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# STAYLAM: A FORTRAN PROGRAM FOR THE SUCTION TRANSITION ANALYSIS OF A YAWED WING LAMINAR BOUNDARY LAYER

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# STAYLAM: A FORTRAN PROGRAM FOR THE SUCTION TRANSITION ANALYSIS OF A YAWED WING LAMINAR BOUNDARY LAYER

By James E. Carter


## SUMMARY

A computer program called STAYLAM is presented for the computation of the compressible laminar boundary-layer flow over a yawed infinite wing including distributed suction. This program is restricted to the transonic speed range or less due to the approximate treatment of the compressibility effects. The prescribed suction distribution is permitted to change discontinuously along the chord measured perpendicular to the wing leading-edge. Estimates of transition are made by considering leading-edge contamination, cross-flow instability, and instability of the Tollmien-Schlichting type. A program listing is given in addition to user instructions and a sample case.


## INTRODUCTION

At the present time there is significant effort being made to implement boundary-layer suction on a wing to maintain laminar flow thereby resulting in a net drag reduction. Clearly such studies require a computer program which analyses the compressible laminar boundary layer on a swept wing and includes tests based on the latest technology to determine whether or not transition will occur for a given suction distribution. Based on the current state of the art for boundary-layer computations for finite swept wings and that for transition estimates, it is clear that such a program would be most complex and thus difficult to use. Hence, in the present program a number of approximations have been made in order to simplify the analysis; nonetheless, this program should be useful, particularly for preliminary design.

## SYMBOLS

| | |
|---|---|
| a | speed of sound |
| $C_p$ | pressure coefficient |
| $C_f$ | skin-friction coefficient |
| L | reference length |
| M | Mach number |
| m,n | indices for x- and z-directions, respectively |
| p | static pressure |
| Q | free stream velocity |
| Re | free stream Reynolds number |
| T | static temperature |
| u | velocity component in x-direction |
| $u_s$ | velocity component in direction of inviscid streamline |
| $u_c$ | cross flow velocity component |
| U | transformed velocity at the boundary-layer edge in the x-direction |
| V | velocity component at the boundary-layer edge in the y-direction ($V = V' = Q_\infty^* \sin \psi$) |
| w | velocity component in the z-direction |
| x | coordinate along the surface measured perpendicularly to the leading edge |

| | |
|---|---|
| $y$ | coordinate along the surface measured parallel to the leading edge |
| $z$ | coordinate measured perpendicularly to surface |
| $\alpha$ | weighting factor in finite-difference scheme |
| $\gamma$ | ratio of specific heats |
| $\Delta x$ | grid spacing in x-direction |
| $\Delta z$ | grid spacing in z-direction |
| $\delta^*$ | displacement thickness |
| $\theta$ | momentum thickness |
| $\lambda_2$ | pressure gradient parameter = $\frac{\theta^2}{\nu} \frac{du_e^*}{dx^*}$ |
| $\mu$ | molecular viscosity coefficient |
| $\nu$ | kinematic viscosity coefficient |
| $\rho$ | density |
| $\tau$ | shear stress at surface |
| $\phi$ | angle between direction of flow at the boundary-layer edge and the x-direction |
| $\psi$ | angle of shear of wing |

Superscripts:

| | |
|---|---|
| $*$ | dimensional, untransformed quantity |
| $'$ | dimensional quantity after Stewartson compressibility transformation |

Subscripts:

| | |
|---|---|
| $e$ | edge of boundary layer |
| $n$ | normal to leading edge of wing |
| $x$ | in the x-direction |
| $y$ | in the y-direction |
| $\infty$ | free stream quantity |

## GENERAL DESCRIPTION

The present program, STAYLAM, was developed by modifying a program presented by Beasley (ref. 1) for the calculation of the incompressible laminar boundary layer and prediction of transition on an infinite sheared wing. In Beasley's program the second-order accurate Crank-Nicolson finite-difference scheme is used to compute the boundary layer from the attachment line to some desired point downstream. These boundary-layer results are then analyzed to determine whether or not leading-edge instability or cross-flow instability occurs. The Owen-Randall criterion is used for the cross-flow instability test. The Tollmien-Schlichting type of instability is estimated by using a correlation given by Stuart (ref. 2) of the critical Reynolds number as a function of the external pressure gradient. The point where transition is completed is then estimated by using a correlation given by Granville (ref. 3). These same tests are used in the present program; the only modification which has been made is that the input quantities to these tests are the actual compressible values, not the corresponding incompressible values given by the Stewartson transformation. It should be noted that the transition tests in the present program can be replaced or supplemented with relative ease.

The Beasley program has been modified by the inclusion of distributed wall suction, compressibility effects, and the finite-difference scheme has been generalized to be of arbitrary accuracy between first and second order in the streamwise, marching variable. Figure 1 gives a typical distribution of suction velocities and explains the nomenclature used in inputting this distribution to the program. Note that the suction is allowed to change discontinuously at a prescribed number of locations along the airfoil. It was found that the Beasley program, modified to include suction, gave distributions of the local skin-friction coefficient which showed significant oscillations in a region of discontinuous suction. These oscillations were eliminated by using a first-order accurate finite-difference scheme in the streamwise marching variable, instead of the second-order accurate Crank-Nicolson scheme used by Beasley. The oscillations were expected in using the Crank-Nicolson scheme due to its known neutral stability in the wall region. The first-order accurate scheme suppresses the oscillations caused by the discontinuous suction since it has greater damping. For the same accuracy the first-order scheme requires more streamwise grid points than the second-order scheme; however, calculations showed that both schemes yield about the same result if approximately 100 grid points are used from the leading to trailing edge. Appendix A gives further details of the finite-difference scheme.

The Stewartson (ref. 4) transformation has been used to account for compressibility effects. Details of this transformation along with the Blasius transformation used by Beasley and the coordinate system are presented in Appendix B. The Prandtl number is assumed to be unity and the total temperature is assumed to be the same as the free stream value. A further approximation is made in the treatment of the streamwise pressure gradient term which allows the incompressible infinite swept wing equations to be obtained after the Stewartson transformation. This latter approximation restricts the use of the present program to speeds in the transonic range or lower. Since the present interest in LFC (laminar flow control) is in the transonic speed range it is felt that this simplifying approximation is justified.

Several calculations were made to verify the accuracy of STAYLAM. First, the incompressible boundary layer on a circular cylinder with a constant suction velocity was computed and comparisons were made with the results obtained by Terrill (ref. 5) for the same case. Excellent agreement was found in the momentum and displacement thicknesses, and skin friction distributions. The estimate of the separation point from the present program differed from that of Terrill by only $0.1^{\circ}$. A second test case was a comparison between the results from the present program and the analytic solution for the compressible asymptotic suction profile (ref. 3) which is obtained by applying constant suction on a flat plate. Excellent agreement was obtained in the streamwise and normal velocity distributions.

## PROGRAM USAGE

The program was written in the FORTRAN programming language for use on the Control Data 6000 Series Computer Systems under the NOS. 1.1 operating system at Langley Research Center. Included in the output is a plot of the distributions of the $x$ and $y$ skin-friction coefficients, $C_{f_x}$ and $C_{f_y}$, versus the non-dimensional surface distance measured perpendicular to the leading edge. Some modification to the program might be required to obtain plots on a different computer system.

The input and output for STAYLAM are discussed in the next two sections. The program listing is given in Appendix D and a sample case is discussed in Appendix E.

# INPUT

| Read Order | Variables | | Format |
|---|---|---|---|
| 1 | ITS, J, TOL, DZ, DS, USTEP, WF† | | 2I5,5F10.5 |
| 2 | IBLC | | I5 |
| 3 | MSMAX | (Skip if IBLC = 0) | I5 |
| 4 | WWALL(MS), SDS(MS) MS = 1, MSMAX | | 2F10.5 |
| 5 | INC, AMINF3D, GAMMA | | I5,2F10.2 |
| 6 | B | | 8A10 |
| 7 | INT3, CH | | I5, F10.5 |
| 8 | ISY, INT4, RHO | (Skip if INT3 = 0) | 2I5,F10.5 |
| 9 | XA(N), ZA(N) (INT4 pairs of values) | | 2E16.8 |
| 10 | ISP | | I5 |
| 11 | IFPT, INT1, NL1ST, DX | | 3I5,2F10.5 |
| 12 | OPX(N), N = 2, NL1STP1 (Skip if IFPT ≠ 2) | | 8F10.5 |
| 13 | C | | 8A10 |
| 14 | PSI, DTRIP | | 8F10.5 |
| 15 | INTRL, IFR | | 2I5 |
| 16 | RNL(I), I = 1, INTRL | | 8F10.5 |
| 17 | INTV, L | | 2I5 |
| 18 | XV(I), UM(I), I = 2, LP1 | | 2E16.8 |
| 19 | MGRAD, XV(1) (if INC = 0) | | 2F10.5 |
| 20 | VGRAD, XV(1) (if INC = 1) | | 2F10.5 |

†Input which has been added to original Beasley program is underlined.

21 ALPHA, S1, S3 (skip if MGRAD or VGRAD > 0) 3F10.5

22 KUE

The definitions of these input variables are as follows:

ITS Maximum number of iterations in subroutine WUV to calculate the u profile.

J Number of steps in z direction.

TOL Iterative tolerance.

DZ Step length in z direction.

DS Standard step length in x direction, made non-dimensional with respect to airfoil chord.

USTEP Maximum permissible increase in velocity at edge of boundary layer across one step.

WF Accuracy control on finite-difference expression for x derivatives. WF = 0.5 gives second-order accuracy (Crank-Nicolson scheme); WF = 1.0 gives first-order accuracy.

IBLC Suction parameter. IBLC = 0, no suction; IBLC = 1, distributed suction permitted.

MSMAX Total number of values of suction velocity.

WWALL Array of suction velocity values = $\frac{W^*}{Q^*_\infty}\sqrt{\frac{Q^*_\infty L^*}{\nu^*_\infty}}$ . For suction WWALL(MS) < 0.

SDS Array of nondimensional locations along airfoil measured from attachment line, where value of suction velocity changes discontinuously. Set SDS(MSMAX) > surface distance from attachment line to trailing edge.

INC Compressibility parameter. INC = 1, flow is incompressible. INC = 0, flow is compressible and Stewartson transformation is used.

| | |
|---|---|
| AMINF3D | Free stream Mach number. |
| GAMMA | Ratio of specific heats; usually $\gamma = 1.4$. |
| B | Main title. |
| INT3 | = 0: velocity data will be given at x co-ordinates, that is, at distances from the attachment line measured around the airfoil surface. |
| | = 1: velocity data will be given at chord-wise stations. |
| CH | Airfoil chord, measured perpendicularly to leading edge. |
| ISY | = 0: airfoil is cambered. |
| | = 1: airfoil is symmetrical. |
| INT4 | Initially is the number of pairs of co-ordinates to be read, subsequently becomes the total number of pairs of airfoil co-ordinates stored, including the lower surface and leading edge. |
| RHO | Nose radius of the airfoil in plane perpendicular to the leading edge. |
| XA | Coordinates of geometric data, measured perpendicularly to the leading edge and in the plane through the leading and trailing edges. |
| ZA | Coordinates of geometric data, measured perpendicularly to the plane through the leading and trailing edges. For a symmetrical airfoil XA and ZA are read from the leading edge to the trailing edge and include values at both points. For a cambered airfoil the geometrical data are read from the trailing edge on the lower surface to the trailing edge on the upper surface. Values of XA for the lower surface must have negative signs, and values of |

ZA must have signs as appropriate.

ISP — Surface parameter indicator. ISP = 2, upper surface calculation; ISP = 0, lower surface calculation.

IFPT — = 1: Complete print-out at end of all steps.

= 2: Complete print-out at points given in list.

= 3: Complete print-out at points at which velocity data is given.

= 4: Complete print-out at points DX apart, where DX is given as data.

In current program set IFPT = 3 and the print-out has been modified so that the complete print-out (boundary-layer profiles) is printed every 10% chord. This modification can be eliminated by several program changes in subroutine PRINT.

INT1 — Velocity profiles are printed out at values of z corresponding to $n = 1,2,3,\ldots(\mathrm{INT1} + 1),\ 2(\mathrm{INT1}) + 1,\ 3(\mathrm{INT1}) + 1,\ldots,N$

NLIST — Number of points in output list.

DX — Interval between listed output points (when IFPT = 4), made non-dimensional with respect to the airfoil chord.

OPX — Points at which full output is required.

C — Sub-title.

PSI — Angle of shear.

DTRIP — Trip-wire diameter.

INTRL — Number of values of Reynolds number to be read.

IFR — = 1. Data Reynolds number = $\dfrac{Q^*_\infty L^* \sec \psi}{\nu^*_\infty}$

= 2. Data Reynolds number = $\dfrac{Q^*_\infty L^*}{\nu^*_\infty}$

= 3. Data Reynolds number = $\dfrac{Q^*_\infty L^* \cos \psi}{\nu^*_\infty}$

In present program use IFR = 2 as this Reynolds number definition has been assumed in the suction velocity and in the skin-friction coefficient calculations.

RNL — Reynolds number.

INTV — = 1: Velocity data is given as U.

= 2: Velocity data is given as $U \sec \psi$.

= 3: Velocity data is given as $C_p$.

If flow is compressible set INTV = 1. See UM description for further explanation of input in compressible case.

L — Initially is the number of velocity data points read in, subsequently is the total number of points at which the velocity distribution is defined, including the attachment line.

XV — Coordinates of velocity data. Use the same sign convention as that for XA to indicate whether the upper or lower surface is to be computed.

UM — For incompressible flow, UM is initially the velocity data, subsequently, U. For compressible flow UM is initially $M_{e_n}$. After the Stewartson transformation, it is U. The velocity (or Mach number) data, XV and UM, are read from the attachment line towards the trailing edge, but attachment-line values must not be included and the data need not extend all the way to the trailing edge.

MGRAD — Mach number gradient (nondimensional) at the attachment line in a plane perpendicular to the leading edge = $\frac{dM_{e_n}}{dx}$.

VGRAD Velocity gradient (nondimensional) at the attachment line in a plane perpendicular to the leading edge = $\frac{dU'/Q_n^*}{dx} = \frac{dU}{dx} \sec \psi$

XV(1) Location of attachment line. Use same sign convention as that used for XA.

ALPHA Incidence of airfoil in streamwise plane.

S1,S3 Quantities used in equations (53-54) in reference 1.

KUE Parameter for more data on step.

= 1: Read more data from ITS.

= 2: Read more data from B.

= 3: Read more data from ISY.

= 4: Read more data from IFPT.

= 5: Read more data from C.

= 6: Read more data from INTV.

= 7: Stop.

The input is printed and labeled as described above. In addition the following quantities are also printed along with the input.

STH Non-dimensional surface distance measured from lower surface trailing edge.

TH Transformed chordwise station X. Lower surface, $\theta = \cos^{-1}(2|X| - 1)$; upper surface, $\theta = 2\pi - \cos^{-1}(2X - 1)$.

FSTH Second derivative of surface distance with respect to $\theta$. Used in cubic spline interpolation.

FZTH Second derivation of Z (measured perpendicularly to the plane through the leading and trailing edges) with respect to $\theta$. Used in cubic spline interpolation.

SXV Non-dimensional surface distance measured from attachment line to point at which the inviscid velocity, Mach number, or pressure coefficient data is prescribed.

SXVINC Transformed surface distance corresponding to SXV; same as $x'/L^*$ in equation (B4).

