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GRUMFOIL: A Computer Code for the Viscous Transonic Flow Over Airfoils

H. R. Mead and R. E. Melnik

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GRUMFOIL: A Computer Code for the Viscous Transonic Flow Over Airfoils

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NOMENCLATURE

| | |
|----------------|---|
| C_D | Drag coefficient based on integrated pressures and skin friction (without base drag contribution) |
| C_{D_B} | Drag coefficient including estimated base drag contribution |
| C_{D_∞} | Form drag coefficient based on computed momentum thickness at "infinity" |
| $C_{D_{sy}}$ | Form drag coefficient based on momentum thickness at the trailing edge (Squire-Young formula) |
| C_f | Skin friction coefficient, $\tau_w / \frac{1}{2} \rho_e U_e^2$ |
| C_L | Lift coefficient based on integrated pressure distribution |
| C_{LC} | Lift coefficient based on circulation determined by "Kutta" condition. This is the quantity inputted into the Kutta condition in the inverse mode |
| C_M | Moment coefficient based on integrated pressure distribution |
| C_p | Pressure coefficient |
| H | Boundary layer shape factor, δ^* / θ |
| \bar{H} | Transformed incompressible boundary layer shape factor |
| I, J | Grid point labels in the ω, r directions |
| M | Mach number |
| M_c | Mach number parameter used in inviscid switch function |
| P_i | Relaxation factors in the multi-grid/ADI scheme |
| Q | Boundary source strength, $\rho_e U_e \delta^*$ |
| Q_c | Parameter appearing in inviscid switch function ($Q_c = M_c^2$) |
| Re | Reynolds number |
| s | Arc length along airfoil and wake |
| U | Velocity parallel to body and wake surfaces |
| V | Velocity normal to body and wake surface |
| X, Y | Cartesian coordinates along and normal to chord plane |
| α | Angle of attack |

NOMENCLATURE (CON'T)

| | |
|---------------|---|
| δ | Boundary layer thickness |
| δ^* | Boundary layer displacement thickness |
| θ | Boundary layer momentum thickness |
| $\tilde{\pi}$ | Cole's wake parameter |
| $\nu_{1,2,3}$ | Parameters controlling artificial viscosity |
| ρ | Density |
| τ_w | Skin friction |

SUBSCRIPTS

| | |
|----------|--|
| B,T | Denotes values on lower and upper surfaces of body and wake respectively |
| CORR | Denotes quantity corrected for wind tunnel interference |
| e | Denotes boundary layer edge values and inviscid surface values |
| te | Denotes quantity evaluated at trailing edge |
| ∞ | Denotes free stream quantity |

1. INTRODUCTION

The computer program, GRUMFOIL, described in this report is for the computation of steady, viscous, transonic flow over two dimensional airfoils. The code is applicable to flows with freestream Mach numbers less than one and high Reynolds numbers for which the boundary layers are thin and turbulent over most of the airfoil surface. Our formulation makes use of a local analytic solution to correct for strong interaction and normal pressure gradient effects at trailing edges. The local solution is based on a formal asymptotic analysis for airfoils with cusped trailing edges. Although strictly applicable only to airfoils with small included trailing edge angles, the present code can be applied to airfoils with arbitrarily large trailing edge angles but probably with reduced accuracy of the trailing edge correction procedure. The code is intended primarily for use with airfoils with sharp trailing edges but can be applied with some approximation to airfoils with small trailing edge bluntness. The latest version of the code, which is described in this volume, can treat flows with separation and appears to be useful up to and including maximum lift.

The GRUMFOIL code employs a zonal type viscid/inviscid approach to viscous flows. It is based on a finite difference solution of the potential flow equation for the inviscid flow, integral entrainment methods for the laminar and turbulent boundary layers and wakes, and a complete set of matching conditions coupling the inviscid and viscid flow fields. A detailed description of the basic theoretical and numerical formulation employed in the GRUMFOIL code is given in Ref. 1.

Several versions of the GRUMFOIL code have been developed over the years. The preliminary MCMJ-4 version, which was completed in early 1981, follows the formulation in Ref. 1. That version employed Jameson's (Refs. 2 and 3) mixed flow relaxation technique for solving the conservative full potential equation using a circle plane ("O" type) coordinate system (A nonconservative option was also provided.). The method employed a direct solver (Ref. 3) to accelerate convergence. The turbulent boundary layer was solved using the standard form of Green's lag-entrainment method. A direct iterative scheme was used to treat the coupling between the viscid and inviscid solutions.

This user manual applies to the most recent version of the code, designated MCMJ-9N. This version incorporates several improvements to both the numerical procedures used to solve the equations and to the turbulence model employed in the lag-entrainment method.

The improvement to the numerics involved: A switch from the SLOR-Hybrid method for solving the potential equations to Jameson's multi-grid ADI method (Ref. 4), a more accurate far field treatment, and a more robust second-order artificial viscosity relation. The modifications to the lag-entrainment method were directed at improving the prediction of separated flows. We also replaced the direct method used for the viscous coupling with Carter's semi-inverse method, thus allowing for the use of more realistic velocity profile relations for separated flow. These changes greatly increased the speed and reliability of the code, and significantly reduced the spatial truncation error. The new MCMJ-9N version runs about ten times faster than earlier versions of the code and achieves the same accuracy with half the number of mesh points in each direction.

The modifications to the turbulent closure relations used in the standard lag-entrainment method were directed at improving its predictions of separated flows. Integral entrainment methods require the specification of certain velocity profile and equilibrium entrainment relations in order to arrive at a closed system of equations. In the original Green's lag-entrainment method, which was used in the early versions of GRUMFOIL, these were determined from empirical correlations for attached turbulent boundary layers. The original method was not intended to be used for separated flows, and it is not surprising that it did not perform well in the GRUMFOIL code when applied to such cases. The present MCMJ-9N version of the code incorporates more realistic velocity profile and equilibrium entrainment relations aimed at improving the prediction of separated flows.

The GRUMFOIL code is based on the potential flow equation which ignores entropy increases across the shock wave and the associated vorticity downstream. Recently, Hafez (Ref. 5) has developed a simple approximate procedure for partially accounting for nonisentropic flow effects. In his method the entropy effect on the shock relations is accounted for, but the effects due to the downstream vorticity are neglected. Results presented in Ref. 5 for strong shock cases, where the entropy effect is certainly

important, clearly demonstrated the effectiveness of his approach. This type of correction is likely to be important in viscous transonic flows near maximum lift where strong shock waves and separated flows are present. Consequently, we have incorporated the Hafez entropy correction into the current version of the GRUMFOIL code.

All the modifications discussed above, except for the entrainment relation changes and entropy corrections, are fully described in Ref. 6. The latter improvements will be reported on in a future publication that will deal with the extended capabilities of the new code for separated flows.

In addition to the above revisions, we have also incorporated an improved expression for the base pressure which is used in the code to make an estimate of the base drag contribution to the total drag. The correction is based on Hoerner's correlation for base drag on small rearward facing steps (Ref. 7). For completeness, we have included the new expression used for the base pressure in the following section.

The present report is intended to serve as a user's manual for the MCMJ-9N version of the GRUMFOIL code. In the following section we provide general instructions for running the code and for interpreting the output. In Section 3, PROGRAM DESCRIPTION, we provide a more detailed description of the program which should be helpful for setting up the input data file and for understanding how the code functions. A sample calculation including all inputs and selected output data is included in the Appendix.

2. GENERAL OPERATING INSTRUCTIONS

In this section we provide some general information that is useful for running the MCMJ-9N version of the GRUMFOIL code. We identify all the parameters that are needed to set up a computation and provide some information that is helpful in interpreting the output data. More detailed information that is required to set-up the input data set and to read the output is provided in the following section. The present section is divided in two parts-one dealing with the input data and the other with the output.

2.1 Input Data

Two classes of input data are required - one defines the physical problem being addressed and the other establishes the program configuration selected for the computation. In most cases the user need only concern himself with the first data class which fixes the parameters defining the physical problem such as free stream Mach number M_∞ , Reynolds number Re , and so on. The second set of data fixes the program configuration and sets things such as the mesh configuration, artificial viscosity, and the velocity profile and entrainment relations. Ordinarily the program will be run with these parameters set at suggested preset values which will be appropriate for most problems except near maximum lift where there are extensive regions of separation present.

2.1.1 Problem Definition

This information defines the problem being addressed. The user must first specify the value of the five constants:

$IBL, LMODE, M_\infty, Re$ and either α or C_L .

The parameter IBL determines whether the computation is to be inviscid ($IBL=0$) or viscous ($IBL=1$) and the constant, $LMODE$, determines whether it is to be a direct, α prescribed, ($LMODE=0$) or inverse, C_L prescribed, ($LMODE=-1$) computation. The user is cautioned not to run in the inverse mode at or near maximum lift. If a C_L is prescribed that is greater than maximum lift no solution exists and the code will fail. The quantities M_∞ , Re , α , and C_L are the free stream Mach number, chord Reynolds number, angle of attack and lift coefficient respectively. The problem definition is completed by specifying the airfoil ordinates, $Y(X)$,

which need not be normalized by any particular reference length and by giving the value of the trailing edge included angle (in degrees), θ_{te} , and the slope of the trailing edge bisector. When neither is known accurately, their true values will be computed within the program from the tabulated ordinates if θ_{te} is given a dummy negative value.

The program has been written to permit a sequence of problems to be solved for a specified set of values of M_∞ and α or C_L . To exercise this option the user must specify the ranges (M_1, M_2) , (C_{L1}, C_{L2}) or (α_1, α_2) of parameters over which solutions are sought and the increments ΔC_L , $\Delta\alpha$ and ΔM_∞ with which the program is to increment the values of M_∞ , α or C_L .

The parameters identified above provide the minimum data that needs to be specified to carry out a given calculation. Although the remaining parameters to be discussed below can usually be left at their preassigned values there may be occasions where it is desirable to change them. The following discussion is intended as a guide to help understand the rationale to be used in deciding when and how these values should be changed. The remaining parameters essentially control the numerical and theoretical formulation to be used in the computation. The program configuration parameters fall into four main groups: 1) inviscid solution, 2) boundary layer solution, 3) viscid/inviscid relaxation parameters, and 4) convergence tolerances.

2.1.2 Inviscid Solution

The parameters in this group control the numerical method used to solve the inviscid potential flow equation. The Hafez entropy correction is controlled by the parameter IRH and is either 0 or 1,

$$IRH = \begin{cases} 0 & \text{No entropy correction} \\ 1 & \text{Entropy correction applied} \end{cases}$$

The default value is IRH=0 so that the entropy correction is not applied in the baseline version. The meshes employed in the inviscid calculation are controlled by the parameters,

FNC, FNR, FMESH and GMESH

The potential flow calculation is ordinarily carried out on a sequence of macro-meshes. A complete solution is first carried out using multi-grid, on the coarsest macro-mesh. The parameters FNR and FNC specify the number of

mesh divisions in the R and ω directions on the coarse grid respectively, where R , ω are polar coordinates in the circle plane. The multi-grid method employs a sequence of coarser "micro" meshes that are formed by deleting grid points from the preceding micro-mesh. The parameter GMESH, specifies the number of micro-grids employed in the multi-grid solution on each macro-grid, and must be specified for each macro-grid. The value of GMESH must be chosen so that the coarsest grid used in the multi-grid solver contains at least two divisions in R . The parameter, FMESH, specifies the number of macro-grids to be employed. If FMESH is greater than one, the solutions carried out on the coarser grids will be used to generate initial data on the succeeding macro-meshes. In the baseline configuration the code is set-up to use three macro-grids (FMESH=3), starting from a (40x8) Mesh (FNC=40 and FNR=8). Thus, the computations will be carried out on a sequence of three grids (40x8), (80x16) and (160x32) with the multi-grid parameter GMESH set to 3., 4., 5., respectively. In order to avoid runaway divergence in an inviscid calculation a maximum number of multi-grid cycles must be assigned. Typically, 25 is used for the parameter TOTO on each macro-mesh. In a viscid calculation the boundary layer is updated after each complete multi-grid cycle, therefore, TOTO is always set to 2.

The artificial viscosity is controlled by three parameters VIS1, VIS2, and VIS3 which correspond to the parameters ν_1 , ν_2 , ν_3 used in Ref. 6. The quantity VIS2 determines the order of the scheme - second order if VIS2=0 and first-order if VIS2=1. The quantities VIS1 and VIS3 set the levels of the first- and second-order artificial viscosities respectively. The baseline program is set to run second-order accurate (VIS2=0) with VIS1=1 and VIS3=2. The switch function which turns off the artificial viscosity at subsonic points is controlled by the parameter Q_C . The value set for Q_C determines the local Mach number, M_C , ($Q_C = M_C^2$) at which the artificial viscosity is reduced to zero. We recommend a default value of $Q_C = 0.90$.

The Parameters, P_i ($i=1 \rightarrow 5$) are relaxation parameters employed in the ADI scheme. The constants P_1 , P_2 , P_3 are proportional to the α_1 , α_2 , α_3 constants in Ref. 4 that set the so-called ϕ_t , $\phi_{\omega t}$ and $\phi_{r t}$ temporal damping terms in the iterative operator. The P_4 and P_5 terms are equal to the relaxation factor multiplying the residual at supersonic and subsonic points

respectively. The relaxation values will usually not have to be changed from the default values set in the baseline code, which are

$$\begin{array}{ll} P_1 = .25 & P_4 = .60, .70, .80 \\ P_2 = .45 & P_5 = 1.5 \\ P_3 = .45 & \end{array}$$

The three values of P_4 are the values on the three macro grids (40x8), (80x16) and (160x32). The other P_i can generally be kept the same on the three macro-grids.

The last parameter that must be set in the inviscid calculations is NINV which is associated with an iteration that determines the angle of attack from the Kutta condition when the program is operated in the inverse mode (LMODE = -1). In this mode the Kutta condition reduces to a non-linear algebraic equation which must be solved by iteration to determine the angle of attack. The parameter NINV sets the number of cycles that are to be carried out in this computation. The default value is NINV = 4. This is sufficient for calculations carried out to maximum residual levels of 10^{-6} to 10^{-7} . The value of NINV should be increased if higher levels of convergence are sought in the inviscid computations.

2.1.3 Boundary Layer Solution Procedure

This group of parameters controls the formulation used for the boundary layer computation. The quantities ICURV and IDIV control the terms appearing in Green's lag-entrainment method for the effects of curvature and mean dilation on turbulence. These terms are included if ICURV and IDIV are set to one (default) and are dropped if they are set to zero. The present code provides some options on the choice of the velocity profile, equilibrium entrainment and skin friction relations that can be used with the lag-entrainment method. The velocity profile relation is controlled by the value of the parameter, IH1HB. The various possibilities are described in Ref. 6.

| | |
|---------|---|
| IH1HB=1 | relation in original Green's lag-entrainment method |
| IH1HB=2 | East, Smith and Merryman |
| IH1HB=3 | Le Balleur |

The choice of the equilibrium entrainment relation is controlled by the value of the parameter IMCE. Two options are provided. The value IMCE=1 selects the equilibrium entrainment relation employed in the original Green's lag-entrainment relation. As mentioned previously this relation greatly overestimates the levels of entrainment in separation zones. The choice IMCE = 2 employs an equilibrium entrainment relation proposed by Le Balleur (Ref. 8) for separated flows. It is based on a smooth blend between Michel's (Ref. 9) entrainment relation for attached flow and a mixing layer type formula for separated flow.

Although these various formulations for the velocity and equilibrium relations are clearly improvements to the original method when the flow is separated we do not yet know which is the best one to use in general. On the basis of limited calculations we recommend, at this time, the values IH1HB=3 and IMCE=2 which have been set as the default values in the code.

The skin friction relation employed in the original Green's lag-entrainment method does not produce realistic predictions of the skin-friction levels in regions of reversed flow. Since the contributions of the skin friction to the momentum balance is not important in separated flow zones, the skin friction was set to zero in such regions in the original GRUMFOIL code. An improved skin friction correlation that produces reasonable predictions of skin friction in regions of reversed flow was proposed by Swafford in Ref. 10 on the basis of limited separated flow data. The present version of the code allows for the choice of using either the original Green's or Swafford's skin friction relation in the turbulent boundary layer solution. This option is controlled by the value of a parameter ICF. The original Green's skin friction relation will be employed if ICF=1 while Swafford's will be used if ICF=2. A default value, ICF=2, using Swafford's skin friction relation has been set in the baseline version of the code.

The user must also specify how the transition point locations are to be determined. These are controlled by the values of the parameters XTRANU, XTRANL, and KT where the quantities XTRANU and XTRANL are the transition point locations in percent chord on the upper and lower surfaces of the airfoil, respectively, and KT is a parameter that specifies the method for determining the natural transition point locations. The choices KT=1, 2, or 3 will select the natural transition criteria of Crabtree (Ref. 11); Michel (Ref. 12); or

Stevens, Goradia, and Braden (Ref. 13); respectively. In these cases the parameters XTRANU and XTRANL should both be set to zero. If the user wishes to directly assign the location of the transition points on the upper and lower surface of the airfoil, he should set KT=4 and set the parameters XTRANU and XTRANL to the desired locations in percent chord. Finally, if KT=1, 2, or 3 and XTRANU and XTRANL are assigned non-zero values, the program will select the most forward of the two possible transition positions. Since KT=1 and XTRANU,L = .10 are defaults, this is the default mode of code operation.

The program will also check for laminar separation and will use Crabtree's criteria (Ref. 11) to decide if it is a short or long bubble leading-edge separation. In either case, all other transition criteria will be bypassed and the transition point will be set to the laminar separation point position. This procedure is physically sound only if the leading edge separation is of the short bubble type. For long bubble separation, the procedure, though not physically correct, will assure that a solution will be completed.

We have found it desirable to override the user specified input values of XTRANU and XTRANL under two circumstances. First, if the selected transition point location is upstream of the stagnation point the code will automatically reset the assigned transition point to the trailing edge and the calculation will continue effectively as if in the natural transition mode. This is a physically sensible procedure since transition to turbulent flow should not be possible if a transition point location is chosen to be upstream of the stagnation point in a strong, favorable pressure gradient. The second set of circumstances where we have found it desirable to alter the assigned transition point locations is where, although the transition point is downstream of the stagnation point, it is too close to the stagnation point. We have found that the code will frequently fail in the turbulent boundary layer solution if transition is assigned too close to the stagnation point in a strong, favorable pressure gradient. Therefore, a Reynolds number based upon the momentum thickness at the assigned transition point is calculated; if it is less than 225, we reassign the transition point to the first grid point downstream where this Reynolds number is greater than 225. In both of the cases described above, a notification message is printed in the tabular output.

In order to prevent run-away divergent solutions we have set a maximum on the number of global viscid-inviscid cycles. This is controlled by the parameters, ITBLM0, ITBLM1, and ITBLM2, which specify the maximum number of global cycles on each mesh. These have been given default values 22, 22 and 30 on the coarse, medium and fine meshes, respectively. They can be increased if further cycles are needed in slowly convergent solutions as is usually required when extensive separation is present.

2.1.4 Viscid-Inviscid Relaxation Parameters

The global viscid-inviscid calculation requires significant underrelaxation to achieve convergence. Separate relaxation factors are introduced into the solutions for the source strength on the airfoil, the source strength in the wake and for the wake curvature terms. These are given by RQE, RQW and RBW, respectively. The values of these relaxation factors can be set to different values on each of the macro-grids. The interaction on each macro-grid starts with the values assigned to RQE, RQW and RBW and are slowly increased to larger values as the iteration proceeds. The final values are multiples of the initial values given by the factors WRQ, WRQW and WRBW. We must also set values of an auxiliary relaxation factor RTE which controls the iteration of a constant that appears in the wake thickness coupling conditions. The default values set for these parameters are given in the following table.

| <u>COARSE GRID (40X8)</u> | |
|----------------------------|------------|
| WRQO = 5.0 | RQEO = 0.2 |
| WRQWO = 5.0 | RQWO = 0.2 |
| WRBWO = 5.0 | RBWO = 0.2 |
| | RTEO = 1.0 |
| <u>MEDIUM GRID (80X16)</u> | |
| WRQ1 = 1.0 | RQE1 = 1.0 |
| WRQW1 = 1.0 | RQW1 = 1.0 |
| WRBW1 = 1.0 | RBW1 = 0.4 |
| | RTE1 = 1.0 |

FINE GRID (160X32)

WRQ2 = 1.0 RQE2 = 0.8
WRQW2= 1.0 RQW2 = 0.4
WRBW2=1.0 RBW2 = 0.20
 RTE2 = 0.10

These values produce rapid and sure convergence for attached flows with shock waves that are not too strong. For more difficult problems with extensive separation, use the following reduced values (shown underlined):

COARSE GRID (40X8)

WRQ0 = 4.0 RQE0 = 0.2
WRQW0= 2.5 RQW0 = 0.2
WRBW0= 1.5 RBW0 = 0.2
 RTE0 = 1.0

MEDIUM GRID (80X16)

WRQ1 = 1.0 RQE1 = 0.5
WRQW1= 1.0 RQW1 = 0.4
WRBW1= 1.0 RBW1 = 0.2
 RTE1 = 1.0

FINE GRID (160X32)

WRQ2 = 1.0 RQE2 = 0.2
WRQW2= 1.0 RQW2 = 0.2
WRBW2= 1.0 RBW2 = 0.1
 RTE2 = 0.05

The use of these reduced values will help convergence but at the expense of longer run times.

2.1.5 Convergence Tolerances

The solution is terminated when certain monitored quantities are reduced below prescribed tolerances. The four quantities monitored during the calculations are: 1) the maximum residual, 2) the change in angle of attack or lift coefficient, 3) the change in trailing edge pressure, and 4) the maximum difference between the boundary layer and inviscid solutions for the inviscid streamwise velocity on the airfoil surface and in the wake. The parameters controlling the tolerances with the recommended default values are

| | |
|----------------------------|--|
| COV = 0.5×10^{-4} | Maximum residual |
| COVA, COVL = 0.005 | Change in angle or attack or lift coefficient |
| COVP = 0.001 | Change in trailing edge pressure |
| DUCR = 0.01 | Difference in viscous and inviscid streamwise velocity |

Terminating the solution at these values will usually produce solutions with the angle of attack, lift coefficient and pressures converged to three decimal places, and the drag coefficient to four places.

2.1.6 Experimental Data

The program allows the user to input experimental data for the pressure distribution $C_p(x)$; displacement and momentum thickness $\delta^*(x)$ and $\theta(x)$; and skin friction coefficient, $C_f(x)$. These data will be incorporated into the final solution output plots.

2.1.7 Summary Recommendations For Difficult Cases

The program has been organized so that it will run with a minimum amount of user supplied data. Ordinarily, for most cases the user will have to supply only data that define the physical problem being addressed. The data which control the program configuration has been set at default values that provide a reasonable compromise between convergence speed and reliability. The default values should be satisfactory for all cases that result in attached or mildly separated flow. Adjustment of some of the program configuration parameters will be necessary for cases near maximum lift which involve extensive regions of separated flow. In the following, we summarize the changes that we have found to be effective for these more difficult cases.

If, for supercritical cases, the inviscid solution shows oscillatory convergence or divergence as evidenced by the plot of convergence history included in the output, this is usually an indication that the ADI relaxation factor, P_4 , is too large. Convergence can be improved by reducing the value of P_4 by a decrement of 0.1 or 0.2 on the offending grid.

If there is extensive separation, it is always necessary to use the smaller set of global relaxation factors given earlier. In these cases the global viscous-inviscid interaction will be significantly slowed thus requiring the program to run longer to achieve the same level of convergence. There-

fore, the parameters ITBLMO, ITBLM1, and ITBLM2, which set the maximum number of global iterations on each of the three macro-meshes, should be increased to 100, 150 and 150, respectively, to allow for the larger number of iterations required.

We have also found that, in the separated flow cases near maximum lift it is very helpful to start the calculation on the next finer macro-mesh (80 x 16). Under these circumstances only two macro-meshes are used (FNC = 80, FNR = 16, and FMESH = 2) and it is necessary to use the reduced global relaxation factors appropriate to the finer mesh start as follows:

| <u>FIRST GRID (80X16)</u> | |
|-----------------------------|-------------|
| WRQ0 = 2.0 | RQE0 = 0.15 |
| WRQW0 = 1.5 | RQW0 = 0.10 |
| WRBW0 = 1.0 | RBW0 = 0.10 |
| | RTE0 = 1.0 |
| <u>SECOND GRID (160X32)</u> | |
| WRQ1 = 1.0 | RQE1 = 0.2 |
| WRQW1 = 1.0 | RQW1 = 0.2 |
| WRBW1 = 1.0 | RBW1 = 0.1 |
| | RTE1 = 0.05 |

These recommendations are intended only as helpful guidelines for treating separated flow cases near maximum lift. The user may have to experiment with the setting of these parameters in order to obtain successful solutions for these cases.

2.2 Output Data

Various options are provided to the user in selecting the amount of output data desired. The procedure for controlling the output is described in the following section. The principle mode for data output is in the form of graphs of the pressure distribution, the distribution of various boundary layer quantities, and a plot of convergence history. For completeness, the values of the forces, moments, and other numerical data of interest are also included in the plots.

The graphical output data consists of six plots. (A seventh plot is produced if experimental pressure data is to be plotted.) The first plot contains two surface pressure distributions; one is the "outer" inviscid

solution and the other is the viscous composite solution. The difference in these two pressure distributions is indicative of the pressure correction across the boundary layer. The numerical data on the bottom of the plot includes the solution for the lift, drag, and moment coefficients, C_L , C_D , and C_M as computed from an integration of the composite pressure distribution. Also included are: a title identifying the airfoil geometry; the free stream Mach number, M ; the angle of attack, ALF ; the "circulatory" lift coefficient CLC ; the number of inviscid iterations carried out on the particular grid corresponding to the plot, NIT ; the number of mesh division ($NC \times NR$) employed in the ω ; and R directions, the value of the maximum residual in the inviscid solution at convergence, $RSID$; the value of the trailing edge pressure, $CPTE$, and a drag coefficient, CDB , which includes a contribution for the base drag of blunt based airfoils. The circulatory lift coefficient, CLC , is the value of lift computed from the Kutta condition in the direct mode (α prescribed) or inputted into the Kutta condition, (C_L prescribed). The value of CLC should agree with the value determined from the integration of the outer inviscid pressure distribution around the airfoil in limit of zero mesh. We have found agreement to within 0.005 on the 160×32 grid.

The base drag contribution to the total drag is obtained from an adaptation of Hoerner's correlation (Ref. 7) for rearward facing steps. In using Hoerner's result to compute the base drag on airfoils with a small trailing edge thickness we have assumed that one of the dividing streamlines could be replaced by a solid surface. For completeness we write out the expressions used to compute the total drag including our approximation for the base drag. It can be written in the form,

$$CDB = CD - \Delta C_D$$

where the base drag contribution ΔC_D is given by

$$\Delta C_D = \left\{ C_{pte} - \frac{M_{te}^2}{M_\infty^2} \frac{1 + 0.2 M_\infty^2}{1 + 0.2 M_{te}^2} \right\}^{3.5} C_{pB} H_{te} \cos \alpha$$

where C_{pte} , and M_{te} are the trailing edge pressure and Mach number as computed from the viscous composite solution, H_{te} is the base height of the airfoil in percent chord, α is the angle of attack, and C_{pB} is the incompressible base pressure coefficient normalized by trailing edge values from the viscous

composite solution. The base pressure coefficient, C_{pB} , is determined from Hoerner's correlation. It is written in the form:

$$C_{pB} = 0.231 (H_{te}/\bar{\delta})^{1/3}$$

where $\bar{\delta}$ is a boundary layer thickness parameter defined by

$$\bar{\delta} = \delta_{max} + \delta_{min} = \delta_{TOTAL}$$

The quantities δ_{max} and δ_{min} are the larger and smaller values of the boundary layer thickness at the trailing edge on the upper and lower sides of the airfoil, respectively. These results are consistent with Hoerner's correlation in the limits $\delta_{min}/\delta_{max} = 0$ and $\delta_{min}/\delta_{max} = 1$ within the approximation that the dividing streamline can be replaced by a solid surface. The above expression provides a simple linear interpolation in $\delta_{min}/\delta_{max}$ between the two limits. The expression for the base drag is intended as a simple and very rough estimate, and is considered an improvement over the expression used in the earlier versions of GRUMFOIL which neglected the contribution of the base pressure term, C_{pB} .

