J,YOUT(J),YIN(NIN)                                      00002886
      STOP                                                              00002887
C                                                                       00002888
  100 FORMAT(/5X,'SUBROUTINE SPLINE'/)                                  00002889
  101 FORMAT(/5X,'ERROR IN INPUT   XIN(1)='E12.4,5X,'XIN(2)='E12.4/)    00002890
  102 FORMAT(/5X,'ERROR IN INPUT   I='I5,5X,'XIN(I)='E12.4,5X,'XIN(I+1)=00002891
     1'E12.4/)                                                          00002892
  103 FORMAT(/5X,'XOUT(J) IS OUT OF RANGE   J='I5,5X,'XOUT(J)='E12.4,5X,00002893
     1'XIN(NIN)='E12.4/)                                                00002894
  104 FORMAT(/5X,'YOUT(J) IS OUT OF RANGE   J='I5,5X,'YOUT(J)='E12.4,5X,00002895
     1'YIN(NIN)='E12.4/)                                                00002896
C                                                                       00002897
      END
C ***** SUPERPOSES THE VORTEX BC POTENTIALS AT INFINITY *****
      SUBROUTINE VORBCI(BETA,QUAN2,QUAN3)
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)00000007
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),                   00000008
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(9900000009
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),                      00000010
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,00000011
     4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP100000012
     5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4                                  00000013
      COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1, 00000014
     1JMAX,JCON,JMAX1,NSSP,IW                                           00000015
      COMMON/VORTEX/VORCIR,IVLOC,XV,YV,IVOR,JVOR
      QUAN1=-.5*VORCIR/PI
```

```
      IVORP1=IVOR+1
      IF (IVLOC.EQ.1) GO TO 910
      P(IMAX,1)=P(IMAX,1)+QUAN1*QUAN2
      P(IMAX,JMAX)=P(IMAX,JMAX)+QUAN1*(PI-QUAN2)
      P(1,JMAX)=P(1,JMAX)+QUAN1*(PI+QUAN2)
      P(1,1)=P(1,1)+QUAN1*(2.*PI-QUAN2)
      GO TO 920
  910 P(1,JMAX)=P(1,JMAX)+QUAN1*QUAN2
      P(1,1)=P(1,1)+QUAN1*(PI-QUAN2)
      P(IMAX,1)=P(IMAX,1)+QUAN1*(PI+QUAN2)
      P(IMAX,JMAX)=P(IMAX,JMAX)+QUAN1*(2.*PI-QUAN2)
  920 IF (ALP.EQ.0.0) GO TO 980
      QUAN4=ATAN(BETA/TAN(ALP))
      IF (IVLOC.EQ.1) GO TO 950
      IF (ALP.GT.0.0) GO TO 930
      DO 922 J=2,JMAX1
        P(IMAX,J)=P(IMAX,J)+QUAN1*(PI+QUAN4)
  922   P(1,J)=P(1,J)+QUAN1*(2.*PI+QUAN4)
      GO TO 940
  930 DO 932 J=2,JMAX1
        P(IMAX,J)=P(IMAX,J)+QUAN1*QUAN4
  932   P(1,J)=P(1,J)+QUAN1*(PI+QUAN4)
  940 DO 943 I=2,IMAX1
  943   P(I,JMAX)=P(I,JMAX)+QUAN1*(PI-QUAN3)
      DO 946 I=2,IVOR
  946   P(I,1)=P(I,1)+QUAN1*(2.*PI-QUAN3)
      DO 949 I=IVORP1,IMAX1
  949   P(I,1)=P(I,1)+QUAN1*(-QUAN3)
      RETURN
  950 IF (ALP.GT.0.0) GO TO 960
      DO 952 J=2,JMAX1
        P(1,J)=P(1,J)+QUAN1*(PI+QUAN4)
  952   P(IMAX,J)=P(IMAX,J)+QUAN1*(2.*PI+QUAN4)
      GO TO 970
  960 DO 962 J=2,JMAX1
        P(1,J)=P(1,J)+QUAN1*QUAN4
  962   P(IMAX,J)=P(IMAX,J)+QUAN1*(PI+QUAN4)
  970 DO 973 I=2,IMAX1
  973   P(I,1)=P(I,1)+QUAN1*(PI-QUAN3)
      DO 976 I=2,IVOR
  976   P(I,JMAX)=P(I,JMAX)+QUAN1*(-QUAN3)
      DO 979 I=IVORP1,IMAX1
  979   P(I,JMAX)=P(I,JMAX)+QUAN1*(2.*PI-QUAN3)
      RETURN
  980 IF (IVLOC.EQ.1) GO TO 990
      DO 983 J=2,JMAX1
        P(1,J)=P(1,J)-.75*VORCIR
  983   P(IMAX,J)=P(IMAX,J)-.25*VORCIR
      DO 986 I=2,IMAX1
  986   P(I,JMAX)=P(I,JMAX)-.5*VORCIR