U Non-dimensional transformed surface velocity $= \frac{a_\infty^*}{a_e^*}\frac{u_e^*}{Q_\infty^*} = \frac{M_{e_n}}{M_\infty}$

THXV Value of $\theta$ at the points where the velocity data is prescribed, XV.

FUTH Second derivative of U with respect to $\theta$. Used in cubic spline interpolation.

FSVSINC Second derivative of SXV with respect to SXVINC. Used in cubic spline interpolation.

## OUTPUT

The displacement and momentum thicknesses, skin-friction values, and results of the transition estimates are printed at each location on the airfoil where a boundary-layer calculation is made. These locations are determined by the USTEP criterion, or if this is satisfied, then the computation is made at regular DS intervals. Furthermore, since IFPT = 3, computations are also made at the same locations at which the velocity (or Mach number) data is prescribed. Note that these latter computations are only temporary; hence results from these stations do not form upstream conditions for the next downstream station. The skin-friction coefficients are not computed at these intermediate stations.

The boundary-layer profiles are printed at approximately every 10 per cent chord. The information printed at each boundary-layer station and an explanation of the boundary-layer profiles is given as follows:

X — Non-dimensional chord location.

S — Transformed incompressible coordinate measured along airfoil from attachment line; same as $x$ in equation (12) in Appendix B.

SCOMP — Non-dimensional surface distance measured from attachment line.

U — Non-dimensional transformed velocity at the boundary-layer edge $= \frac{a^*_\infty}{a^*_e} \frac{u^*_e}{Q^*_\infty} = \frac{M_{e_n}}{M_\infty}$ .

AME3D — Mach number at the boundary-layer edge. See equation (18) in Appendix B.

DU/D(S/L) — Transformed inviscid velocity gradient, $\frac{dU}{dx}$ .

DELTA1 — Scaled displacement thickness $= \sqrt{\frac{URe_\infty}{x}} \left(\frac{\delta^*}{L^*}\right)$ .

THETA1 — Scaled momentum thickness $= \sqrt{\frac{URe_\infty}{x}} \left(\frac{\theta}{L^*}\right)$.

(DU/DZ)Z=0 — Scaled skin-friction coefficient in $x$ direction =

$$\left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right)^{\frac{2\gamma-1}{\gamma-1}} \left.\frac{\partial u}{\partial z}\right|_{z=0} .$$

(DV/DZ)Z=0 — Scaled skin-friction coefficient in $y$ direction =

$$\left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right)^{\frac{3\gamma-1}{2(\gamma-1)}} \left.\frac{\partial v}{\partial z}\right|_{z=0} .$$

AIRFOIL SLOPE — Local airfoil slope in degrees in plane perpendicular to the leading edge.

| | |
|---|---|
| (DIMENSIONAL Z)/ CHORD | Multiplicative factor to convert scaled displacement and momentum thicknesses into actual thickness divided by the chord. |
| DELTA1/C | $\delta^*/L^*$ |
| THETA1/C | $\theta/L^*$ |
| CFX | Skin-friction coefficient x direction = $\dfrac{\tau_x^*}{\frac{1}{2}\rho_\infty^* Q_\infty^{*2}} = \dfrac{2U^{3/2}}{\sqrt{xRe_\infty}}\,\mathrm{DUDZ}\big\vert_{z=0}$. |
| CFY | Skin-friction coefficient in y direction = $\dfrac{\tau_y^*}{\frac{1}{2}\rho_\infty^* Q_\infty^{*2}} = 2\sin\psi\sqrt{\dfrac{U}{xRe_\infty}}\,\mathrm{DVDZ}\big\vert_{z=0}$. |
| CDFX | Skin-friction drag coefficient in direction perpendicular to leading edge based on chord measured perpendicular to leading edge. |
| CDFXINF | Total skin-friction drag coefficient in free stream direction based on chord measured parallel to free stream. |
| CHI(OWEN-RANDALL) | Cross-flow Reynolds number = $\chi = Re_\infty \displaystyle\int_0^\infty \frac{u_c^*}{Q_\infty^*}\, d(z^*/L^*)$ |
| RTHETA | Reynolds number based on momentum thickness = $\dfrac{u_e^*\theta}{\nu_{min}^*}$ where $\nu_{min}^*$ is the minimum of $\nu_\infty^*$ or $\nu_e^*$. |
| RTHETCRIT | Critical momentum thickness Reynolds number from Stuart (ref. 2) for prediction of instability in the Tollmien-Schlichting sense. |
| LAM2 | Pressure gradient parameter, $\lambda_2 = \dfrac{\theta^2}{\nu_{min}^*}\dfrac{du_e^*}{dx^*}$ |

$$= (\text{THETA1})^2 \left( \frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2} \right)^{\frac{3\gamma-1}{2(\gamma-1)}} \frac{\left(1 + \frac{\gamma-1}{2} M_\infty^2 \cos^2\psi\right)^{1/2}}{\left(1 + \frac{\gamma-1}{2} M_\infty^2 U^2\right)^{3/2}} \frac{x}{U} \frac{dU}{dx}$$

INSTAB. RE . NO. — Momentum thickness Reynolds number at estimated point of laminar instability as determined from Stuart correlation.

RTC-RTI — Critical momentum thickness Reynolds number minus momentum thickness Reynolds number at the point of laminar instability from Granville correlation.

LAM2BAR — Average value of $\lambda_2 = \dfrac{\displaystyle\int_{xi}^{x_{tr}} \lambda_2 \left( \frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2} \right)^{\frac{3\gamma-1}{2(\gamma-1)}} dx}{\frac{x^*_{tr}}{L^*} - \frac{x^*_i}{L^*}}$

Z — Transformed coordinate normal to surface, z.

ZCOMP — Scaled coordinate normal to surface $= \sqrt{\dfrac{URe_\infty}{x}} \dfrac{z^*}{L^*}$

W — Transformed velocity component normal to surface, w. See equation (12) in Appendix B.

U — Velocity tangent to surface in x direction $= \dfrac{u^*}{u^*_e} = \dfrac{u}{U}$.

V — Velocity tangent to surface in y direction $= \dfrac{v^*}{v^*_e} = \dfrac{v^*}{Q^*_\infty \sin\psi}$.

STV — Velocity component in direction of inviscid streamline $= \dfrac{u^*_s}{u^*_{s_e}}$. See Appendix C for further explanation.

CFV — Velocity component perpendicular to direction of inviscid streamline (cross-flow component) $= \dfrac{u^*_c}{Q^*_\infty}$. See Appendix C for further explanation.

T — Static temperature ratio $= \dfrac{T^*}{T^*_\infty}$.

RHOD — Density ratio $= \dfrac{\rho^*}{\rho^*_\infty}$.

# APPENDIX A

## FINITE-DIFFERENCE SCHEME

The computational molecule for the finite-difference scheme is shown in the accompanying sketch. The point of evaluation moves from the midpoint between lines m and m + 1 as $\alpha$, the weighting factor, varies from 0.5 to 1.0. With derivatives evaluated at the point $x = (m + \alpha)\Delta x$, $z = n\Delta z$ the following finite-difference approximations are given.

$$\frac{\partial u}{\partial x} = \frac{u_{m+1,n} - u_{m,n}}{\Delta x} + (\alpha - 1/2)\Delta x \frac{\partial^2 u}{\partial x^2} + O(\Delta x^2) \tag{A1}$$

$$\frac{\partial u}{\partial z} = (1 - \alpha)\left(\frac{u_{m,n+1} - u_{m,n-1}}{2\Delta z}\right) + \alpha\left(\frac{u_{m+1,n+1} - u_{m+1,n-1}}{2\Delta z}\right) + O(\Delta z^2) \tag{A2}$$

$$\frac{\partial^2 u}{\partial z^2} = (1 - \alpha)\left(\frac{u_{m,n+1} - 2u_{m,n} + u_{m,n-1}}{\Delta z^2}\right) + \alpha\left(\frac{u_{m+1,n+1} - 2u_{m+1,n} + u_{m+1,n-1}}{\Delta z^2}\right) + O(\Delta z^2) \tag{A3}$$

From the truncation error it is seen that if $\alpha = 0.5$ the scheme is second-order accurate, which is the Crank-Nicolson scheme used by Beasley. First-order accuracy is obtained if $\alpha = 1$ and this scheme is sometimes referred to as a fully implicit finite-difference scheme. In the program the weighting factor $\alpha$ is designated as WF, and should be restricted to the range $0.5 \leq \text{WF} \leq 1.0$. It should be noted that if $\alpha = 0.5$ the normal component of velocity which is printed is the value at $m + 1/2, n$; otherwise, for $\alpha > 0.5$ the value is at $m + 1,n$.

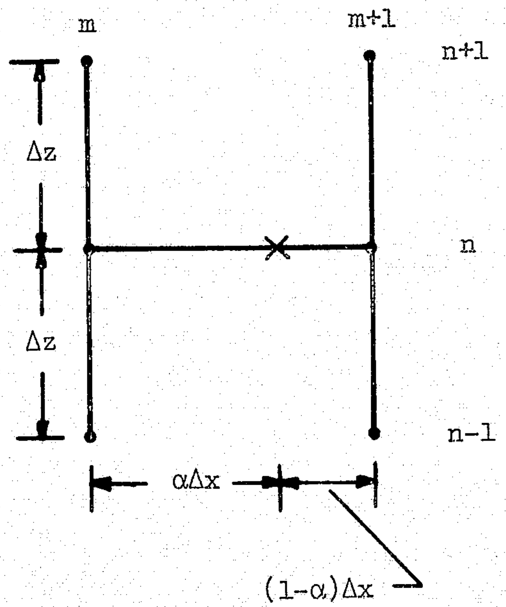


Figure A-1. Finite-difference molecule.

## APPENDIX B

## GOVERNING EQUATIONS

The compressible, laminar boundary-layer equations are given as follows for the flow over an infinite, swept wing:

$$\frac{\partial \rho^* u^*}{\partial x^*} + \frac{\partial \rho^* w^*}{\partial z^*} = 0 \tag{B1}$$

$$\rho^* u^* \frac{\partial u^*}{\partial x^*} + \rho^* w^* \frac{\partial u^*}{\partial z^*} = \rho_e^* u_e^* \frac{du_e^*}{dx^*} + \frac{\partial}{\partial z^*} \left(\mu^* \frac{\partial u^*}{\partial z^*}\right) \tag{B2}$$

$$\rho^* u^* \frac{\partial v^*}{\partial x^*} + \rho^* w^* \frac{\partial v^*}{\partial z^*} = \frac{\partial}{\partial z^*} \left(\mu^* \frac{\partial v^*}{\partial z^*}\right) \tag{B3}$$

The coordinate system is explained in figure B-1.

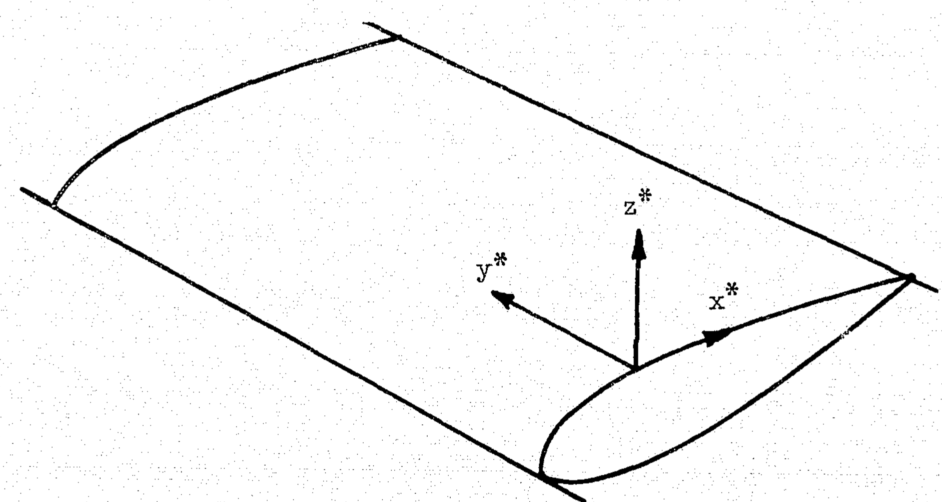


Figure B-1. Yawed wing coordinate system.

The Stewartson transformation, which is given by

$$x' = \int_0^{x^*} \frac{p_e^*}{p_\infty^*} \frac{a_e^*}{a_\infty^*} dx^* \tag{B4}$$

$$z' = \int_0^{z^*} \frac{a_e^*}{a_\infty^*} \frac{\rho^*}{\rho_\infty^*} dz^* \tag{B5}$$

$$u' = \frac{a_\infty^*}{a_e^*} u \tag{B6}$$

$$w' = \frac{a_\infty^* p_\infty^*}{a_e^* p_e^*} \left(u' \frac{\partial z'}{\partial x^*} + \frac{\rho^*}{\rho_\infty^*} w^*\right) \tag{B7}$$

is applied to equations (B1) - (B3). In addition it is assumed that the Prandtl number is unity, the total temperature equals the free stream value, and the viscosity coefficient varies linearly with the temperature. The transformed equations are:

$$\frac{\partial u'}{\partial x'} + \frac{\partial w'}{\partial z'} = 0 \tag{B8}$$

$$u' \frac{\partial u'}{\partial x'} + w' \frac{\partial u'}{\partial z'} = \left[1 + \frac{\frac{\gamma-1}{2} M_\infty^2 \sin^2 \psi}{1 + \frac{\gamma-1}{2} M_\infty^2 \cos^2\psi} \left(1 - \frac{v^{*2}}{Q_\infty^{*2} \sin^2\psi}\right)\right] u_e' \frac{du_e'}{dx'}$$
$$+ \nu_\infty^* \frac{\partial^2 u'}{\partial z'^2} \tag{B9}$$

$$u' \frac{\partial v^*}{\partial x'} + w' \frac{\partial v^*}{\partial z'} = \nu_\infty^* \frac{\partial^2 v^*}{\partial z'^2} \tag{B10}$$

The coefficient of the external velocity gradient in equation (B9) gives rise to a coupling between the $x$ and $y$ momentum equations which is not present in incompressible flow. This coefficient varies from its maximum value at the surface to unity at the boundary-layer edge as $v^*$ approaches its edge value $Q_\infty^* \sin \psi$. This maximum value increases as the Mach number and sweep angle increase; nevertheless, this coefficient remains close to unity for flows in the transonic speed range, which is the present area of interest. For example the maximum value of this coefficient is 1.06 or less for $\psi = 35^\circ$ and free stream Mach numbers of one or less. In the present program this coefficient is set equal to unity and the $x$ momentum equation becomes

$$u' \frac{\partial u'}{\partial x'} + w' \frac{\partial u'}{\partial z'} = u_e' \frac{du_e'}{dx'} + \nu_\infty^* \frac{\partial^2 u'}{\partial z'^2} \tag{B11}$$

Thus it is seen that with the given assumptions the Stewartson transformation converts the compressible equations into an equivalent incompressible formulation. This formulation is the starting point for Beasley's analysis which will be repeated for convenience.