The second plot provides a graphical presentation of the iteration history. The figure includes plots of the trailing edge pressure and the logarithm of the "error" in the inviscid solution. The "error" is defined as the ratio of the average residual to its initial value on the particular grid for which the results apply. The unit of "work" is defined to be equal to the equivalent number of SLOR steps. Information is included at the bottom which gives the value of the average residual at the start and finish of the computation, RESID1 and RESID2 respectively; the number of inviscid cycles, NIT, the total value of work at the end of the computation; and the overall convergence rate which is defined by

$$RATE = \left(\frac{RESID2}{RESID1} \right)^{1/Work}$$

The third plot presents the solution for the displacement thickness, δ^* , and shape factor, H, on the upper and lower surfaces of the airfoil and in the wake. Numerical data at the bottom of the plot include the values of free stream Mach number; angle of attack; the transition option employed through the value of KT; and the actual transition point locations employed in the computations on the upper and lower surfaces of the airfoil, XTRANU and

XTRANL, respectively. Also included are the values of the skin friction drag and form drag. The quantities CDF, CDFT and CDFB are total skin friction drag and the contributions from the upper and lower surface boundary layers, respectively, as computed from integrations of the skin friction distribution. Two values of the form drag are given: one, CDSY, computed from the Squire-Young formula, and the other, CDINF, determined from the computed momentum thickness at the last point in the far wake. The contributions from the momentum thickness of the upper, CDIT, and lower, CDIB, sides of the wake are also given. The form drag should equal the total drag in subcritical (shockless) flow, and should equal the total drag less the wave drag in supercritical flow with shock waves.

The fourth plot presents the solution for the momentum thicknesses and skin friction distribution on the upper and lower surfaces of the airfoil and wake (The skin friction is assumed to be zero in the wake.). As discussed previously, the skin friction is set to zero in separated flow regions if ICF=1.

The fifth plot presents the solutions for the entrainment coefficient, CE, and the equivalent source velocity which is used as a boundary condition in the inviscid outer solution. On the airfoil surface, $0 < x < 1$, the quantity, V, represents the equivalent source velocity on the upper and lower sides of the airfoil while in the wake, $x > 1.0$, it represents the average of the source velocity on each side of the wake streamline. The sixth plot repeats the viscous solution for pressure distribution and numerical data given in the first plot.

If experimental data for the pressure distribution is included in the input data, a seventh plot will be generated that compares the experimental pressures with the viscous composite solution. As described in the next section, the program is structured to make it convenient to specify the plot scales desired. We also permit the user to input a blockage correction in the form of a corrected free stream Mach number. If the program is run at a corrected Mach number, and the experimental Mach number is included with the input of experimental data, the program will calculate blockage corrections to the experimental pressure distribution and lift and drag according to the formulas

$$C_{p \text{ corr}} = [A M_{\infty}^2 / M_{\text{corr}}^2] C_p + \frac{10(A-1)}{7 M_{\text{corr}}^2}$$

$$C_{L \text{ corr}}, C_{D \text{ corr}} = [A M_{\infty}^2 / M_{\text{corr}}^2] C_L, C_D$$

where

$$A = \left[\frac{5 + M_{\text{corr}}^2}{5 + M_{\infty}^2} \right]^{3.5}$$

When running the code in the inverse mode with the lift coefficient chosen to match the experimental lift coefficient, it is necessary to make a slight adjustment to the input lift coefficient. This small correction is necessary because the lift coefficient computed from the integrated pressure will differ slightly from the circulatory lift coefficient, CLC, which is the quantity input into the Kutta condition in the inverse mode. If we wish the theoretical integrated lift coefficient to agree with the experimental value of the lift coefficient, we must slightly adjust the value of the input value of CLC. The appropriate increment is usually very small and can be quickly estimated by trial and error. The increment DCLC, if included in the input data, is written at the bottom of this plot. Its default value is 0.0.

The graphical data is available in tabular form along with tables of other properties of the solution that may be of interest. The procedures for selecting the desired output options are described in the following section along with further details for interpreting the tabular output data and for setting up the input data deck.

3. PROGRAM DESCRIPTION

3.1 Program Structure

This subsection contains a note on compiler and linkage information followed by a list of subroutines (with a brief description of each), a subroutine tree diagram and a simplified flow chart of the program logic. The program is written in FORTRAN 66 and requires each do loop to be executed at least once.

3.1.1 Compiler & Linkage Information

At Grumman, the program is run in double precision on the IBM 370/3081 by employing the AUTODBL feature of the Fortran H extended compiler. This recommended precision is about the normal level for CDC machines. The program requires about 1000 K bytes of storage in the mode run at Grumman. Some installations may require overlay.

3.1.2 Subroutine Glossary

We now list the principle subroutines used in the program along with a very brief definition of their function. In subroutines GRAPH, CVPLT, and AUXPLT are calls to a number of Calcomp routines which are members of a Grumman library. The user will probably have to modify these routines slightly to make them compatible with the user's graphics installation. The normal operation of subroutine RELAX produces a large number of underflows. We use subroutine ERRSET, a member of our IBM Fortran library, to suppress their write out. The user should find an equivalent replacement.

| | |
|-------|---|
| COMAP | Transforms airfoil into unit circle. |
| SPLIF | Cubic spline fit routine. |
| CONTO | Determines arc length, slopes, and curvature of the profile. |
| ARCL | Calculates arc length using the first three derivatives of x and y. |
| PARAF | Parabolic fit routine. |
| INTPL | Interpolation using Taylor Series. |
| SURFL | Constructs the derivative of arc length by conjugation. |

| | |
|--------|--|
| CONJ | Conjugation by fast Fourier transform. |
| FOUCF | Determines the Fourier coefficients by fast Fourier transform. |
| FFORM | Fast Fourier transform. |
| BLDATA | Reads and writes the values of the parameters for the viscous calculations. |
| CPXC | Corrects experimental values of C_L , C_D , and C_p to match a change in indicated experimental Mach number, and scales variables for plotting. |
| DISC | Calculates the mapping modulus exterior to the unit circle. |
| FARFL | Calculates the far field functions. |
| ESTIM | Initializes the reduced velocity potential to zero. |
| AIRFL | Evaluates airfoil coordinates at circle plane nodal points (equal circle angle increments). |
| LE | Calculates circle plane index of leading edge. |
| INVBL | Provides an initial parabolic distribution of source velocity over the rear portion of the profile (on both surfaces) to precondition the first inviscid solution. |
| CUT | Calculates the coordinates of the cut ($\theta = 0^\circ$ in circle plane) and its local slope. |
| DGAM | Computes the change in circulation along the wake due to its curvature. |
| DELTAJ | Calculates function used in determining jump in potential across wake more accurately. |
| RELAX | Solution of the flow equations in divergence form using rotated difference scheme - Relaxation step. |
| STAG | Uses the stagnation point location to determine the index for the start of the upper or lower surface relaxation sweep on every mesh. |
| XPAND | Reorders certain macro-mesh arrays to conform to each micro-mesh expansion or contraction. |
| ADD | Adds correction to the solution on a finer mesh using second-order interpolation and smooths the result. |
| VELO | Calculates surface velocities, Mach numbers, and pressures. |

QWK Calculates the velocity on each side of the wake and the ordinates of the wake streamline.

WAKE Forms basic arrays for edge velocity and coordinates of the profile and wake for boundary layer calculation.

JUMPC Calculates a surface shock position as the last upstream point in a supersonic region.

JUMP Calculates the pressure downstream of a shock treated as an isentropic compression and also from the Rankine-Hugoniot relations.

XTRAP Determines trailing-edge values of functions by linear extrapolation.

FORCS Calculates force and moment coefficients from Simpson's Rule integration of pressures in circle plane.

CPLOT Generates a crude pressure plot around airfoil and into wake.

CHART Generates a Mach number distribution chart for the whole flow field. (Can be made to generate similar charts for the total velocity or either of the component velocities by changing the last parameter in the calling statement.)

SONICA Stores a switch function along each radius of the computational plane for use in the calculation of the sonic line.

SONICB
SONIC Calculate the coordinates of the sonic line.

GRAPH
CVPLT
AUXPLT Calcomp plotting package for C_p , δ^* , H , θ , C_f , C_E , and V_σ (source velocity) plots. Also for the convergence history of the average residual and trailing edge pressure. Also for auxilliary C_p plot of assignable scale to be used in comparisons with experiment.

VISCAL Calculates the boundary layer over the airfoil and into the wake. Uses a direct solution for the laminar run and an inverse solution for the turbulent flow. Corrected source velocities are computed from the updated source strength function and introduced into the boundary conditions of the inviscid solution.

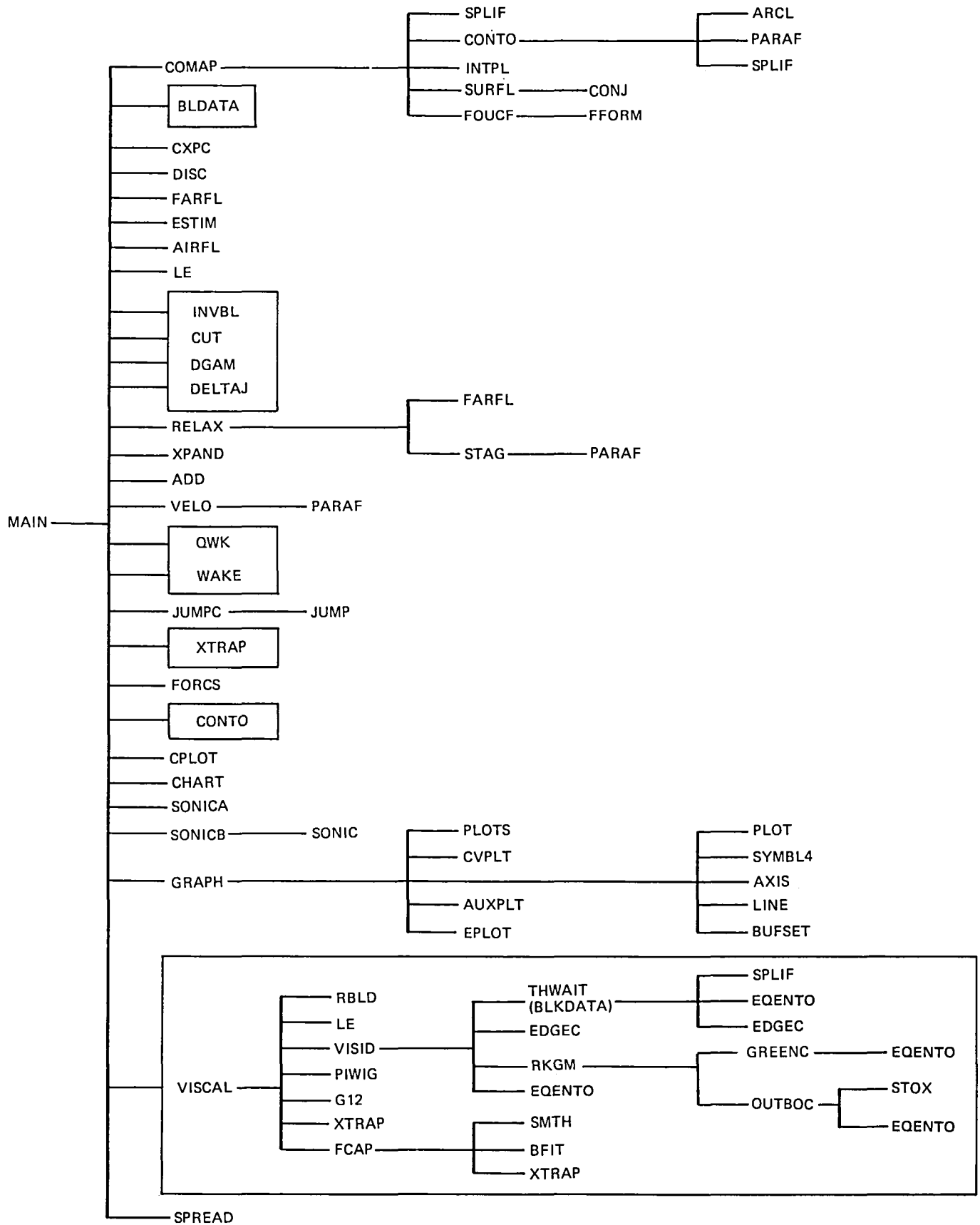
VISID Initializes the laminar and turbulent boundary layer calculations.

THWAIT Calculates laminar boundary layer by Thwaite's integral method, tests for transition, and generates initial values of C_f , H , and δ^* for the turbulent boundary layer

| | |
|---------|--|
| | calculations. Also integrates C_f to get the laminar contribution to the skin friction drag. |
| BLKDATA | Initializes arrays of Thwaite's functions for laminar boundary layer calculation. |
| EQENTO | Calculates equilibrium entrainment coefficient. |
| EDGECE | Uses linear fits to the boundary layer source strength/edge velocity and curvature to calculate their derivatives which are used in interpolation. |
| RKGM | Runge-Kutta-Gil solution of Green's modified lag-entrainment turbulent boundary layer equations. |
| GREENC | Evaluates the right hand side of Green's equations which are written in terms of circle plane coordinates and source velocity. |
| OUTBOC | Loads the arrays for UEV, C_f , δ^* , and θ at circle plane nodal points. |
| STOX | Prints out table of boundary layer characteristics as well as UEI and UEV. It also prints out the maximum difference between UEI and UEV and its position as well as the average difference. |
| PIWIG | Iterative solution for the boundary layer thickness from the skin friction and displacement thickness using law of the wall. |
| G12 | Solutions of the universal trailing edge correction functions. |
| FCAP | Calculates the flow deflection angles along the wake. |
| SMTH | Uses running average smoothing for uniformly spaced function. |
| BFIT | Assigns parabolic variation of the flow wake angle near the trailing edge with zero at the trailing edge. |
| SPREAD | Linear interpolation of expanded arrays at mesh division. |

3.1.3 Subroutine Calling Sequence

The accompanying Subroutine Tree (Fig. 1) shows how the various program subroutines are called. In addition, the subroutines which are related specifically to the viscous calculation are enclosed in rectangles.



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Fig. 1 Subroutine Tree

3.1.4 Program Flow Chart

The simplified flow chart in Fig. 2 gives a general overall view of the program. The main features to be noted are:

- o The IBL branches where we switch to either a viscous calculation (IBL = 1) or an inviscid calculation (IBL = 0).
- o The ADI branch for expanding and contracting meshes.
- o The convergence check on the relaxation procedure.
- o The looping back for boundary layer iteration.
- o The looping back for mesh division.
- o The looping back after incrementing Mach number, angle of attack or lift coefficient.

3.2 Input Data File

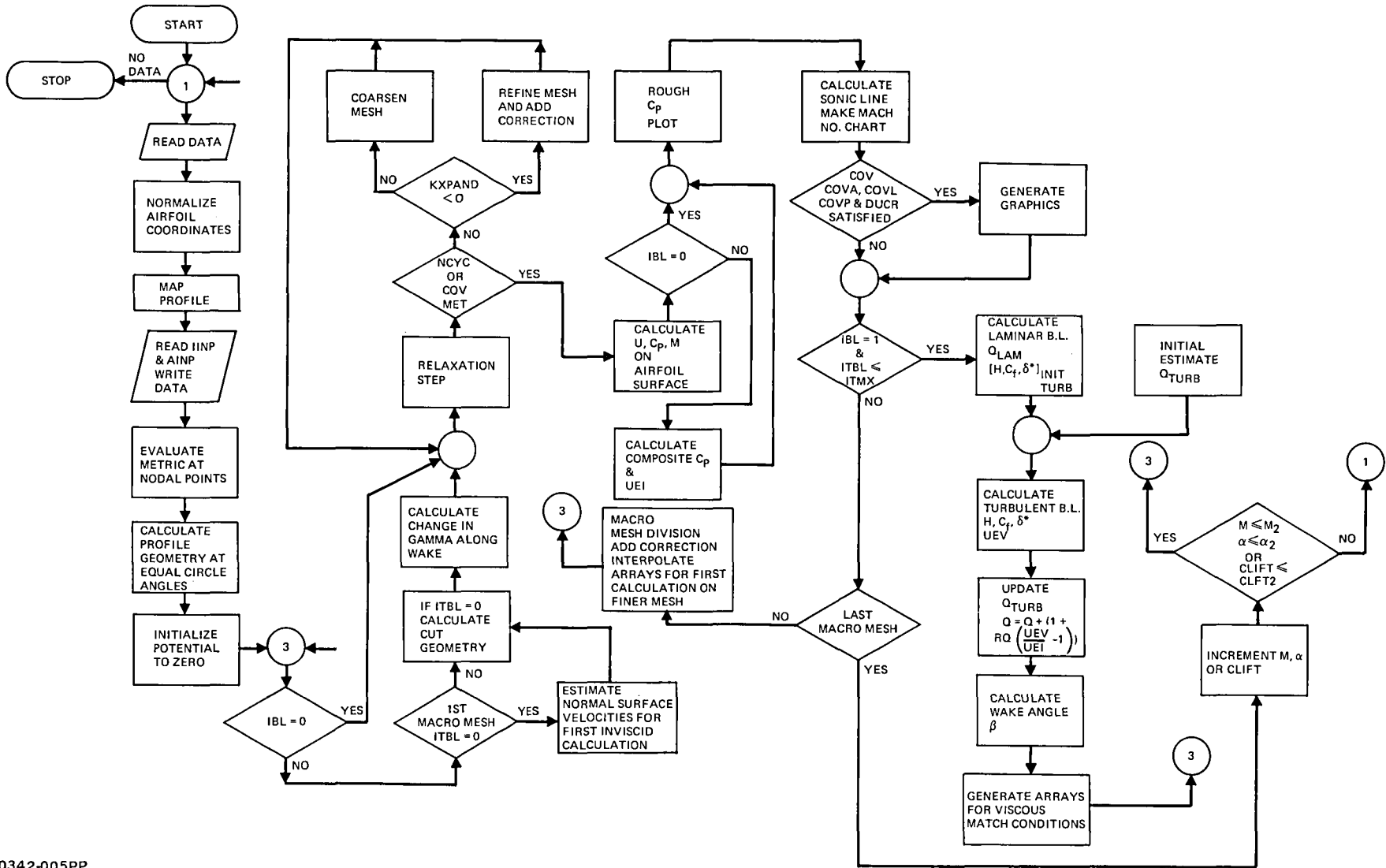
This section lists and defines all essential parameters for executing program GRUMFOIL (MCMJ-9N). They are given in the order in which they are used in setting up a calculation. It should be emphasized that the majority of listed parameters in the program NAMELISTS rarely need to be changed from their default values. At the end of this section, Fig. 3 depicts the makeup of an input data file as an equivalent card image file. The data file used to generate the sample case is listed in the Appendix.

A number of header cards are placed in the data file to help in its organization and as cues for the user. They are necessary parts of the data file and must be included. The labels shown on them, identifying the values of the parameters which appear on the following card or cards, match the variable names read by the program. These names are defined below and the pertinent program read and format statements are also included.

The first entry in the file is used to describe the run. A maximum of 80 characters can be used for an alpha-numeric description of the profile and flow situation being analyzed. The statements in the program are

```
READ(IREAD,530)      (TITLE(I),I=1,20)  
                    530 FORMAT(20A4)
```

In the above, IREAD represents the system input data set reference number. Similarly, within the code IWRT is used to designate the output number. These parameters are set at the beginning of the main program and



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Fig. 2 Simplified Flow Chart

must be modified to comply with the system being used. The next record is used as a header card to identify the items to be read from the following record. This first dummy entry as indicated from the sample case shows FNC FNR and FMESH. It is read from the program by:

```
READ(IREAD,500)
500 FORMAT (1X)
```

The next record contains the actual values of these three parameters and is read from the program by:

```
READ(IREAD,510)FNC,FNR,FMESH
510 FORMAT (8F10.6)
```

where:

| | | |
|--------|-----------------|---|
| FNC: | REAL Cols 1-10 | Number of angular divisions on the first, coarse macro-mesh. Suggested minimum 40., maximum on the final macro-mesh is 192. |
| FNR: | REAL Cols 11-20 | Number of radial divisions on the first, coarse macro-mesh. Suggested minimum 8., maximum on the final macro-mesh is 32. |
| FMESH: | REAL Cols 21-30 | Number of macro-meshes to complete calculation. Usually 3. |

The next record is used to establish the program mode. The pertinent statements in the code are:

```
READ(IREAD,661)ICASE,IBL,LMODE,IOPUT
661 FORMAT (I1,I4,5I5)
```

where:

| | | |
|-------|------------------------------|---|
| ICASE | Integer 1 → 9 Col 1 | Used to identify run or data set number. |
| IBL | Integer 0 or 1 in Col 5 | 0 inviscid mode 1 boundary layer included |
| LMODE | Integer 0 or -1 in Cols 9-10 | 0 direct mode; α prescribed, find C_L -1 inverse mode; C_L prescribed, find α |
| IOPUT | Integer 0 → 7 in Col 15 | IOPUT is one of two parameters used to control the printed and graphical output of the code. This one effects material which is produced for both inviscid and viscous calculations. It is also used to print some material which |

TABLE I - Output Generated for Various Values of IOPUT

| IOPUT → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|--|---|---|---|---|---|---|---|---|
| OUTPUT ↓ | | | | | | | | |
| Final Mesh Calcomp Plots. *Convergence Summary Table Each Mesh. | ↓ | | | | | | | |
| Airfoil Geometry. Final Mesh: convergence, shock position, forces, surface pressure table, Richardson extrapolation of forces. | | ↓ | | | | | | |
| All Meshes: convergence, shock position, forces, *wake pressures and circulation for last boundary layer iterate. | | | ↓ | | | | | |
| Mapping Convergence All Rough C_D Plots. *Convergence, shock position, forces for every boundary layer iterate. | | | | ↓ | | | | |
| *All Meshes: body and wake curvature for last boundary layer iterate. | | | | | ↓ | | | |
| Mapping Coefficients. Intermediate Mesh Calcomp Plots. | | | | | | ↓ | | |
| Final Mesh Mach Number Chart. | | | | | | | ↓ | |
| Intermediate Meshes: surface pressure table, Mach number chart, *for every boundary layer iterate. | | | | | | | | ↓ |

only applies to a viscous run. The accompanying Table I indicates the increasing amount of material generated by increasing values of IOPUT. The items marked by an asterisk only apply to viscous cases. We recommend the value 1 for this parameter. The second parameter, IOUT, which controls boundary layer output is described later.

The next record or continuations thereof refers to a NAMELIST statement with 25 arguments. The record must be included but need not have any entries, in which case, all default values will be used. The program read statement is:

```
READ(IREAD,MXF)
```

where the parameters are:

| <u>Parameter</u> | <u>Comments</u> | <u>Default</u> |
|------------------|--|----------------|
| NINV | Integer, number of iterations used to determine angle of attack from the Kutta condition when program is operated in the inverse mode (LMODE = -1). Can be doubled if convergence levels in an inviscid case below 10^{-10} is sought. | 4 |
| IRH | Integer, Hafez entropy correction, = 0 no entropy correction, = 1 entropy correction applied. | 0 |
| COVA | Real, convergence criterion applied to angle of attack when program is run in the inverse mode. If this criterion and that for the relaxation convergence, and COVP, and DUCR are met, no further boundary layer iterations are done on the particular mesh. | .005 |
| COVL | Real, convergence criterion applied to lift coefficient when program is run in normal mode. If this criterion and that for the relaxation convergence, and COVP, and DUCR are met, no further boundary layer iterations are done on the particular mesh. | .005 |
| COVP | Real, convergence criterion applied to the trailing edge pressure. If COV, COVA or COVL and DUCR are also satisfied, no further boundary layer iterations are done on the particular macro-mesh. | .001 |

| <u>Parameter</u> | <u>Comments</u> | <u>Default</u> |
|------------------------------|---|------------------|
| DUCR | Real, convergence criterion applied to the maximum difference between UEI, the inviscid velocity distribution, and UEV the edge velocity from the boundary layer equations. Check is made on upper and lower surfaces and in the wake. If COV, COVA, or COVL and COVP are also satisfied, no further boundary layer iterations are done on the particular macro-mesh. | .01 |
| ITBLMO, ITBLM1, ITBLM2 | Integer, maximum number of boundary layer iterations on successive macro-meshes. They are meant to limit time spent on poorly converging cases. In cases with large separation zones, when reduced relaxation factors are called for, increasing these parameters (e.g., 100,150,150) may be required for satisfactory convergence. | 22, 22, 30 |

The remaining 16 NAMELIST parameters are designed to be used in comparisons with experimental data. Six are used to generate an auxiliary scaled pressure plot of results generated by the code. The user selects the scale as detailed below (defaults produce the same scale as used by the code). Seven are used when experimental data are available to add to the auxiliary pressure plot. A blockage correction will automatically be applied to these data when the calculation Mach number is different from the experimental Mach number. The last two are used when experimental boundary layer data are available to add to the δ^* , θ , H, and C_f plots.

| | | |
|---------------------------------|---|------------------------|
| IPSW | Integer, = 0 no auxilliary pressure plot = 1 auxilliary pressure plot made. | 0 |
| XPLT,YPLT | Real, length in inches of the x axis and C_p axis respectively. | 5.,8. |
| CP1 CP2 | Real, maximum and minimum C_p ordinates. | 1.2, -2.0 |
| DTIC | Real, C_p increments between ordinate tic marks. | .4 |
| AMXP,ALXP, CLXP,CDXP CMXP | Real, experimental values of Mach number, angle of attack, lift coefficient, drag coefficient and moment coefficient, respectively. | .5,0., 0.,0., 0. |
| DCLC | Real, increment in input lift coefficient, CLFT1, required to match calculated and experimental lift due to difference in circulatory lift and integrated pressure distribution. Requires two runs. | 0. |

| <u>Parameter</u> | <u>Comments</u> | <u>Default</u> |
|------------------|---|----------------|
| NXP,NXL | Integer, total number of experimental pressure points and number of points on lower surface, respectively. If NXP=0, program will not expect any data. The pressure data $C_p(x)$ appears later on in the data set. If NXP > 0, program sets IPSW=1. | 0,0 |
| KPTS,KLS | Integer, total number of boundary layer data points and number of points on lower surface, respectively. If KPTS=0 program will not expect any data. The data $\delta^*(x)$, $\theta(x)$, and $C_f(x)$ follows the pressure data, if any, and appears later on in the data set. | 0,0 |

The next record in the data set is another dummy header and is read from the program by:

```
READ(IREAD,500)
500 FORMAT (1X)
```

This record gives the names of the parameters used in controlling the numerics of the relaxation process, i.e., maximum number of multi-grid cycles, convergence criteria, ADI constants and the number of micro-meshes. It is followed by as many records as there are macro-meshes and they are read from the program as:

```
READ(IREAD,510)TOTO(I),COVO(I),P10(I),P20(I),P30(I),P40(I),P50(I),GMESH(I)
510 FORMAT(8F10.6)
```

where:

| | | |
|---------|------------------|--|
| TOTO(I) | REAL Cols 1 - 10 | Maximum number of multi-grid cycles to limit unnecessary computations in poorly converging situations. For an inviscid calculation, 25 is a reasonable value for each macro-mesh. It may have to be increased in difficult cases to obtain the desired degree of convergence. For viscous calculations, use 2 on each macro-mesh in order to update boundary layers most frequently. |
| COV(I) | REAL Cols 11-20 | Convergence criterion on maximum residual $.5 \times 10^{-4}$ for each macromesh is usually sufficient (right justified). |

P10(I) REAL Cols 21-30
 P20(I) REAL Cols 31-40
 P30(I) REAL Cols 41-50
 P50(I) REAL Cols 61-70
 P40(I) REAL Cols 51-60

[These ADI parameters can be kept constant with a small sacrifice in convergence as:] .25
 .45
 .45
 1.5

Supersonic relaxation factor. For inviscid cases use .8 for each macro-mesh with incremental reduction to .5 in cases where divergence or oscillatory convergence is seen in the residual. For viscous cases, use .6, .7, and .8 on the three macro-meshes to allow for the unsettling effect of the boundary layer in the early stages. They can be reduced as convergence warrants.

GMESH(I) REAL Cols 71-80

The number of micro-meshes associated with each macro-mesh. Since a micro-mesh is derived from a macro-mesh by halving the number of divisions in each direction, care must be taken to prevent the number of radial divisions from falling below 2. Similarly, the values of GMESH must be chosen with due regard for the values of FNC and FNR in that each halving must result in integer values for the micro-mesh divisions.

Another dummy header identifying QC, VIS1, VIS2 and VIS3 follows read by:

```
READ (IREAD,500)
500 FORMAT (1X)
```

The next record contains the values of the four parameters read by:

```
READ(IREAD,510)QC,VIS1,VIS2,VIS3
510 FORMAT (8F10.6)
```

where:

| | | |
|------|-----------------|---|
| QC | REAL Cols 1-10 | Lower bound on square of local flow field Mach number where artificial viscosity is switched on. A value of .9 is suggested. For cases where convergence appears to hang up a reduction to .85 may help with little loss in accuracy of forces if the solution is second-order. |
| VIS1 | REAL Cols 11-20 | First-order artificial viscosity factor. Use 1.0 |
| VIS2 | REAL Cols 21-30 | Switch to established order of artificial viscosity 0. = second-order 1. = first-order |

VIS3 REAL Cols 31-40 Second-order artificial viscosity factor.
Use 2.0.