      DO 989 I=2,IVOR
  989   P(I,1)=P(I,1)-VORCIR
      RETURN
  990 DO 993 J=2,JMAX1
        P(1,J)=P(1,J)-.25*VORCIR
  993   P(IMAX,J)=P(IMAX,J)-.75*VORCIR
      DO 996 I=2,IMAX1
  996   P(I,1)=P(I,1)-.5*VORCIR
      DO 999 I=IVORP1,IMAX1
  999   P(I,JMAX)=P(I,JMAX)-VORCIR
      RETURN
```

```
      END
//GO.SYSIN DD *
 TEST CASE TO SEE IF IT WILL WORK
&FINP
  M=0.10,ALP=+0.0,RN=8.0+04,XLBDLY=-0.44,XV=-.70,YV=-.2,VORCIR=-.3,
  XPC=.5,CONV=1.E-06,XLSEP=0.1,RADUS=0.0158,CLALP=0.105,
&END
&IINP
  IKASE=1,ITACT=0,LP=50,IMASS=0,ILAM=1,ITEUPC=0,ITELWC=0,NHALF=0,
  IPRT1=1,MITER=50,
&END
  71
0.000000  0.000000  0.000503  0.003959  0.002013  0.007839  0.004525  0.011637
0.008035  0.015347  0.012536  0.018965  0.018019  0.022483  0.024472  0.025893
0.031883  0.029189  0.040236  0.032361  0.049516  0.035400  0.059702  0.038297
0.070776  0.041043  0.082713  0.043630  0.095492  0.046049  0.109084  0.048292
0.123464  0.050351  0.138603  0.052221  0.154469  0.053896  0.171031  0.055372
0.188255  0.056645  0.206107  0.057714  0.224551  0.058578  0.243550  0.059238
0.263065  0.059695  0.283058  0.059952  0.303487  0.060014  0.324312  0.059886
0.345491  0.059575  0.366981  0.059086  0.388739  0.058430  0.410721  0.057613
0.432883  0.056646  0.455180  0.055538  0.477567  0.054300  0.500000  0.052940
0.522432  0.051471  0.544819  0.049901  0.567116  0.048243  0.589278  0.046505
0.611260  0.044698  0.633018  0.042832  0.654508  0.040917  0.675687  0.038963
0.696512  0.036978  0.716941  0.034971  0.736934  0.032952  0.756449  0.030929
0.775448  0.028911  0.793892  0.026905  0.811745  0.024921  0.828969  0.022966
0.845531  0.021049  0.861397  0.019178  0.876535  0.017359  0.890915  0.015602
0.904508  0.013914  0.917286  0.012303  0.929224  0.010776  0.940298  0.009339
0.950484  0.008002  0.959764  0.006769  0.968117  0.005647  0.975528  0.004643
0.981981  0.003760  0.987463  0.003006  0.991964  0.002382  0.995475  0.001893
0.997987  0.001542  0.999496  0.001331  1.000000  0.001260
     0.0       1.0       0.0       0.0
  71T
0.000000  0.000000  0.000503 -0.003959  0.002013 -0.007839  0.004525 -0.011637
0.008035 -0.015347  0.012536 -0.018965  0.018019 -0.022483  0.024472 -0.025893
0.031883 -0.029189  0.040236 -0.032361  0.049516 -0.035400  0.059702 -0.038297
0.070776 -0.041043  0.082713 -0.043630  0.095492 -0.046049  0.109084 -0.048292
0.123464 -0.050351  0.138603 -0.052221  0.154469 -0.053896  0.171031 -0.055372
0.188255 -0.056645  0.206107 -0.057714  0.224551 -0.058578  0.243550 -0.059238
0.263065 -0.059695  0.283058 -0.059952  0.303487 -0.060014  0.324312 -0.059886
0.345491 -0.059575  0.366981 -0.059086  0.388739 -0.058430  0.410721 -0.057613
0.432883 -0.056646  0.455180 -0.055538  0.477567 -0.054300  0.500000 -0.052940
0.522432 -0.051471  0.544819 -0.049901  0.567116 -0.048243  0.589278 -0.046505
0.611260 -0.044698  0.633018 -0.042832  0.654508 -0.040917  0.675687 -0.038963
0.696512 -0.036978  0.716941 -0.034971  0.736934 -0.032952  0.756449 -0.030929
0.775448 -0.028911  0.793892 -0.026905  0.811745 -0.024921  0.828969 -0.022966
0.845531 -0.021049  0.861397 -0.019178  0.876535 -0.017359  0.890915 -0.015602
0.904508 -0.013914  0.917286 -0.012303  0.929224 -0.010776  0.940298 -0.009339
0.950484 -0.008002  0.959764 -0.006769  0.968117 -0.005647  0.975528 -0.004643
0.981981 -0.003760  0.987463 -0.003006  0.991964 -0.002382  0.995475 -0.001893
0.997987 -0.001542  0.999496 -0.001331  1.000000 -0.001260
     0.0      -1.0       0.0       0.0
```