Beasley applied the Blasius transformation given by

$$\left.\begin{aligned}
x &= \frac{x'}{L^*} & z &= \left(\frac{U'x'}{\nu_\infty^*}\right)^{1/2} \frac{z'}{x'} \\
U &= \frac{U'}{Q_\infty^*} & V &= \frac{V'}{Q_\infty^*} \\
u &= \frac{u'}{U'} & v &= \frac{v^*}{V'} \\
w &= \frac{w'}{U'} \left(\frac{U'x'}{\nu_\infty^*}\right)^{1/2} & &
\end{aligned}\right\} \tag{B12}$$

to equations (B8), (B11), and (B10), respectively, and obtained

$$x \frac{\partial u}{\partial x} + \frac{x}{U}\frac{dU}{dx} u + \frac{z}{2}(\frac{x}{U}\frac{dU}{dx} - 1) \frac{\partial u}{\partial z} + \frac{\partial w}{\partial z} = 0 \tag{B13}$$

$$xu \frac{\partial u}{\partial x} + [w + \frac{uz}{2} (\frac{x}{U}\frac{dU}{dx} - 1)] \frac{\partial u}{\partial z} = (1 - u^2) \frac{x}{U}\frac{dU}{dx} + \frac{\partial^2 u}{\partial z^2} \tag{B14}$$

$$xu \frac{\partial v}{\partial x} + [w + \frac{uz}{2} (\frac{x}{U}\frac{dU}{dx} - 1)] \frac{\partial v}{\partial z} = \frac{\partial^2 v}{\partial z^2} \tag{B15}$$

The surface boundary conditions including suction are given as

$$z = 0, \; u = v = 0$$

$$w = \frac{\left(1 + \frac{\gamma-1}{2}M_e^2\right)^{1/2}}{\left(1 + \frac{\gamma-1}{2}M_\infty^2\right)^{3/2}} \sqrt{\frac{x}{U}} \left(\frac{w^*\sqrt{Re_\infty}}{Q_\infty^*}\right) \tag{B16}$$

The edge conditions are

$$z \to \infty \qquad u \to 1, \qquad v \to 1 . \tag{B17}$$

Note that in equation (B16) the Mach number of the inviscid flow is given as

$$M_e^2 = \frac{M_\infty^2 \left[U^2\left(1 + \frac{\gamma-1}{2} M_\infty^2\right) + \sin^2\psi\right]}{1 + \frac{\gamma-1}{2} M_\infty^2 \cos^2\psi} \tag{B18}$$

The scaled, non-dimensional suction velocity, $\frac{w^*\sqrt{Re_\infty}}{Q_\infty^*}$, is referred to as WWALL in STAYLAM and is part of the input.

After the solution is obtained in terms of transformed, incompressible variables the corresponding compressible quantities are obtained as follows:

$$\frac{x^*}{L^*} = \int_0^x \left(\frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2}\right)^{\frac{3\gamma-1}{2(\gamma-1)}} dx \tag{B19}$$

$$\frac{z^*}{L^*} = \sqrt{\frac{x}{URe_\infty}} \left(\frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2}\right)^{\frac{3\gamma-1}{2(\gamma-1)}} \int_0^z \frac{T^*}{T_\infty^*} dz \tag{B20}$$

$$\frac{T^*}{T_\infty^*} = 1 + \frac{\gamma - 1}{2} M_\infty^2 \left\{1 - \left[\left(\frac{u^*}{Q_\infty^*}\right)^2 + \left(\frac{v^*}{Q_\infty^*}\right)^2\right]\right\} \tag{B21}$$

$$\frac{u^*}{Q_\infty^*} = \left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right)^{1/2} uU \tag{B22}$$

$$\frac{v^*}{Q_\infty^*} = v \sin \psi \tag{B23}$$

$$\frac{\rho^*}{\rho_\infty^*} = \left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right)^{\frac{\gamma}{\gamma-1}} \frac{T_\infty^*}{T^*} \tag{B24}$$

The momentum and displacement thicknesses are given by

$$\frac{\theta}{L^*} = \sqrt{\frac{x}{URe_\infty}} \left(\frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \int_0^\infty u(1 - u) dz \tag{B25}$$

$$\frac{\delta^*}{L^*} = \left(\frac{z^*}{L^*}\right)_e - \sqrt{\frac{x}{URe_\infty}} \left(\frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \int_0^{z_e} udz \tag{B26}$$

where the subscript $e$ denotes the edge of the boundary layer. The local skin-friction coefficients are

$$C_{f_x} = 2U \sqrt{\frac{U}{xRe_\infty}} \left( \frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2} \right)^{\frac{2\gamma-1}{\gamma-1}} \left. \frac{\partial u}{\partial z} \right|_{z=0} \tag{B27}$$

$$C_{f_y} = 2 \sin \psi \sqrt{\frac{U}{xRe_\infty}} \left( \frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2} \right)^{\frac{3\gamma-1}{2(\gamma-1)}} \left. \frac{\partial v}{\partial z} \right|_{z=0} \tag{B28}$$

## APPENDIX C

## VELOCITY COMPONENTS

The resolution of the velocity components at any point in the boundary layer into the streamwise and crossflow components, respectively, is given as follows:

$$u_s^* = u^* \cos \phi + v^* \sin \phi \tag{C1}$$

$$u_c^* = v^* \cos \phi - u^* \sin \phi \tag{C2}$$

These components are non-dimensionalized by the free stream velocity, $Q_\infty^*$, and the Stewartson transformation is incorporated to give

$$\frac{u_s^*}{Q_\infty^*} = \left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right)^{1/2} u\, U \cos \phi + v \sin \psi \sin \phi \tag{C3}$$

$$\frac{u_c^*}{Q_\infty^*} = U\left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right)^{1/2} (v - u) \sin \phi \tag{C4}$$

Note that at the boundary-layer edge

$$\frac{u_{s_e}^*}{Q_\infty^*} = \left[U^2\left(\frac{1 + \frac{\gamma-1}{2} M_\infty^2}{1 + \frac{\gamma-1}{2} M_e^2}\right) + \sin^2\psi\right]^{1/2} \tag{C5}$$

$$u_c^* = 0 \tag{C6}$$

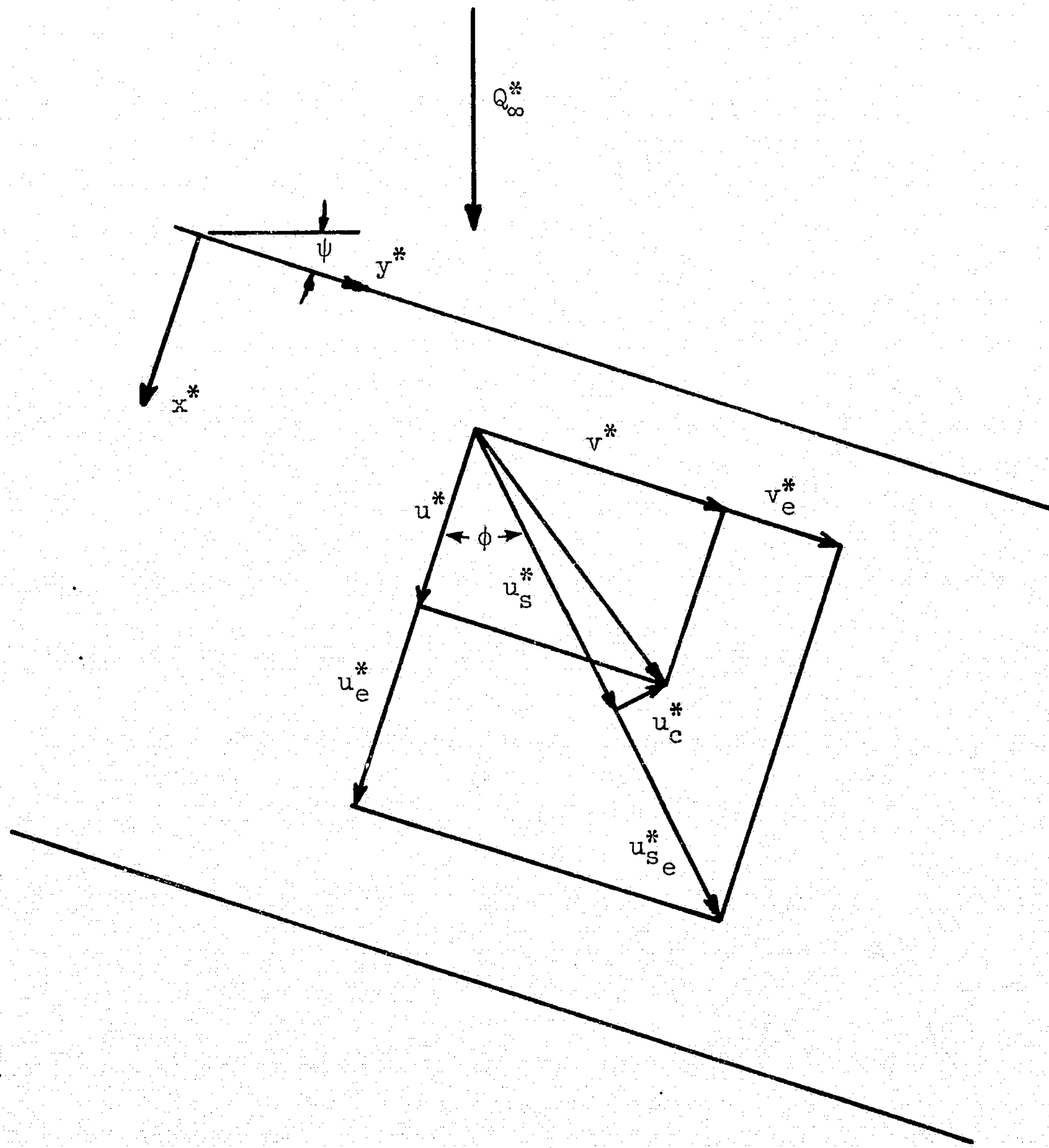


Figure C-1. Resolution of velocity components.