Another dummy header record is read by:
 READ(IREAD,500)
 500 (1X)

which identifies the parameters for angle of attack and Mach number variation that the user assigns on the next record which is read from the program as:

 READ(IREAD,510)AL1,AL2,STEP,FM1,FM2,DMACH
 510 FORMAT (8F10.6)

| | | |
|-------|-----------------|---|
| AL1 | REAL Cols 1-10 | Initial angle of attack in degrees. |
| AL2 | REAL Cols 11-20 | Final angle of attack in degrees. |
| STEP | REAL Cols 21-30 | Incremental angle of attack in degrees (+ or -). |
| FM1 | REAL Cols 31-40 | Initial Mach number. |
| FM2 | REAL Cols 41-50 | Final Mach number. |
| DMACH | REAL Cols 51-60 | Incremental Mach number (+ or -). In inverse mode AL1, AL2, and STEP may be left blank, and if only AL1 and FM1 are used, four other parameters are left blank. |

Similarly, another header for describing the lift coefficient variation is read:

 READ(IREAD,500)
 500 FORMAT (1X)

followed by the actual values and read from the code by:

 READ(IREAD,510)CLFT1,CLFT2,DCLFT
 510 FORMAT (8F10.6)

where:

| | | |
|-------|-----------------|--|
| CLFT1 | REAL Cols 1-10 | Initial lift coefficient. |
| CLFT2 | REAL Cols 11-20 | Final lift coefficient. |
| DCLFT | REAL Cols 21-30 | Incremental lift coefficient (+ or -). In direct mode CLFT1,CLFT2 and DCLFT may be left blank, and if only CLFT1 is used, two remaining parameters are left blank. |

Read another header by

```
READ(IREAD,500)
500 (1X)
```

Then,

```
READ(IREAD,510)FSYM,FNU,FNL
510 FORMAT (8F10.6)
```

where:

| | | |
|------|-----------------|--|
| FSYM | REAL Cols 1-10 | must be ± 1 . or ± 2 . + symmetrical profile, only upper surface ordinates needed. - unsymmetrical profile, lower surface ordinates also needed. = ± 1 surface slopes are computed in program. = ± 2 surface slopes are given. |
| FNU | REAL Cols 11-20 | Number of points on upper surface (suggested minimum for definition, 30). |
| FNL | REAL Cols 21-30 | Number of points on lower surface (suggested minimum for definition, 30). For symmetrical profile set FNL = FNU. |

Read a header which identifies items to be read by next read statement

```
READ(IREAD,500)
500 FORMAT (1X)
READ(IREAD,510)TRAIL,SLOPT
510 FORMAT (8F10.6)
```

where

| | | |
|-------|-----------------|--|
| TRAIL | REAL Cols 1-10 | Trailing edge included angle in degrees. If a negative number is used, program will compute the actual angle. |
| SLOPT | REAL Cols 11-20 | Trailing edge slope. If surface slopes of profile are given ($ FSYM =2$), TRAIL must also be given and SLOPT is not required. If surface slopes of profile are not given, TRAIL will be calculated if a negative value is read in and SLOPT is not required; however, if positive TRAIL read in, SLOPT must also be read in. |

The next group of records defines the profile in terms of its ordinates and surface slopes. The surface slopes should only be prescribed if they are very accurately known since the program will calculate them from the ordinates. The x-values of the trailing edge must be equal on the upper and lower surface; however, the y-values need not be equal, in which case the

airfoil has an open trailing edge. If the profile is symmetric, only the cards describing the upper surface should be supplied.

Read a header which identifies items to be read from the next FNU records defining the upper surface of the profile.

```
READ(IREAD,500)
500 FORMAT (1X)
```

Then:

```
READ(IREAD,510) X(I), Y(I), SLOP
510 FORMAT (8F10.6)
```

| | | |
|------|-----------------|--|
| X(I) | REAL Cols 1-10 | X ordinates of upper surface from LE to TE. |
| Y(I) | REAL Cols 11-20 | Y ordinates of upper surface. |
| SLOP | REAL Cols 21-30 | slopes on upper surface, in degrees. Can be left blank unless very accurately known. |

Read a header which identifies items to be read from the next FNL records defining the lower surface of the profile.

```
IF FSYM < 0. READ (IREAD,500)
500 FORMAT (1X)
```

Then:

```
READ(IREAD,510) X(I),Y(I), SLOP
510 FORMAT (8F10.6)
```

| | | |
|------|-----------------|--|
| X(I) | REAL Cols 1-10 | X ordinates of lower surface from LE to TE. |
| Y(I) | REAL Cols 11-20 | Y ordinates of lower surface. |
| SLOP | REAL Cols 21-30 | slopes on lower surface, in degrees. Can be left blank unless very accurately known. |

The convention for slopes is as follows: the horizontal tangent to the lower surface corresponds to 0° , the vertical tangent at the leading edge corresponds to -90° , and the horizontal tangent to the upper surface corresponds to -180° .

The next two input records refer to NAMELIST statements which control the details of the boundary layer calculation. Default values are used for any unspecified parameters. These records are always included, however, for inviscid runs they function as dummies.

The first record controls seven integer parameters using the read statement:

READ(IREAD,IINP)

| <u>Parameter</u> | <u>Comments</u> | <u>Default</u> |
|---|---|----------------|
| KT = 1 Ref. 11 = 2 Ref. 12 = 3 Ref. 13 = 4 | <p>Transition options: Natural transition mode. User selects one of three possible forms. If user makes this choice, he must also set XTRANU,L = 0.</p> <p>Transition fixed mode. User assigns transition point on upper and on lower surface. XTRANU > 0. and XTRANL > 0.</p> <p>Combined mode. User sets KT=1,2, or 3 and also sets XTRANU > 0. and XTRANL > 0. In this mode program will choose the earlier occurring of the two transition locations, fixed or natural. This is a good mode of operation if transition locations are not known. Since the default values of XTRANU,L = .10, this is default mode of code operation. Note: If short or long bubble leading edge separation is detected within the program, immediate transition is assumed and any user selected options are overridden.</p> | 1 |
| ICURV | Longitudinal curvature term in turbulence model: = 0 term out, = 1 term in. | 1 |
| IDIV | Mean dilatation term in turbulence model: = 0 term out, = 1 term in. | 1 |
| IH1HB =1 =2 =3 | <p>Turbulent velocity profile used with the lag-entrainment method (see Ref. (6)): relation in Green's original lag-entrainment method</p> <p>East, Smith and Merryman</p> <p>Green-LeBalleur</p> | 3 |
| IMCE =1 =2 | <p>Equilibrium entrainment model: relation in Green's original lag-entrainment method</p> <p>blend of Michel's and a free mixing layer</p> | 2 |
| ICF =1 =2 | <p>Skin friction relation: relation in Green's original lag-entrainment method</p> <p>Swafford's</p> | 2 |

| <u>Parameter</u> | <u>Comments</u> | <u>Default</u> |
|------------------|---|----------------|
| IOUT | Output parameter for boundary layer results: | -1 |
| =1 | prints out all tables after every boundary layer iterate | |
| =0 | prints out all tables after the last boundary layer iterate on each macro-mesh | |
| =-1 | prints out all tables after the last boundary layer iterate on the final macro-mesh | |

The next record to be read controls 26 NAMELIST parameters, all of which are real, using the read statement:

READ(IREAD,AINP)

| | | |
|------------------------|--|-------------------|
| REYNO | Reynolds number based on chord | NONE |
| XTRANU, XTRANL | Specified transition point on upper and on lower surface | .10, .10 |
| VMAX, VMAXT | Sets upper bound on source velocity, V, near shock waves, the trailing edge, and in the wake. Used to prevent divergence during early stages of iteration due to nonphysical boundary layer behavior. $V = VMAX$ if $V > VMAX$. Also provides a reasonable model of interaction near strong shock waves where V could be greater than VMAX. VMAXT is invoked upstream and within .95 of trailing edge. (VSMAX is a similar parameter for the symmetrical source velocity downstream of the trailing edge and is VMAXT/2.) | .50, .50 |
| RQE0, RQE1, RQE2 | Base relaxation factor applied to the source strength on the airfoil. One value assignable to each macro-mesh. In difficult cases drop RQE1 to .5 and RQE2 to .2. | .2, 1.0, .8 |
| WRQ0, WRQ1, WRQ2 | A multiplicative factor used with RQE to provide a buildup to the maximum on each macro-mesh. This is particularly important on the coarse mesh when the calculation starts off. In fact, for difficult cases, only WRQ0 is changed to 4.0 or 3.5. | 5., 1., 1. |
| RQW0, RQW1, RQW2 | Base relaxation factor applied to the source strength in the wake. One value assignable to each macro-mesh. In difficult cases drop RQW1 to .4 and RQW2 to .2. | .2, 1.0, .4 |

| <u>Parameter</u> | <u>Comments</u> | <u>Default</u> |
|---------------------------|---|-------------------|
| WRQWO, WRQW1, WRQW2 | A multiplicative factor used with RQW to provide a buildup to the maximum on each macro-mesh. Here too, the buildup is important on the first macro-mesh and, in difficult cases, WRQWO is reduced to 2.5. | 5., 1., 1. |
| RBWO, RBW1, RBW2 | Base relaxation factor applied to the wake angle. One value is assignable to each macro-mesh and, in difficult cases, RBW1 is dropped to .2 and RBW2 is dropped to .1. | .2, .4, .2 |
| WRBWO, WRBW1, WRBW2 | A multiplicative factor used with RBW to provide a buildup to the maximum on each macro-mesh. Again the buildup is important on the first macro-mesh and, in difficult cases, WRBWO is reduced to 1.5. | 5., 1., 1. |
| RTEO, RTE1, RTE2 | Under-relaxation of a program generated constant used in the calculation of the wake source velocity is very helpful in achieving boundary layer convergence. This is especially true on the finest macro-mesh and, in fact, no relaxation is applied to the earlier meshes under usual conditions. For difficult cases RTE2 is reduced to .05. | 1., 1., .1, |

At this point in the data set, experimental data may be introduced. The data can be of two main types. If both types are available, the pressure data are inserted first and are followed by the boundary layer data. For either type the lower surface data are read first followed by the upper surface data. Within these categories the data may be in any order. The user will have alerted the program that data is to be expected here by assigning non zero values to NXP and/or KPTS in the MXF NAMELIST.

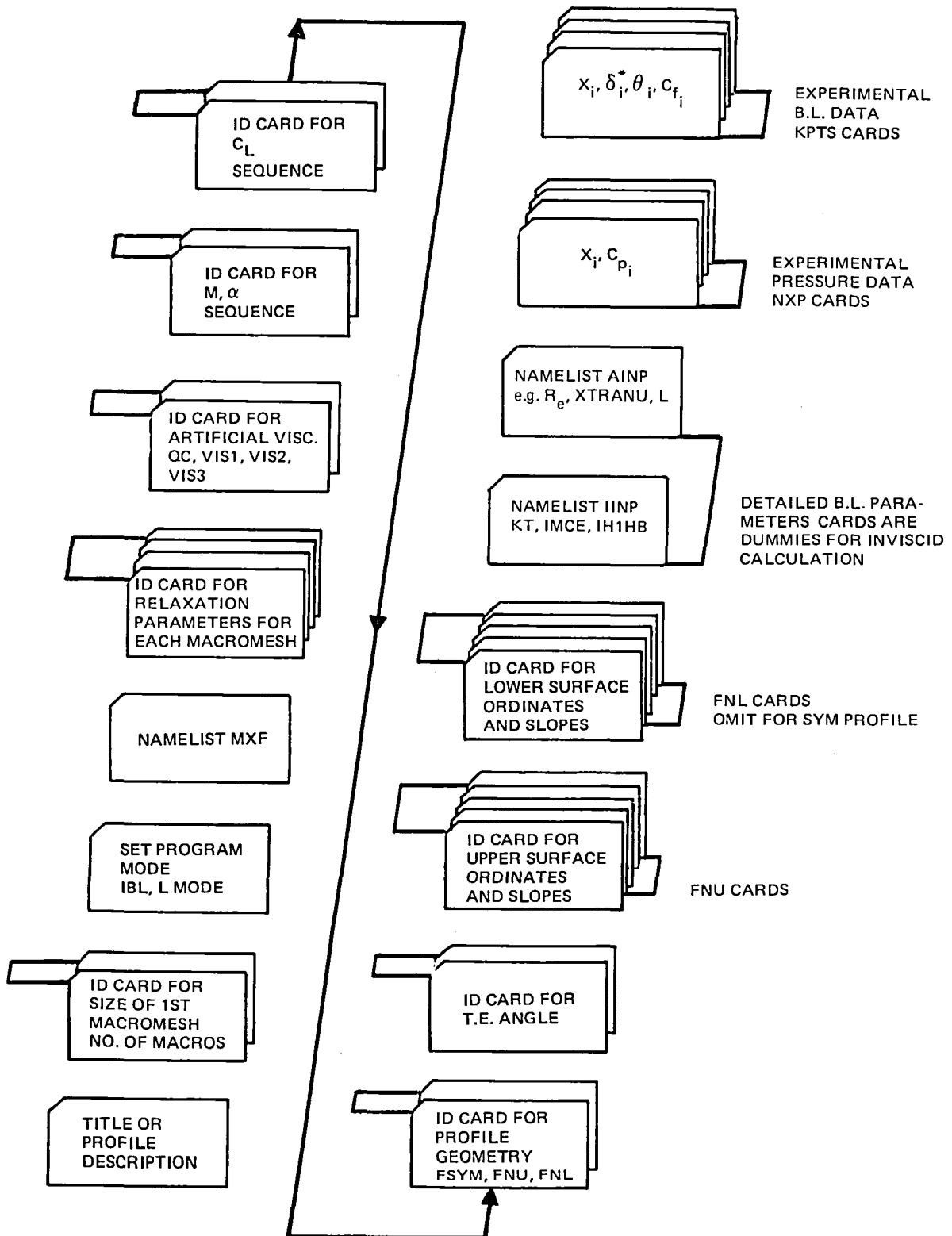
The program will then read NXP records from:

```
READ(IREAD,32) XXP(I), CPXPI(I)
      32 FORMAT (2E10.7)
```

where:

```
XXP(I)    REAL Cols 1-10    X location of pressure tap
CPXPI(I)  REAL Cols 11-20   Cp at location X
```

Next the program reads KPTS records from:



0342-008PP

Fig. 3 Card Images of Input File

```
READ(IREAD,510)XDAT(I),DSDAT(I),THDAT(I),CFDAT(I)
      510 FORMAT (8F10.6)
```

where:

| | | |
|----------|-----------------|--------------------------|
| XDAT(I) | REAL Cols 1-10 | X location of data point |
| DSDAT(I) | REAL Cols 11-20 | δ^* at location X |
| THDAT(I) | REAL Cols 21-30 | θ at location X |
| CFDAT(I) | REAL Cols 31-40 | C_f at location X |

If, for some reason, any of the parameters δ^* , θ , or C_f are missing at some X location, the user should put in a dummy value of 1.0 for the parameter. The code will recognize this special value and not attempt to plot the point.

When the code has processed all the information contained in the data set thus far, the program returns to statement number one. It is ready to process the data for another profile, or as many as computing time will allow. At this point the user turns the program off by adding the first three records of a final data file. On the first record, which specifies the new title, the user (at his option) could type the phrase, "End of Calculation". This is appropriate since this phrase will be the last thing printed by the code. The next record, a dummy labeled FNC is followed by the third and final record with the value 0. for FNC. The program uses this value of FNC to branch to a STOP.

3.3 Output Description

Much of the output for either an inviscid or viscous calculation is controlled by the output parameter IOPUT as indicated in Table I. A reasonable amount of paper is generated when this parameter equals 1. For the boundary layer characteristics the output parameter is IOUT, and if -1 is used, this material will only be printed for the last boundary layer calculation on the last macro-mesh. The included sample case was run with IOPUT = 1 and IOUT = -1. The first item in the Appendix is the data file which produced the output given as the second item in the Appendix.

The following description of the output makes reference to the sample output included in the Appendix. The solution output is provided in a series of tables and graphs. Since the graphical output was described in some detail

in Section 2.2, we will only describe the tabular output. The tabular results are presented in the following eight major blocks:

1. Program identification block,
2. Title or profile description,
3. Initial data,
4. Coarse grid convergence data,
5. Boundary layer solution results,
6. Inviscid iteration quantities,
7. Inviscid solution quantities
8. Fine grid convergence data

The position of each of these blocks is indicated by the corresponding numbers in the sample output.

3.3.1 Program Identification (1)

This block identifies the version of the code being used and the date that it was released.

3.3.2 Title or Profile Description (2)

The second block of data, (2), identifies the profile and case being run, the prescribed lift coefficient (or angle of attack if a direct problem were being run) and the free stream Mach number.

3.3.3 Initial Data (3)

This set of data contains all the additional information required to run the program. The data in Block (3) includes tables giving the airfoil geometry, values of parameters controlling the inviscid computation, and the viscous calculations. It also includes a tabular listing of experimental data, if provided by the user, which is used for comparison with the numerical solution in the graphical output. The airfoil geometry table in this block provides a listing of arc length, normalized (by chord length) coordinates, surface slope, and curvature. The table is followed by the values of four important geometric properties of the airfoil, namely: leading edge radius, trailing edge angle, leading edge slope and trailing edge slope.

Diagnostic checks are made at selected points in the program to insure its proper operation. If preset conditions are not met, the program will stop and a diagnostic message will be printed. The first such message will appear following the airfoil identifier (block 2) if, for a viscous calculation, the trailing edge values of X are unequal. Another program stop will occur and a diagnostic message will be written following the airfoil geometry table, if more than 50 iterations are needed to converge the circle plane mapping. In this instance the user is urged to check the profile ordinates for a mistype. Scanning the profile curvature in the table can be helpful in locating a bad point.

The inviscid calculation parameters appear in the next set of entries following the geometry table. These include: mode of code operation (LMODE, NINV, and IRH); the artificial viscosity parameters (QC, VIS1, VIS2, and VIS3); the output parameter, IOPUT, which controls the inviscid solution output; the multi-grid-ADI parameters.

The parameters controlling the viscous calculation are given in the next set of entries. Subheadings in this data block are self-explanatory.

The experimental data for pressure coefficient that is supplied for plotting purposes is listed in a table of X and C_p . Since AMXP and FM1 are equal (see data file), there is no Mach number correction to the data, and the third column is the same as the second, and the corrected and uncorrected forces are also equal.

The scaling parameters that control an auxiliary plot showing a comparison of experimental and theoretical surface pressures are listed following the pressure coefficient table. The fact that experimental C_p data is given triggers the auxiliary plot. The scalings given in the sample output are default values.

If experimental data for boundary layer properties are supplied (for incorporation into the graphical output) a table of such data will be included in the output following the pressure data. Since such data was supplied in the sample test case, a table of X , δ^* , θ , and C_f appears at the end of the block (3) output.

3.3.4 Coarse Grid Convergence Data (4)

The program is set-up to use three macro-grids in carrying out the solution. The convergence history of the solution on the first two grids is given in the fourth (4) block of output data. The convergence tables summarize how various flow quantities change as the iterative solution progresses.

In an uneventful situation the only output for the first macro-mesh is the convergence summary table (output section 4). However, before discussing this table, we offer a few words about less routine operation. At various points in the program several parameters are checked to see if they fall within reasonable physical limits. If these limits are exceeded, a limit value is assigned and a flag is printed. These flags may appear on any mesh early-on and just be transient in that they disappear as convergence proceeds. If they persist, however, the fix is to reduce the boundary layer relaxation factors on the problem macro-mesh.

A more frequent occurrence is, as shown in the sample case, the indication of a movement of the transition point. This can be due to a change in the solution or due to the users specified transition point being too close to the stagnation point. If a shift occurs, the code smooths the source strength Q in the vicinity of the transition point to soften its effect on the solution. The relevant information as well as the unsmoothed and smoothed values of Q and their locations are also printed. Under some conditions the transition point moves back and forth and the solution doesn't converge. Usually this problem can be brought under control by reducing RQE and/or using $KT = 4$.

In the convergence tables the quantity NIT is the number of complete multigrid cycles; $RMAX$ is the maximum residual; $VTOP$, $VBOT$, and $VSYM$ are trailing edge values of the source velocities on the top and bottom surfaces and the symmetrical wake value; $DELT$ and $DELB$ are the boundary layer thickness for the top and bottom surfaces at the trailing edge or at $SEPT$ and $SEPB$ points upstream of the trailing edge in separated flow; DUT and DUB show respectively the maximum difference between UEI and UEV on the top and bottom side of the airfoil and wake. The integers listed under $I-J$ are the grid labels identifying the grid point on the airfoil or wake where the maximum difference DUT or DUB occurs. An unsigned integer indicates that the maximum

occurs on the airfoil at the point I noted in the table. A minus sign indicates it occurs in the wake at the point J in the table. The values of I fall in the range $3 < I < NC + 3$ where $I = 3$ and $NC + 3$ are the lower and upper surface trailing edge points respectively. The index J falls in the range $2 < J < NR + 2$ where $J = 2$ is the wake point at infinity and $J = NR + 2$ is the wake point at the trailing edge. The quantity, BJMX is the maximum difference between boundary layer iterates of the wake angle which is located at grid point, JMX, on the wake axis. Note that the code generates an initial approximation to the source strength Q to obtain the first boundary layer solution. It then updates this solution fifteen successive times before returning the updated boundary conditions to the inviscid calculation, and thus, ITBL starts at 15. Note also that the last line (22) in the table, ITBL=36, which corresponds the maximum number of iterates specified for this macro-mesh, was the cause for ending the first mesh calculation since the convergence checks on RMAX, AL, CPTC, DUT, and DUB have not been met. However, since the convergence is generally monotonic, this is an acceptable first mesh solution.

Mesh division is undergone, interpolation of pertinent arrays accomplished, a solution obtained, and the second macro-mesh results are printed. At mesh division it is possible for the transition point to shift simply because there are more nodal points on the refined mesh as shown in the sample case. The convergence table shows that almost all the convergence conditions have been met in 26 boundary layer iterations. After the first mesh division, five successive boundary layer passes are made before returning updated boundary conditions to the inviscid calculation, and, thus, ITBL starts out at 5. This is done to help the solution negotiate mesh division. On the second mesh division only two successive boundary layer passes are made.

3.3.5 Boundary Layer Solution Results (5).

On the third mesh the full boundary layer output is presented. The first table lists the upper surface boundary layer parameters. \bar{H} is Green's shape parameter and CE is the entrainment coefficient. Printed at the bottom of the table are the location and value of the maximum difference in UEI and UEV as well as the average difference.

A LAMBDA flag is printed when the effects of the ICURV and IDIV turbulence modeling terms exceed reasonable physical values. Next is shown the iterative solutions for $\tilde{\pi}$ and δ at the trailing edge given the values of δ^* and C_f from the boundary layer solution. A parallel set of results for the lower surface follows. Next, a short table of various drag quantities is presented. The quantity, CDINF is the profile drag coefficient calculated from momentum thickness far downstream; CDSY is the profile drag coefficient calculated from Squire-Young formula based on trailing edge momentum thickness; CDINFT and CDIFB are the top and bottom surface contributions to CDINF; CDF is the total skin friction drag coefficient while CDFT and CDFB are the top and bottom surface contributions to CDF.

3.3.6 Inviscid Iteration Quantities (6)

The next table, identified as iterative solution, lists the ADI and artificial viscosity parameters, and the mesh geometry for the finest macro-mesh. This is followed by the relaxation solution for the last boundary layer iterate. The table headings are mainly self-explanatory. The tenth column is the circulation or angle of attack for LMODE=0 or -1, respectively. The next column, headed work, is the cumulative value of the equivalent SLOR steps that have taken place from the first relaxation step on the current macro-mesh to the current cycle. The last column refers to the number of supersonic points in the flow field. The next two lines specify: the average residual from the first relaxation step on the current macro-mesh; the average residual from the last relaxation step on the current macro-mesh; the cumulative work, an overall convergence rate based on the cumulative work; and an overall convergence rate based on the cumulative number of cycles. Another line is only printed when the Hafez entropy correction is made, IRH=1. It identifies the correction at the body surface for the last shock point on the surface. The index I refers to the location of the point where the correction is made; EDSR is equal to the exponential of the entropy jump across the shock wave divided by the gas constant; the next two terms are the Mach numbers upstream and downstream of the shock respectively. If a shock were present on the lower surface, this line would be printed out first and a second line would be printed if a shock were on the upper surface.

The next line gives the macro-mesh number, the cumulative number of boundary layer iterates and the cumulative number of multigrid cycles for this

mesh. Following this is a series of lines giving the approximate shock location, and pressure computed from the "exact" and irrotational jump conditions based on the Mach number at the first supersonic point upstream of the shock wave at the body surface. These four lines are printed for every shock on the profile.

3.3.7 Inviscid Solution Quantities (7)

The first two lines in this block provide: the angle of attack (calculated in the sample case), Mach No., CL calculated from the circulation (given in the sample case). The next line gives the CL, CD, CDB (base drag included), and moment-computed for the composite surface pressure distribution.

The next table summarizes the solution for the airfoil surface properties in terms of the coordinates of the nodal points on the final mesh starting at the lower surface trailing edge and moving around the profile to the upper surface trailing edge. In addition to the arc length, it lists the uncorrected or inviscid: Mach No., velocity ratio, density, mass flow, and pressure coefficient. The last column is the corrected or composite pressure distribution.

3.3.8 Fine Grid Convergence Data (8)

The final mesh convergence summary table is given in this block. The nomenclature is the same as used in the coarse grid convergence tables discussed in subsection 3.3.4. The Richardson extrapolation of the angle of attack, CL, CDB and CM from the last two macro-meshes is the final calculated result to be printed.

The formal end of the calculation repeats the program title block and prints the end of calculation title.

Both the printed and graphical output were generated with the Xerox 9700 printer. In the case of the graphics, rotation of the plots and their scaling reflect changes made by the 9700 and not contained within the program.