# PROGRAM LISTING

```
      PROGRAM STAYLAM(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT)

C     MASTER LAMINAR BOUNDARY LAYER

      COMMON/SUBWUV/J,ITS,TOL,IFCON,DS,DS1,DZ,WF,SH,UMGH,AO,CON3,CON6,
     1CON7,G,AN(170),BDO(170),BN(170),BNO(170),BND(170),CN(170),DDO(170)
     2,DN(170),BD1,DNO(170),DND(170),UM1(170),UMG(170),WM(170),WM1(170),
     3WNO(170),U(4),ANO(170)
      COMMON/SFX/STH(365),TH(365),FSTH(365),INT4,FZTH(365)
      COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
     1SXV(365),SXVINC(365),FSVSINC(365),L,SATT,INT3,CH,ISP
      COMMON/RESULTS/WM2(170),UM2(170),VM2(170),DELTA1,THETA1,NO,DUDZ
     1,DVDZ
      COMMON/GEOM/XA(365),ZA(365)
      DIMENSION XAHLD(365),ZAHLD(365)
      COMMON/TEST/RNL(10),INTRL,IFR
      COMMON/OPLIST/OPX(200),OPS(200)
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMES3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
      REAL MGRAD
      DIMENSION S(2),B(8),C(8)
      DIMENSION UM1H(170),UM2H(170),VM2H(170)
      DIMENSION WWALL(15),SDS(15)
      DIMENSION VCFX2(200),VCFY2(200),HSCOMP(200),LABEL(8)
     1,LAB(8),INFO(30)
      REAL KMAX(10)

      PI=3.14159265
      DTR=.017453292
      CALL PSEUDO
      CALL LEROY

C READ BOUNDARY LAYER CALCULATION PARAMETERS
C MAXIMUM NO. OF ITERATIONS, NO. OF STEPS IN Z DIRECTION, ITERATIVE
C TOLERANCE, STEPLENGTHS IN Z AND X DIRECTIONS, AND MAX VARIATION IN U
C ACROSS ONE STEP, WEIGHTING FACTOR FOR FINITE DIFFERENCE SCHEME

      CALL JPARAMS(INFO)
      ENCODE(80,425,LAB(1)) INFO(1),INFO(23),INFO(22)
  425 FORMAT(A7,3X,2A10,50X)
   24 READ(1,6)ITS,J,TOL,DZ,DS,USTEP,WF
    6 FORMAT(2I5,5F10.5)

      WRITE(2,103)
  103 FORMAT(1H1/1X65(2H*=)//
     149X,*INPUT  +  SOME COMPUTED QUANTITIES*
     2//1X65(2H*=)/)
      WRITE(2,400)ITS,J,TOL,DZ,DS,USTEP,WF
  400 FORMAT(5H ITS=,I5,2X,2HJ=,I5,2X,4HTOL=,F10.5,2X,3HDZ=,F10.5,2X,
     13HDS=,F10.5,2X,6HUSTEP=,F10.5,2X,3HWF=F10.5)

C READ BOUNDARY LAYER SUCTION OR INJECTION PARAMETER,IBLC.
C IBLC=0, NO SUCTION OR INJECTION PERMITTED.
C IBLC=1, DISCONTINUOUS SUCTION OR INJECTION PERMITTED.

      READ(1,77)IBLC
   77 FORMAT(I5)
      IF(IBLC.EQ.0)GO TO 78

C READ SUCTION OR INJECTION VELOCITY PARAMETER,WWALL(MS)= W/Q*SQRT(QL/NU
```

```
C ) WHICH IS ALLOWED TO CHANGE DISCONTINUOUSLY AT SDS(MS) LOCATIONS. A
C TOTAL OF MSMAX LOCATIONS ARE PERMITTED.

      READ(1,77)MSMAX
      READ(1,502)(WWALL(MS),SDS(MS),MS=1,MSMAX)
      WRITE(2,79)
   79 FORMAT(/* IBLC=1 DISCONTINUOUS SUCTION OR INJECTION GIVEN BELOW*)
      WRITE(2,80) MSMAX
   80 FORMAT(/1X29HSUCTION OR INJECTION VELOCITY,5X10HS LOCATION,
     15X6HMSMAX=I5)
      WRITE(2,81)(WWALL(MS),SDS(MS),MS=1,MSMAX)
   81 FORMAT(10X,9HWWALL(MS),20X7HSDS(MS)/(10XF10.5,15XF10.5))
      GO TO 82
   78 WRITE(2,84)
   84 FORMAT(/* IBLC=0 NO SUCTION OR INJECTION PERMITTED*/)
      WWALL(1)=0.0$ SDS(1)=100000.
   82 CONTINUE
C
C READ COMPRESSIBILITY PARAMETER,INC, AND FREESTREAM MACH NO.,AMINF3D
C       INC=1    FLOW IS INCOMPRESSIBLE
C       INC=0    FLOW IS COMPRESSIBLE, COMPUTATION MADE IN STEWARTSON
C                      TRANSFORMED VARIABLES
C
      READ 85,INC,AMINF3D,GAMMA
   85 FORMAT(I5,2F10.2)
      IF(INC.EQ.1) AMINF3D=0.
      PRINT 86,INC,AMINF3D,GAMMA
   86 FORMAT(/* INC=*I2,*    AMINF3D=*E16.8,*    GAMMA=*E16.8)
      IF(INC.EQ.1) GO TO 88
      PRINT 87
   87 FORMAT(* COMPRESSIBLE FLOW(INC=0).  STEWARTSON TRANSFORMATION USED
     1*)
      GO TO 90
   88 PRINT 89
   89 FORMAT(* INCOMPRESSIBLE FLOW (INC=1).*)
   90 CONTINUE
C
C CONSTANTS NEEDED FOR COMPRESSIBLE FLOW CALCULATION
C
      GM1=GAMMA-1.
      GP1=GAMMA+1.
      GAM1=(3.*GAMMA-1.)/(2.*GM1)
      GAM2=GP1/(2.*GM1)
      GAM3=GAMMA/GM1
      GAM4=(2.*GAMMA-1.)/(GAMMA-1.)
      AMFS3D=.5*GM1*AMINF3D**2
C READ MAIN TITLE (COLS 1->72)
   74 READ(1,151)B
  151 FORMAT(8A10)
      WRITE(2,420)B
  420 FORMAT(1H0,3HB= ,8A10)

C READ GEOMETRY PARAMETER AND CHORD LENGTH
C IF INT3=0 VELOCITY DATA WILL BE GIVEN AT INTERVALS MEASURED AROUND THE
C AEROFOIL SURFACE AND NO GEOMETRICAL DATA IS REQUIRED

      READ(1,72)INT3,CH
   72 FORMAT(I5,F10.5)
      WRITE(2,401)INT3,CH
  401 FORMAT(1H0,5HINT3=,I5,2X,3HCH=,F10.5)
```

```
C MUST DISTANCES AROUND SURFACE BE CALCULATED
      IF(INT3.EQ.0)GO TO 75

C READ GEOMETRIC DATA
C SYMMETRY PARAMETER, NO. OF PAIRS OF CO-ORDINATES, NOSE RADIUS.
C IF ISY=0 AEROFOIL IS CAMBERED, IF ISY=1 AEROFOIL IS SYMMETRICAL.

   76 READ(1,100)ISY,INT4,RHO
  100 FORMAT(2I5,2F10.5)
      WRITE(2,402)ISY,INT4,RHO
  402 FORMAT(1H0,4HISY=,I5,2X,5HINT4=,I5,2X,4HRHO=,E16.8)
      RHO=RHO/CH

C READ (INT4) PAIRS OF  X  AND  Z

      N1=(INT4-1)*ISY+1
      N2=(INT4-1)*ISY+INT4
      READ(1,510)(XAHLD(N),ZAHLD(N),N=N1,N2)
  510 FORMAT(2E16.8)
  502 FORMAT(2F10.5)
C
C READ ISP, SURFACE PARAMETER
C ISP=2  UPPER SURFACE CALCULATION
C ISP=0  LOWER SURFACE CALCULATION
C
      READ(1,100) ISP
      WRITE(2,101) ISP
  101 FORMAT(/* ISP=*I2)
      IF(ISP.EQ.2) GO TO 107
      DO 105 N=1,INT4
      I=INT4-N+1
      XA(I)=-XAHLD(N)
  105 ZA(I)=-ZAHLD(N)
      GO TO 110
  107 DO 109 N=1,INT4
      XA(N)=XAHLD(N)
  109 ZA(N)=ZAHLD(N)
  110 CONTINUE

C CALCULATE DISTANCES AROUND SURFACE CORRESPONDING TO DISTANCES
C ALONG CHORD LINE.
      CALL GEOMTRY (ISY,RHO,CH)
      WRITE(2,403)(N,XA(N),ZA(N),STH(N),TH(N),FSTH(N),FZTH(N),N=N1,N2)
  403 FORMAT(1H0,4X1HN,5X5HXA(N),11X5HZA(N),11X6HSTH(N),10X5HTH(N),
     110X7HFSTH(N),8X7HFZTH(N)/
     2(1X,I5,6E16.8))

C READ TWO OUTPUT PARAMETERS, NO. OF POINTS IN OUTPUT LIST (IF IFPT=2)
C AND OUTPUT INTERVAL IN X (IF IFPT=4).
C IFPT=1. FULL PRINT OUT EVERY STEP, IFPT=2. FULL P/O AT POINTS IN LIST,
C IFPT=3. FULL P/O AT VELOCITY DATA POINTS, IFPT=4. FULLP/O AT EVERY
C NTH STANDARD O/P STEP,DX. IN Z DIRECTION EVERY INT1 POINT IS PRINTED.

   75 READ(1,106)IFPT,INT1,NLIST,DX
      NLISTP1=NLIST+1
  106 FORMAT(3I5,2F10.5)
      WRITE(2,404)IFPT,INT1,NLIST,DX
  404 FORMAT(1H0,5HIFPT=,I5,2X,5HINT1=,I5,2X,6HNLIST=,I5,2X,3HDX=,F10.5)
```

```
      IF(IFPT.NE.2)GO TO 310
C  READ LIST OF OUTPUT POINTS
      READ (1,501)(OPX(N),N=2,NLISTP1)
  501 FORMAT(8F10.5)
      WRITE(2,405)(OPX(N),N=2,NLISTP1)
  405 FORMAT(1H0,6HOPX(N)/(1H ,8(F10.5,2X)))
  310 CONTINUE

C READ SUB-TITLE
   73 READ(1,151)C
      WRITE(2,421)C
  421 FORMAT(1H0,3HC= ,8A10)

C READ ANGLE OF SHEAR (IN DEGREES) AND TRIPWIRE DIAMETER.

      READ(1,501)PSI,DTRIP
      WRITE(2,406)PSI,DTRIP
  406 FORMAT(1H0,4HPSI=,F10.5,2X,6HDTRIP=,F10.5)

      PSI=DTR*PSI

      COSP=COS(PSI)
      SINP=SIN(PSI)

C READ NUMBER OF VALUES OF REYNOLDS NUMBER AND DEFINITION PARAMETER
C IFR=1, RN=QL*SEC(PSI)/NU, IFR=2, RN=QL/NU, IFR=3, RN=QL*COS(PSI)/NU

      READ(1,100)INTRL,IFR
      READ(1,501)(RNL(I),I=1,INTRL)
      WRITE(2,407)INTRL,IFR
  407 FORMAT(1H0,6HINTRL=,I2,2X,4HIFR=,I2)
      WRITE(2,408)(RNL(I),I=1,INTRL)
  408 FORMAT(1H0,6HRNL(I)/(1H ,8(F10.1,2X)))

C READ VELOCITY DATA PARAMETER AND NO. OF PAIRS OF VALUES TO FOLLOW
C INTV=1, U FOLLOW, INTV=2, U*SEC(PSI) FOLLOW, INTV=3, CPS FOLLOW.

   98 READ(1,100)INTV,L
      LP1=L+1
      READ(1,510)(XV(I),UM(I),I=2,LP1)
      IF(ISP.EQ.2) GO TO 112
      DO 108 I=2,LP1
  108 XV(I)=-XV(I)
  112 ICOUNT=0
      WRITE(2,409)INTV,L
  409 FORMAT(1H0,5HINTV=,I2,2X,2HL=,I3)
      IF(INC.EQ.0) PRINT 503
  503 FORMAT(/* FLOW IS COMPRESSIBLE AND THE FOLLOWING UM(I) IS THE MACH
     1 NO. DISTRIBUTION NORMAL TO THE LEADING EDGE (MEN)*)
      WRITE(2,410)(I,XV(I),UM(I),I=2,LP1)
      IF (INC.EQ.1) GO TO 505
      AMINFR=1./AMINF3D
      DO 504 I=2,LP1
  504 UM(I)=UM(I)*AMINFR
  505 CONTINUE
  410 FORMAT(1H0,4X1HI,3X5HXV(I),5X5HUM(I)/(1X,I5,2F10.5))

      UM(1)=0.0

C CONVERT VELOCITY DATA TO U.
```

```
      IF(INTV.NE.1)CALL VELOCTS   (INTV,COSP)

C READ VELOCITY GRADIENT AT ATTACHMENT LINE AND, IF VGRAD > 0 AND
C INT3 NOT = 0 , DISTANCE FROM LEADING EDGE TO ATTACHMENT LINE .
      IF (INC.EQ.1) GO TO 422
C
C FLOW IS COMPRESSIBLE.  READ IN MGRAD=DMEN/DSCOMP. THEN COMPUTE VIA THE
C     STEWARTSON TRANSFORMATION THE TRANSFORMED INCOMPRESSIBLE VELOCITY
C     GRADIENT,  VGRAD,  WHERE
C          VGRAD=D(UPRIME/DN)/DSINC
C                =VGRAD/AMINF3D*DSCOMP/DSINC*SEC(PSI)
C
      READ(1,501) MGRAD,XV(1)
      IF(ISP.EQ.2) GO TO 113
      XV(1)=-XV(1)
  113 WRITE(2,428) MGRAD
  428 FORMAT(/* MGRAD=*E16.8)
      RATIO=1./(1.+AMFS3D*COSP**2)
      VGRAD=MGRAD/AMINF3D*RATIO**GAM1/COSP
      GO TO 427
  422 READ(1,501) VGRAD,XV(1)
  427 WRITE(2,411) VGRAD,XV(1)
  411 FORMAT(1H0,6HVGRAD=,F10.5,2X,6HXV(1)=,E16.8)
      IF(VGRAD.GT.0.) GO TO 122

      IF(ISY.EQ.0.OR.INT3.EQ.0)GO TO 14

C READ DATA FOR S/R TO COMPUTE (DU/DX)A.L.
      READ(1,501)ALPHA,S1,S3
      WRITE(2,412)ALPHA,S1,S3
  412 FORMAT(1H0,6HALPHA=,F8.5,2X,3HS1=,F8.5,2X,3HS3=,F8.5)
      ALPHA=ALPHA/COSP
      GO TO 13

   14 WRITE(2,312)
  312 FORMAT(55H0VELOCITY GRADIENT MUST BE SPFCIFIED WITH THIS GEOMETRY)
      GO TO 21

C COMPUTE VELOCITY GRADIENT AT ATTACHMENT LINE
   13 CALL VGRADAT(ALPHA,RHO,S1,S3,VGRAD,XV(1))
      XV(1)=XV(1)*CH

C INTERPOLATE FROM TABLES TO FIND DISTANCES FROM ATTACHMENT LINE TO
C POINTS AT WHICH VELOCITY DATA IS GIVEN.
  122 CALL STHFRMX (L+1,XV,SXV,THXV,DSDT,INT3,CH,XV(1),SATT)
      PRINT 511,SATT
  511 FORMAT(/* NON-DIMENSIONAL DISTANCE FROM LOWER SURFACE TRAILING EDG
     1E (IF UPPER SURFACE IS TO BE COMPUTED,ISP=2), OR FROM UPPER SURFAC
     2E*/*  TRAILING EDGE (IF LOWER SURFACE IS TO BE COMPUTED,ISP=0) TO
     3ATTACHMENT LINE = SATT/CH =*E16.8/)
      IF (INC.EQ.1) GO TO 508
C
C FLOW IS COMPRESSIBLE.  USE THE STEWARTSON TRANSFORMATION IN
C     S/R  SINCFRS  TO TRANSFORM THE ACTUAL SURFACE DISTANCE,S, INTO AN
C     EQUIVALENT INCOMPRESSIBLE DISTANCE, SINC
C
      CALL SINCFRS(LP1,SXV,SXVINC,UM,DSCDSI1,DSCDSI2)
      GO TO 507
  508 DO 506 N=1,LP1
  506 SXVINC(N)=SXV(N)
```

```
      GO TO 509
C
C     FROM SXVINC AND SXV(SXVINC) COMPUTE FSVSINC  FOR INTERPOLATION
C        FROM INCOMPRESSIBLE, TRANSFORMED (STEWARTSON) PLANE TO
C        COMPRESSIBLE, PHYSICAL PLANE
C
  507 CALL CSG(SXVINC,SXV,FSVSINC,LP1,DSCDSI1, DSCDSI2)
  509 CONTINUE

C WRITE MAIN AND SUB TITLES
      WRITE(2,83)B,C
   83 FORMAT(1H1,8A10/1H0,8A10)

      WRITE(2,414)
  414 FORMAT(1H0,31HREYNOLDS NUMBER DEFINED BY RN= )
      IF(IFR.EQ.1)WRITE(2,415)
      IF(IFR.EQ.2)WRITE(2,416)
      IF(IFR.EQ.3)WRITE(2,417)
  415 FORMAT(1H+,31X,14HQL*SEC(PSI)/NU)
  416 FORMAT(1H+,31X,10HQL/NU      )
  417 FORMAT(1H+,31X,14HQL*COS(PSI)/NU)
   91 WRITE(2,92)VGRAD
   92 FORMAT(39H0VELOCITY GRADIENT AT ATTACHMENT LINE= ,F8.2)

      L=L+1

      LP1=L+1
C FROM THETA AND U(THETA) COMPUTE FUTH FOR VELOCITY INTERPOLATIONS.
      CALL CSG(THXV,UM,FUTH,L,DSDT*VGRAD*COSP,(UM(L)-UM(L-1))/(THXV(L)-
     1THXV(L-1)))
C
C     WRITE TABLE OF VELOCITY DATA
      CALL XSCPPNT(INTV)

      NLIST=NLIST+1

C COMPILE LIST OF OUTPUT POINTS IF REQUIRED.
      IF(IFPT.NE.1)CALL PLIST(IFPT,NLIST,SXV,SXVINC,L,DS,INT3,CH,XV(1),
     1DX,INC)

C IS WING SHEARED
      IF(PSI.LT..00001)GO TO 26


C GUESS AT VELOCITIES AT ATTACHMENT LINE
   26 A=J
      DO 9 N=2,J
      UM1(N)=(N-1)/A
    9 CONTINUE

C CONSTANT
      AO=-0.5/(DZ*DZ)

C SET STEP COUNT
      M=1
      MS=1

      IFCON=0

C BOUNDARY CONDITIONS INCLUDING SUCTION OR INJECTION.
```

```
      UM1(1)=UMG(1)=UM2(1)=VM2(1)=0.
      WCON1=(1.+AMFS3D*COSP**2)**(-.5)/(1.+AMFS3D)
      WM(1)=WWALL(1)/SQRT(VGRAD*COSP)*WCON1
      UM2(J+1)=VM2(J+1)=1.

C GO TO S/R WUV TO COMPUTE W, U AND V AT ATTACHMENT LINE.

      CALL WUV(1,S(2))

      ANGLE1=ANGLE2=.5*PI
      SCOMP=0.
      AME3D=SQRT((AMINF3D**2*SINP**2)/(1.+AMFS3D*COSP**2))

C WRITE ATTACHMENT LINE PROFILES

C LEADING EDGE CONTAMINATION TEST

      WRITE(2,104)
  104 FORMAT(1H1/1X65(2H*-)//64X6HOUTPUT//1X65(2H*-))
      CALL        CONTAM(VGRAD,DTRIP,CH,COSP,SINP,THETA1,RATIO)
      CALL PRINT(XV(1),0.,0.,VGRAD*COSP,J,DZ,INT1,1,0.,0,ANGLE2)

      DO 18 N=1,INTRL
      KMAX(N)=0.0
   18 CONTINUE
      S(1)=0.
      SCOMP1=0.
      U(1)=UM(1)
      DSZ=DS

      NEXT=1
      SNEXT=-1.0
      INTHOLD=0
      LAST=0
      IST=1
      CFX1=0.
      CDFX=0.
      CDFXINF=0.
      CFY1=2.*SINP*(VGRAD*COSP/RNL(1))**.5*DVDZ

C ADVANCE STEP COUNT
   11 M=M+1
      LC=0

C CALCULATE LENGTH OF NEXT STEP IN X DIRECTION

   10 CALL STPLNTH  (SNEXT,S,INTHOLD,DS,DS1,DSZ,NEXT,NLIST,LAST,
     1IFPT,LC,ILP,U,USTEP,DUDS,X,SH,ITC,ANGLE2,WF)

C IS COMPUTATION TO END
      IF(LAST.EQ.2)GO TO 239

C DOES THIS STEP END AT A LISTED OUTPUT POINT
      IF(ILP.NE.1)GO TO 49

C STORE U(M-2), U(M-1) AND V(M-1) PROFILES WHILE A STEP ENDING AT A
C LISTED OUTPUT POINT IS COMPUTED
      DO 46 N=2,J
      UM1H(N)=UM1(N)
      UM2H(N)=UM2(N)
```

```
      VM2H(N)=VM2(N)
   46 CONTINUE

   49 CONTINUE

C VARIABLES INDEPENDENT OF N
      UAVG=WF*U(2)+(1.-WF)*U(1)
      G=WF**2/4.*(SH/(UAVG*DS1)*(U(2)-U(1))-1.)
      CON1=1./DZ**2
      CON2=(1.-WF)/WF
      CON3=SH/(DS1*UAVG)
      CON4=(1.-WF)*SH/DS1
      CON5=((1.-WF)/WF)**2
      CON6=SH*DZ/(2.*WF*DS1*UAVG)
      CON7=SH/DS1

C VARIABLES DEPENDENT ON N
      DO 3 N=2,J
      G1=G*(UM2(N+1)-UM2(N-1))
      ANO(N)=CON2*G*(N-1)*UM2(N)
      WNO(N)=CON6*((2.*WF-1.)*U(2)+2.*(1.-WF)*U(1))*(UM2(N)+UM2(N-1))
     1-(4*N-6)*(1.-WF)*DZ/(2.*WF**3)*G*(UM2(N)-UM2(N-1))
      IF(WF.LT..501)WNO(N)=.5*WNO(N)
      BNO(N)=-4.*WF*AO+CON2*(N-1)*G*(UM2(N+1)-UM2(N-1))
      IF(WF.GE..75) GO TO 512
      BNO(N)=CON3*WF*(3.-4.*WF)*U(2)*UM2(N)+BNO(N)
  512 DNO(N)=CON3*(U(2)-U(1)+((2.*WF-1.)*(1.-WF)*U(2)+2.*(1.-WF)**2*U(1)
     1)*UM2(N)*UM2(N))+CON1*(1.-WF)*(UM2(N+1)-2.*UM2(N)+UM2(N-1))
     2-CON5*(N-1)*UM2(N)*(UM2(N+1)-UM2(N-1))*G
      BDO(N)=CON4*UM2(N)+2.*WF*CON1
      DDO(N)=CON4*VM2(N)*UM2(N)+(1.-WF)*CON1*(VM2(N+1)-2.*VM2(N)+VM2(N-1
     1))-CON5*G*(N-1)*UM2(N)*(VM2(N+1)-VM2(N-1))

C EXTRAPOLATE TO ESTIMATE UM PROFILE
      IF(M.GT.3)GO TO 2
      UMG(N)=UM2(N)
      GO TO 3

    2 UMG(N)=UM2(N)+DS1/DS2*(UM2(N)-UM1(N))

    3 CONTINUE

C COMPLETE THE SPECIFICATION OF SURFACE SUCTION OR INJECTION VELOCITY,W.

      IF(IBLC.EQ.0)GO TO 201
      WCON2=SQRT(1.+.5*(GAMMA-1.)*AME3D**2)/(1.+AME3D)**1.5
      SHCOMP=WF*SCOMP+(1.-WF)*SCOMP1
      IF(SDS(MS).GT.SHCOMP) GO TO 200
      MS=MS+1
  200 WM(1)=WWALL(MS)*(SH/UAVG)**.5*(WF*WCON2+(1.-WF)*WCON1)
      GO TO 202
  201 WM(1)=0.
  202 CONTINUE

C COMPUTE  WM,  UM  AND VM  PROFILES

      CALL WUV(M,S(2))

C COMPUTE SKIN FRICTION DRAG,BASED ON REYNOLDS NUMBER DEFINITION,IFR=2
C AND THE FIRST VALUE IN REYNOLDS NUMBER ARRAY,RNL(I).
```

```
C CFX=TAUX/(.5*RHOINF*QINF**2)
C CFY=TAUY/(.5*RHOINF*QINF**2)
C CDFX = SKIN FRICTION DRAG COEFFICIENT IN DIRECTION PERPENDICULAR TO LE
C      BASED ON CHORD MEASURED PERPENDICULAR TO LE
C CDFXINF = TOTAL SKIN FRICTION DRAG COEFFICIENT IN FREESTREAM DIRECTION
C      BASED ON CHORD MEASURED PARALLEL TO FREESTREAM

      IF(ILP.EQ.1)GO TO 203
      ICOUNT=ICOUNT+1
      DSCOMP=SCOMP-SCOMP1
      CFX2=2.*U(2)*(U(2)/(RNL(1)*S(2)))**.5*DUDZ
      CFY2=2.*SINP*(U(2)/(RNL(1)*S(2)))**.5*DVDZ
      DCDFX=.5*DSCOMP*(COS(ANGLE1)*CFX1+COS(ANGLE2)*CFX2)
      VCFY2(ICOUNT)=1000.*CFY2
      VCFX2(ICOUNT)=1000.*CFX2
      HSCOMP(ICOUNT)=SCOMP
      CDFX=CDFX+DCDFX
      CDFXINF=CDFXINF+DCDFX*COSP+.5*SINP*DSCOMP*(CFY2+CFY1)
  203 CONTINUE

C HAS ITERATION CONVERGED
      IF(IFCON.EQ.1)GO TO 239

C HAS STEP LENGTH BEEN HALVED TWICE ALREADY
      IF(LC.EQ.2)GO TO 238

C HALVE STEP LENGTH AND TRY AGAIN
      LC=LC+1
      GO TO 10

  238 IFCON=3
      LAST=2

C DETERMINE IF PRINT OUT IS TO BE COMPLETE, PARTIAL OR SKIPPED
  239 CALL IFPRINT(IFPT,ILP,LAST,JACKPOT)

      IF(JACKPOT.EQ.0)GO TO 5

C COMPUTE CROSS-FLOW VELOCITIES
      IF(PSI.GT..0001) CALL CRSSFLW(J,DZ,U(2))

C WRITE BOUNDARY-LAYER CALCULATION RESULTS AS REQUIRED
      CALL  PRINT(X,S(2),U(2),DUDS,J,DZ,INT1,JACKPOT,PSI,LC,ANGLE2)

C CALCULATE DIMENSIONALISING FACTORS
      CALL DMNSION(S(2),U(2),COSP,DELTA1,THETA1,ILP,CFX2,CFY2,CDFX,
     1CDFXINF)

C RE-LAMINARISATION TEST
      IF(KMAX(INTRL).GT.-0.5)CALL RELAM(U,S,SINP,COSP,KMAX)

C IS PRINT-OUT COMPLETE
      IF(JACKPOT.EQ.2)GO TO 5

C CROSS-FLOW INSTABILITY TEST
      IF(PSI.GT..0001)
     1 CALL       INSTAB(COSP,S(2),U(2),CH,RATIO,AME3D,AMINF3D)

C VISCOUS INSTABILITY TEST
   50 CALL TRANS(S(2),DUDS,THETA1,U(2),U(1),IST,JACKPOT)
```

```
C IS STEP JUST ENDED THE LAST ONE REQUIRED