4. REFERENCES

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**APPENDIX
SAMPLE CASE**

DATA FILE

RAE 2822 CASE 9 SAMPLE CASE FOR LANGLEY FINAL REPORT

```

FNC      FNR      FMESH
40.      8.       3.
1 1 -1 1
&MXF DCLC=.0053,
AMXP=.730,ALXP=3.19,CLXP=.803,CDXP=.0168,CMXP=-.099,
NXP=102,NXL=50,KPTS=11,KLS=2,&END
TOTO      COVO      P10      P20      P30      P40      P50      GMESH
2.         .5E-4 .25      .45      .45      .6       1.5      3.
2.         .5E-4 .25      .45      .45      .7       1.5      4.
2.         .5E-4 .25      .45      .45      .8       1.5      5.
QC         VIS1      VIS2      VIS3
.90        1.        0.00     2.00
AL1        AL2        STEP     FM1      FM2      DMACH
2.23       .000      .000     .730    .000    .000
CLFT1      CLFT2      DCLFT
.803       .000      .000
FSYM       FNU       FNL
-1.        65.      65.
TRAIL      SLOPT
-1.5

```

UPPER SURFACE

```

X          Y
0.000000  0.000000
0.000602  0.003165
0.002408  0.006306
0.005412  0.009416
0.009607  0.012480
0.014984  0.015489
0.021530  0.018441
0.029228  0.021348
0.038060  0.024219
0.048005  0.027062
0.059039  0.029874
0.071136  0.032644
0.084265  0.035360
0.098396  0.038011
0.113495  0.040585
0.129524  0.043071
0.146447  0.045457
0.164221  0.047729
0.182803  0.049874
0.202150  0.051885
0.222215  0.053753
0.242949  0.055470
0.264302  0.057026
0.286222  0.058414
0.308658  0.059629
0.331555  0.060660
0.354858  0.061497
0.378510  0.062133
0.402455  0.062562
0.426635  0.062779
0.450991  0.062774
0.475466  0.062530
0.500000  0.062029
0.524534  0.061254
0.549009  0.060194
0.573365  0.058845
0.597545  0.057218
0.621490  0.055344
0.645142  0.053258
0.668445  0.050993
0.691342  0.048575
0.713778  0.046029
0.735698  0.043377
0.757051  0.040641
0.777785  0.037847
0.797850  0.035017
0.817197  0.032176
0.835779  0.029347
0.853553  0.026554
0.870476  0.023817
0.886505  0.021153

```


| | |
|----------|----------|
| 0.901604 | 0.018580 |
| 0.915735 | 0.016113 |
| 0.928864 | 0.013769 |
| 0.940961 | 0.011562 |
| 0.951995 | 0.009508 |
| 0.961940 | 0.007622 |
| 0.970772 | 0.005915 |
| 0.978470 | 0.004401 |
| 0.985016 | 0.003092 |
| 0.990393 | 0.002001 |
| 0.994588 | 0.001137 |
| 0.997592 | 0.000510 |
| 0.999398 | 0.000128 |
| 1.000000 | 0.000000 |

| | |
|---|---|
| X | Y |
|---|---|

LOWER SURFACE

| | |
|----------|-----------|
| 0.000000 | 0.000000 |
| 0.000602 | -0.003160 |
| 0.002408 | -0.006308 |
| 0.005412 | -0.009443 |
| 0.009607 | -0.012559 |
| 0.014984 | -0.015649 |
| 0.021530 | -0.018707 |
| 0.029228 | -0.021722 |
| 0.038060 | -0.024685 |
| 0.048005 | -0.027586 |
| 0.059039 | -0.030416 |
| 0.071136 | -0.033170 |
| 0.084265 | -0.035843 |
| 0.098396 | -0.038431 |
| 0.113495 | -0.040929 |
| 0.129524 | -0.043326 |
| 0.146447 | -0.045610 |
| 0.164221 | -0.047773 |
| 0.182803 | -0.049805 |
| 0.202150 | -0.051694 |
| 0.222215 | -0.053427 |
| 0.242949 | -0.054994 |
| 0.264302 | -0.056376 |
| 0.286222 | -0.057547 |
| 0.308658 | -0.058459 |
| 0.331555 | -0.059046 |
| 0.354858 | -0.059236 |
| 0.378510 | -0.058974 |
| 0.402455 | -0.058224 |
| 0.426635 | -0.056979 |
| 0.450991 | -0.055257 |
| 0.475466 | -0.053099 |
| 0.500000 | -0.050563 |
| 0.524534 | -0.047719 |
| 0.549009 | -0.044642 |
| 0.573365 | -0.041397 |
| 0.597545 | -0.038043 |
| 0.621490 | -0.034631 |
| 0.645142 | -0.031207 |
| 0.668445 | -0.027814 |
| 0.691342 | -0.024495 |
| 0.713778 | -0.021289 |
| 0.735698 | -0.018232 |
| 0.757051 | -0.015357 |
| 0.777785 | -0.012690 |
| 0.797850 | -0.010244 |
| 0.817197 | -0.008027 |
| 0.835779 | -0.006048 |
| 0.853553 | -0.004314 |
| 0.870476 | -0.002829 |
| 0.886505 | -0.001592 |
| 0.901604 | -0.000600 |
| 0.915735 | 0.000157 |
| 0.928864 | 0.000694 |
| 0.940961 | 0.001033 |
| 0.951995 | 0.001197 |
| 0.961940 | 0.001212 |
| 0.970772 | 0.001112 |
| 0.978470 | 0.000935 |
| 0.985016 | 0.000719 |

```

0.990393 0.000497
0.994588 0.000296
0.997592 0.000137
0.999398 0.000035
1.000000 0.000000
&IINP &END
&AINP REYND=6.5E6,XTRANU=.030,XTRANL=.030,
WRQO=4.,WRQWO=3.,WRBWO=2.,
RQE1=.60,RQW1=.40,RBW1=.20,
RQE2=.3,RQW2=.20,RBW2=.10,&END
.0000      0.7963
.0002      1.0157
.0007      1.0912
.0015      1.1315
.0025      1.1257
.0036      1.0944
.0047      1.0467
.0060      0.9971
.0073      0.9400
.0087      0.8967
.0104      0.8441
.0125      0.7849
.0146      0.7309
.0186      0.6501
.0271      0.5652
.0375      0.4393
.0500      0.3447
.0625      0.2776
.0750      0.2263
.1500      0.0203
.2000     -0.0641
.2500     -0.1462
.3000     -0.2246
.3250     -0.2635
.3500     -0.2960
.3750     -0.3162
.4000     -0.3187
.4250     -0.2987
.4500     -0.2673
.4750     -0.2292
.5000     -0.1836
.5250     -0.1441
.5500     -0.0971
.5750     -0.0522
.6000     -0.0108
.6196      0.0168
.6500      0.0594
.7000      0.1200
.7500      0.1786
.7750      0.2038
.8000      0.2281
.8250      0.2471
.8500      0.2657
.8750      0.2792
.9000      0.2917
.9250      0.2965
.9500      0.2922
.9750      0.2640
.9875      0.2381
.9937      0.2100
.0002      0.3761
.0007      0.0491
.0015     -0.1075
.0025     -0.3348
.0036     -0.4609
.0047     -0.5852
.0060     -0.6827
.0073     -0.7675
.0087     -0.8198
.0104     -0.8572
.0125     -0.9113
.0146     -0.9608
.0187     -1.0439
.0271     -0.9157
.0375     -1.1741

```

| | | | |
|-------|---------|---------|---------|
| .0500 | -1.1973 | | |
| .0625 | -1.1771 | | |
| .0750 | -1.1697 | | |
| .1000 | -1.1123 | | |
| .1500 | -1.0981 | | |
| .2000 | -1.0834 | | |
| .2208 | -1.0890 | | |
| .2500 | -1.1110 | | |
| .3000 | -1.1535 | | |
| .3250 | -1.1658 | | |
| .3500 | -1.1727 | | |
| .3750 | -1.1917 | | |
| .4000 | -1.2085 | | |
| .4250 | -1.2290 | | |
| .4500 | -1.2420 | | |
| .4750 | -1.2593 | | |
| .5000 | -1.2853 | | |
| .5250 | -1.3097 | | |
| .5500 | -1.1249 | | |
| .5750 | -0.7552 | | |
| .6000 | -0.6338 | | |
| .6196 | -0.5681 | | |
| .6500 | -0.4949 | | |
| .6771 | -0.4370 | | |
| .7000 | -0.3915 | | |
| .7500 | -0.2983 | | |
| .7750 | -0.2535 | | |
| .8000 | -0.2103 | | |
| .8250 | -0.1654 | | |
| .8500 | -0.1226 | | |
| .8750 | -0.0760 | | |
| .9000 | -0.0325 | | |
| .9250 | 0.0114 | | |
| .9500 | 0.0570 | | |
| .9750 | 0.1012 | | |
| .9875 | 0.1232 | | |
| .9937 | 0.1347 | | |
| .152 | .000325 | .000196 | .003983 |
| 1.00 | .003233 | .001982 | 0. |
| .179 | .000303 | .000378 | .002700 |
| .319 | .001060 | .000516 | .002723 |
| .404 | .001311 | .000626 | .002489 |
| .498 | .001533 | .000731 | .002533 |
| .574 | .003395 | .001418 | .001049 |
| .65 | .004956 | .002043 | .000901 |
| .75 | .006884 | .002999 | .000831 |
| .90 | .008958 | .004360 | .000959 |
| 1.00 | .014433 | .006510 | 0. |

END OF CALCULATION
FNC
0.

SAMPLE OUTPUT

```

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
X GRUMMAN AEROSPACE CORP. PROGRAM GRUMFOIL (MCMJ-9N) 2-22-85 X
X AIRFOIL ANALYSIS IN TRANSONIC VISCOUS FLOW X
X DEVELOPED BY R.MELNIK, R.CHOW, H.HEAD, AND A.JAMESON X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    
```

(1)

```

RAE 2822 CASE 9 SAMPLE CASE FOR LANGLEY FINAL REPORT
INITIAL DATA CLC= 0.8030 MACH NO= 730
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    
```

(2)

AIRFOIL COORDINATES

| ARC LENGTH | X | Y | THETA | KURV |
|------------|--------|---------|-----------|----------|
| -1.0157 | 1.0000 | 0.0 | -3.3511 | -1.5337 |
| -1.0151 | 0.9994 | 0.0000 | -3.3042 | -1.5337 |
| -0.0183 | 0.9976 | 0.0001 | -3.1570 | -1.5337 |
| -0.0183 | 0.9946 | 0.0003 | -2.9077 | -1.3588 |
| -1.0061 | 0.9904 | 0.0005 | -2.5777 | -1.3843 |
| -1.0007 | 0.9850 | 0.0007 | -2.1508 | -1.3846 |
| -0.9941 | 0.9785 | 0.0009 | -1.6280 | -1.4018 |
| -0.9864 | 0.9708 | 0.0011 | -1.0048 | -1.4235 |
| -0.9776 | 0.9619 | 0.0012 | -0.2968 | -1.3746 |
| -0.9677 | 0.9520 | 0.0012 | 0.4611 | -1.2855 |
| -0.9566 | 0.9410 | 0.0010 | 1.2259 | -1.1337 |
| -0.9445 | 0.9289 | 0.0007 | 1.9707 | -1.0145 |
| -0.9314 | 0.9157 | 0.0002 | 2.7033 | -0.9318 |
| -0.9172 | 0.9016 | -0.0006 | 3.4148 | -0.8231 |
| -0.9021 | 0.8865 | -0.0016 | 4.0903 | -0.7353 |
| -0.8860 | 0.8705 | -0.0028 | 4.7195 | -0.6307 |
| -0.8690 | 0.8536 | -0.0043 | 5.2988 | -0.5597 |
| -0.8512 | 0.8358 | -0.0060 | 5.8322 | -0.4829 |
| -0.8325 | 0.8172 | -0.0080 | 6.3145 | -0.4182 |
| -0.8130 | 0.7979 | -0.0102 | 6.7489 | -0.3604 |
| -0.7928 | 0.7778 | -0.0127 | 7.1444 | -0.3226 |
| -0.7719 | 0.7571 | -0.0154 | 7.5071 | -0.2831 |
| -0.7504 | 0.7357 | -0.0182 | 7.8159 | -0.2413 |
| -0.7282 | 0.7138 | -0.0213 | 8.0485 | -0.1495 |
| -0.7056 | 0.6913 | -0.0245 | 8.2027 | -0.0880 |
| -0.6824 | 0.6684 | -0.0278 | 8.2796 | -0.0281 |
| -0.6589 | 0.6451 | -0.0312 | 8.2745 | 0.0357 |
| -0.6350 | 0.6215 | -0.0346 | 8.1872 | 0.0919 |
| -0.6108 | 0.5975 | -0.0380 | 8.0183 | 0.1518 |
| -0.5864 | 0.5734 | -0.0414 | 7.7608 | 0.2165 |
| -0.5618 | 0.5490 | -0.0446 | 7.3976 | 0.2994 |
| -0.5371 | 0.5245 | -0.0477 | 6.9132 | 0.3861 |
| -0.5124 | 0.5000 | -0.0506 | 6.2835 | 0.5040 |
| -0.4878 | 0.4755 | -0.0531 | 5.4938 | 0.6136 |
| -0.4632 | 0.4510 | -0.0553 | 4.5609 | 0.7117 |
| -0.4388 | 0.4266 | -0.0570 | 3.5085 | 0.7928 |
| -0.4146 | 0.4025 | -0.0582 | 2.3753 | 0.8410 |
| -0.3906 | 0.3785 | -0.0590 | 1.2086 | 0.8591 |
| -0.3670 | 0.3549 | -0.0592 | 0.0690 | 0.8226 |
| -0.3437 | 0.3316 | -0.0590 | -0.9903 | 0.7642 |
| -0.3208 | 0.3087 | -0.0585 | -1.9236 | 0.6581 |
| -0.2983 | 0.2862 | -0.0575 | -2.7128 | 0.5688 |
| -0.2764 | 0.2643 | -0.0564 | -3.3905 | 0.5090 |
| -0.2550 | 0.2429 | -0.0550 | -4.0162 | 0.5177 |
| -0.2342 | 0.2222 | -0.0534 | -4.6287 | 0.5164 |
| -0.2140 | 0.2021 | -0.0517 | -5.2538 | 0.5670 |
| -0.1946 | 0.1828 | -0.0498 | -5.9064 | 0.6049 |
| -0.1759 | 0.1642 | -0.0478 | -6.5853 | 0.6628 |
| -0.1580 | 0.1464 | -0.0456 | -7.3049 | 0.7401 |
| -0.1409 | 0.1295 | -0.0433 | -8.0875 | 0.8598 |
| -0.1247 | 0.1135 | -0.0409 | -8.9409 | 0.9782 |
| -0.1094 | 0.0984 | -0.0384 | -9.8713 | 1.1438 |
| -0.0950 | 0.0843 | -0.0358 | -10.9217 | 1.4085 |
| -0.0816 | 0.0711 | -0.0332 | -12.1396 | 1.7646 |
| -0.0692 | 0.0590 | -0.0304 | -13.5697 | 2.2593 |
| -0.0578 | 0.0480 | -0.0276 | -15.2787 | 2.9778 |
| -0.0475 | 0.0381 | -0.0247 | -17.3455 | 3.9866 |
| -0.0382 | 0.0292 | -0.0217 | -19.8826 | 5.5206 |
| -0.0299 | 0.0215 | -0.0187 | -23.0924 | 8.0326 |
| -0.0227 | 0.0150 | -0.0156 | -27.2729 | 12.1562 |
| -0.0165 | 0.0096 | -0.0124 | -32.9483 | 19.7790 |
| -0.0112 | 0.0054 | -0.0094 | -40.9610 | 33.7494 |
| -0.0069 | 0.0024 | -0.0063 | -52.5599 | 59.4550 |
| -0.0032 | 0.0006 | -0.0032 | -69.2299 | 101.2577 |
| 0.0 | 0.0 | 0.0 | -89.9793 | 126.0630 |
| 0.0032 | 0.0006 | 0.0032 | -110.7857 | 101.5355 |
| 0.0069 | 0.0024 | 0.0063 | -127.5640 | 60.5029 |
| 0.0112 | 0.0054 | 0.0094 | -139.3802 | 34.8578 |
| 0.0164 | 0.0096 | 0.0125 | -147.6151 | 20.4829 |
| 0.0226 | 0.0150 | 0.0155 | -153.4577 | 12.6174 |
| 0.0298 | 0.0215 | 0.0184 | -157.6677 | 7.8488 |
| 0.0380 | 0.0292 | 0.0213 | -160.7500 | 5.2272 |
| 0.0473 | 0.0381 | 0.0242 | -163.0861 | 3.5538 |
| 0.0576 | 0.0480 | 0.0271 | -164.9134 | 2.6128 |
| 0.0690 | 0.0590 | 0.0299 | -166.4288 | 2.0329 |
| 0.0814 | 0.0711 | 0.0326 | -167.7276 | 1.6207 |
| 0.0948 | 0.0843 | 0.0354 | -168.8585 | 1.3236 |
| 0.1092 | 0.0984 | 0.0380 | -169.8620 | 1.1129 |
| 0.1245 | 0.1135 | 0.0406 | -170.7642 | 0.9430 |
| 0.1407 | 0.1295 | 0.0431 | -171.5855 | 0.8246 |
| 0.1578 | 0.1464 | 0.0456 | -172.3493 | 0.7354 |
| 0.1757 | 0.1642 | 0.0477 | -173.0706 | 0.6697 |
| 0.1944 | 0.1828 | 0.0499 | -173.7457 | 0.5902 |
| 0.2139 | 0.2021 | 0.0519 | -174.3771 | 0.5429 |
| 0.2341 | 0.2222 | 0.0538 | -174.9762 | 0.4950 |
| 0.2549 | 0.2429 | 0.0555 | -175.5508 | 0.4689 |
| 0.2763 | 0.2643 | 0.0570 | -176.1075 | 0.4387 |
| 0.2982 | 0.2862 | 0.0584 | -176.6395 | 0.4069 |
| 0.3207 | 0.3087 | 0.0596 | -177.1598 | 0.4016 |
| 0.3436 | 0.3316 | 0.0607 | -177.6822 | 0.3939 |
| 0.3669 | 0.3549 | 0.0615 | -178.2013 | 0.3832 |
| 0.3906 | 0.3785 | 0.0621 | -178.7167 | 0.3711 |
| 0.4145 | 0.4025 | 0.0626 | -179.2287 | 0.3692 |
| 0.4387 | 0.4266 | 0.0628 | -179.7443 | 0.3751 |
| 0.4631 | 0.4510 | 0.0628 | -180.2849 | 0.3996 |
| 0.4876 | 0.4755 | 0.0625 | -180.8635 | 0.4255 |

(3)

XX

MESH NUMBER 1 RESULTS

LOWER SURFACE TRANSITION POINT HAS MOVED FROM I= 19 TO I= 20 ITBL= 16
SOURCE STRENGTH HAS BEEN SMOOTHED ISTAG= 22.5 ILE= 23

| I | X | Q |
|----|------------|------------|
| 20 | 0.4335D-01 | 0.4970D-04 |
| 19 | 0.7968D-01 | 0.6677D-04 |
| 18 | 0.1256D+00 | 0.2850D-03 |
| 17 | 0.1799D+00 | 0.3977D-03 |

| I | X | QSMTH |
|----|------------|------------|
| 20 | 0.4335D-01 | 0.4970D-04 |
| 19 | 0.7968D-01 | 0.1674D-03 |
| 18 | 0.1256D+00 | 0.2850D-03 |
| 17 | 0.1799D+00 | 0.3977D-03 |

CONVERGENCE SUMMARY TABLE MESH 1

| ITBL | NIT | RMAX | AL/CL | CDB | CPTC | VTOP | VBOT | VSYM | DELT | DELB | SEPT | SEPB | DUT | I-J | DUB | I-J | BJMX | JMX | |
|------|-----|-----------|-------|--------|--------|-----------|-----------|------------|--------|--------|------|------|-----|------|-----|------|------|--------|---|
| 15 | 4 | 0.77D-02 | 2.243 | 0.0107 | 0.2673 | 0.448D-01 | 0.131D-01 | -0.604D-01 | .02508 | .01299 | 0 | 0 | 0 | .031 | 41 | .016 | -8 | 0.0000 | 2 |
| 16 | 6 | 0.10D-01 | 2.137 | 0.0161 | 0.2715 | 0.439D-01 | 0.140D-01 | -0.597D-01 | .02581 | .01741 | 0 | 0 | 0 | .186 | 32 | .279 | -4 | -.0071 | 2 |
| 17 | 8 | 0.98D-02 | 2.104 | 0.0182 | 0.2731 | 0.431D-01 | 0.140D-01 | -0.589D-01 | .02626 | .01952 | 0 | 0 | 0 | .307 | 33 | .267 | -4 | -.0078 | 2 |
| 18 | 10 | 0.59D-02 | 2.195 | 0.0172 | 0.2708 | 0.433D-01 | 0.135D-01 | -0.574D-01 | .02623 | .01748 | 0 | 0 | 0 | .325 | 34 | .124 | 13 | -.0067 | 2 |
| 19 | 12 | 0.16D-02 | 2.123 | 0.0160 | 0.2676 | 0.447D-01 | 0.131D-01 | -0.561D-01 | .02590 | .01577 | 0 | 0 | 0 | .282 | 34 | .038 | 18 | -.0054 | 2 |
| 20 | 14 | -0.14D-02 | 2.156 | 0.0158 | 0.2639 | 0.472D-01 | 0.121D-01 | -0.547D-01 | .02548 | .01464 | 0 | 0 | 0 | .208 | 34 | .001 | -3 | -.0040 | 2 |
| 21 | 16 | -0.18D-02 | 2.214 | 0.0161 | 0.2587 | 0.507D-01 | 0.109D-01 | -0.543D-01 | .02514 | .01384 | 0 | 0 | 0 | .122 | 34 | .088 | -3 | 0.0028 | 8 |
| 22 | 18 | -0.22D-02 | 2.286 | 0.0164 | 0.2526 | 0.544D-01 | 0.106D-01 | -0.560D-01 | .02511 | .01338 | 0 | 0 | 0 | .083 | 36 | .040 | 16 | 0.0031 | 8 |
| 23 | 20 | -0.24D-02 | 2.352 | 0.0167 | 0.2476 | 0.574D-01 | 0.109D-01 | -0.587D-01 | .02544 | .01339 | 0 | 0 | 0 | .092 | 36 | .040 | -4 | 0.0036 | 8 |
| 24 | 22 | -0.21D-02 | 2.400 | 0.0169 | 0.2442 | 0.594D-01 | 0.110D-01 | -0.611D-01 | .02606 | .01345 | 0 | 0 | 0 | .087 | 36 | .035 | -4 | 0.0039 | 8 |
| 25 | 24 | -0.14D-02 | 2.437 | 0.0171 | 0.2413 | 0.611D-01 | 0.108D-01 | -0.630D-01 | .02682 | .01348 | 0 | 0 | 0 | .075 | 36 | .023 | -4 | 0.0036 | 8 |
| 26 | 26 | -0.10D-02 | 2.470 | 0.0172 | 0.2384 | 0.627D-01 | 0.106D-01 | -0.645D-01 | .02759 | .01346 | 0 | 0 | 0 | .065 | 36 | .016 | 18 | 0.0030 | 7 |
| 27 | 28 | -0.90D-03 | 2.501 | 0.0173 | 0.2352 | 0.644D-01 | 0.103D-01 | -0.658D-01 | .02832 | .01342 | 0 | 0 | 0 | .059 | 36 | .014 | 18 | 0.0027 | 7 |
| 28 | 30 | -0.87D-03 | 2.530 | 0.0174 | 0.2320 | 0.661D-01 | 0.101D-01 | -0.670D-01 | .02899 | .01338 | 0 | 0 | 0 | .054 | 36 | .013 | 18 | 0.0024 | 7 |
| 29 | 32 | -0.80D-03 | 2.557 | 0.0175 | 0.2288 | 0.677D-01 | 0.991D-02 | -0.681D-01 | .02960 | .01336 | 0 | 0 | 0 | .050 | 36 | .011 | 18 | 0.0022 | 7 |
| 30 | 34 | -0.73D-03 | 2.582 | 0.0177 | 0.2258 | 0.692D-01 | 0.979D-02 | -0.691D-01 | .03016 | .01335 | 0 | 0 | 0 | .045 | 36 | .010 | 18 | 0.0021 | 7 |
| 31 | 36 | -0.67D-03 | 2.606 | 0.0178 | 0.2229 | 0.707D-01 | 0.972D-02 | -0.699D-01 | .03067 | .01335 | 0 | 0 | 0 | .041 | 36 | .009 | 18 | 0.0019 | 7 |
| 32 | 38 | -0.60D-03 | 2.628 | 0.0179 | 0.2201 | 0.721D-01 | 0.967D-02 | -0.706D-01 | .03111 | .01335 | 0 | 0 | 0 | .037 | 36 | .008 | 18 | 0.0018 | 7 |
| 33 | 40 | -0.53D-03 | 2.648 | 0.0180 | 0.2174 | 0.735D-01 | 0.965D-02 | -0.711D-01 | .03150 | .01336 | 0 | 0 | 0 | .033 | 36 | .008 | 18 | 0.0017 | 7 |
| 34 | 42 | -0.68D-03 | 2.667 | 0.0181 | 0.2148 | 0.748D-01 | 0.966D-02 | -0.716D-01 | .03182 | .01337 | 0 | 0 | 0 | .029 | 36 | .007 | -4 | 0.0017 | 7 |
| 35 | 44 | -0.64D-03 | 2.684 | 0.0182 | 0.2125 | 0.761D-01 | 0.968D-02 | -0.721D-01 | .03209 | .01337 | 0 | 0 | 0 | .027 | 36 | .006 | -4 | 0.0016 | 7 |
| 36 | 46 | -0.19D-03 | 2.699 | 0.0183 | 0.2101 | 0.773D-01 | 0.972D-02 | -0.724D-01 | .03229 | .01339 | 0 | 0 | 0 | .023 | 36 | .007 | -4 | 0.0015 | 7 |

(4)

MESH NUMBER 2 RESULTS

LOWER SURFACE TRANSITION POINT HAS MOVED FROM I= 37 TO I= 36 ITBL= 1
SOURCE STRENGTH HAS BEEN SMOOTHED ISTAG= 41.5 ILE= 42

```

I      X      Q
36 0.6018D-01 0.5843D-04
35 0.7962D-01 0.2029D-03
34 0.1015D+00 0.2296D-03
33 0.1256D+00 0.2563D-03
    
```

```

I      X      QSMTH
36 0.6018D-01 0.5843D-04
35 0.7962D-01 0.1431D-03
34 0.1015D+00 0.2089D-03
33 0.1256D+00 0.2563D-03
    
```

USER'S LOWER SURFACE TRANSITION POINT TOO CLOSE TO STAGNATION POINT
RESET TO XTL=0.060 FOR THIS MESH

CONVERGENCE SUMMARY TABLE MESH 2

| ITBL | NIT | RMAX | AL/CL | CDB | CPTE | VTOP | VBOT | YSYM | DELTA | DELTA SEPT | SEPB | DUT | I-J | DUB | I-J | BJMX | JMX |
|------|-----|-----------|-------|--------|--------|-----------|-----------|-------------|---------|------------|------|-------|-----|-------|-----|--------|-----|
| 4 | 4 | -0.740-02 | 3.069 | 0.0164 | 0.3741 | 0.459D-01 | 0.211D-01 | -0.253D+00 | 0.03343 | 0.01329 | 0 | 0.142 | 67 | 0.049 | -16 | 0.0041 | 12 |
| 6 | 6 | -0.360-02 | 2.921 | 0.0175 | 0.2454 | 0.111D-01 | 0.154D-01 | -0.186D+00 | 0.03376 | 0.01311 | 2 | 0.177 | 66 | 0.059 | -14 | 0.0075 | 12 |
| 7 | 8 | -0.120-02 | 2.906 | 0.0176 | 0.2388 | 0.495D-01 | 0.144D-01 | -0.131D+00 | 0.03422 | 0.01456 | 0 | 0.125 | 66 | 0.080 | -4 | 0.0017 | 2 |
| 8 | 10 | 0.110-02 | 2.848 | 0.0178 | 0.1992 | 0.554D-01 | 0.127D-01 | -0.107D+00 | 0.03448 | 0.01445 | 0 | 0.122 | 66 | 0.040 | -4 | 0.0010 | 2 |
| 9 | 12 | 0.990-03 | 2.818 | 0.0179 | 0.1681 | 0.608D-01 | 0.120D-01 | -0.995D-01 | 0.03478 | 0.01431 | 0 | 0.098 | 66 | 0.032 | -4 | 0.0015 | 10 |
| 10 | 14 | 0.920-03 | 2.790 | 0.0178 | 0.1490 | 0.647D-01 | 0.119D-01 | -0.793D-01 | 0.03503 | 0.01410 | 0 | 0.069 | 66 | 0.019 | -4 | 0.0019 | 10 |
| 11 | 16 | 0.820-03 | 2.766 | 0.0177 | 0.1386 | 0.674D-01 | 0.123D-01 | -0.711D-01 | 0.03520 | 0.01392 | 0 | 0.044 | 66 | 0.014 | -16 | 0.0021 | 10 |
| 12 | 18 | 0.700-03 | 2.747 | 0.0176 | 0.1344 | 0.693D-01 | 0.129D-01 | -0.653D-01 | 0.03527 | 0.01386 | 0 | 0.034 | 69 | 0.014 | -16 | 0.0021 | 10 |
| 13 | 20 | 0.590-03 | 2.734 | 0.0176 | 0.1347 | 0.707D-01 | 0.137D-01 | -0.617D-01 | 0.03519 | 0.01383 | 0 | 0.030 | 69 | 0.016 | -16 | 0.0020 | 10 |
| 14 | 22 | 0.490-03 | 2.724 | 0.0175 | 0.1373 | 0.715D-01 | 0.145D-01 | -0.594D-01 | 0.03507 | 0.01380 | 0 | 0.029 | 65 | 0.016 | -16 | 0.0018 | 10 |
| 15 | 24 | 0.380-03 | 2.719 | 0.0174 | 0.1411 | 0.720D-01 | 0.152D-01 | -0.583D-01 | 0.03492 | 0.01378 | 0 | 0.031 | 65 | 0.015 | -16 | 0.0015 | 10 |
| 16 | 26 | 0.270-03 | 2.716 | 0.0174 | 0.1453 | 0.724D-01 | 0.158D-01 | -0.579D-01 | 0.03476 | 0.01376 | 0 | 0.031 | 65 | 0.013 | -16 | 0.0013 | 9 |
| 17 | 28 | 0.180-03 | 2.714 | 0.0173 | 0.1492 | 0.724D-01 | 0.163D-01 | -0.580D-01 | 0.03461 | 0.01374 | 0 | 0.030 | 65 | 0.011 | -16 | 0.0010 | 8 |
| 18 | 30 | 0.120-03 | 2.713 | 0.0173 | 0.1528 | 0.726D-01 | 0.168D-01 | -0.583D-01 | 0.03448 | 0.01374 | 0 | 0.028 | 65 | 0.009 | -16 | 0.0008 | 7 |
| 19 | 32 | 0.810-04 | 2.712 | 0.0173 | 0.1558 | 0.726D-01 | 0.172D-01 | -0.588D-01 | 0.03436 | 0.01374 | 0 | 0.026 | 65 | 0.007 | -16 | 0.0007 | 6 |
| 20 | 34 | 0.650-04 | 2.712 | 0.0172 | 0.1583 | 0.726D-01 | 0.175D-01 | -0.593D-01 | 0.03426 | 0.01373 | 0 | 0.024 | 65 | 0.007 | -3 | 0.0005 | 6 |
| 21 | 36 | 0.530-04 | 2.711 | 0.0172 | 0.1603 | 0.725D-01 | 0.177D-01 | -0.598D-01 | 0.03417 | 0.01373 | 0 | 0.022 | 65 | 0.006 | -3 | 0.0004 | 5 |
| 22 | 38 | 0.500-04 | 2.711 | 0.0172 | 0.1619 | 0.725D-01 | 0.179D-01 | -0.602D-01 | 0.03410 | 0.01372 | 0 | 0.020 | 65 | 0.006 | -3 | 0.0004 | 5 |
| 23 | 40 | 0.510-04 | 2.710 | 0.0172 | 0.1631 | 0.724D-01 | 0.180D-01 | -0.606D-01 | 0.03404 | 0.01371 | 0 | 0.018 | 65 | 0.006 | -3 | 0.0003 | 5 |
| 24 | 42 | 0.500-04 | 2.710 | 0.0172 | 0.1641 | 0.724D-01 | 0.181D-01 | -0.609D-01 | 0.03399 | 0.01371 | 0 | 0.016 | 65 | 0.005 | -3 | 0.0002 | 5 |
| 25 | 44 | 0.480-04 | 2.709 | 0.0172 | 0.1649 | 0.723D-01 | 0.182D-01 | -0.612D-01 | 0.03394 | 0.01370 | 0 | 0.015 | 65 | 0.005 | -3 | 0.0002 | 5 |
| 26 | 46 | 0.200-04 | 2.708 | 0.0171 | 0.1656 | 0.722D-01 | 0.182D-01 | -0.6140D-01 | 0.03391 | 0.01370 | 0 | 0.013 | 65 | 0.005 | -3 | 0.0002 | 5 |

MESH NUMBER 3 RESULTS

LOWER SURFACE TRANSITION POINT HAS MOVED FROM I= 69 TO I= 70 ITBL= 1
SOURCE STRENGTH HAS BEEN SMOOTHED ISTAG= 79.5 ILE= 82

```

I      X      Q
70 0.5140D-01 0.5577D-04
69 0.6017D-01 0.5929D-04
68 0.6958D-01 0.1106D-03
67 0.7961D-01 0.1619D-03
    
```

```

I      X      QSMTH
70 0.5140D-01 0.5577D-04
69 0.6017D-01 0.8318D-04
68 0.6958D-01 0.1106D-03
67 0.7961D-01 0.1619D-03
    
```

UPPER SURFACE

| | X | CF | D-STAR | D-THETA | H | HBAR | Q | CE | UEI | UEV |
|------------|------------|------------|------------|---------|------|------------|------------|--------|--------|--------|
| 0.2010D-02 | 0.1800D+11 | 0.2043D-04 | 0.9340D-05 | 2.19 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.1361D-02 | 0.2939D+00 | 0.1128D-04 | 0.5542D-05 | 2.04 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 0.0785 | 0.0 |
| 0.3183D-03 | 0.2371D-01 | 0.3152D-04 | 0.1492D-04 | 2.11 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 0.3493 | 0.0 |
| 0.8786D-05 | 0.1397D-01 | 0.2753D-04 | 0.1152D-04 | 2.39 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 0.6492 | 0.0 |
| 0.4305D-03 | 0.9461D-02 | 0.3003D-04 | 0.1134D-04 | 2.65 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 0.9278 | 0.0 |
| 0.1586D-02 | 0.6806D-02 | 0.3711D-04 | 0.1284D-04 | 2.89 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.1455 | 0.0 |
| 0.3480D-02 | 0.5080D-02 | 0.4770D-04 | 0.1541D-04 | 3.10 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.2968 | 0.0 |
| 0.6112D-02 | 0.3884D-02 | 0.6090D-04 | 0.1864D-04 | 3.27 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.3998 | 0.0 |
| 0.9478D-02 | 0.3015D-02 | 0.7631D-04 | 0.2237D-04 | 3.41 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.4646 | 0.0 |
| 0.1358D-01 | 0.2418D-02 | 0.9316D-04 | 0.2655D-04 | 3.51 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.5031 | 0.0 |
| 0.1842D-01 | 0.1962D-02 | 0.1086D-03 | 0.3094D-04 | 3.51 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.5264 | 0.0 |
| 0.2399D-01 | 0.1624D-02 | 0.1249D-03 | 0.3558D-04 | 3.51 | 0.0 | 0.8899D-04 | 0.0 | 0.0 | 1.5380 | 0.0 |
| 0.3028D-01 | 0.5247D-02 | 0.8585D-04 | 0.4052D-04 | 2.12 | 1.47 | 0.8899D-04 | 0.1184D-01 | 1.5422 | 1.5422 | 1.5422 |
| 0.3729D-01 | 0.4492D-02 | 0.1237D-03 | 0.5790D-04 | 2.14 | 1.48 | 0.1282D-03 | 0.1341D-01 | 1.5416 | 1.5437 | 1.5371 |
| 0.4499D-01 | 0.4213D-02 | 0.1622D-03 | 0.7724D-04 | 2.10 | 1.46 | 0.1684D-03 | 0.1324D-01 | 1.5394 | 1.5418 | 1.5418 |
| 0.5336D-01 | 0.4094D-02 | 0.1928D-03 | 0.9278D-04 | 2.08 | 1.43 | 0.1999D-03 | 0.1209D-01 | 1.5371 | 1.5371 | 1.5371 |
| 0.6239D-01 | 0.3892D-02 | 0.2314D-03 | 0.1118D-03 | 2.07 | 1.43 | 0.2399D-03 | 0.1216D-01 | 1.5350 | 1.5415 | 1.5415 |
| 0.7206D-01 | 0.3727D-02 | 0.2724D-03 | 0.1326D-03 | 2.05 | 1.42 | 0.2829D-03 | 0.1245D-01 | 1.5331 | 1.5357 | 1.5357 |
| 0.8236D-01 | 0.3633D-02 | 0.3101D-03 | 0.1522D-03 | 2.04 | 1.41 | 0.3224D-03 | 0.1223D-01 | 1.5316 | 1.5324 | 1.5324 |
| 0.9326D-01 | 0.3554D-02 | 0.3491D-03 | 0.1725D-03 | 2.02 | 1.40 | 0.3631D-03 | 0.1187D-01 | 1.5307 | 1.5314 | 1.5314 |
| 0.1047D+00 | 0.3481D-02 | 0.3887D-03 | 0.1930D-03 | 2.01 | 1.39 | 0.4043D-03 | 0.1159D-01 | 1.5303 | 1.5308 | 1.5308 |
| 0.1168D+00 | 0.3411D-02 | 0.4298D-03 | 0.2144D-03 | 2.00 | 1.39 | 0.4471D-03 | 0.1137D-01 | 1.5304 | 1.5306 | 1.5306 |
| 0.1294D+00 | 0.3350D-02 | 0.4708D-03 | 0.2357D-03 | 2.00 | 1.38 | 0.4897D-03 | 0.1116D-01 | 1.5310 | 1.5310 | 1.5310 |
| 0.1425D+00 | 0.3296D-02 | 0.5126D-03 | 0.2573D-03 | 1.99 | 1.37 | 0.5330D-03 | 0.1093D-01 | 1.5322 | 1.5321 | 1.5321 |
| 0.1562D+00 | 0.3247D-02 | 0.5544D-03 | 0.2790D-03 | 1.99 | 1.37 | 0.5762D-03 | 0.1072D-01 | 1.5337 | 1.5336 | 1.5336 |
| 0.1703D+00 | 0.3199D-02 | 0.5977D-03 | 0.3013D-03 | 1.98 | 1.37 | 0.6209D-03 | 0.1054D-01 | 1.5355 | 1.5352 | 1.5352 |
| 0.1849D+00 | 0.3156D-02 | 0.6408D-03 | 0.3236D-03 | 1.98 | 1.36 | 0.6653D-03 | 0.1038D-01 | 1.5376 | 1.5371 | 1.5371 |
| 0.1999D+00 | 0.3116D-02 | 0.6846D-03 | 0.3461D-03 | 1.98 | 1.36 | 0.7103D-03 | 0.1022D-01 | 1.5398 | 1.5393 | 1.5393 |
| 0.2154D+00 | 0.3080D-02 | 0.7285D-03 | 0.3687D-03 | 1.98 | 1.35 | 0.7553D-03 | 0.1007D-01 | 1.5423 | 1.5418 | 1.5418 |
| 0.2312D+00 | 0.3046D-02 | 0.7729D-03 | 0.3915D-03 | 1.97 | 1.35 | 0.8007D-03 | 0.9909D-02 | 1.5450 | 1.5445 | 1.5445 |
| 0.2474D+00 | 0.3015D-02 | 0.8173D-03 | 0.4142D-03 | 1.97 | 1.35 | 0.8459D-03 | 0.9748D-02 | 1.5479 | 1.5474 | 1.5474 |

(5)

| | | | | | | | | | |
|------------|------------|------------|------------|------|------|------------|------------|--------|--------|
| 0.2640D+00 | 0.2984D-02 | 0.8624D-03 | 0.4371D-03 | 1.97 | 1.34 | 0.8916D-03 | 0.9603D-02 | 1.5508 | 1.5504 |
| 0.2809D+00 | 0.2955D-02 | 0.9077D-03 | 0.4601D-03 | 1.97 | 1.34 | 0.9375D-03 | 0.9463D-02 | 1.5539 | 1.5535 |
| 0.2981D+00 | 0.2926D-02 | 0.9527D-03 | 0.4828D-03 | 1.97 | 1.34 | 0.9829D-03 | 0.9306D-02 | 1.5572 | 1.5570 |
| 0.3156D+00 | 0.2897D-02 | 0.9977D-03 | 0.5054D-03 | 1.97 | 1.34 | 0.1028D-02 | 0.9125D-02 | 1.5609 | 1.5607 |
| 0.3330D+00 | 0.2868D-02 | 0.1043D-02 | 0.5280D-03 | 1.98 | 1.33 | 0.1077D-02 | 0.8927D-02 | 1.5647 | 1.5645 |
| 0.3512D+00 | 0.2840D-02 | 0.1087D-02 | 0.5506D-03 | 1.98 | 1.33 | 0.1127D-02 | 0.8740D-02 | 1.5684 | 1.5682 |
| 0.3694D+00 | 0.2812D-02 | 0.1127D-02 | 0.5721D-03 | 1.98 | 1.33 | 0.1177D-02 | 0.8559D-02 | 1.5720 | 1.5718 |
| 0.3876D+00 | 0.2784D-02 | 0.1178D-02 | 0.5945D-03 | 1.98 | 1.33 | 0.1227D-02 | 0.8388D-02 | 1.5774 | 1.5774 |
| 0.4061D+00 | 0.2756D-02 | 0.1222D-02 | 0.6158D-03 | 1.98 | 1.33 | 0.1250D-02 | 0.8154D-02 | 1.5819 | 1.5824 |
| 0.4246D+00 | 0.2728D-02 | 0.1264D-02 | 0.6359D-03 | 1.99 | 1.32 | 0.1290D-02 | 0.7918D-02 | 1.5868 | 1.5878 |
| 0.4432D+00 | 0.2700D-02 | 0.1309D-02 | 0.6574D-03 | 1.99 | 1.32 | 0.1333D-02 | 0.7675D-02 | 1.5923 | 1.5932 |
| 0.4619D+00 | 0.2672D-02 | 0.1351D-02 | 0.6767D-03 | 2.00 | 1.32 | 0.1373D-02 | 0.7428D-02 | 1.5990 | 1.5981 |
| 0.4806D+00 | 0.2644D-02 | 0.1399D-02 | 0.6989D-03 | 2.00 | 1.32 | 0.1416D-02 | 0.6785D-02 | 1.6056 | 1.6072 |
| 0.4993D+00 | 0.2616D-02 | 0.1416D-02 | 0.7049D-03 | 2.01 | 1.32 | 0.1430D-02 | 0.6565D-02 | 1.6119 | 1.6136 |
| 0.5179D+00 | 0.2588D-02 | 0.1520D-02 | 0.7458D-03 | 2.01 | 1.32 | 0.1515D-02 | 0.6679D-02 | 1.6149 | 1.6172 |
| 0.5366D+00 | 0.2560D-02 | 0.1528D-02 | 0.7570D-03 | 2.02 | 1.34 | 0.1571D-02 | 0.6791D-02 | 1.6073 | 1.6016 |
| 0.5551D+00 | 0.2304D-02 | 0.1784D-02 | 0.8802D-03 | 2.03 | 1.39 | 0.1846D-02 | 0.1426D-01 | 1.5443 | 1.5478 |
| 0.5736D+00 | 0.1433D-02 | 0.2222D-02 | 0.1009D-02 | 2.20 | 1.66 | 0.2377D-02 | 0.2492D-01 | 1.4029 | 1.3954 |
| 0.5921D+00 | 0.5418D-03 | 0.4393D-02 | 0.1641D-02 | 2.68 | 2.14 | 0.4717D-02 | 0.3127D-01 | 1.2873 | 1.2914 |
| 0.6104D+00 | 0.3339D-03 | 0.5317D-02 | 0.1816D-02 | 2.93 | 2.39 | 0.5695D-02 | 0.3281D-01 | 1.2463 | 1.2523 |
| 0.6286D+00 | 0.3678D-03 | 0.5302D-02 | 0.1866D-02 | 2.84 | 2.34 | 0.5664D-02 | 0.3384D-01 | 1.2220 | 1.2263 |
| 0.6466D+00 | 0.4399D-03 | 0.5616D-02 | 0.2081D-02 | 2.70 | 2.23 | 0.5980D-02 | 0.3462D-01 | 1.2026 | 1.2039 |
| 0.6645D+00 | 0.5370D-03 | 0.5497D-02 | 0.2152D-02 | 2.55 | 2.12 | 0.5835D-02 | 0.3494D-01 | 1.1843 | 1.1849 |
| 0.6823D+00 | 0.6326D-03 | 0.5595D-02 | 0.2302D-02 | 2.43 | 2.02 | 0.5920D-02 | 0.3500D-01 | 1.1671 | 1.1685 |
| 0.6998D+00 | 0.7156D-03 | 0.5625D-02 | 0.2407D-02 | 2.34 | 1.95 | 0.5932D-02 | 0.3481D-01 | 1.1549 | 1.1535 |
| 0.7170D+00 | 0.7874D-03 | 0.5697D-02 | 0.2519D-02 | 2.26 | 1.89 | 0.5989D-02 | 0.3429D-01 | 1.1410 | 1.1399 |
| 0.7340D+00 | 0.8422D-03 | 0.5731D-02 | 0.2631D-02 | 2.21 | 1.85 | 0.6080D-02 | 0.3379D-01 | 1.1283 | 1.1269 |
| 0.7507D+00 | 0.8816D-03 | 0.5930D-02 | 0.2746D-02 | 2.16 | 1.80 | 0.6198D-02 | 0.3390D-01 | 1.1158 | 1.1143 |
| 0.7670D+00 | 0.9052D-03 | 0.6112D-02 | 0.2864D-02 | 2.13 | 1.80 | 0.6357D-02 | 0.3307D-01 | 1.1037 | 1.1018 |
| 0.7830D+00 | 0.9176D-03 | 0.6295D-02 | 0.2979D-02 | 2.11 | 1.79 | 0.6522D-02 | 0.3281D-01 | 1.0914 | 1.0895 |
| 0.7987D+00 | 0.9177D-03 | 0.6538D-02 | 0.3113D-02 | 2.10 | 1.79 | 0.6746D-02 | 0.3265D-01 | 1.0791 | 1.0772 |
| 0.8139D+00 | 0.9089D-03 | 0.6786D-02 | 0.3240D-02 | 2.09 | 1.79 | 0.6971D-02 | 0.3259D-01 | 1.0671 | 1.0649 |
| 0.8288D+00 | 0.8913D-03 | 0.7089D-02 | 0.3385D-02 | 2.09 | 1.80 | 0.7250D-02 | 0.3263D-01 | 1.0551 | 1.0528 |
| 0.8431D+00 | 0.8677D-03 | 0.7395D-02 | 0.3523D-02 | 2.10 | 1.81 | 0.7528D-02 | 0.3277D-01 | 1.0433 | 1.0409 |
| 0.8570D+00 | 0.8379D-03 | 0.7757D-02 | 0.3678D-02 | 2.11 | 1.82 | 0.7858D-02 | 0.3299D-01 | 1.0318 | 1.0293 |
| 0.8704D+00 | 0.8041D-03 | 0.8121D-02 | 0.3825D-02 | 2.14 | 1.84 | 0.8187D-02 | 0.3328D-01 | 1.0206 | 1.0179 |
| 0.8833D+00 | 0.7565D-03 | 0.8430D-02 | 0.3988D-02 | 2.14 | 1.87 | 0.8510D-02 | 0.3367D-01 | 1.0098 | 1.0070 |
| 0.8956D+00 | 0.7249D-03 | 0.8966D-02 | 0.4142D-02 | 2.16 | 1.89 | 0.8951D-02 | 0.3401D-01 | 0.9993 | 0.9964 |
| 0.9074D+00 | 0.6814D-03 | 0.9444D-02 | 0.4309D-02 | 2.19 | 1.92 | 0.9382D-02 | 0.3444D-01 | 0.9894 | 0.9863 |
| 0.9185D+00 | 0.6370D-03 | 0.9925D-02 | 0.4465D-02 | 2.22 | 1.96 | 0.9814D-02 | 0.3489D-01 | 0.9800 | 0.9768 |
| 0.9291D+00 | 0.5919D-03 | 0.1045D-01 | 0.4628D-02 | 2.26 | 1.99 | 0.1028D-01 | 0.3536D-01 | 0.9712 | 0.9679 |
| 0.9390D+00 | 0.5473D-03 | 0.1097D-01 | 0.4781D-02 | 2.30 | 2.03 | 0.1076D-01 | 0.3561D-01 | 0.9630 | 0.9597 |
| 0.9482D+00 | 0.5036D-03 | 0.1152D-01 | 0.4932D-02 | 2.34 | 2.07 | 0.1125D-01 | 0.3581D-01 | 0.9556 | 0.9522 |
| 0.9568D+00 | 0.4617D-03 | 0.1207D-01 | 0.5072D-02 | 2.38 | 2.12 | 0.1174D-01 | 0.3600D-01 | 0.9488 | 0.9454 |
| 0.9646D+00 | 0.4220D-03 | 0.1262D-01 | 0.5203D-02 | 2.43 | 2.16 | 0.1223D-01 | 0.3617D-01 | 0.9427 | 0.9394 |
| 0.9717D+00 | 0.3848D-03 | 0.1317D-01 | 0.5335D-02 | 2.47 | 2.21 | 0.1272D-01 | 0.3635D-01 | 0.9374 | 0.9341 |
| 0.9781D+00 | 0.3504D-03 | 0.1369D-01 | 0.5471D-02 | 2.52 | 2.26 | 0.1321D-01 | 0.3653D-01 | 0.9321 | 0.9287 |
| 0.9837D+00 | 0.3186D-03 | 0.1421D-01 | 0.5530D-02 | 2.57 | 2.31 | 0.1366D-01 | 0.3659D-01 | 0.9287 | 0.9256 |
| 0.9885D+00 | 0.2897D-03 | 0.1469D-01 | 0.5609D-02 | 2.62 | 2.35 | 0.1409D-01 | 0.3666D-01 | 0.9253 | 0.9224 |
| 0.9925D+00 | 0.2629D-03 | 0.1516D-01 | 0.5682D-02 | 2.67 | 2.40 | 0.1452D-01 | 0.3668D-01 | 0.9225 | 0.9197 |
| 0.9957D+00 | 0.2379D-03 | 0.1558D-01 | 0.5735D-02 | 2.72 | 2.45 | 0.1491D-01 | 0.3667D-01 | 0.9203 | 0.9176 |
| 0.9981D+00 | 0.2136D-03 | 0.1601D-01 | 0.5779D-02 | 2.77 | 2.50 | 0.1530D-01 | 0.3666D-01 | 0.9185 | 0.9160 |
| 0.9995D+00 | 0.1891D-03 | 0.1643D-01 | 0.5809D-02 | 2.83 | 2.55 | 0.1570D-01 | 0.3666D-01 | 0.9168 | 0.9149 |
| 0.1000D+01 | 0.1644D-03 | 0.1686D-01 | 0.5827D-02 | 2.89 | 2.61 | 0.1610D-01 | 0.3668D-01 | 0.9180 | 0.9143 |
| 0.1001D+01 | 0.0 | 0.1683D-01 | 0.5839D-02 | 2.88 | 2.60 | 0.1606D-01 | 0.3667D-01 | 0.9178 | 0.9142 |
| 0.1002D+01 | 0.0 | 0.1679D-01 | 0.5845D-02 | 2.86 | 2.58 | 0.1597D-01 | 0.3665D-01 | 0.9172 | 0.9139 |
| 0.1003D+01 | 0.0 | 0.1658D-01 | 0.5858D-02 | 2.83 | 2.55 | 0.1582D-01 | 0.3661D-01 | 0.9164 | 0.9134 |
| 0.1006D+01 | 0.0 | 0.1640D-01 | 0.5885D-02 | 2.79 | 2.51 | 0.1565D-01 | 0.3657D-01 | 0.9153 | 0.9127 |
| 0.1009D+01 | 0.0 | 0.1613D-01 | 0.5900D-02 | 2.73 | 2.47 | 0.1538D-01 | 0.3655D-01 | 0.9139 | 0.9119 |
| 0.1014D+01 | 0.0 | 0.1585D-01 | 0.5934D-02 | 2.67 | 2.41 | 0.1510D-01 | 0.3656D-01 | 0.9125 | 0.9110 |
| 0.1019D+01 | 0.0 | 0.1545D-01 | 0.5949D-02 | 2.60 | 2.34 | 0.1471D-01 | 0.3660D-01 | 0.9109 | 0.9101 |
| 0.1026D+01 | 0.0 | 0.1503D-01 | 0.5982D-02 | 2.51 | 2.26 | 0.1431D-01 | 0.3668D-01 | 0.9098 | 0.9094 |
| 0.1034D+01 | 0.0 | 0.1447D-01 | 0.5978D-02 | 2.42 | 2.18 | 0.1377D-01 | 0.3682D-01 | 0.9088 | 0.9090 |
| 0.1043D+01 | 0.0 | 0.1389D-01 | 0.5980D-02 | 2.32 | 2.09 | 0.1322D-01 | 0.3702D-01 | 0.9085 | 0.9092 |
| 0.1054D+01 | 0.0 | 0.1322D-01 | 0.5949D-02 | 2.22 | 1.99 | 0.1259D-01 | 0.3732D-01 | 0.9090 | 0.9102 |
| 0.1067D+01 | 0.0 | 0.1252D-01 | 0.5897D-02 | 2.12 | 1.90 | 0.1194D-01 | 0.3779D-01 | 0.9104 | 0.9121 |
| 0.1082D+01 | 0.0 | 0.1183D-01 | 0.5833D-02 | 2.03 | 1.81 | 0.1130D-01 | 0.3822D-01 | 0.9132 | 0.9151 |
| 0.1100D+01 | 0.0 | 0.1112D-01 | 0.5735D-02 | 1.94 | 1.72 | 0.1065D-01 | 0.3857D-01 | 0.9172 | 0.9190 |
| 0.1121D+01 | 0.0 | 0.1046D-01 | 0.5635D-02 | 1.86 | 1.64 | 0.1004D-01 | 0.3882D-01 | 0.9220 | 0.9241 |
| 0.1146D+01 | 0.0 | 0.9792D-02 | 0.5499D-02 | 1.78 | 1.57 | 0.9437D-02 | 0.3896D-01 | 0.9274 | 0.9299 |
| 0.1175D+01 | 0.0 | 0.9260D-02 | 0.5401D-02 | 1.71 | 1.51 | 0.8956D-02 | 0.3898D-01 | 0.9337 | 0.9359 |
| 0.1209D+01 | 0.0 | 0.8734D-02 | 0.5276D-02 | 1.66 | 1.45 | 0.8478D-02 | 0.3884D-01 | 0.9402 | 0.9422 |
| 0.1250D+01 | 0.0 | 0.8288D-02 | 0.5173D-02 | 1.60 | 1.40 | 0.8074D-02 | 0.3848D-01 | 0.9465 | 0.9488 |
| 0.1298D+01 | 0.0 | 0.7843D-02 | 0.5045D-02 | 1.55 | 1.35 | 0.7668D-02 | 0.3792D-01 | 0.9527 | 0.9553 |
| 0.1357D+01 | 0.0 | 0.7519D-02 | 0.4973D-02 | 1.51 | 1.31 | 0.7375D-02 | 0.3716D-01 | 0.9590 | 0.9612 |
| 0.1420D+01 | 0.0 | 0.7185D-02 | 0.4875D-02 | 1.47 | 1.27 | 0.7088D-02 | 0.3614D-01 | 0.9649 | 0.9668 |
| 0.1520D+01 | 0.0 | 0.6908D-02 | 0.4802D-02 | 1.44 | 1.24 | 0.6815D-02 | 0.3484D-01 | 0.9705 | 0.9722 |
| 0.1635D+01 | 0.0 | 0.6647D-02 | 0.4725D-02 | 1.41 | 1.21 | 0.6574D-02 | 0.3325D-01 | 0.9757 | 0.9773 |
| 0.1785D+01 | 0.0 | 0.6424D-02 | 0.4663D-02 | 1.38 | 1.18 | 0.6369D-02 | 0.3135D-01 | 0.9805 | 0.9822 |
| 0.1988D+01 | 0.0 | 0.6206D-02 | 0.4595D-02 | 1.35 | 1.15 | 0.6167D-02 | 0.2913D-01 | 0.9850 | 0.9868 |
| 0.2276D+01 | 0.0 | 0.6032D-02 | 0.4551D-02 | 1.33 | 1.13 | 0.6005D-02 | 0.2659D-01 | 0.9889 | 0.9906 |
| 0.2716D+01 | 0.0 | 0.5876D-02 | 0.4513D-02 | 1.30 | 1.11 | 0.5859D-02 | 0.2367D-01 | 0.9924 | 0.9937 |
| 0.3465D+01 | 0.0 | 0.5721D-02 | 0.4472D-02 | 1.28 | 1.08 | 0.5713D-02 | 0.2023D-01 | 0.9953 | 0.9971 |
| 0.5032D+01 | 0.0 | 0.5561D-02 | 0.4424D-02 | 1.26 | 1.06 | 0.5566D-02 | 0.1603D-01 | 0.9976 | 1.0017 |
| 0.1047D+02 | 0.0 | 0.5379D-02 | 0.4373D-02 | 1.23 | 1.04 | 0.5375D-02 | 0.1081D-01 | 0.9992 | 0.9988 |
| 0.1019D+01 | 0.0 | 0.1545D-01 | 0.5949D-02 | 2.60 | 2.34 | 0.1471D-01 | 0.3660D-01 | 0.9109 | 0.9101 |
| 0.1026D+01 | 0.0 | 0.1503D-01 | 0.5982D-02 | 2.51 | 2.26 | 0.1431D-01 | 0.3668D-01 | 0.9098 | 0.9094 |
| 0.1034D+01 | 0.0 | 0.1447D-01 | 0.5978D-02 | 2.42 | 2.18 | 0.1377D-01 | 0.3682D-01 | 0.9088 | 0.9090 |
| 0.1043D+01 | 0.0 | 0.1389D-01 | 0.5980D-02 | 2.32 | 2.09 | 0.1322D-01 | 0.3702D-01 | 0.9085 | 0.9092 |
| 0.1054D+01 | 0.0 | 0.1322D-01 | 0.5949D-02 | 2.22 | 1.99 | 0.1259D-01 | 0.3732D-01 | 0.9090 | 0.9102 |
| 0.1067D+01 | 0.0 | 0.1252D-01 | 0.5897D-02 | 2.12 | 1.90 | 0.1194D-01 | 0.3779D-01 | 0.9104 | 0.9121 |
| 0.1082D+01 | 0.0 | 0.1183D-01 | 0.5833D-02 | 2.03 | 1.81 | 0.1130D-01 | 0.3822D-01 | 0.9132 | 0.9151 |
| 0.1100D+01 | 0.0 | 0.1112D-01 | 0.5735D-02 | 1.94 | 1.72 | 0.1065D-01 | 0.3857D-01 | 0.9172 | 0.9190 |
| 0.1121D+01 | 0.0 | 0.1046D-01 | 0.5635D-02 | 1.86 | | | | | |