      IF(LAST.EQ.1) GO TO 27

C DOES LAST STEP END AT A LISTED OUTPUT POINT
      IF(ILP.EQ.1)GO TO 47

      U(1)=U(2)
      S(1)=S(2)
      SCOMP1=SCOMP
      WCON1=WCON2
      DSZ=DS1
      CFX1=CFX2
      CFY1=CFY2
      ANGLE1=ANGLE2
      GO TO 11

C REPLACE U(M-2), U(M-1) AND V(M-1) PROFILES WITH THOSE STORED AT START
C OF LAST STEP
   47 DO 48 N=2,J
      UM1(N)=UM1H(N)
      UM2(N)=UM2H(N)
      VM2(N)=VM2H(N)
   48 CONTINUE
      GO TO 11

   27 WRITE(2,19)
   19 FORMAT(63H0LAMINAR FLOW CALCULATED TO END OF DATA OR LAST POINT RE
     1QUESTED)
      GO TO 21
    5 WRITE(2,20)
   20 FORMAT(11H0SEPARATION)

C READ CUE TO READ MORE DATA OR TO FINISH
   21 READ(1,100)KUE
      WRITE(2,413)KUE
  413 FORMAT(1H1,4HKUE=,I2)

C
C PLOT INSTRUCTIONS FOR  X  AND  Y  SKIN FRICTION DISTRIBUTIONS
C
      NPTS=ICOUNT
      HGT=.14$   HGT1=.14$   HGT2=.06$  HGT3=.05
      NP1=NPTS+1
      NP2=NPTS+2
      YORG=0.$  XORG=0.
      XSCALE=.2
      XPG=5.
      YPG=6.
      XDV=0.$   XTIC=-1.
      YDV=0.$  YTIC=-1.
      ORG=0.
      CALL BSCALE(VCFX2,YPG,NPTS,1,1.,-1,ORG)
      YSCALE=VCFY2(NP2)=VCFX2(NP2)
      VCFX2(NPTS+1)=VCFY2(NPTS+1)=YORG
      VCFX2(NPTS+2)=VCFY2(NPTS+2)=YSCALE
      HSCOMP(NPTS+1)=XORG
      HSCOMP(NPTS+2)=XSCALE
      CALL CALPLT(2.,3.,-3)
      CALL AXES(0.0,0.0,90.,YPG,VCFX2(NP1),VCFX2(NP2),YTIC,YDV,1H ,HGT1,
```

```
     1+1)
      CALL NOTATE(-.5,2.5,HGT,9H CFX*1000,90.,9)
      CALL NOTATE(-.75,2.5,HGT,9H CFY*1000,90.,9)
      CALL AXES(0.0,0.0,0.0,XPG,HSCOMP(NP1),HSCOMP(NP2),XTIC,XDV,
     116HSURFACE DISTANCE,HGT1,-16)
      CALL LINE(HSCOMP,VCFX2,NPTS,1,+1,3,.06)
      CALL LINE(HSCOMP,VCFY2,NPTS,1,+1,4,.05)
      CALL NOTATE(.5,YPG,HGT,27HSKIN FRICTION DISTRIBUTIONS,0.,27)
      HGL=.14
      XPLT=.5+.5*HGL
      YPLT=YPG-.40+.5*HGL
      CALL NOTATE(XPLT,YPLT,HGL,3,0.,-1)
      CALL NOTATE(1.0,YPG-.40,HGT,3HCFX,0.,3)
      YPLT=YPG-.70+.5*(HGL-.02)
      CALL NOTATE(XPLT,YPLT,HGL-.02,4,0.,-1)
      CALL NOTATE(1.0,YPG-.70,HGT,3HCFY,0.,3)
      PSID=PSI*57.29577951
      ENCODE(80,423,LABEL(1)) AMINF3D,PSID,RNL(1)
  423 FORMAT(8HAMINF3D=F5.3,3X,4HPSI=F4.1,3X7HRNL(1)=1PE9.2,37X)
      CALL NOTATE(0.,-1.00,HGT,LABEL(1),0.,80)
      ENCODE(80,426,LABEL(1)) CDFX,CDFXINF
  426 FORMAT(5HCDFX=,F7.5,5X,8HCDFXINF=F7.5,48X)
      CALL NOTATE(0.,-1.25,HGT,LABEL(1),0.,80)
      CALL NOTATE(0.,-1.50,HGT,LAB(1),0.,80)
      IF(KUE.EQ.1)GO TO 24
      IF(KUE.EQ.2)GO TO 74
      IF(KUE.EQ.3)GO TO 76
      IF(KUE.EQ.4)GO TO 75
      IF(KUE.EQ.5)GO TO 73
      IF(KUE.EQ.6)GO TO 98
      CALL CALPLT(0.,0.,999)
      STOP 0101
      END


      SUBROUTINE SINCFRS(J,SXV,SXVINC,UM,DSCDSI1,DSCDSI2)
      DIMENSION SXV(1),SXVINC(1),UM(1)
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMFS3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
C
C     USE STEWARTSON TRANSFORMATION TO CONVERT SXV,THE PHYSICAL DISTANCE
C        AROUND THE AIRFOIL AT WHICH MACH NO. IS GIVEN, TO SXVINC, AN
C        EQUIVALENT INCOMPRESSIBLE COORDINATE
C
      GM1=GAMMA-1.
      DENOMR=1./(1.+AMFS3D*COSP**2)
      SXVINC(1)=0.
      CON=(1.+AMFS3D)**GAM1
      FAC1=1.+AMFS3D
      DO 10 N=2,J
      AME3DN=AMINF3D**2*(UM(N)**2*FAC1+SINP**2)*DENOMR
      AME3DN1=AMINF3D**2*(UM(N-1)**2*FAC1+SINP**2)*DENOMR
      AMEN=1.+.5*GM1*AME3DN
      AMEN1=1.+.5*GM1*AME3DN1
   10 SXVINC(N)=.5*CON*(AMEN**(-GAM1)+AMEN1**(-GAM1))*
     1(SXV(N)-SXV(N-1))+SXVINC(N-1)
      AME3D1=AMINF3D**2*(UM(1)**2*FAC1+SINP**2)*DENOMR
      AME3DJ=AMINF3D**2*(UM(J)**2*FAC1+SINP**2)*DENOMR
      AME1=1.+.5*GM1*AME3D1
```

```
      AMEJ=1.+.5*GM1*AME3DJ
      DSCDSI1=AMEI**GAM1/CON
      DSCDSI2=AMEJ**GAM1/CON
      RETURN
      END


      SUBROUTINE WUV(M,S)

C COMPUTES W, U AND V PROFILES.

      COMMON/SUBWUV/J,ITS,TOL,IFCON,DS,DS1,DZ,WF,SH,UMGH,AO,CON3,CON6,
     1CON7,G,AN(170),BDO(170),BN(170),BNO(170),BND(170),CN(170),DDO(170)
     2,DN(170),BD1,DNO(170),DND(170),UM1(170),UMG(170),WM(170),WM1(170),
     3WNO(170),U(4),AND(170)
      COMMON/RESULTS/WM2(170),UM2(170),VM2(170),DELTA1,THETA1,NO,DUDZ
     1,DVDZ
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMES3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
      DIMENSION UP(170),Y(170)

      NO=0

C EVALUATION OF W

   11 DO 2 N=2,J
      IF(M.NE.1)GO TO 1
C W AT ATTACHMENT LINE
      WM(N)=WM(N-1)-0.5*DZ*(UM1(N)+UM1(N-1))
      GO TO 2

C W AT X(M-1/2)
    1 FACT=-WF*CON6*(2.*U(2)+(1.-2.*WF)/WF*U(1))*(UMG(N)+UMG(N-1))
     1-(4*N-6)*.5*DZ/WF**2*(UMG(N)-UMG(N-1))*G
      IF(WF.LT..501) GO TO 50
      WM(N)=WM(N-1)-(1.-WF)/WF*(WM1(N)-WM1(N-1))+WNO(N)+FACT
      GO TO 2
   50 WM(N)=WM(N-1)+WNO(N)+.5*FACT
    2 CONTINUE

C EVALUATION OF UM,N

      DO 4 N=2,J
      IF(M.NE.1)GO TO 3

      AN(N)=0.5*WM(N)/DZ+2*AO
      BN(N)=UM1(N)-4*AO
      CN(N)=-AN(N)+4*AO
      DN(N)=1
      GO TO 4

    3 IF(WF.LT..501) GO TO 51
      AN(N)=2.*WF*AO+.5*WF/DZ*(WF*WM(N)+(1.-WF)*WM1(N))+(N-1)*G*UMG(N)
     1+ANO(N)
      DN(N)=DNO(N)+CON3*U(1)*(1.-WF)*(4.*WF-1.)*UM2(N)*UMG(N)-.5/DZ*(1.-
     1WF)*(UM2(N+1)-UM2(N-1))*(WF*WM(N)+(1.-WF)*WM1(N))
      GO TO 52
   51 AN(N)=       AO+.25/DZ*WM(N)+(N-1)*G*UMG(N)+ANO(N)
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```
      DN(N)=DNO(N)+.5*CON3*U(1)*UM2(N)*UMG(N)-.25/DZ*(UM2(N+1)-UM2(N-1))
     1*WM(N)
   52 BN(N)=CON3*(2.*WF**2*U(2)+WF*(1.-2.*WF)*U(1))*UMG(N)+BND(N)
      CN(N)=-AN(N)+4.*WF*AO
      FACT=-CON3*WF*(3.-4.*WF)*U(2)*UM2(N)*UMG(N)
      IF(WF.LT..75) GO TO 4
      DN(N)=DN(N)+FACT
    4 CONTINUE

      UP(J)=BN(J)
      DO 5 K=3,J
      N=J-K+3
      UP(N-1)=BN(N-1)-AN(N-1)*CN(N)/UP(N)
    5 CONTINUE

      Y(J)=DN(J)-AN(J)
      DO 6 K=3,J
      N=J-K+3
      Y(N-1)=DN(N-1)-AN(N-1)*Y(N)/UP(N)
    6 CONTINUE

      UMG(2)=Y(2)/UP(2)
      DO 7 N=3,J
      UMG(N)=(Y(N)-CN(N)*UMG(N-1))/UP(N)
    7 CONTINUE

C COUNT NUMBER OF ITERATIONS
      NO=NO+1
      IF(NO.LT.3) GO TO 22

      IF(TOL.GT.ABS(UMGH-UMG(2))/DZ)GO TO 8
C CHECK NUMBER OF ITERATIONS
      IF(NO.GE.ITS)GO TO 12

C STORE U NEAREST SURFACE FOR CONVERGENCE CHECK
   22 UMGH=UMG(2)
      IF(M.NE.1)GO TO 11

      DO 37 N=2,J
      UM1(N)=UMG(N)
   37 CONTINUE
      GO TO 11

C ITERATION HAS NOT CONVERGED
   12 IFCON=2
      RETURN

C ITERATION HAS CONVERGED
    8 IFCON=1

C EVALUATION OF VM,N

      DO 16 N=2,J

      IF(M.GT.1)GO TO 21
      BND(N)=-4*AO
      DND(N)=0
      GO TO 16

   21 BND(N)=BDO(N)+WF*CON7*UMG(N)
```

```
      IF(WF.LT..501) GO TO 53
      FACT=.5/DZ*(1.-WF)*(WF*WM(N)+(1.-WF)*WM1(N))
      GO TO 54
   53 FACT=.25/DZ*WM(N)
   54 DND(N)=DDO(N)+CON7*WF*VM2(N)*UMG(N)-(VM2(N+1)-VM2(N-1))*(FACT+(1.-
     1WF)/WF*(N-1)*G*UMG(N))

   16 CONTINUE

      UP(J)=BND(J)
      DO 17 K=3,J
      N=J-K+3
      UP(N-1)=BND(N-1)-AN(N-1)*CN(N)/UP(N)
   17 CONTINUE

      Y(J)=DND(J)-AN(J)
      DO 18 K=3,J
      N=J-K+3
      Y(N-1)=DND(N-1)-AN(N-1)*Y(N)/UP(N)
   18 CONTINUE

      VM2(2)=Y(2)/UP(2)
      DO 19 N=3,J
      VM2(N)=(Y(N)-CN(N)*VM2(N-1))/UP(N)
   19 CONTINUE

      DO 23 N=1,J
C STORE W PROFILE FOR POSSIBLE PRINTING OUT.
      WM2(N)=WM(N)
C U PROFILE AT END OF STEP BECOMES PROFILE AT START OF NEXT STEP.
      UM1(N)=UM2(N)
      UM2(N)=UMG(N)
      WM1(N)=WM(N)
   23 CONTINUE
C
C     COMPUTE TEMPERATURE RATIO,  T(N)=T/TINF  AND  DENSITY RATIO,
C        RHOD(N)=RHO/RHOINF,  AND THE COMPRESSIBLE (ACTUAL) NORMAL
C        COORDINATE, ZCOMP(N)=Z/C
C
      IF(M.GT.1)GO TO 25
      U(2)=0.
      RATIO=1./(1.+AMFS3D*COSP**2)
   25 ZCON=RATIO**GAM1
      DELCON=RATIO**GAM2
      RHOCON=RATIO**(-GAM3)
      CFCONX=RATIO**(-GAM4)
      CFCONY=RATIO**(-GAM1)
      UCON=RATIO**(-.5)*U(2)
      ZCOMP(1)=0.
      JP1=J+1
      DO 26 N=1,JP1
      URATIO=UCON*UM2(N)
      VRATIO=SINP*VM2(N)
      T(N)=1.+AMFS3D*(1.-URATIO**2-VRATIO**2)
      RHOD(N)=RHOCON/T(N)
      IF (N.EQ.1) GO TO 26
      ZCOMP(N)=ZCON*.5*(T(N)+T(N-1))*DZ+ZCOMP(N-1)
   26 CONTINUE

C CALCULATE DISPLACEMENT AND MOMENTUM THICKNESSES.
```

```
      DELTA1=1.0
      THETA1=0
      N=1
      IS=1
   40 N=N+1
      DELTA1=DELTA1+(1-UM2(N))*(3+IS)
      THETA1=THETA1+(UM2(N)*(1-UM2(N))*(3+IS))
      IS=-IS
      IF(UM2(N).GE.1.0-TOL*DZ)GO TO 41