USER'S LOWER SURFACE TRANSITION POINT TOO CLOSE TO STAGNATION POINT
 RESET TO XTL=0.043 FOR THIS MESH

USER'S LOWER SURFACE TRANSITION POINT TOO CLOSE TO STAGNATION POINT
 RESET TO XTL=0.051 FOR THIS MESH

LOWER SURFACE

| | CF | D-STAR | D-THETA | H | HBAR | Q | CE | UEI | UEV |
|------------|------------|------------|------------|------|------|------------|------------|--------|----------|
| 0.20100-02 | 0.18000+11 | 0.20430-04 | 0.93400-05 | 2.19 | 0.0 | 0.56090-04 | 0.0 | 0.0 | 0.0 |
| 0.31450-02 | 0.11840+00 | 0.16050-04 | 0.78730-05 | 2.04 | 0.0 | 0.56090-04 | 0.0 | 0.1375 | 0.0 |
| 0.56650-02 | 0.15950-01 | 0.45880-04 | 0.19770-04 | 2.32 | 0.0 | 0.56090-04 | 0.0 | 0.3001 | 0.0 |
| 0.89120-02 | 0.99950-02 | 0.49680-04 | 0.20370-04 | 2.44 | 0.0 | 0.56090-04 | 0.0 | 0.4229 | 0.0 |
| 0.12880-01 | 0.71260-02 | 0.56950-04 | 0.22810-04 | 2.50 | 0.0 | 0.56090-04 | 0.0 | 0.5172 | 0.0 |
| 0.17570-01 | 0.54480-02 | 0.65650-04 | 0.25830-04 | 2.54 | 0.0 | 0.56090-04 | 0.0 | 0.5920 | 0.0 |
| 0.22960-01 | 0.43620-02 | 0.75160-04 | 0.29150-04 | 2.58 | 0.0 | 0.56090-04 | 0.0 | 0.6527 | 0.0 |
| 0.29950-01 | 0.36080-02 | 0.85270-04 | 0.32650-04 | 2.61 | 0.0 | 0.56090-04 | 0.0 | 0.7027 | 0.0 |
| 0.35830-01 | 0.30590-02 | 0.94760-04 | 0.36280-04 | 2.61 | 0.0 | 0.56090-04 | 0.0 | 0.7445 | 0.0 |
| 0.43280-01 | 0.26490-02 | 0.10450-03 | 0.40910-04 | 2.61 | 0.0 | 0.56090-04 | 0.0 | 0.7799 | 0.0 |
| 0.51400-01 | 0.88040-02 | 0.63270-04 | 0.43770-04 | 1.45 | 1.31 | 0.56090-04 | 0.90000-02 | 0.8104 | 0.8104 |
| 0.60170-01 | 0.51140-02 | 0.11440-03 | 0.70410-04 | 1.63 | 1.46 | 0.10390-03 | 0.10760-01 | 0.8374 | 0.8412 |
| 0.69580-01 | 0.48860-02 | 0.13270-03 | 0.81840-04 | 1.62 | 1.46 | 0.12200-03 | 0.12140-01 | 0.8617 | 0.8574 |
| 0.79610-01 | 0.46390-02 | 0.16760-03 | 0.10450-03 | 1.60 | 1.43 | 0.15640-03 | 0.11230-01 | 0.8835 | 0.8790 |
| 0.90240-01 | 0.46170-02 | 0.18210-03 | 0.11430-03 | 1.59 | 1.41 | 0.17270-03 | 0.10190-01 | 0.9034 | 0.9044 |
| 0.10150+00 | 0.44190-02 | 0.21080-03 | 0.13220-03 | 1.60 | 1.40 | 0.20280-03 | 0.99750-02 | 0.9218 | 0.9271 |
| 0.11320+00 | 0.42140-02 | 0.24400-03 | 0.15250-03 | 1.60 | 1.40 | 0.23670-03 | 0.10320-01 | 0.9392 | 0.9415 |
| 0.12560+00 | 0.41120-02 | 0.27090-03 | 0.16960-03 | 1.60 | 1.39 | 0.26500-03 | 0.10210-01 | 0.9552 | 0.9560 |
| 0.13840+00 | 0.40230-02 | 0.29910-03 | 0.18750-03 | 1.60 | 1.38 | 0.29490-03 | 0.99460-02 | 0.9700 | 0.9708 |
| 0.15180+00 | 0.39360-02 | 0.32810-03 | 0.20600-03 | 1.60 | 1.38 | 0.32630-03 | 0.97490-02 | 0.9841 | 0.9846 |
| 0.16560+00 | 0.38640-02 | 0.35710-03 | 0.22380-03 | 1.60 | 1.37 | 0.35680-03 | 0.95380-02 | 0.9976 | 0.9982 |
| 0.17990+00 | 0.37950-02 | 0.38620-03 | 0.24190-03 | 1.60 | 1.37 | 0.38820-03 | 0.93580-02 | 1.0106 | 1.0113 |
| 0.19460+00 | 0.37260-02 | 0.41680-03 | 0.26090-03 | 1.60 | 1.36 | 0.42120-03 | 0.92260-02 | 1.0233 | 1.0234 |
| 0.20970+00 | 0.36660-02 | 0.44680-03 | 0.27940-03 | 1.60 | 1.36 | 0.45380-03 | 0.90850-02 | 1.0356 | 1.0352 |
| 0.22510+00 | 0.36120-02 | 0.47700-03 | 0.29790-03 | 1.60 | 1.35 | 0.48670-03 | 0.89210-02 | 1.0478 | 1.0469 |
| 0.24100+00 | 0.35660-02 | 0.50680-03 | 0.31620-03 | 1.60 | 1.35 | 0.51950-03 | 0.87100-02 | 1.0602 | 1.0588 |
| 0.25710+00 | 0.35270-02 | 0.53490-03 | 0.33330-03 | 1.60 | 1.35 | 0.55070-03 | 0.84290-02 | 1.0729 | 1.0712 |
| 0.27350+00 | 0.34920-02 | 0.56290-03 | 0.35020-03 | 1.61 | 1.34 | 0.58210-03 | 0.80840-02 | 1.0862 | 1.0841 |
| 0.29040+00 | 0.34610-02 | 0.58920-03 | 0.36580-03 | 1.61 | 1.35 | 0.61240-03 | 0.76590-02 | 1.1000 | 1.0977 |
| 0.30770+00 | 0.34310-02 | 0.61480-03 | 0.38060-03 | 1.62 | 1.46 | 0.64130-03 | 0.72100-02 | 1.1140 | 1.1135 |
| 0.32490+00 | 0.33850-02 | 0.64340-03 | 0.39680-03 | 1.62 | 1.33 | 0.67360-03 | 0.68240-02 | 1.1272 | 1.1244 |
| 0.34120+00 | 0.33320-02 | 0.67290-03 | 0.41290-03 | 1.63 | 1.34 | 0.70660-03 | 0.66000-02 | 1.1387 | 1.1357 |
| 0.35860+00 | 0.32630-02 | 0.71000-03 | 0.43320-03 | 1.64 | 1.34 | 0.74720-03 | 0.66000-02 | 1.1474 | 1.1444 |
| 0.37610+00 | 0.31860-02 | 0.74750-03 | 0.45340-03 | 1.65 | 1.34 | 0.78760-03 | 0.68850-02 | 1.1525 | 1.1497 |
| 0.39370+00 | 0.30890-02 | 0.79790-03 | 0.48200-03 | 1.66 | 1.35 | 0.84270-03 | 0.74770-02 | 1.1537 | 1.1506 |
| 0.41150+00 | 0.29910-02 | 0.85320-03 | 0.51140-03 | 1.67 | 1.36 | 0.89840-03 | 0.82800-02 | 1.1508 | 1.1475 |
| 0.42950+00 | 0.28870-02 | 0.91940-03 | 0.54850-03 | 1.68 | 1.37 | 0.96660-03 | 0.92180-02 | 1.1440 | 1.1409 |
| 0.44760+00 | 0.27880-02 | 0.98730-03 | 0.58670-03 | 1.68 | 1.38 | 0.10350-02 | 0.10270-01 | 1.1337 | 1.1310 |
| 0.46590+00 | 0.26830-02 | 0.10730-02 | 0.63540-03 | 1.69 | 1.40 | 0.11210-02 | 0.11400-01 | 1.1210 | 1.1180 |
| 0.48430+00 | 0.25900-02 | 0.11690-02 | 0.68910-03 | 1.69 | 1.41 | 0.12060-02 | 0.12600-01 | 1.1062 | 1.1031 |
| 0.50290+00 | 0.25030-02 | 0.12570-02 | 0.74170-03 | 1.69 | 1.42 | 0.13010-02 | 0.13540-01 | 1.0901 | 1.0872 |
| 0.52160+00 | 0.24260-02 | 0.13560-02 | 0.80040-03 | 1.69 | 1.43 | 0.13960-02 | 0.14520-01 | 1.0734 | 1.0706 |
| 0.54050+00 | 0.23580-02 | 0.14640-02 | 0.86470-03 | 1.69 | 1.43 | 0.14980-02 | 0.15420-01 | 1.0567 | 1.0538 |
| 0.55940+00 | 0.23000-02 | 0.15730-02 | 0.93050-03 | 1.69 | 1.44 | 0.15990-02 | 0.16210-01 | 1.0403 | 1.0373 |
| 0.57840+00 | 0.22510-02 | 0.16860-02 | 0.99900-03 | 1.69 | 1.44 | 0.17020-02 | 0.16910-01 | 1.0243 | 1.0214 |
| 0.59740+00 | 0.22070-02 | 0.18000-02 | 0.10700-02 | 1.68 | 1.45 | 0.18050-02 | 0.17540-01 | 1.0088 | 1.0059 |
| 0.61640+00 | 0.21690-02 | 0.19190-02 | 0.11430-02 | 1.68 | 1.45 | 0.19100-02 | 0.18110-01 | 0.9938 | 0.9909 |
| 0.63550+00 | 0.21340-02 | 0.20390-02 | 0.12180-02 | 1.67 | 1.45 | 0.20160-02 | 0.18640-01 | 0.9794 | 0.9765 |
| 0.65460+00 | 0.21010-02 | 0.21640-02 | 0.12970-02 | 1.67 | 1.45 | 0.21240-02 | 0.19150-01 | 0.9654 | 0.9625 |
| 0.67370+00 | 0.20710-02 | 0.22910-02 | 0.13800-02 | 1.66 | 1.46 | 0.22330-02 | 0.19630-01 | 0.9519 | 0.9490 |
| 0.69280+00 | 0.20430-02 | 0.24210-02 | 0.14580-02 | 1.66 | 1.46 | 0.23410-02 | 0.20080-01 | 0.9390 | 0.9361 |
| 0.71060+00 | 0.20190-02 | 0.25510-02 | 0.15400-02 | 1.66 | 1.46 | 0.24490-02 | 0.20490-01 | 0.9267 | 0.9239 |
| 0.72900+00 | 0.19960-02 | 0.26800-02 | 0.16230-02 | 1.65 | 1.46 | 0.25560-02 | 0.20890-01 | 0.9152 | 0.9123 |
| 0.74720+00 | 0.19780-02 | 0.28110-02 | 0.17070-02 | 1.65 | 1.46 | 0.26620-02 | 0.21250-01 | 0.9044 | 0.9015 |
| 0.76510+00 | 0.19650-02 | 0.29290-02 | 0.17850-02 | 1.64 | 1.46 | 0.27570-02 | 0.21570-01 | 0.8944 | 0.8916 |
| 0.78260+00 | 0.19560-02 | 0.30470-02 | 0.18630-02 | 1.64 | 1.46 | 0.28510-02 | 0.21870-01 | 0.8853 | 0.8826 |
| 0.79980+00 | 0.19500-02 | 0.31550-02 | 0.19360-02 | 1.63 | 1.46 | 0.29350-02 | 0.22130-01 | 0.8771 | 0.8744 |
| 0.81650+00 | 0.19460-02 | 0.32640-02 | 0.20100-02 | 1.62 | 1.45 | 0.30210-02 | 0.22380-01 | 0.8694 | 0.8668 |
| 0.83280+00 | 0.19450-02 | 0.33600-02 | 0.20770-02 | 1.62 | 1.45 | 0.30940-02 | 0.22620-01 | 0.8624 | 0.8598 |
| 0.84850+00 | 0.19460-02 | 0.34550-02 | 0.21440-02 | 1.61 | 1.45 | 0.31670-02 | 0.22850-01 | 0.8561 | 0.8537 |
| 0.86370+00 | 0.19520-02 | 0.35310-02 | 0.22010-02 | 1.60 | 1.44 | 0.32240-02 | 0.23060-01 | 0.8507 | 0.8483 |
| 0.87840+00 | 0.19620-02 | 0.36050-02 | 0.22580-02 | 1.60 | 1.44 | 0.32810-02 | 0.23250-01 | 0.8462 | 0.8438 |
| 0.89230+00 | 0.19780-02 | 0.36500-02 | 0.22980-02 | 1.59 | 1.43 | 0.33130-02 | 0.23400-01 | 0.8426 | 0.8403 |
| 0.90560+00 | 0.19990-02 | 0.36910-02 | 0.23370-02 | 1.58 | 1.42 | 0.33440-02 | 0.23520-01 | 0.8400 | 0.8380 |
| 0.91820+00 | 0.20280-02 | 0.36970-02 | 0.23560-02 | 1.57 | 1.41 | 0.33470-02 | 0.23590-01 | 0.8387 | 0.8367 |
| 0.92990+00 | 0.20620-02 | 0.36970-02 | 0.23730-02 | 1.56 | 1.40 | 0.33470-02 | 0.23590-01 | 0.8385 | 0.8367 |
| 0.94090+00 | 0.21050-02 | 0.36610-02 | 0.23670-02 | 1.55 | 1.39 | 0.33170-02 | 0.23530-01 | 0.8396 | 0.8380 |
| 0.95100+00 | 0.21630-02 | 0.36100-02 | 0.23600-02 | 1.53 | 1.38 | 0.32870-02 | 0.23470-01 | 0.8427 | 0.8410 |
| 0.96020+00 | 0.22100-02 | 0.35420-02 | 0.23290-02 | 1.52 | 1.37 | 0.32250-02 | 0.23170-01 | 0.8459 | 0.8448 |
| 0.96840+00 | 0.22720-02 | 0.34570-02 | 0.22930-02 | 1.51 | 1.35 | 0.31610-02 | 0.22810-01 | 0.8513 | 0.8504 |
| 0.97580+00 | 0.23410-02 | 0.33490-02 | 0.22400-02 | 1.49 | 1.34 | 0.30780-02 | 0.22340-01 | 0.8580 | 0.8573 |
| 0.98220+00 | 0.24100-02 | 0.32400-02 | 0.21860-02 | 1.48 | 1.32 | 0.29950-02 | 0.21790-01 | 0.8655 | 0.8652 |
| 0.98760+00 | 0.24770-02 | 0.31310-02 | 0.21280-02 | 1.47 | 1.31 | 0.29100-02 | 0.21120-01 | 0.8736 | 0.8735 |
| 0.99200+00 | 0.25410-02 | 0.30270-02 | 0.20710-02 | 1.46 | 1.30 | 0.28310-02 | 0.20330-01 | 0.8817 | 0.8819 |
| 0.99550+00 | 0.25990-02 | 0.29310-02 | 0.20170-02 | 1.45 | 1.29 | 0.27560-02 | 0.19320-01 | 0.8896 | 0.8899 |
| 0.99800+00 | 0.26450-02 | 0.28600-02 | 0.19760-02 | 1.45 | 1.28 | 0.27010-02 | 0.17880-01 | 0.8965 | 0.8969 |
| 0.99950+00 | 0.26900-02 | 0.27960-02 | 0.19350-02 | 1.44 | 1.27 | 0.26470-02 | 0.16760-01 | 0.9034 | 0.9041 |
| 0.10000+01 | 0.27410-02 | 0.27390-02 | 0.18900-02 | 1.44 | 1.26 | 0.25740-02 | 0.16100-01 | 0.9100 | 0.9119 |
| 0.10010+01 | 0.0 | 0.26820-02 | 0.18670-02 | 1.44 | 1.26 | 0.25580-02 | 0.16090-01 | 0.9178 | 0.9125 |
| 0.10020+01 | 0.0 | 0.26880-02 | 0.18720-02 | 1.44 | 1.26 | 0.25640-02 | 0.16120-01 | 0.9172 | 0.9122 |
| 0.10030+01 | 0.0 | 0.27010-02 | 0.18810-02 | 1.44 | 1.26 | 0.25740-02 | 0.16200-01 | 0.9164 | 0.9111 |
| 0.10060+01 | 0.0 | 0.27080-02 | 0.18860-02 | 1.44 | 1.26 | 0.25790-02 | 0.16300-01 | 0.9153 | 0.9098 |
| 0.10090+01 | 0.0 | 0.27250-02 | 0.18990-02 | 1.44 | 1.26 | 0.25920-02 | 0.16430-01 | 0.9139 | 0.9081 |
| 0.10140+01 | 0.0 | 0.27420-02 | 0.19120-02 | 1.43 | 1.26 | 0.26050-02 | 0.16590-01 | 0.9125 | 0.9063 |
| 0.10190+01 | 0.0 | 0.27480-02 | 0.19180-02 | 1.43 | 1.26 | 0.26090-02 | 0.16760-01 | 0.9109 | 0.9052 |
| 0.10260+01 | 0.0 | 0.27500-02 | 0.19220-02 | 1.43 | 1.26 | 0.26090-02 | 0.16940-01 | 0.9098 | 0.9042 |
| 0.10340+01 | 0.0 | 0.27590-02 | 0.19330-02 | 1.43 | 1.26 | 0.26160-02 | 0.17160-01 | 0.9098 | 0.9030 |
| 0.10430+01 | 0.0 | 0.27610-02 | 0.19380-02 | 1.42 | 1.25 | 0.26160-02 | 0.17390-01 | 0.9085 | 0.9023 |
| 0.10540+01 | 0.0 | 0.27450-02 | 0.19340-02 | 1.42 | 1.25 | 0.26020-02 | 0.17620-01 | 0.9090 | 0.9024 |
| 0.10670+01 | 0.0 | 0.27330-02 | 0.19330-02 | 1.41 | 1.24 | 0.25920-02 | 0.17850-01 | 0.9104 | 0.9037 |
| 0.10820+01 | 0.0 | 0.26790-02 | 0.19060-02 | 1.41 | 1.23 | 0.25460-02 | 0.18040-01 | 0.9132 | 0.9070</ |

| | | | | | | | | | |
|------------|-----|------------|------------|------|------|------------|------------|--------|--------|
| 0.2716D+01 | 0.0 | 0.1862D-02 | 0.1489D-02 | 1.25 | 1.06 | 0.1852D-02 | 0.1242D-01 | 0.9924 | 0.9886 |
| 0.3465D+01 | 0.0 | 0.1828D-02 | 0.1476D-02 | 1.24 | 1.05 | 0.1821D-02 | 0.1075D-01 | 0.9953 | 0.9919 |
| 0.5032D+01 | 0.0 | 0.1794D-02 | 0.1462D-02 | 1.23 | 1.04 | 0.1791D-02 | 0.8658D-02 | 0.9976 | 0.9957 |
| 0.1047D+02 | 0.0 | 0.1757D-02 | 0.1450D-02 | 1.21 | 1.02 | 0.1753D-02 | 0.5715D-02 | 0.9992 | 0.9943 |

X-JMAX= 1.067 JMAX= 22 DUMAX= 0.007 DUAVG= 0.003
 ISTAG= 79.5 ILE= 82

UPPER LIMIT ON LAMBDA EXCEEDED ON LOWER SURFACE

| | | | |
|---|---|--------------|--------------|
| I | K | PIW | DELTA |
| 1 | 1 | 0.300000D+01 | 0.0 |
| 2 | 2 | 0.132903D+01 | 0.669482D-02 |
| 3 | 3 | 0.105861D+01 | 0.114980D-01 |
| 4 | 4 | 0.996900D+00 | 0.130084D-01 |
| 5 | 5 | 0.981683D+00 | 0.134104D-01 |
| 6 | 6 | 0.977858D+00 | 0.135134D-01 |
| 7 | 7 | 0.976892D+00 | 0.135395D-01 |
| 8 | 8 | 0.976648D+00 | 0.135461D-01 |

CDINF= 0.1165D-01 CDSY= 0.1141D-01
 CDINF1= 0.8746D-02 CDINF8= 0.2901D-02
 CDF= 0.5950D-02 CDF1= 0.3228D-02 CDF8= 0.2723D-02

(6)

ITERATIVE SOLUTION

| | | | | | | | | | | | | |
|---------------|---------------|-----------|--------------|---------------|-------------|--------|------|-------------|-----------|---------|-----|-----|
| P1 | P2 | P3 | P4 | P5 | QC | VIS1 | VIS2 | VIS3 | | | | |
| 0.2500 | 0.4500 | 0.4500 | 0.8000 | 1.5000 | 0.9000 | 1.0000 | 0.0 | 2.0000 | | | | |
| ANG DIVISIONS | RAD | DIVISIONS | N MESH | | | | | | | | | |
| 160 | | 32 | 5 | | | | | | | | | |
| CYCLE | MAX CORREC | I | J | AVG CORREC | MAX RESIDAL | I | J | AVG RESIDAL | CIRC/ALFA | WORK | N | SUP |
| 1 | 0.6286D-04 | 128 | 34 | 0.6303D-05 | -0.9488D-04 | 128 | 34 | 0.3521D-06 | 0.0848 | 75.7773 | 518 | 518 |
| 2 | 0.4213D-04 | 3 | 3 | 0.4565D-05 | -0.5426D-04 | 88 | 33 | 0.2983D-06 | 0.0848 | 77.5469 | 518 | 518 |
| 2 | 0.0 | 0 | 0 | 0.0 | 0.4235D-04 | 94 | 28 | 0.1783D-06 | 0.0848 | 77.5469 | 518 | 518 |
| AVG RESIDAL 1 | AVG RESIDAL 2 | WORK | REDUCTN/WORK | REDUCTN/CYCLE | | | | | | | | |
| 0.2368638D-03 | 0.1783229D-06 | 77.5469 | 0.9114 | 0.8795 | | | | | | | | |

MESH NO.= 3 BL ITER NO.= 28 CUM-NIT= 56

X= 0.57363 AT THE SHOCK
 CP= -0.84878 UPSTREAM
 CP= -0.48826 DOWNSTREAM, RANKINE-HUGONIOT
 CP= -0.47624 DOWNSTREAM, ISENTROPIC

ANG OF ATTACK MACH NO CL(CIRCULATN)
 2.7063 0.7300 0.7977

CL = 0.80308 CD = 0.0166 CDB = 0.01661 CM = -0.0875

(7)

COORDINATES OF AIRFOIL MAPPED FROM CIRCLE AND PRESSURE DISTRIBUTION

| | | | | | | | | |
|------------|--------|---------|---------|---------|---------|-----------|--------|--------|
| ARC LENGTH | X | Y | MACH NO | V/V0 | DENSITY | MASS FLOW | CP | CPC |
| -1.0184 | 1.0000 | 0.0 | -0.6862 | -0.9454 | 1.0286 | -0.9724 | 0.1078 | 0.1612 |
| -1.0179 | 0.9995 | 0.0000 | -0.6677 | -0.9220 | 1.0404 | -0.9593 | 0.1530 | 0.1881 |
| -1.0164 | 0.9980 | 0.0001 | -0.6544 | -0.9050 | 1.0489 | -0.9493 | 0.1853 | 0.2012 |
| -1.0139 | 0.9955 | 0.0003 | -0.6460 | -0.8943 | 1.0542 | -0.9428 | 0.2056 | 0.2143 |
| -1.0104 | 0.9920 | 0.0004 | -0.6382 | -0.8843 | 1.0591 | -0.9366 | 0.2244 | 0.2292 |
| -1.0060 | 0.9876 | 0.0006 | -0.6311 | -0.8752 | 1.0635 | -0.9308 | 0.2414 | 0.2443 |
| -1.0005 | 0.9822 | 0.0008 | -0.6243 | -0.8664 | 1.0678 | -0.9251 | 0.2577 | 0.2595 |
| -0.9942 | 0.9758 | 0.0010 | -0.6182 | -0.8586 | 1.0715 | -0.9200 | 0.2721 | 0.2733 |
| -0.9868 | 0.9684 | 0.0011 | -0.6129 | -0.8518 | 1.0747 | -0.9155 | 0.2846 | 0.2855 |
| -0.9785 | 0.9602 | 0.0012 | -0.6086 | -0.8463 | 1.0774 | -0.9117 | 0.2947 | 0.2953 |
| -0.9693 | 0.9510 | 0.0012 | -0.6055 | -0.8423 | 1.0792 | -0.9090 | 0.3020 | 0.3025 |
| -0.9592 | 0.9409 | 0.0010 | -0.6036 | -0.8398 | 1.0804 | -0.9073 | 0.3066 | 0.3069 |
| -0.9483 | 0.9299 | 0.0007 | -0.6028 | -0.8387 | 1.0809 | -0.9065 | 0.3085 | 0.3088 |
| -0.9365 | 0.9182 | 0.0003 | -0.6028 | -0.8388 | 1.0809 | -0.9066 | 0.3084 | 0.3086 |
| -0.9240 | 0.9056 | -0.0004 | -0.6039 | -0.8401 | 1.0803 | -0.9075 | 0.3060 | 0.3062 |
| -0.9107 | 0.8923 | -0.0012 | -0.6050 | -0.8426 | 1.0791 | -0.9092 | 0.3014 | 0.3015 |
| -0.8966 | 0.8784 | -0.0022 | -0.6086 | -0.8462 | 1.0774 | -0.9117 | 0.2948 | 0.2949 |
| -0.8820 | 0.8637 | -0.0034 | -0.6121 | -0.8508 | 1.0752 | -0.9148 | 0.2865 | 0.2866 |

| | | | | | | | | |
|---------|--------|---------|---------|---------|--------|---------|---------|---------|
| -0.8667 | 0.8485 | -0.0048 | -0.6163 | -0.8562 | 1.0727 | -0.9184 | 0.2766 | 0.2767 |
| -0.8509 | 0.8328 | -0.0064 | -0.6212 | -0.8624 | 1.0697 | -0.9225 | 0.2651 | 0.2651 |
| -0.8345 | 0.8165 | -0.0081 | -0.6266 | -0.8694 | 1.0663 | -0.9271 | 0.2521 | 0.2522 |
| -0.8177 | 0.7998 | -0.0100 | -0.6325 | -0.8771 | 1.0626 | -0.9320 | 0.2379 | 0.2380 |
| -0.8004 | 0.7826 | -0.0121 | -0.6390 | -0.8854 | 1.0586 | -0.9372 | 0.2224 | 0.2225 |
| -0.7827 | 0.7651 | -0.0143 | -0.6461 | -0.8944 | 1.0542 | -0.9426 | 0.2064 | 0.2065 |
| -0.7647 | 0.7473 | -0.0167 | -0.6539 | -0.9044 | 1.0498 | -0.9483 | 0.1896 | 0.1897 |
| -0.7463 | 0.7290 | -0.0192 | -0.6624 | -0.9152 | 1.0438 | -0.9553 | 0.1660 | 0.1660 |
| -0.7278 | 0.7106 | -0.0217 | -0.6715 | -0.9268 | 1.0380 | -0.9620 | 0.1438 | 0.1438 |
| -0.7090 | 0.6920 | -0.0244 | -0.6812 | -0.9390 | 1.0318 | -0.9689 | 0.1201 | 0.1201 |
| -0.6900 | 0.6733 | -0.0271 | -0.6914 | -0.9519 | 1.0252 | -0.9759 | 0.0950 | 0.0951 |
| -0.6710 | 0.6544 | -0.0299 | -0.7022 | -0.9654 | 1.0182 | -0.9830 | 0.0687 | 0.0687 |
| -0.6518 | 0.6355 | -0.0326 | -0.7134 | -0.9794 | 1.0109 | -0.9901 | 0.0411 | 0.0411 |
| -0.6326 | 0.6164 | -0.0354 | -0.7250 | -0.9938 | 1.0033 | -0.9971 | 0.0123 | 0.0123 |
| -0.6134 | 0.5974 | -0.0381 | -0.7371 | -1.0088 | 0.9953 | -1.0040 | -0.0176 | -0.0176 |
| -0.5941 | 0.5784 | -0.0407 | -0.7497 | -1.0243 | 0.9870 | -1.0109 | -0.0488 | -0.0488 |
| -0.5750 | 0.5594 | -0.0433 | -0.7628 | -1.0403 | 0.9782 | -1.0177 | -0.0813 | -0.0813 |
| -0.5559 | 0.5405 | -0.0457 | -0.7762 | -1.0567 | 0.9692 | -1.0242 | -0.1148 | -0.1148 |
| -0.5369 | 0.5216 | -0.0481 | -0.7900 | -1.0734 | 0.9600 | -1.0304 | -0.1491 | -0.1491 |
| -0.5181 | 0.5029 | -0.0502 | -0.8039 | -1.0901 | 0.9506 | -1.0362 | -0.1836 | -0.1836 |
| -0.4994 | 0.4843 | -0.0522 | -0.8174 | -1.1062 | 0.9414 | -1.0415 | -0.2172 | -0.2172 |
| -0.4809 | 0.4659 | -0.0540 | -0.8298 | -1.1210 | 0.9330 | -1.0459 | -0.2480 | -0.2480 |
| -0.4626 | 0.4476 | -0.0555 | -0.8405 | -1.1337 | 0.9257 | -1.0495 | -0.2747 | -0.2747 |
| -0.4444 | 0.4295 | -0.0568 | -0.8492 | -1.1440 | 0.9198 | -1.0522 | -0.2962 | -0.2962 |
| -0.4264 | 0.4115 | -0.0578 | -0.8550 | -1.1508 | 0.9158 | -1.0539 | -0.3106 | -0.3106 |
| -0.4086 | 0.3937 | -0.0586 | -0.8575 | -1.1537 | 0.9141 | -1.0546 | -0.3168 | -0.3168 |
| -0.3909 | 0.3761 | -0.0590 | -0.8564 | -1.1525 | 0.9148 | -1.0543 | -0.3141 | -0.3141 |
| -0.3734 | 0.3586 | -0.0592 | -0.8521 | -1.1474 | 0.9178 | -1.0531 | -0.3033 | -0.3033 |
| -0.3560 | 0.3412 | -0.0594 | -0.8447 | -1.1392 | 0.9228 | -1.0508 | -0.2851 | -0.2851 |
| -0.3388 | 0.3240 | -0.0599 | -0.8350 | -1.1272 | 0.9294 | -1.0477 | -0.2610 | -0.2610 |
| -0.3218 | 0.3070 | -0.0584 | -0.8238 | -1.1140 | 0.9370 | -1.0438 | -0.2333 | -0.2333 |
| -0.3049 | 0.2901 | -0.0577 | -0.8121 | -1.1000 | 0.9450 | -1.0395 | -0.2042 | -0.2042 |
| -0.2883 | 0.2735 | -0.0569 | -0.8006 | -1.0862 | 0.9528 | -1.0349 | -0.1755 | -0.1755 |
| -0.2718 | 0.2571 | -0.0559 | -0.7896 | -1.0729 | 0.9602 | -1.0302 | -0.1481 | -0.1481 |
| -0.2557 | 0.2410 | -0.0549 | -0.7791 | -1.0602 | 0.9673 | -1.0255 | -0.1220 | -0.1220 |
| -0.2398 | 0.2251 | -0.0537 | -0.7689 | -1.0478 | 0.9741 | -1.0207 | -0.0967 | -0.0967 |
| -0.2243 | 0.2097 | -0.0524 | -0.7590 | -1.0356 | 0.9808 | -1.0157 | -0.0718 | -0.0718 |
| -0.2091 | 0.1946 | -0.0510 | -0.7489 | -1.0233 | 0.9878 | -1.0105 | -0.0469 | -0.0469 |
| -0.1943 | 0.1799 | -0.0495 | -0.7389 | -1.0112 | 0.9943 | -1.0049 | -0.0213 | -0.0213 |
| -0.1800 | 0.1656 | -0.0479 | -0.7281 | -0.9976 | 1.0013 | -0.9989 | 0.0048 | 0.0048 |
| -0.1661 | 0.1518 | -0.0463 | -0.7172 | -0.9841 | 1.0084 | -0.9924 | 0.0316 | 0.0316 |
| -0.1526 | 0.1384 | -0.0446 | -0.7059 | -0.9700 | 1.0158 | -0.9854 | 0.0595 | 0.0595 |
| -0.1396 | 0.1256 | -0.0428 | -0.6940 | -0.9552 | 1.0235 | -0.9776 | 0.0887 | 0.0887 |
| -0.1272 | 0.1132 | -0.0409 | -0.6813 | -0.9392 | 1.0317 | -0.9690 | 0.1198 | 0.1198 |
| -0.1152 | 0.1015 | -0.0390 | -0.6676 | -0.9218 | 1.0405 | -0.9592 | 0.1532 | 0.1532 |
| -0.1038 | 0.0902 | -0.0370 | -0.6531 | -0.9034 | 1.0497 | -0.9483 | 0.1885 | 0.1885 |
| -0.0930 | 0.0796 | -0.0349 | -0.6376 | -0.8835 | 1.0595 | -0.9361 | 0.2259 | 0.2259 |
| -0.0827 | 0.0696 | -0.0328 | -0.6205 | -0.8616 | 1.0700 | -0.9220 | 0.2655 | 0.2655 |
| -0.0731 | 0.0602 | -0.0307 | -0.6018 | -0.8382 | 1.0815 | -0.9056 | 0.3109 | 0.3109 |
| -0.0641 | 0.0514 | -0.0285 | -0.5810 | -0.8104 | 1.0940 | -0.8865 | 0.3593 | 0.3593 |
| -0.0556 | 0.0433 | -0.0263 | -0.5578 | -0.7798 | 1.1077 | -0.8638 | 0.4127 | 0.4127 |
| -0.0478 | 0.0358 | -0.0240 | -0.5310 | -0.7445 | 1.1230 | -0.8361 | 0.4729 | 0.4729 |
| -0.0407 | 0.0291 | -0.0217 | -0.4997 | -0.7027 | 1.1404 | -0.8013 | 0.5413 | 0.5413 |
| -0.0342 | 0.0230 | -0.0193 | -0.4625 | -0.6526 | 1.1600 | -0.7571 | 0.6193 | 0.6193 |
| -0.0283 | 0.0176 | -0.0169 | -0.4179 | -0.5920 | 1.1822 | -0.6998 | 0.7077 | 0.7077 |
| -0.0230 | 0.0129 | -0.0145 | -0.3636 | -0.5172 | 1.2068 | -0.6241 | 0.8068 | 0.8068 |
| -0.0183 | 0.0089 | -0.0121 | -0.2962 | -0.4266 | 1.2340 | -0.5266 | 0.9150 | 0.9150 |
| -0.0143 | 0.0057 | -0.0097 | -0.2092 | -0.3081 | 1.2604 | -0.3782 | 1.0257 | 1.0257 |
| -0.0108 | 0.0031 | -0.0072 | -0.0955 | -0.1374 | 1.2823 | -0.1762 | 1.1161 | 1.1161 |
| -0.0077 | 0.0014 | -0.0048 | 0.0545 | 0.0785 | 1.2862 | 0.1010 | 1.1325 | 1.1325 |
| -0.0050 | 0.0003 | -0.0023 | 0.2439 | 0.3494 | 1.2506 | 0.4369 | 0.9855 | 0.9855 |
| -0.0025 | 0.0000 | -0.0002 | 0.4599 | 0.6492 | 1.1614 | 0.7539 | 0.6246 | 0.6246 |
| 0.0 | 0.0004 | 0.0027 | 0.6723 | 0.9278 | 1.0375 | 0.9626 | 0.1418 | 0.1418 |
| 0.0027 | 0.0016 | 0.0051 | 0.8504 | 1.1454 | 0.9189 | 1.0526 | -0.2992 | -0.2992 |
| 0.0058 | 0.0035 | 0.0076 | 0.9830 | 1.2967 | 0.8282 | 1.0739 | -0.6218 | -0.6218 |
| 0.0094 | 0.0061 | 0.0100 | 1.0774 | 1.3987 | 0.7643 | 1.0691 | -0.8406 | -0.8406 |
| 0.0135 | 0.0095 | 0.0124 | 1.1408 | 1.4644 | 0.7024 | 1.0579 | -0.9804 | -0.9804 |
| 0.0183 | 0.0136 | 0.0148 | 1.1796 | 1.5035 | 0.6522 | 1.0483 | -1.0627 | -1.0627 |
| 0.0237 | 0.0184 | 0.0171 | 1.2027 | 1.5263 | 0.6225 | 1.0417 | -1.1104 | -1.1104 |
| 0.0297 | 0.0240 | 0.0194 | 1.2140 | 1.5374 | 0.6753 | 1.0382 | -1.1335 | -1.1335 |
| 0.0364 | 0.0303 | 0.0217 | 1.2184 | 1.5417 | 0.6725 | 1.0368 | -1.1425 | -1.1425 |
| 0.0437 | 0.0373 | 0.0240 | 1.2181 | 1.5414 | 0.6727 | 1.0369 | -1.1419 | -1.1419 |
| 0.0518 | 0.0450 | 0.0262 | 1.2160 | 1.5394 | 0.6740 | 1.0376 | -1.1376 | -1.1376 |
| 0.0604 | 0.0534 | 0.0285 | 1.2137 | 1.5371 | 0.6755 | 1.0383 | -1.1330 | -1.1330 |
| 0.0697 | 0.0624 | 0.0307 | 1.2116 | 1.5351 | 0.6768 | 1.0389 | -1.1288 | -1.1288 |
| 0.0796 | 0.0721 | 0.0328 | 1.2097 | 1.5332 | 0.6780 | 1.0395 | -1.1249 | -1.1249 |
| 0.0902 | 0.0824 | 0.0350 | 1.2082 | 1.5317 | 0.6790 | 1.0400 | -1.1218 | -1.1218 |
| 0.1013 | 0.0933 | 0.0371 | 1.2072 | 1.5308 | 0.6796 | 1.0403 | -1.1197 | -1.1197 |
| 0.1129 | 0.1047 | 0.0391 | 1.2068 | 1.5304 | 0.6798 | 1.0404 | -1.1189 | -1.1189 |
| 0.1251 | 0.1168 | 0.0411 | 1.2069 | 1.5305 | 0.6798 | 1.0404 | -1.1191 | -1.1191 |
| 0.1379 | 0.1294 | 0.0431 | 1.2075 | 1.5311 | 0.6794 | 1.0402 | -1.1204 | -1.1204 |
| 0.1512 | 0.1425 | 0.0449 | 1.2086 | 1.5322 | 0.6787 | 1.0399 | -1.1227 | -1.1227 |
| 0.1649 | 0.1562 | 0.0467 | 1.2102 | 1.5337 | 0.6777 | 1.0394 | -1.1259 | -1.1259 |
| 0.1791 | 0.1703 | 0.0485 | 1.2120 | 1.5355 | 0.6765 | 1.0388 | -1.1296 | -1.1296 |
| 0.1938 | 0.1849 | 0.0501 | 1.2144 | 1.5375 | 0.6752 | 1.0381 | -1.1337 | -1.1337 |
| 0.2089 | 0.1999 | 0.0517 | 1.2163 | 1.5397 | 0.6738 | 1.0375 | -1.1383 | -1.1383 |
| 0.2245 | 0.2154 | 0.0531 | 1.2189 | 1.5422 | 0.6722 | 1.0367 | -1.1435 | -1.1435 |
| 0.2404 | 0.2312 | 0.0545 | 1.2216 | 1.5448 | 0.6705 | 1.0358 | -1.1490 | -1.1490 |
| 0.2567 | 0.2474 | 0.0558 | 1.2246 | 1.5478 | 0.6686 | 1.0348 | -1.1550 | -1.1550 |
| 0.2733 | 0.2640 | 0.0570 | 1.2276 | 1.5507 | 0.6667 | 1.0338 | -1.1611 | -1.1611 |
| 0.2902 | 0.2809 | 0.0581 | 1.2308 | 1.5537 | 0.6647 | 1.0328 | -1.1674 | -1.1674 |
| 0.3074 | 0.2981 | 0.0591 | 1.2342 | 1.5571 | 0.6626 | 1.0316 | -1.1742 | -1.1742 |
| 0.3249 | 0.3156 | 0.0600 | 1.2380 | 1.5607 | 0.6602 | 1.0304 | -1.1818 | -1.1818 |
| 0.3427 | 0.3333 | 0.0607 | 1.2420 | 1.5646 | 0.6577 | 1.0290 | -1.1898 | -1.1898 |
| 0.3606 | 0.3512 | 0.0614 | 1.2462 | 1.5686 | 0.6550 | 1.0275 | -1.1981 | -1.1981 |
| 0.3787 | 0.3694 | 0.0619 | 1.2506 | 1.5728 | 0.6523 | 1.0260 | -1.2067 | -1.2067 |
| 0.3970 | 0.3876 | 0.0623 | 1.2552 | 1.5772 | 0.6495 | 1.0244 | -1.2157 | -1.2157 |
| 0.4155 | 0.4061 | 0.0626 | 1.2600 | 1.5818 | 0.6465 | 1.0227 | -1.2252 | -1.2252 |
| 0.4340 | 0.4246 | 0.0628 | 1.2651 | 1.5867 | 0.6433 | 1.0208 | -1.2351 | -1.2351 |
| 0.4526 | 0.4432 | 0.0628 | 1.2709 | 1.5922 | 0.6398 | 1.0186 | -1.2463 | -1.2463 |
| 0.4713 | 0.4619 | 0.0627 | 1.2780 | 1.5989 | 0.6354 | 1.0160 | -1.2598 | -1.2598 |
| 0.4900 | 0.4806 | 0.0624 | 1.2849 | 1.6053 | 0.6312 | 1.0133 | -1.2730 | -1.2730 |
| 0.5087 | 0.4993 | 0.0620 | 1.2916 | 1.6117 | 0.6271 | 1.0107 | -1.2861 | -1.2861 |
| 0.5273 | 0.5179 | 0.0615 | 1.2948 | 1.6147 | 0.6252 | 1.0095 | -1.2911 | -1.2911 |
| 0.5460 | 0.5366 | 0.0608 | 1.2985 | 1.6070 | 0.6252 | 1.0127 | -1.2763 | -1.2763 |
| 0.5646 | 0.5551 | 0.0599 | 1.2820 | 1.5438 | 0.6712 | 1.0361 | -1.1468 | -1.1468 |
| 0.5831 | 0.5731 | 0.0588 | 1.0511 | 1.4025 | 0.7619 | 1.0686 | -0.8488 | -0.8488 |
| 0.6016 | 0.5921 | 0.0576 | 0.9747 | 1.2876 | 0.8338 | 1.0736 | -0.6023 | -0.6023 |
| 0.6199 | 0.6104 | 0.0562 | 0.9385 | 1.2470 | 0.8586 | 1.0707 | -0.5151 | -0.5151 |
| 0.6382 | 0.6286 | 0.0547 | 0.9168 | 1.2223 | 0.8735 | 1.0677 | -0.4624 | -0.4624 |
| 0.6563 | 0.6466 | 0.0531 | 0.8994 | 1.2024 | 0.8854 | 1.0646 | -0.4199 | -0.4199 |
| 0.6743 | 0.6645 | 0.0514 | 0.8835 | 1.1841 | 0.8963 | 1.0613 | -0.3810 | -0.3810 |
| 0.6921 | 0.6823 | 0.0496 | 0.8687 | 1.1669 | 0.9064 | 1.0577 | -0.3446 | -0.3446 |
| 0.7097 | 0.6998 | 0.0476 | 0.8582 | 1.1545 | 0.9136 | 1.0548 | -0.2892 | -0.2892 |
| 0.7271 | 0.7170 | 0.0457 | 0.8464 | 1.1406 | 0.9200 | 1.0513 | -0.2626 | -0.2626 |
| 0.7442 | 0.7340 | 0.0436 | 0.8357 | 1.1280 | 0.9250 | 1.0479 | -0.2364 | -0.2364 |
| 0.7610 | 0.7507 | 0.0415 | 0.8251 | 1.1155 | 0.9362 | 1.0443 | -0.2111 | -0.2111 |
| 0.7775 | 0.7670 | 0.0393 | 0.8149 | 1.1033 | 0.9431 | 1.0405 | -0.1854 | -0.1854 |
| 0.7937 | 0.7830 | 0.0371 | 0.8046 | 1.0910 | 0.9501 | 1.0365 | | |

| | | | | | | | | |
|--------|--------|--------|--------|--------|--------|--------|---------|---------|
| 0.8249 | 0.8139 | 0.0327 | 0.7844 | 1.0666 | 0.9637 | 1.0279 | -0.1351 | -0.1361 |
| 0.8399 | 0.8288 | 0.0304 | 0.7744 | 1.0545 | 0.9704 | 1.0233 | -0.1104 | -0.1115 |
| 0.8544 | 0.8431 | 0.0282 | 0.7647 | 1.0426 | 0.9769 | 1.0186 | -0.0861 | -0.0874 |
| 0.8685 | 0.8570 | 0.0260 | 0.7552 | 1.0311 | 0.9833 | 1.0138 | -0.0626 | -0.0641 |
| 0.8821 | 0.8704 | 0.0238 | 0.7460 | 1.0197 | 0.9894 | 1.0089 | -0.0396 | -0.0414 |
| 0.8951 | 0.8833 | 0.0217 | 0.7371 | 1.0088 | 0.9953 | 1.0040 | -0.0176 | -0.0196 |
| 0.9076 | 0.8956 | 0.0196 | 0.7285 | 0.9982 | 1.0010 | 0.9991 | 0.0037 | 0.0013 |
| 0.9196 | 0.9074 | 0.0176 | 0.7203 | 0.9880 | 1.0064 | 0.9943 | 0.0239 | 0.0211 |
| 0.9309 | 0.9185 | 0.0156 | 0.7125 | 0.9783 | 1.0115 | 0.9895 | 0.0432 | 0.0399 |
| 0.9416 | 0.9291 | 0.0137 | 0.7052 | 0.9691 | 1.0163 | 0.9849 | 0.0613 | 0.0573 |
| 0.9516 | 0.9390 | 0.0119 | 0.6983 | 0.9605 | 1.0208 | 0.9804 | 0.0783 | 0.0734 |
| 0.9610 | 0.9482 | 0.0102 | 0.6918 | 0.9523 | 1.0250 | 0.9761 | 0.0942 | 0.0881 |
| 0.9697 | 0.9568 | 0.0086 | 0.6857 | 0.9447 | 1.0289 | 0.9720 | 0.1091 | 0.1013 |
| 0.9777 | 0.9646 | 0.0071 | 0.6799 | 0.9374 | 1.0326 | 0.9680 | 0.1233 | 0.1131 |
| 0.9850 | 0.9717 | 0.0057 | 0.6744 | 0.9304 | 1.0362 | 0.9641 | 0.1368 | 0.1234 |
| 0.9915 | 0.9781 | 0.0045 | 0.6687 | 0.9233 | 1.0398 | 0.9600 | 0.1505 | 0.1326 |
| 0.9972 | 0.9837 | 0.0034 | 0.6628 | 0.9158 | 1.0435 | 0.9557 | 0.1648 | 0.1402 |
| 1.0021 | 0.9885 | 0.0024 | 0.6562 | 0.9073 | 1.0478 | 0.9506 | 0.1810 | 0.1467 |
| 1.0062 | 0.9925 | 0.0016 | 0.6484 | 0.8974 | 1.0527 | 0.9446 | 0.1999 | 0.1520 |
| 1.0095 | 0.9957 | 0.0009 | 0.6390 | 0.8854 | 1.0586 | 0.9372 | 0.2224 | 0.1562 |
| 1.0118 | 0.9981 | 0.0004 | 0.6278 | 0.8710 | 1.0655 | 0.9281 | 0.2492 | 0.1593 |
| 1.0133 | 0.9995 | 0.0001 | 0.6227 | 0.8645 | 1.0687 | 0.9238 | 0.2613 | 0.1624 |
| 1.0138 | 1.0000 | 0.0000 | 0.5987 | 0.8333 | 1.0834 | 0.9028 | 0.3182 | 0.1612 |

(8)

CONVERGENCE SUMMARY TABLE MESH 3

| ITBL | NIT | RMAX | AL/CL | CDB | CPTE | YTOP | YBOT | VSYM | DELT | DELB | SEPT | SEPB | DUT | I-J | DUB | I-J | BXM | JMX |
|------|-----|-----------|-------|--------|--------|-----------|-----------|------------|--------|--------|------|------|-------|-----|------|-----|---------|-----|
| 2 | 4 | -0.110-02 | 2.725 | 0.0146 | 0.4027 | 0.4410-01 | 0.2900-01 | -0.2050+00 | 0.3493 | 0.1299 | 0 | 0 | 0.282 | 125 | .219 | -3 | 0.0024 | 2 |
| 3 | 6 | -0.130-02 | 2.756 | 0.0157 | 0.2550 | 0.5980-01 | 0.2170-01 | -0.1660+00 | 0.3409 | 0.1234 | 0 | 0 | 0.105 | 129 | .128 | -23 | 0.0008 | 2 |
| 4 | 8 | -0.130-02 | 2.797 | 0.0165 | 0.1404 | 0.6580-01 | 0.1750-01 | -0.1040+00 | 0.3351 | 0.1219 | 0 | 0 | 0.145 | 128 | .090 | 5 | 0.0013 | 2 |
| 5 | 10 | -0.120-02 | 2.822 | 0.0168 | 0.1254 | 0.6580-01 | 0.1620-01 | -0.7700-01 | 0.3312 | 0.1238 | 0 | 0 | 0.182 | 128 | .063 | 59 | 0.0019 | 2 |
| 6 | 12 | -0.930-03 | 2.842 | 0.0171 | 0.1438 | 0.6360-01 | 0.1580-01 | -0.7740-01 | 0.3293 | 0.1285 | 0 | 0 | 0.201 | 128 | .052 | 60 | 0.0022 | 22 |
| 7 | 14 | -0.530-03 | 2.847 | 0.0173 | 0.1614 | 0.6140-01 | 0.1570-01 | -0.8560-01 | 0.3290 | 0.1346 | 0 | 0 | 0.205 | 127 | .042 | 61 | 0.0053 | 23 |
| 8 | 16 | -0.290-03 | 2.841 | 0.0173 | 0.1614 | 0.5990-01 | 0.1560-01 | -0.8780-01 | 0.3303 | 0.1415 | 0 | 0 | 0.194 | 127 | .047 | -4 | 0.0051 | 23 |
| 9 | 18 | -0.370-03 | 2.828 | 0.0173 | 0.1585 | 0.5980-01 | 0.1570-01 | -0.8410-01 | 0.3324 | 0.1469 | 0 | 0 | 0.168 | 127 | .053 | 43 | 0.0022 | 22 |
| 10 | 20 | -0.310-03 | 2.812 | 0.0172 | 0.1569 | 0.5860-01 | 0.1590-01 | -0.7960-01 | 0.3342 | 0.1497 | 0 | 0 | 0.137 | 127 | .053 | 43 | 0.0015 | 22 |
| 11 | 22 | -0.250-03 | 2.795 | 0.0171 | 0.1560 | 0.5850-01 | 0.1620-01 | -0.7470-01 | 0.3360 | 0.1502 | 0 | 0 | 0.107 | 127 | .049 | 47 | 0.0010 | 2 |
| 12 | 24 | -0.270-03 | 2.780 | 0.0170 | 0.1560 | 0.5880-01 | 0.1640-01 | -0.7040-01 | 0.3374 | 0.1490 | 0 | 0 | 0.082 | 128 | .043 | 47 | 0.0006 | 2 |
| 13 | 26 | -0.290-03 | 2.766 | 0.0170 | 0.1562 | 0.5930-01 | 0.1660-01 | -0.6670-01 | 0.3384 | 0.1467 | 0 | 0 | 0.064 | 128 | .035 | 47 | 0.0005 | 19 |
| 14 | 28 | -0.290-03 | 2.754 | 0.0169 | 0.1564 | 0.6000-01 | 0.1670-01 | -0.6350-01 | 0.3390 | 0.1442 | 0 | 0 | 0.048 | 128 | .027 | 51 | -0.0008 | 20 |
| 15 | 30 | -0.250-03 | 2.744 | 0.0168 | 0.1565 | 0.6070-01 | 0.1680-01 | -0.6080-01 | 0.3393 | 0.1418 | 0 | 0 | 0.036 | 128 | .021 | 52 | -0.0011 | 20 |
| 16 | 32 | -0.190-03 | 2.737 | 0.0168 | 0.1568 | 0.6150-01 | 0.1680-01 | -0.5890-01 | 0.3393 | 0.1397 | 0 | 0 | 0.028 | 128 | .016 | 54 | -0.0013 | 20 |
| 17 | 34 | -0.160-03 | 2.730 | 0.0167 | 0.1568 | 0.6220-01 | 0.1670-01 | -0.5700-01 | 0.3391 | 0.1380 | 0 | 0 | 0.021 | 125 | .015 | -22 | -0.0013 | 21 |
| 18 | 36 | -0.150-03 | 2.725 | 0.0167 | 0.1572 | 0.6290-01 | 0.1680-01 | -0.5570-01 | 0.3389 | 0.1367 | 0 | 0 | 0.020 | 125 | .016 | -22 | -0.0014 | 21 |
| 19 | 38 | -0.120-03 | 2.721 | 0.0167 | 0.1578 | 0.6350-01 | 0.1680-01 | -0.5520-01 | 0.3382 | 0.1357 | 0 | 0 | 0.018 | 125 | .017 | -22 | -0.0014 | 21 |
| 20 | 40 | -0.920-04 | 2.718 | 0.0166 | 0.1580 | 0.6400-01 | 0.1680-01 | -0.5470-01 | 0.3376 | 0.1351 | 0 | 0 | 0.016 | 125 | .017 | -22 | -0.0014 | 22 |
| 21 | 42 | -0.660-04 | 2.716 | 0.0166 | 0.1584 | 0.6440-01 | 0.1690-01 | -0.5440-01 | 0.3371 | 0.1346 | 0 | 0 | 0.014 | 125 | .016 | -22 | -0.0013 | 22 |
| 22 | 44 | -0.540-04 | 2.714 | 0.0166 | 0.1590 | 0.6480-01 | 0.1700-01 | -0.5460-01 | 0.3365 | 0.1344 | 0 | 0 | 0.011 | 125 | .015 | -22 | -0.0013 | 22 |
| 23 | 46 | -0.440-04 | 2.711 | 0.0166 | 0.1590 | 0.6510-01 | 0.1710-01 | -0.5400-01 | 0.3362 | 0.1344 | 0 | 0 | 0.013 | 125 | .014 | -22 | -0.0012 | 22 |
| 24 | 48 | -0.540-04 | 2.711 | 0.0166 | 0.1597 | 0.6530-01 | 0.1730-01 | -0.5440-01 | 0.3358 | 0.1345 | 0 | 0 | 0.010 | 125 | .012 | -22 | -0.0011 | 22 |
| 25 | 50 | -0.440-04 | 2.708 | 0.0166 | 0.1598 | 0.6550-01 | 0.1740-01 | -0.5410-01 | 0.3355 | 0.1346 | 0 | 0 | 0.011 | 127 | .011 | -22 | -0.0010 | 22 |
| 26 | 52 | -0.540-04 | 2.708 | 0.0166 | 0.1605 | 0.6570-01 | 0.1760-01 | -0.5470-01 | 0.3351 | 0.1348 | 0 | 0 | 0.008 | 127 | .009 | -22 | -0.0010 | 22 |
| 27 | 54 | -0.410-04 | 2.706 | 0.0166 | 0.1606 | 0.6580-01 | 0.1780-01 | -0.5440-01 | 0.3349 | 0.1350 | 0 | 0 | 0.010 | 127 | .008 | -22 | -0.0009 | 22 |
| 28 | 56 | -0.420-04 | 2.706 | 0.0166 | 0.1612 | 0.6600-01 | 0.1800-01 | -0.5500-01 | 0.3345 | 0.1352 | 0 | 0 | 0.008 | 127 | .007 | -22 | -0.0008 | 22 |