      IF(N.LT.J+1)GO TO 40
   41 DELTA1=DELTA1*DZ/3.0
      THETA1=THETA1*DZ/3.0
      ZEDGE=FLOAT(N-1)*DZ
      DELTA1=ZCOMP(N)-DELCON*(ZEDGE-DELTA1)
      THETA1=DELCON*THETA1

C ESTIMATE  (DU/DZ) AND (DV/DZ) AT  Z=0.
      DUDZ=(2.*UM2(2)-0.5*UM2(3))/DZ*CFCONX
      DVDZ=(2.0*VM2(2)-0.5*VM2(3))/DZ*CFCONY

      RETURN

      END



      FUNCTION THX(X)

C TRANSFORMS X TO THETA

      ARG=2.*ABS(X)-1.
      IF(ARG.LE.1.0) GO TO 2
      WRITE(2,3) X,ARG
    3 FORMAT(///* ERROR NO. 2 DETECTED BY ACOSIN IN FUNCTION THX*/
     1* X=*E16.8,*  ARG=*,E16.8//)
      IF(ARG.GT.1..AND.ARG.LT.1.0000001) ARG=1.
    2 THX=ACOS(ARG)
      IF(X.LT.0.)GO TO 1
      THX=6.2831853-THX
    1 RETURN
      END



      FUNCTION XTH(THETA)

C TRANSFORMS THETA TO X

      XTH=0.5*(1+COS(THETA))
      IF(THETA.GT.3.1415926)GO TO 1
      XTH=-XTH
    1 RETURN
      END
```

```
      SUBROUTINE CSG(X,Y,F,NOP,E1,F1)

C GENERATES SECOND DERIVATIVES FOR USE IN CSI (CUBIC SPLINE)

      DIMENSION X(1),Y(1),F(1),E(365),G(365)

      N2=NOP-1
      DO 4 N=2,N2
      E(N)=2*(X(N+1)-X(N-1))
      F(N)=6*(Y(N+1)-Y(N))/(X(N+1)-X(N))-6*(Y(N)-Y(N-1))/(X(N)-X(N-1))
    4 CONTINUE

      N1=2
      N2=NOP

      E(1)=2*(X(2)-X(1))
      F(1)=6*(Y(2)-Y(1))/(X(2)-X(1))-6*E1
      E(NOP)=2*(X(NOP)-X(NOP-1))
      F(NOP)=-6*(Y(NOP)-Y(NOP-1))/(X(NOP)-X(NOP-1))+6*F1

      DO 8 N=N1,N2
      G(N)=(X(N)-X(N-1))/E(N-1)
      E(N)=E(N)-G(N)*G(N)*E(N-1)
      F(N)=F(N)-G(N)*F(N-1)
    8 CONTINUE

      F(N2)=F(N2)/E(N2)
      DO 9 N3=N1,N2
      N=N1+N2-N3
      F(N-1)=F(N-1)/E(N-1)-G(N)*F(N)
    9 CONTINUE
      RETURN
      END


      SUBROUTINE CSI(X,Y,F,NOP,XI,YI,YX)

C CUBIC SPLINE INTERPOLATION

      DIMENSION X(1),Y(1),F(1)

      DO 12 N=2,NOP
      IF(X(N)-XI)12,12,13
   12 CONTINUE

      N=NOP

   13 A1=0.5*F(N-1)*(X(N)-XI)*(X(N)-XI)/(X(N)-X(N-1))
      B1=0.5*F(N)*(XI-X(N-1))*(XI-X(N-1))/(X(N)-X(N-1))
      C1=Y(N-1)/(X(N)-X(N-1))-F(N-1)*(X(N)-X(N-1))/6
      D1=Y(N)/(X(N)-X(N-1))-F(N)*(X(N)-X(N-1))/6
      YI=(A1*(X(N)-XI)+B1*(XI-X(N-1)))/3+C1*(X(N)-XI)+D1*(XI-X(N-1))
      YX=-A1+B1-C1+D1
      RETURN
      END
```

```
      SUBROUTINE CONTAM(VGRAD,DTRIP,CH,COSP,SINP,THETA1,RATIO)

C TEST FOR CONTAMINATION AT ATTACHMENT LINE

      COMMON/TEST/RNL(10),INTRL,IFR

      WRITE(2,18)
   18 FORMAT(1X,39H*** LEADING-EDGE CONTAMINATION TEST ***)

      DO 1 N=1,INTRL
      WRITE(2,10)RNL(N)

C SCALE REYNOLDS NUMBER TO STANDARD FORM.
C RTHETA=QINF*SINP*THETA/NUEDGE
      IF(IFR.EQ.1)RN=RNL(N)
      IF(IFR.EQ.2)RN=RNL(N)/COSP
      IF(IFR.EQ.3)RN=RNL(N)/COSP**2
      RTHETA=SINP*SQRT(RN/VGRAD)*THETA1/RATIO**1.5
      WRITE(2,11)RTHETA
      IF(RTHETA-100.)2,2,3
    2 WRITE(2,12)
      GO TO 1

    3 IF(RTHETA-240.)4,4,5
    4 IF(DTRIP-.00001)16,6,6
    6 DCRIT=CH*47*SQRT(RTHETA)/(RN*SINP*COSP)
      WRITE(2,13)DCRIT
      IF(DCRIT-DTRIP)7,16,16
    7 WRITE(2,15)
      GO TO 1

   16 WRITE(2,17)
      GO TO 1

    5 WRITE(2,14)
    1 CONTINUE
      RETURN

   10 FORMAT(18H REYNOLDS NUMBER= ,F10.0)
   11 FORMAT(1H+,32X,7HRTHETA=,F8.1)
   12 FORMAT(1H+,67X,34HNO TURBULENT CONTAMINATION AT A.L.)
   13 FORMAT(1H+,51X,6HDCRIT=,F8.4)
   14 FORMAT(1H+,67X,31HTURBULENT CONTAMINATION AT A.L.)
   15 FORMAT(1H+,67X,36HTURBULENT CONTAMINATION AT TRIP WIRE)
   17 FORMAT(1H+,67X,40HTURBULENT CONTAMINATION POSSIBLE AT A.L.)
      END


      SUBROUTINE CRSSFLW (J,DZ,U)

C CALCULATES CROSS-FLOW AND STREAM-FLOW PROFILES AND THICKNESSES.

      COMMON/RESULTS/WM2(170),UM2(170),VM2(170),DELTA1,THETA1,NO,DUDZ
     1,DVDZ
      COMMON/CROSSV/SV(170),CV(170),SDT,CDT,CVM
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMES3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
```

```
C VELOCITY AT EDGE OF BOUNDARY LAYER
      SVJ=SQRT(U**2/RATIO+SINP**2)

C CALCULATE SIN(THETA) WHERE THETA IS ANGLE BETWEEN FLOW AT EDGE OF
C BOUNDARY LAYER AND THE PERPENDICULAR TO THE LEADING EDGE.
      SINTH=SINP/SVJ
      COSTH=SQRT(1-SINTH**2)

      SDT=0.0
      CDT=0.0
      IS=1
      CVM=0.
      SV(1)=CV(1)=0.

      DO 1 N=2,J

C VELOCITY COMPONENT IN DIRECTION OF FLOW AT EDGE OF BOUNDARY LAYER
      SV(N)=(UM2(N)*COSTH*U/SQRT(RATIO)+VM2(N)*SINTH*SINP)/SVJ
C DISPLACEMENT THICKNESS IN DIRECTION OF FLOW AT EDGE OF B.L.
      SDT=SDT+.5*(SV(N)+SV(N-1))*(ZCOMP(N)-ZCOMP(N-1))
C CROSS-FLOW VELOCITY COMPONENT
      CV(N)=U*SINTH*(VM2(N)-UM2(N))/SQRT(RATIO)
C CROSS-FLOW DISPLACEMENT THICKNESS
      CDT=CDT+.5*(CV(N)+CV(N-1))*(ZCOMP(N)-ZCOMP(N-1))
      IS=-IS

      IF(ABS(CV(N))-CVM)1,1,2
    2 CVM=ABS(CV(N))
    1 CONTINUE

      CDT=ABS(CDT)
      SDT=ZCOMP(J)-SDT

      RETURN
      END


      SUBROUTINE DMNSION(S,U,COSP,DELTA1,THETA1,ILP,CFX2,CFY2,CDFX,
     1CDFXINF)

C CALCULATES DIMENSIONALISING FACTOR AND DIMENSIONAL B.L. THICKNESSES.

      COMMON/TEST/RNL(10),INTRL,IFR


      DO 1 N=1,INTRL

C SCALE REYNOLDS NUMBER TO STANDARD FORM.
      IF(IFR.EQ.1)RN=RNL(N)
      IF(IFR.EQ.2)RN=RNL(N)/COSP
      IF(IFR.EQ.3)RN=RNL(N)/COSP**2
      D=SQRT(S/(U*RN*COSP))
      D1=D*DELTA1
      D2=D*THETA1
      IF(ILP.EQ.0)GO TO 4
      WRITE(2,3)RNL(N),D,D1,D2
    3 FORMAT(1X,17HREYNOLDS NUMBER= ,F10.0,2X,23H(DIMENSIONAL Z)/CHORD=)
     1,F8.6,2H)Z,2X,10HDELTA1/C= ,F8.6,2X,10HTHETA1/C= ,F8.6)
```

```
      GO TO 1
    4 WRITE(2,5)RNL(N),D,D1,D2,CFX2,CFY2,CDFX,CDFXINF
    5 FORMAT(1X,17HREYNOLDS NUMBER= ,F10.0,2X,23H(DIMENSIONAL Z)/CHORD=)
     1,F8.6,2H)Z,2X,10HDELTA1/C= ,F8.6,2X,10HTHETA1/C= ,F8.6/
     25H CFX=E10.3,2X4HCFY=E10.3,2X5HCDFX=E10.3,2X8HCDFXINF=E10.3)
    1 CONTINUE

      RETURN
      END



      SUBROUTINE GEOMTRY (I,RHO,CH)

C GIVEN AEROFOIL CO-ORDINATES X AND Z, TRANSFORMS X TO THETA, COMPUTES
C DISTANCES AROUND SURFACE S(X), NOSE RADIUS AND SECOND DERIVATIVES OF
C S(THETA) FOR USE IN CUBIC SPLINE INTERPOLATIONS.

      COMMON/GEOM/XA(365),ZA(365)
      COMMON/SFX/STH(365),TH(365),FSTH(365),INT4,FZTH(365)
      DIMENSION SD(170),THED(170)

      PI=3.14159265
      INT4M1=INT4-1

C IS AEROFOIL CAMBERED
      IF(I.EQ.0) GO TO 102

C SET UP LOWER SURFACE CO-ORDINATES FOR SYMMETRICAL AEROFOIL
      DO 103 N=1,INT4M1
      XA(N)=-XA(2*INT4-N)
      ZA(N)=-ZA(2*INT4-N)
  103 CONTINUE

C TRANSFORM X TO THETA
  102 NL=(INT4-1)*(I+1)
      DO 105 N=2,NL
      TH(N)=THX(XA(N)/CH)
  105 CONTINUE
      TH(1)=0.
      IF(I.EQ.0)GO TO 1

      TH(INT4)=PI
      INT4=(I+1)*INT4-I
      INT4M1=INT4-1

    1 TH(INT4)=2*PI

      DO 145 N=1,INT4
      ZA(N)=ZA(N)/CH
  145 CONTINUE

C COMPUTE INTERPOLATING FUNCTION FOR Z(THETA)
      CALL CSG(TH,ZA,FZTH,INT4,0.0,0.0)

      IF(RHO.GT.0.) GO TO 108

C COMPUTE NOSE RADIUS IF NOT SPECIFIED
      CALL CSI(TH,ZA,FZTH,INT4,PI,ROT,RHO)
```

```
      RHO=2*(RHO**2)

  108 CONTINUE
C     COMPUTE ARC LENGTH STH(N) TO EACH XA(N),ZA(N) AIRFOIL POINT.
C     STH(N) IS MEASURED FROM LOWER SURFACE TRAILING EDGE TO UPPER
C        SURFACE TRAILING EDGE AND IS APPROXIMATED AS THE CHORDAL
C        DISTANCE BETWEEN AIRFOIL COORDINATES.
C

      STH(1)=0.
      DO 111 N=2,INT4
  111 STH(N)=STH(N-1)+SQRT(((XA(N)-XA(N-1))/CH)**2+(ZA(N)-ZA(N-1))**2)

C COMPUTE INTERPOLATING FUNCTIONS FOR S(THETA) AT THETA(X)
      CALL CSG(TH,STH,FSTH,INT4,0.0,0.0)

      RETURN
      END



      SUBROUTINE IFPRINT(IFPT,ILP,LAST,JACKPOT)

C DETERMINES PRINT OUT REQUIRED
C BOTH PARTS-JACKPOT=1, FIRST PART-JACKPOT=3, SECOND PART-JACKPOT=2
C NO PRINT OUT-JACKPOT=0

C HAS NON-CONVERGENCE OCCURRED
      IF(LAST.EQ.2)GO TO 2

C HAS LAST POINT REQUESTED BEEN COMPUTED
      IF(LAST.EQ.1)JACKPOT=1

C IS FULL OUTPUT REQUIRED AT EVERY POINT OR AT THIS PARTICULAR POINT
      IF(IFPT.EQ.1.OR.(IFPT.EQ.2.AND.ILP.EQ.1))JACKPOT=1

C IS FULL OUTPUT REQUIRED AT LISTED POINTS AND THIS IS NOT ONE OF THEM
      IF(IFPT.EQ.2.AND.ILP.EQ.0)JACKPOT=3
      RETURN

C WAS SECOND PART OF PRINT OUT SKIPPED AT END OF LAST SUCCESSFUL STEP
    2 IF(JACKPOT.EQ.3)GO TO 3
      JACKPOT=0
      RETURN

    3 JACKPOT=2
      RETURN
      END



      SUBROUTINE INSTAB(COSP,S,U,CH,RATIO,AME3D,AMINF3D)

C EVALUATES THE CROSS-FLOW REYNOLDS NUMBER, CHI.

      COMMON/TEST/RNL(10),INTRL,IFR
      COMMON/CROSSV/SV(170),CV(170),SDT,CDT,CVM