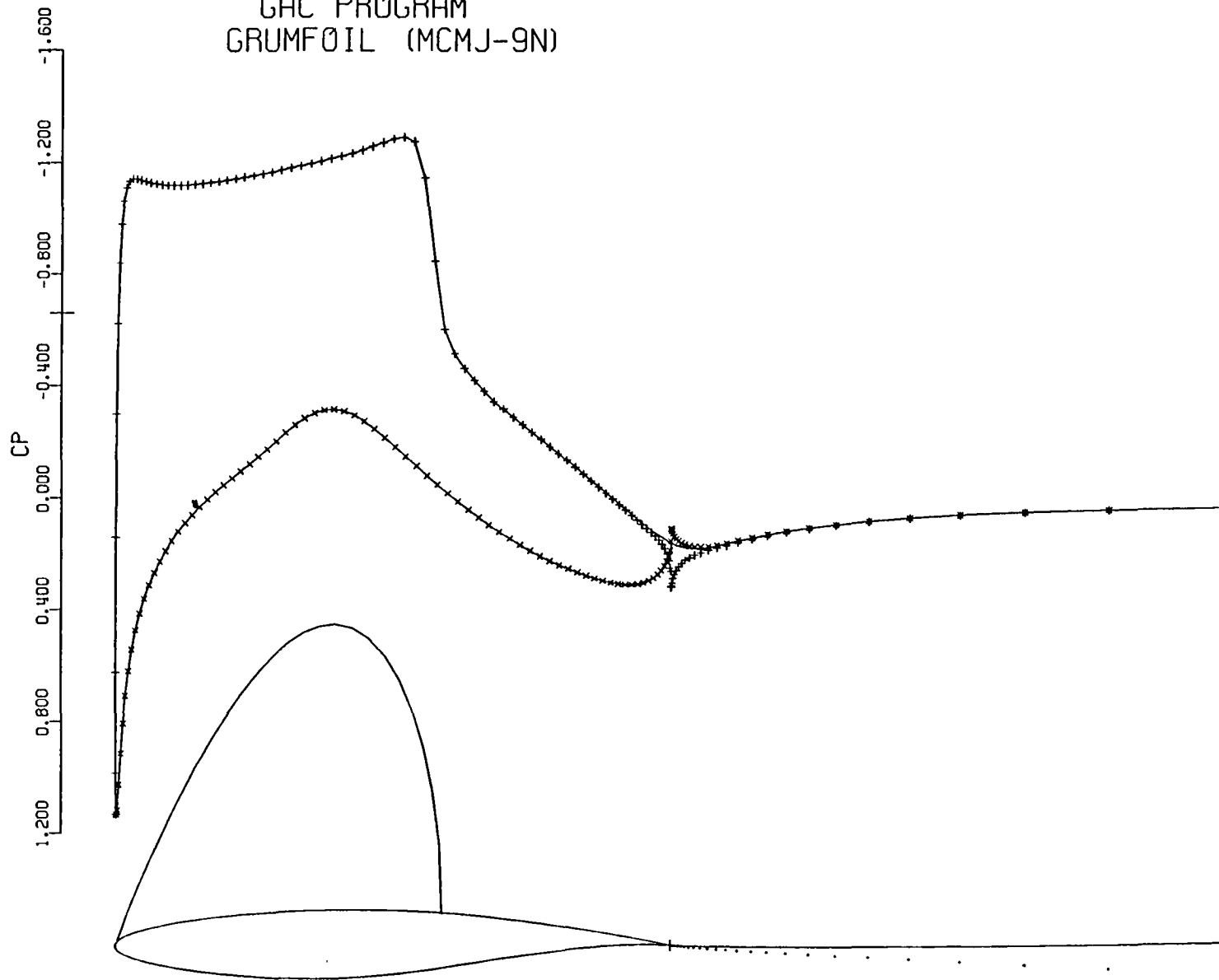
RICHARDSON EXTRAPOLATION OF RESULTS
 ALPHA= 2.7057 CL= 0.80323 CDB= 0.01643 CM=-0.0872

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
X
X GRUMMAN AEROSPACE CORP. PROGRAM GRUMFOIL (MCMJ-9N) 2-22-85 X
X
X AIRFOIL ANALYSIS IN TRANSONIC VISCOUS FLOW X
X
X DEVELOPED BY R.MELNIK, R.CHOW, H.HEAD, AND A.JAMESON X
X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

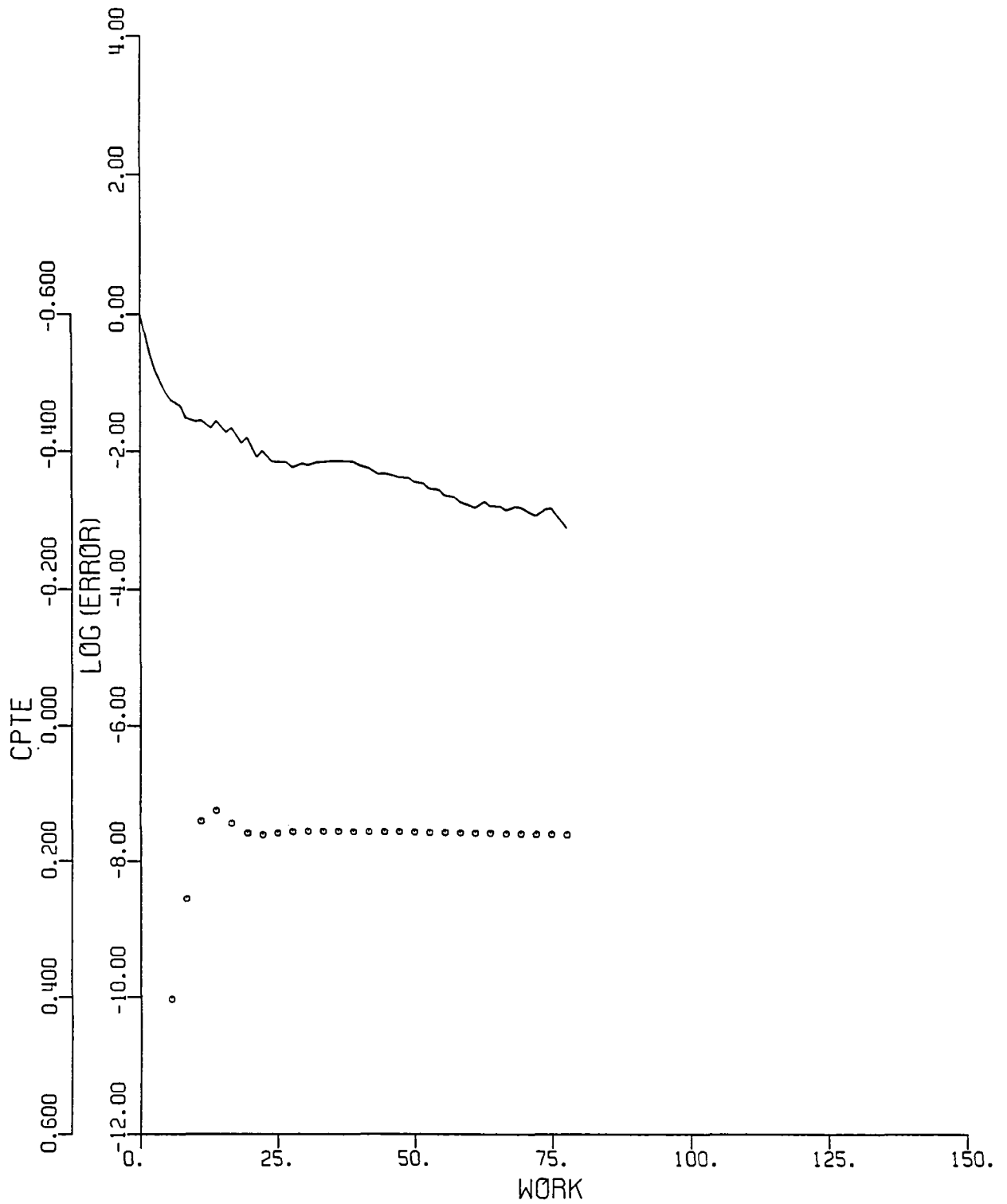
END OF CALCULATION

| SUMMARY OF ERRORS FOR THIS JOB | ERROR NUMBER | NUMBER OF ERRORS |
|--------------------------------|--------------|------------------|
| | 208 | 511 OR OVER |

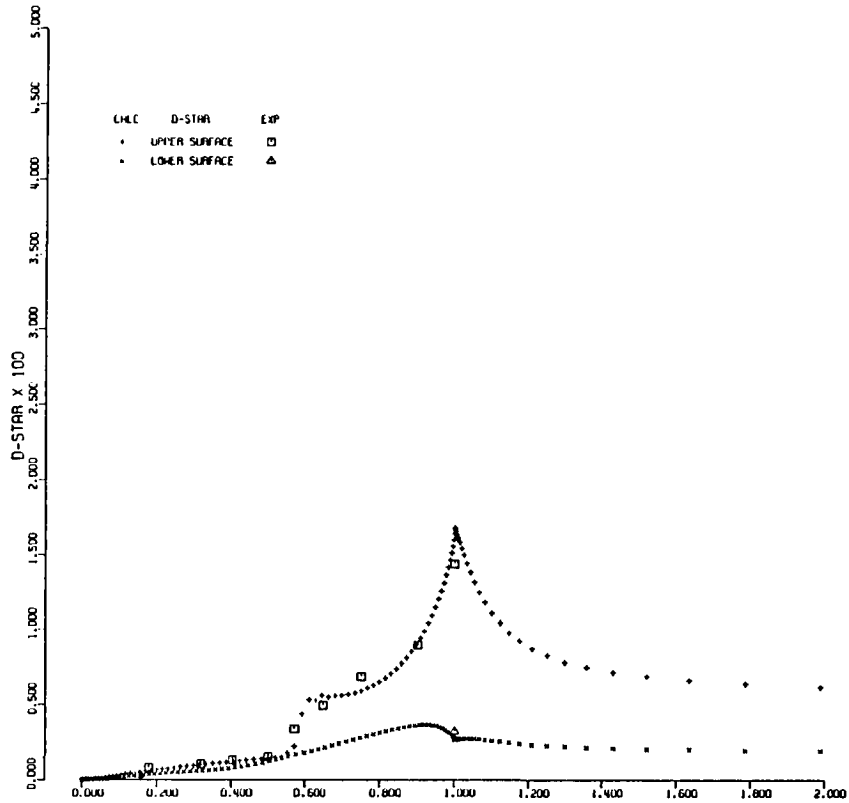
GAC PROGRAM
GRUMFOIL (MCMJ-9N)



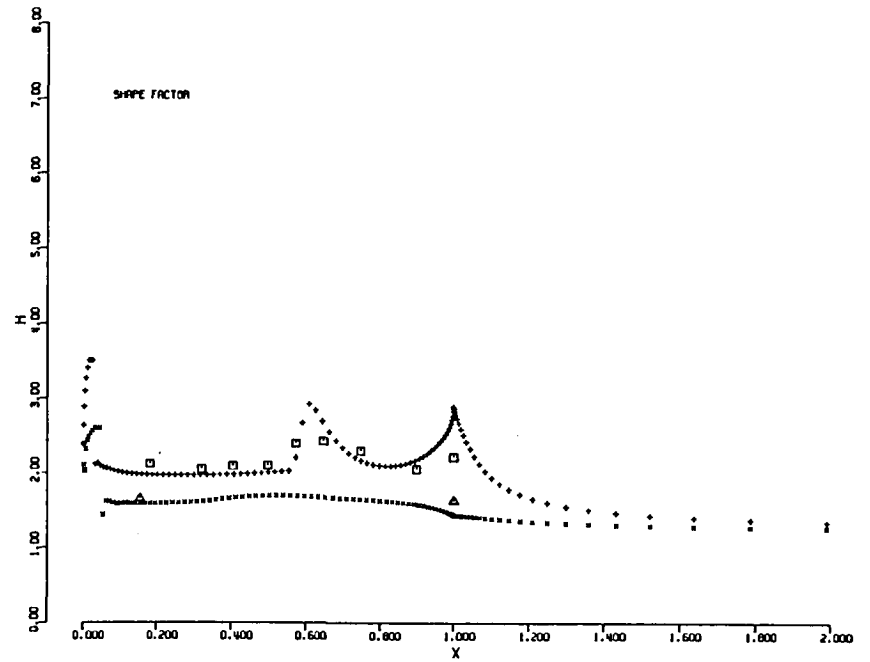
RAE 2822 CASE 9 SAMPLE CASE FOR LANGLEY FINAL REPORT
M=.730 ALF= 2.706 CLC= 0.7977 NIT= 56 MESH=160X32 RSID=.423D-04
CL = 0.8031 CD =0.0166 CDB =0.0166 CM =-.0875 CPTe=0.1612
VARYING WAKE THICK WITH CURV

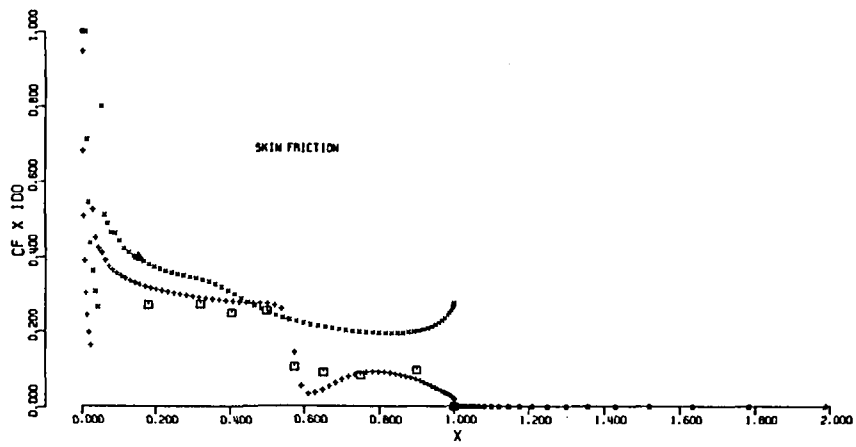
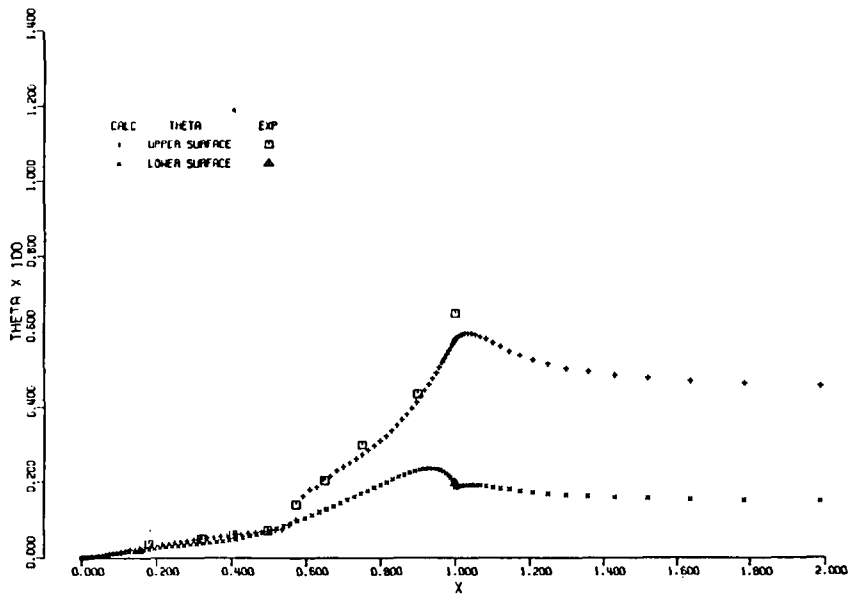


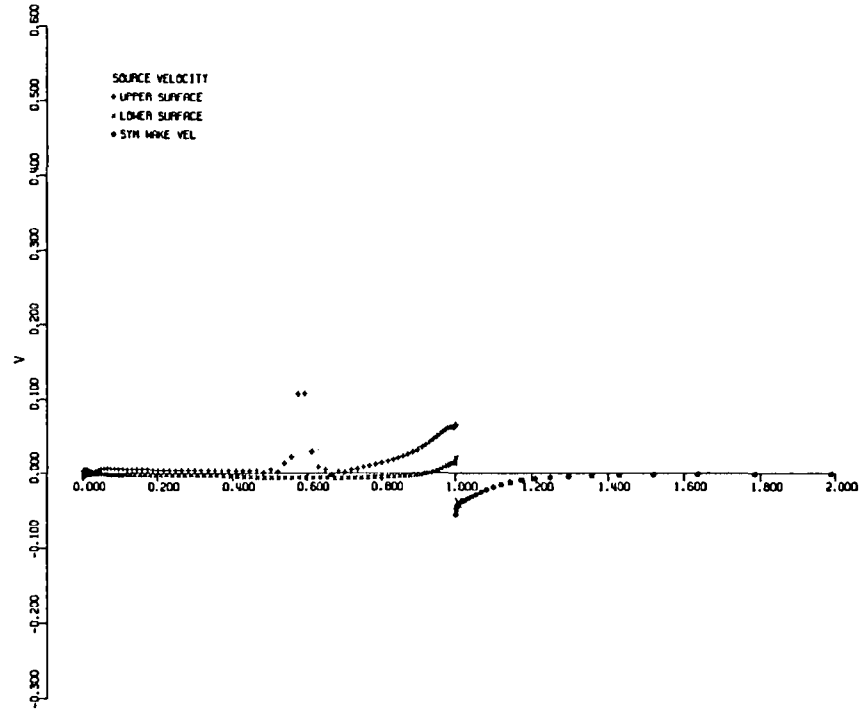
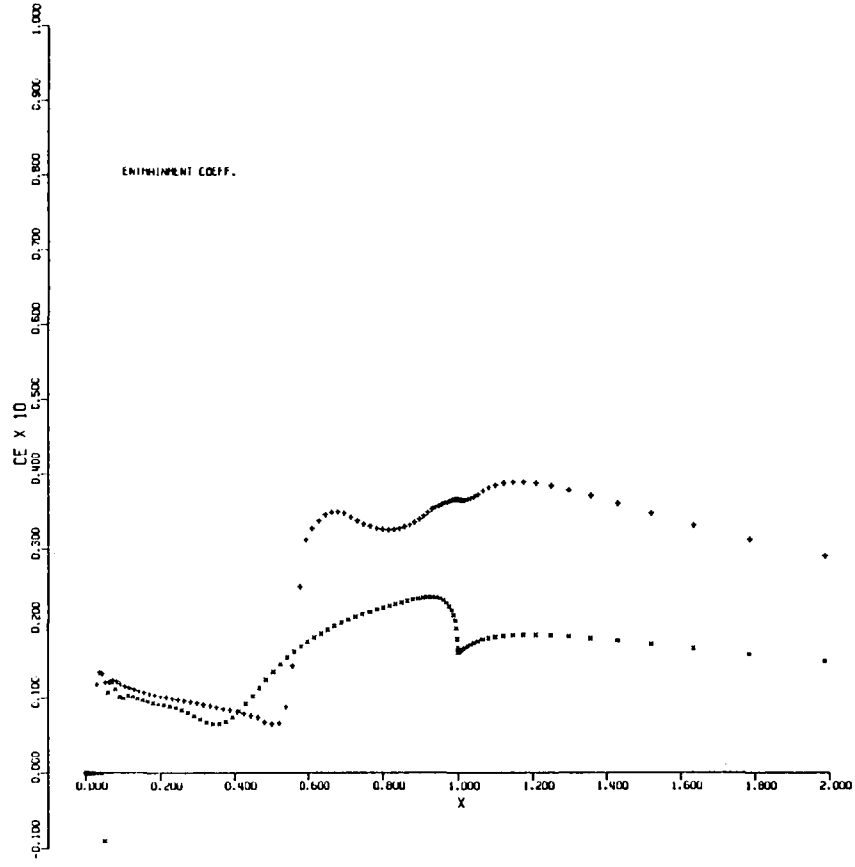
| | | | |
|----------|-----------|-----------------|----------------------|
| RAE 2822 | CASE 9 | SAMPLE CASE FOR | LANGLEY FINAL REPORT |
| MACH | 0.730 | ALPHA | 2.706 |
| RESID1 | 0.237D-03 | RESID2 | 0.178D-06 |
| WORK | 77.55 | RATE | 0.9114 |
| CRID | 160 X 32 | | NIT= 56 |



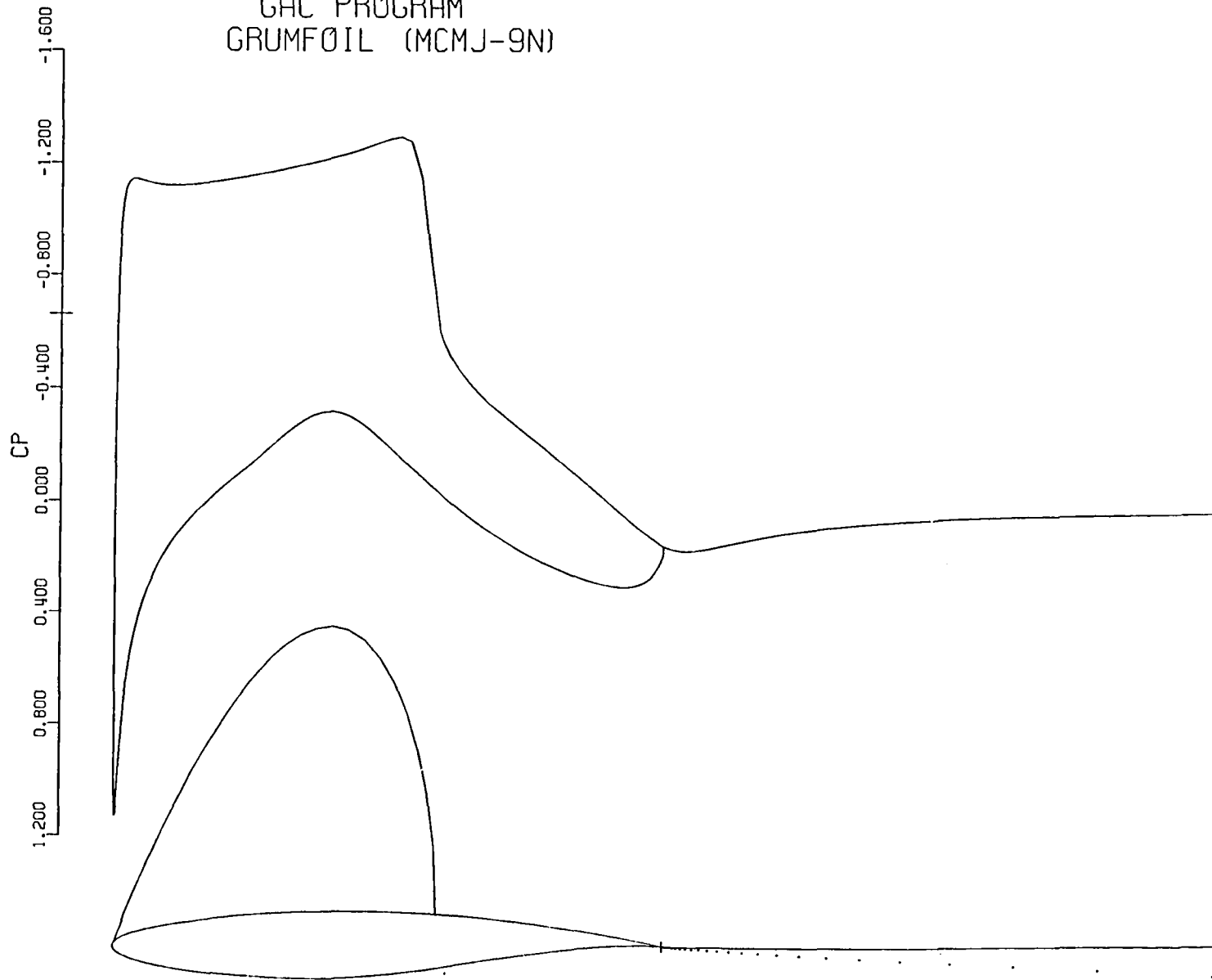
RAE 2B22 CASE 9 SAMPLE CASE FOR LANGLEY FINAL REPORT
 H= 730 RE= 6500*07 ALF= 2.706 KT=1 ITBL= 28 CDF= 0.0060 CDF1=0.0032 CDFB=0.0027
 XTRANU=0.030 XTRANL=0.051 CDST=0.0114 CDINF=0.0116 CDIT=0.0067 CDIB=0.0029



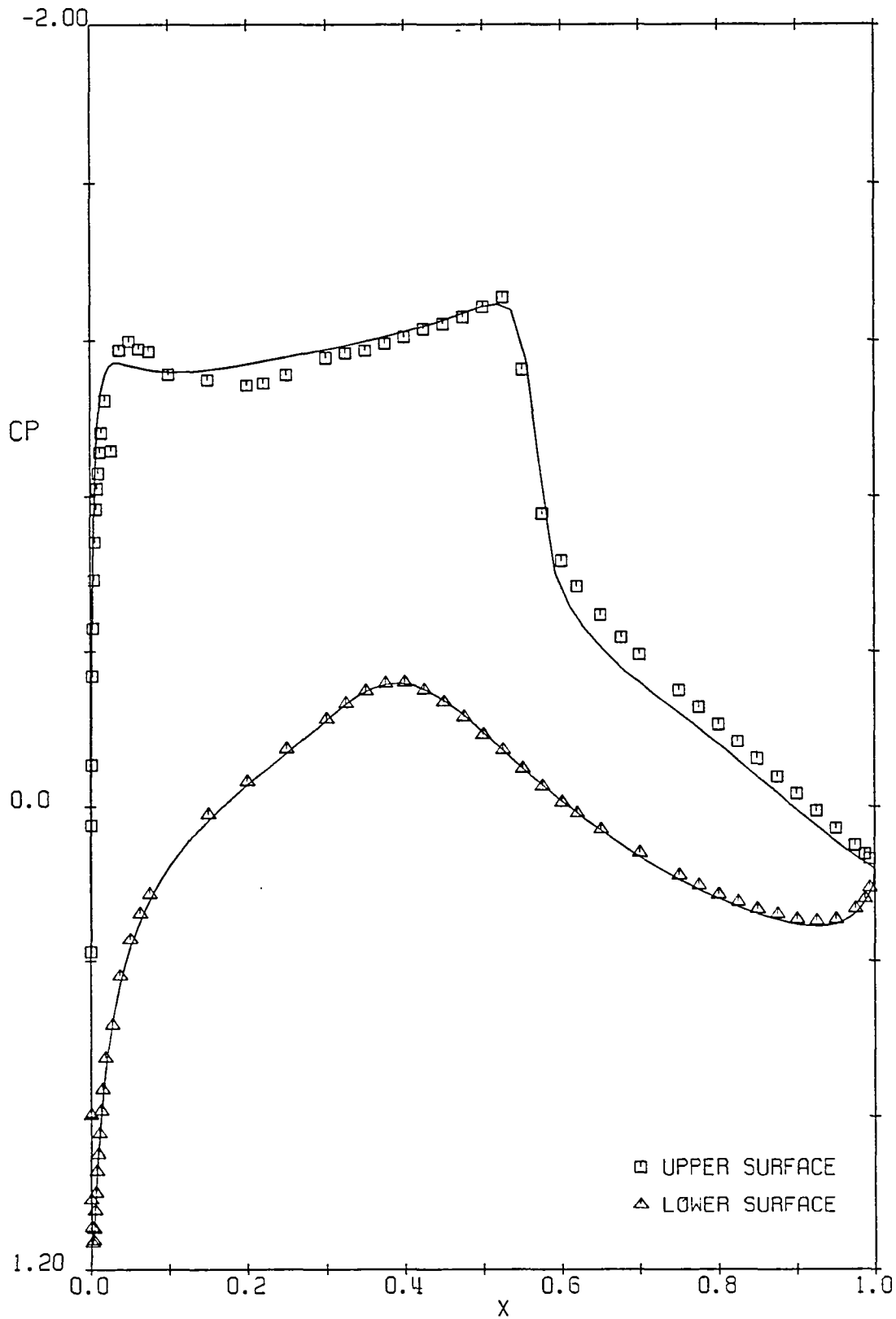




GAC PROGRAM
GRUMFOIL (MCMJ-9N)



RAE 2822 CASE 9 SAMPLE CASE FOR LANGLEY FINAL REPORT
 M=.730 ALF= 2.706 CLC= 0.7977 NIT= 56 MESH=1COX32 RSID=.423D-04
 CL = 0.8031 CD =0.0166 CDB =0.0166 CM =-.0875 CPTC=0.1612
 VARYING WAKE THICK WITH CURV



RAE 2822 CASE 9 SAMPLE CASE FOR LANGLEY FINAL REPORT
 EXP M=.730 ALF= 3.190 CL= 0.8030 CD=0.0168 CM=-0.0990
 CALC M=.730 ALF= 2.706 CL= 0.8031 CDB=0.0166 CM=-0.0875
 CLXPC= 0.8030 CDXPC=0.0168 CMXPC=-0.0990 DCLC=0.0053

| | | | | | |
|---|--|--|--|--|------------------|
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| 7. Author(s) H. R. Mead and R. E. Melnik | | | | 8. Performing Organization Report No. RE-681 | |
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| 16. Abstract This report is a user's manual which describes the operation of the computer program, GRUMFOIL. The program computes the viscous transonic flow over two-dimensional airfoils using a boundary layer type viscid-inviscid interaction approach. The inviscid solution is obtained by a multi-grid method for the full potential equation. The boundary layer solution is based on integral entrainment methods. | | | | | |
| 17. Key Words (Suggested by Author(s)) Computer, Program, User Manual, Viscous Transonic Flow, Airfoils, Viscid/Inviscid Interaction | | | 18. Distribution Statement Unclassified - Unlimited Subject Categories 02 and 34 | | |
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