```

```
C CALCULATE CHI/SQRT(REYNOLDS NUMBER)
C CROSS FLOW REYNOLDS NO, IS BASED ON THE MINIMUM KINEMATIC VISCOSITY
C       COEFFICIENT - EITHER FREE STREAM OR EDGE VALUE
      FACT=1./RATIO**1.5
      IF(AME3D.GT.AMINF3D) FACT=1.
      CORR=COT*SQRT(COSP*S*CH/U)*FACT

      WRITE(2,3)
    3 FORMAT(1X,30H*** SWEEP INSTABILITY TEST ***)

      DO 1 N=1,INTRL

C SCALE REYNOLDS NUMBER TO STANDARD FORM,
      IF(IFR.EQ.1)RN=RNL(N)
      IF(IFR.EQ.2)RN=RNL(N)/COSP
      IF(IFR.EQ.3)RN=RNL(N)/COSP**2

      CHI=CORR*SQRT(RN)
      WRITE(2,4)RNL(N),CHI
    4 FORMAT(1H ,17HREYNOLDS NUMBER= ,F11.0,2X,19HCHI(OWEN-RANDALL)= ,F7
     1.2)
    1 CONTINUE
      RETURN
      END


      SUBROUTINE PLIST(IFPT,NLIST,SXV,SXVINC,L,DS,INT3,CH,XATT,DX,INC)

C  PREPARE LIST OF POINTS WHERE FULL OUTPUT IS REQUIRED

      COMMON/OPLIST/OPX(200),OPS(200)
      DIMENSION SXV(1),DUMP(365),X(2),S(2),SXVINC(1)

      IF(IFPT-3)301,303,304
  301 CALL STHFRMX (NLIST,OPX,OPS,DUMP,D,INT3,CH,XATT,B)
      DO 310 N=2,NLIST
      OPS(N-1)=OPS(N)
  310 CONTINUE
      GO TO 305

  303 NLIST=L-1
      DO 306 N=1,NLIST
      OPS(N)=SXVINC(N+1)
  306 CONTINUE
      GO TO 307

  304 N=1
      IF(INC.EQ.0) GO TO 308
  309 X(2)=N*DX
      CALL STHFRMX (2,X,S,DUMP,D,INT3,CH,XATT,B)
      OPS(N)=S(2)
      IF(OPS(N).GT.SXV(L))GO TO 307
      NLIST=N
      N=N+1
      GO TO 309
  308 DO 311 N=1,L
      OPS(N)=FLOAT(N)*DX
      IF(OPS(N).GT.SXVINC(L)) GO TO 307
  311 NLIST=N
```

```
  307 IFPT=2
  305 RETURN
      END



      SUBROUTINE PRINT(X,S,U,DU,J,DZ,INT1,JACKPOT,PSI,LC,ANGLE2)

      COMMON/RESULTS/WM2(170),UM2(170),VM2(170),DELTA1,THETA1,NO,DUDZ
     1,DVDZ
      COMMON/CROSSV/SV(170),CV(170),SDT,CDT,CVM
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMES3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
      DIMENSION XPRINT(10)
      DATA XPRINT/.1,.2,.3,.4,.5,.6,.7,.8,.9,.99/
      IF(JACKPOT.EQ.2) GO TO 7

      WRITE(2,11) X,S,SCOMP,U,AME3D,DU,NO
   11 FORMAT(1H0,3HX= ,F9.6,4X,3HS= ,F9.6,4X,7HSCOMP= ,F9.6,4X,3HU= ,
     1F9.6,4X7HAME3D= ,F9.6,4X11HDU/D(S/L)= ,F12.6,4XI2,11H ITERATIONS)

      ANG=180./3.14159265*ANGLE2
      IF(LC.NE.0)WRITE(2,20)
      IF(LC.EQ.2)WRITE(2,20)
   20 FORMAT(1H0,40HSTEP-LENGTH HALVED AFTER NON-CONVERGENCE)
      WRITE(2,12)DELTA1,THETA1,DUDZ,DVDZ,ANG
   12 FORMAT(1X,8HDELTA1= ,F8.4,4X,8HTHETA1= ,F8.4,4X,12H(DU/DZ)Z=0 =,
     1F6.4,2X12H(DV/DZ)Z=0 =E10.3,2X14HAIRFOIL SLOPE=E10.3)
      IF(JACKPOT.EQ.3) GO TO 8
C
C TEMPORARY FIX ON PRINT OF VELOCITY PROFILES AT EVERY 10PC CHORD
C
      IF(S.LT.1.E-08) GO TO 7
C
      IF(X.LT..005) K=1
      IF(X.GT.XPRINT(K)) GO TO 7
      GO TO 8

    7 IF(PSI.LT..0001) GO TO 13
      WRITE(2,15)SDT
   15 FORMAT(1H0,36HSTREAM FLOW DISPLACEMENT THICKNESS= ,F10.6)
      WRITE(2,16)CDT
   16 FORMAT(1H0,35HCROSS FLOW DISPLACEMENT THICKNESS= ,F10.6)
      WRITE(2,19)CVM
   19 FORMAT(1H0,26HMAX. CROSS-FLOW VELOCITY= ,F10.6)
   13 WRITE(2,14)
   14 FORMAT(4X1HZ,10X5HZCOMP,8X1HW,11X1HU,11X1HV,10X3HSTV,10X3HCFV,
     19X1HT,9X4HRHOD)

   17 N1=INT1+1
      DO 2 N=1,J
      IF(N.EQ.1.OR.N.EQ.2) GO TO 3
      IF(INT1.GT.2.AND.N.LE.INT1)GO TO 3
      IF(N.EQ.N1.OR.N.EQ.J)GO TO 3
      GO TO 2

    3 Z=N*DZ-DZ
```

```
      IF(PSI.LT..0001)GO TO 1
      WRITE(2,6)Z,ZCOMP(N),WM2(N),UM2(N),VM2(N),SV(N),CV(N),T(N),RHOD(N)
      GO TO 5
    1 WRITE(2,9)Z,ZCOMP(N),WM2(N),UM2(N),VM2(N),T(N),RHOD(N)
    6 FORMAT(9(F10.6,2X))
    9 FORMAT(5(F10.6,2X),24X,2(F10.6,2X))
    5 IF(N.EQ.N1)N1=N1+INT1
    2 CONTINUE
      IF(S.LT.1.E-08) GO TO 8
      K=K+1

    8 RETURN
      END



      SUBROUTINE RELAM(U,S,SINP,COSP,KMAX)

C EVALUATES THE RE-LAMINARISATION PARAMETER, K.
C      (HAS NOT BEEN MODIFIED FOR COMPRESSIBILITY)
C

      DIMENSION U(4),S(2),A(2)
      COMMON/TEST/RNL(10),INTRL,IFR
      REAL KMAX(10)

      WRITE(2,4)
    4 FORMAT(1X,30H*** RELAMINARISATION CHECK ***)

      DO 1 N=1,2
      A(N)=SQRT(U(N)**2+SINP**2)
    1 CONTINUE

      DS=S(2)-S(1)
      DU=U(2)+U(1)
      RCOSPK=4*(A(2)-A(1))*DU/(DS*(A(2)+A(1))**3)

      DO 2 N=1,INTRL
      CAY=RCOSPK/(RNL(N)*COSP)
      IF(IFR.EQ.2)CAY=CAY*COSP
      IF(IFR.EQ.3)CAY=CAY*COSP**2

      IF(CAY.GT.KMAX(N))KMAX(N)=CAY

      WRITE(2,3)RNL(N),CAY,KMAX(N)
    3 FORMAT(1H ,17HREYNOLDS NUMBER= ,F10.0,3X,3HK= ,E10.3,3X,6HKMAX= ,E
     110.3)
    2 CONTINUE

C IF K.LT.1/2 K(MAX) SET PARAMETER TO AVOID COMPUTING K DOWNSTREAM.
      IF(KMAX(INTRL).GT.2*CAY)KMAX(INTRL)=-1.0

      RETURN
      END



      SUBROUTINE STPLNTH (SNEXT,S,INTHOLD,DS,DS1,DSZ,NEXT,NLIST,LAST,
```

```
     1IFPT,LC,ILP,U,USTEP,DUDS,X,SH,ITC,ANGLE2,WF)

C CALCULATES LENGTH OF NEXT STEP.

      COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
     1SXV(365),SXVINC(365),FSVSINC(365),L,SATT,INT3,CH,ISP
      COMMON/OPLIST/OPX(200),OPS(200)
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMFS3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
      DIMENSION U(4),S(2)

      ILP=0
      LINEAR=0

C WAS LAST STEP SUCCESSFUL
      IF(LC.EQ.0)GO TO 9

C HALVE STEP LENGTH AFTER NON-CONVERGENCE
    1 IF(DS1.GT..01*DS)GO TO 11
C STEP LENGTH LESS THAN MINIMUM PERMITTED- END CALCULATION.
      LAST=2
      GO TO 8

   11 DS1=DS1/2.0
      LAST=0
      GO TO 7

    9 IF(SNEXT.LT.0.) GO TO 2
      S(2)=SNEXT
      DS1=S(2)-S(1)
      SNEXT=-1.0
      GO TO 4

    2 IF(INTHOLD.EQ.0)GO TO 33
C VALUE OF NEXT POINT HAS BEEN HELD WHILE A LISTED OUTPUT POINT WAS
C COMPUTED.
      DS1=DSH
C STEP LENGTH IS HELD AT DSH FOR INTHOLD STEPS.
      INTHOLD=INTHOLD-1
      GO TO 7

C STANDARD STEP LENGTH.
   33 DS1=DS
C CHECK RATIO (PROPOSED LENGTH OF NEXT STEP)/(LENGTH OF LAST STEP)
    4 IF(DS1.LT.1.2*DSZ)GO TO 7

C KEEP STEPLENGTH CONSTANT OVER A NUMBER OF STEPS DEPENDING ON ABOVE.
      INTHOLD=INT(5*DS1/DSZ)-5
      IF(INTHOLD.GT.5)INTHOLD=5

C LIMIT LENGTH OF NEXT STEP TO TWICE LAST STEP.
      IF(INTHOLD.EQ.5)DS1=2*DSZ
      DSH=DS1
      INTHOLD=INTHOLD-1

C PROPOSED VALUE AT END OF NEXT STEP.
    7 S(2)=S(1)+DS1
      IF(IFPT.EQ.1) GO TO 10
C IS PROPOSED VALUE OF X LESS THAN THAT OF NEXT LISTED OUTPUT POINT
      IF(S(2).LT.OPS(NEXT)) GO TO 10
```

```
C REPLACE PROPOSED VALUE WITH THAT OF NEXT LISTED OUTPUT POINT
      S(2)=OPS(NEXT)

C IS THIS THE LAST POINT IN OUTPUT LIST
      IF(NEXT+1.EQ.NLIST)LAST=1

C ADVANCE OUTPUT LIST COUNT
      NEXT=NEXT+1
      ILP=1
      IF(INTHOLD.NE.0)SNEXT=S(1)+DSH

C IS PROPOSED VALUE OF X LESS THAN THAT OF LAST VELOCITY DATA POINT
   10 IF (S(2).LT.SXVINC(L)-.0001*DS) GO TO 44

C VALUES AT LAST VELOCITY DATA POINT.
      S(2)=SXVINC(L)
      X=XV(L)
      U(2)=UM(L)
      DUDS=(UM(L)-UM(L-1))/(SXVINC(L)-SXVINC(L-1))
      LAST=1
      GO TO 45

   44 IF (INC.EQ.0) GO TO 46
      SCOMP=S(2)
      GO TO 47
C
C     INTERPOLATE SXV(SXVINC) TO FIND LOCATION IN PHYSICAL PLANE, SCOMP,
C        CORRESPONDING TO LOCATION IN TRANSFORMED, INCOMPRESSIBLE PLANE,
C        S(2)
C
   46 CALL CSI(SXVINC,SXV,FSVSINC,L,S(2),SCOMP,ROT)
C
C     FIND VELOCITY AT END OF PROPOSED STEP
   47 CALL XNDFRMS(SCOMP,U(2),DUDS,X,ITC,ILP,ANGLE2,LINEAR,THETAS)

C DID NON-CONVERGENCE OCCUR IN SUB-ROUTINE XNDFRMS
      IF(ITC.EQ.20)GO TO 15

   45 DS1=S(2)-S(1)

C CHECK THAT USTEP IS NOT EXCEEDED AND REDUCE STEPLENGTH IF NECESSARY.

   17 IF(ABS(U(2)-U(1)).LT.USTEP)GO TO 19
      IF(ILP.EQ.1)NEXT=NEXT-1
      ILP=0

C ITERATION TO FIND S FOR (U(1)+USTEP)
      INTU=0
      S(2)=S(2)-DS1*(1-USTEP/(U(2)-U(1)))
      IF(INC.EQ.0) GO TO 48
      SCOMP=S(2)
      GO TO 12
   48 CALL CSI(SXVINC,SXV,FSVSINC,L,S(2),SCOMP,ROT)
   12 CALL XNDFRMS(SCOMP,U(2),DUDS,X,ITC,ILP,ANGLE2,LINEAR,THETAS)
      IF(ITC.EQ.20)GO TO 15
      IF(ABS(U(2)-U(1)-USTEP).LT..01*USTEP)GO TO 111
      INTU=INTU+1
      IF(INTU.EQ.25) GO TO 24
      S(2)=S(2)-(U(2)-U(1)-USTEP)/DUDS
```

```
      IF(INC.EQ.0) GO TO 48
      SCOMP=S(2)
      GO TO 12

   15 WRITE(2,26)
   26 FORMAT(1H0,41HNON-CONVERGENCE IN X AND U FROM S ROUTINE)
      GO TO 120

   24 IF(ABS(U(2)-U(1)).GT.USTEP) WRITE(2,3)
    3 FORMAT(1H0,* INCREMENT IN U HAS EXCEEDED SET LIMIT*)

C EITHER NON-CONVERGENCE HAS OCCURRED IN FINDING THETAS FOR A GIVEN
C    SCOMP IN S/R XNDFRMS OR NON-CONVERGENCE HAS OCCURRED IN FINDING U(2)
C    THAT SATISFIES THE USTEP CRITERION.  SET U(2)=U(1) + USTEP AND USE
C    LINEAR INTERPOLATION TO FIND  S(2).

  120 LINEAR=1
      U(2)=U(1)+USTEP
      DO 60 N=1,L
      IF(U(2).LT.UM(N))GO TO 65
      IF(SXVINC(N).GT..5)GO TO 63
   60 CONTINUE
   63 PRINT 66
   66 FORMAT(/* LEADING-EDGE LINEAR INTERPOLATION OF U(2) VS. S(2) TO
     1FIND S(2) FOR A GIVEN U(2) RESULTS IN S(2) GREATER THAN .5*)
      STOP 6666
   65 FACT= (U(2)-UM(N-1))/(UM(N)-UM(N-1))
      S(2)=SXVINC(N-1)+(SXVINC(N)-SXVINC(N-1))*FACT
      THETAS=THXV(N-1)+(THXV(N)-THXV(N-1))*FACT
      DUDS=(U(2)-U(1))/(S(2)-S(1))
      IF(INC.EQ.0)GO TO 110
      SCOMP=S(2)
      GO TO 112
  110 CALL CSI(SXVINC,SXV,FSVSINC,L,S(2),SCOMP,ROT)
  112 CALL XNDFRMS(SCOMP,U(2),DUDS,X,ITC,ILP,ANGLE2,LINEAR,THETAS)
  111 LAST=0

C LENGTH OF NEXT STEP.
   19 DS1=S(2)-S(1)
C       S LOCATION OF NEXT STEP
      SH=WF*S(2)+(1.-WF)*S(1)

    8 RETURN
      END


      SUBROUTINE STHFRMX(J,X,S,THXV,DSDT,INT3,CH,XATT,SATT)

C FINDS S(N) AT POINTS X(N) FOR N=1(1)J AND DS/DTHETA AT X(1)
C WHERE S IS MEASURED FROM THE ATTACHMENT LINE.


      COMMON/SFX/STH(365),TH(365),FSTH(365),INT4,FZTH(365)
      DIMENSION X(1),S(1),THXV(1)

      X(1)=XATT
      DO 1 N=1,J
      THXV(N)=THX(X(N)/CH)
```

```
      IF(INT3.EQ.0)GO TO 2

      CALL CSI(TH,STH,FSTH,INT4,THXV(N),S(N),DSDTH)

      IF(N.GT.1)GO TO 3
      DSDT=DSDTH
      GO TO 1

    2 S(N)=X(N)/CH
      GO TO 1

    3 S(N)=S(N)-S(1)

    1 CONTINUE
      SATT=S(1)
      S(1)=0.

      RETURN
      END


      SUBROUTINE TRANS(SC,USSM,THETA1,UTWO,UONE,IST,JACKPOT)

C ESTIMATES THE POSITIONS OF VISCOUS INSTABILITY AND SUBSEQUENT
C TRANSITION.

      COMMON/TEST/RNL(10),INTRL,IFR
      COMMON/SUBTRAN /ROS(17),AM(17),GRAN(13),AMT(13)
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMFS3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
      COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
     1SXV(365),SXVINC(365),FSVSINC(365),L,SATT,INT3,CH,ISP
      DIMENSION SCTR(10),SCI(10),SUMM(10),RTCL(10),RDL(10),RTL(10),
     1RTI(10),SCICOMP(10)

      B=(1./RATIO)**GAM1*SQRT(1.+AMFS3D*COSP**2)/(1.+AMFS3D*UTWO**2)**1.
     15
      IF(IST.NE.1) GO TO 2

C SET CERTAIN STORES TO ZERO WHEN S/R IS ENTERED FOR FIRST TIME.
      SCL=0.0
      SCOMPL=0.0
      RATIOL=1./(1.+AMFS3D*COSP**2)
      DO 4 N=1,INTRL
      SCTR(N)=-0.0
      SCI(N)=-0.0
      SCICOMP(N)=-0.0
      SUMM(N)=0.0
    4 CONTINUE

      IST=0

C EVALUATE (LAMBDA)2 - BASED ON MINIMUM KINEMATIC VISCOSITY COEFFICIENT,
C        EITHER FREE STREAM OR EDGE VALUE
      FACT=1./RATIO**1.5
      IF(AME3D.GT.AMINF3D) FACT=1.
    2 EM=B*SC*USSM*THETA1**2/UTWO*FACT
      WRITE(2,10)
```

```
   10 FORMAT(1X,35H*** TRANSITION TEST (GRANVILLE) ***)
      DO 3 N=1,INTRL
      WRITE(2,11)RNL(N)
   11 FORMAT(1H ,17HREYNOLDS NUMBER= ,F10.0)
      IF(SCTR(N).GT.0.) GO TO 14

C SCALE REYNOLDS NUMBER TO STANDARD FORM.
      IF(IFR.EQ.1)RN=RNL(N)
      IF(IFR.EQ.2)RN=RNL(N)/COSP
      IF(IFR.EQ.3)RN=RNL(N)/COSP**2

C EVALUATE R2
C REYNOLDS NUMBER IS BASED ON MINIMUM KINEMATIC VISCOSITY COEFFICIENT,
C       EITHER FREE STREAM OR EDGE VALUE
      RD=SQRT(RN*SC*UTWO*COSP/RATIO)*THETA1*FACT

      WRITE(2,22) RD
   22 FORMAT(1H+,30X,7HRTHETA=F6.1)
      IF(SCTR(N).GT.0.) GO TO 14
C HAS INSTABILITY BEEN PREDICTED UPSTREAM OF THIS POINT
      IF(SCI(N).GT.0.) GO TO 140

C FIND CRITICAL VALUE OF R2 FROM STUARTS CURVE.
      DO 6 J=2,17
      IF(AM(J).GT.EM)GO TO 7
    6 CONTINUE
      J=17

    7 A=(ROS(J-1)+(ROS(J)-ROS(J-1))*(EM-AM(J-1))/(AM(J)-AM(J-1)))
      RTC=10.**A
      IF(RD.GT.RTC)GO TO 9

      RTCL(N)=RTC
      RDL(N)=RD
      IF(JACKPOT.EQ.3)GO TO 3
      WRITE(2,110)RTC,EM
  110 FORMAT(1H+,44X,11H RTHETCRIT=F6.1,2X,6H LAM2=F6.3,2X,14HNO INSTABI
     1LITY)
      GO TO 3

C INTERPOLATE FOR VALUES AT POINT OF INSTABILITY.
    9 SCI(N)=SCL+(SC-SCL)*(RTCL(N)-RDL(N))/(RD-RTC-RDL(N)+RTCL(N))
      IF(INC.EQ.0) GO TO 20
      SCICOMP(N)=SCI(N)
      GO TO 21
   20 CALL CSI(SXVINC,SXV,FSVSINC,L,SCI(N),SCICOMP(N),ROT)
   21 RTI(N)=RTCL(N)+(RTC-RTCL(N))*(SCI(N)-SCL)/(SC-SCL)
      EMI=EML+(EM-EML)*(SCI(N)-SCL)/(SC-SCL)
      SUMM(N)=0.5*(EM+EMI)*(SC-SCI(N))
      GO TO 8

  140 DIM=0.5*(EM*RATIO**GAM1+EML*RATIOL**GAM1)*(SC-SCL)
      SUMM(N)=SUMM(N)+DIM

C EVALUATE (R2)T-(R2)I
    8 RTMRTI=RD-RTI(N)

C EVALUATE (LAMBDA)2 BAR
      AMB=SUMM(N)/(SCOMP-SCICOMP(N))
```

```
C FIND CRITICAL VALUE OF (R2)T-(R2)I FROM GRANVILLES CURVE.
      DO 15 K=2,13
      IF(AMT(K).GT.AMB) GO TO 16
   15 CONTINUE
      K=13

   16 RTCMRTI=GRAN(K-1)+(AMB-AMT(K-1))*(GRAN(K)-GRAN(K-1))/
     1(AMT(K)-AMT(K-1))

   14 WRITE(2,13)SCICOMP(N)
   13 FORMAT(1H+,44X,20HINSTABILITY AT S/C= ,F6.4)
      IF(SCTR(N).GT.0.)GO TO 5
      IF(RTMRTI.GT.RTCMRTI) GO TO 17
      WRITE(2,19)
   19 FORMAT(1H+,72X,13HNO TRANSITION)
      RTL(N)=RTCMRTI-RTMRTI
      GO TO 100

   17 SCTR(N)=SCOMPL+RTL(N)*(SCOMP-SCOMPL)/(RTMRTI-RTCMRTI+RTL(N))

    5 WRITE(2,18)SCTR(N)
   18 FORMAT(1H+,72X,19HTRANSITION AT S/C= ,F6.4)
  100 WRITE(2,101) RTI(N),RTCMRTI,AMB
  101 FORMAT(17H INSTAB. RE. NO.=F6.1,2X,8HRTC-RTI=F6.1,2X,8HLAM2BAR=F6.
     13)
    3 CONTINUE

      SCL=SC
      SCOMPL=SCOMP
      EML=EM
      RATIOL=RATIO
      RETURN
      END



      BLOCK DATA

C STORE TABLES DERIVED FROM STUARTS AND GRANVILLES CURVES FOR USE IN
C SUB-ROUTINE TRANS.

      COMMON/SUBTRAN /ROS(17),AM(17),GRAN(13),AMT(13)
      DATA ROS/1.392,1.464,1.573,1.7,1.84,2.016,2.224,2.458,2.713,2.956,
     13.155,3.310,3.452,3.57,3.676,3.734,3.768/,AM/-.06,-.05,-.04,-.03,
     2-.02,-.01,0.0,.01,.02,.03,.04,.05,.06,.07,.08,.09,.10/,GRAN/450.,
     3460.,480.,504.,548.,610.,706.,836.,1000.,1195.,1440.,1720.,2046./,
     4AMT/-.035,-.030,-.025,-.02,-.015,-.01,-.005,.0,.005,.010,.015,.02,
     5.025/
      END



      SUBROUTINE VELOCTS (INTV,COSP)

C COMPUTES U FROM DATA

      COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
     1SXV(365),SXVINC(365),FSVSINC(365),L,SATT,INT3,CH,ISP
```

```
      LP1=L+1
      DO 1 N=2,LP1
      IF(INTV.EQ.3)GO TO 3

C INPUT VELOCITIES WERE NON-DIMENSIONALISED W.R.T. FREE STREAM VELOCITY
C PERPENDICULAR TO LEADING EDGE.
      UM(N)=UM(N)*COSP
      GO TO 1

C COMPUTE U FROM PRESSURE COEFFICIENTS
    3 CPUM(N)=UM(N)
      UM(N)=SQRT(COSP**2-CPUM(N))
    1 CONTINUE

      CPUM(1)=COSP**2
      RETURN
      END



      SUBROUTINE VGRADAT(ALPHA,RHO,S1,S3,VGRAD,XV)

C ESTIMATES DU/DS AT ATTACHMENT LINE AND POSITION OF ATTACHMENT LINE.

      INC=1
      IF(ALPHA.LT.0.0)INC=-1
      ALPHA=INC*ALPHA
      A=.017453*ALPHA

      XATT=(TAN(A)*(1+S3))**2/((1+S1)**2+(TAN(A)*(1+S3))**2)
      VGRAD=COS(A)*(1+S1)*(1+XATT)/(RHO+2*XATT)
      XV=-XATT*INC

      RETURN
      END



      SUBROUTINE XNDFRMS(S,U,DUDS,X,ITC,ILP,ANGLE,LINEAR,THETAS)

C FINDS X(S) FROM S BY ITERATIVE METHOD, HENCE U(S) AND DU/DS.

      COMMON/SFX/STH(365),TH(365),FSTH(365),INT4,FZTH(365)
      COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
     1SXV(365),SXVINC(365),FSVSINC(365),L,SATT,INT3,CH,ISP

      COMMON/GEOM/XA(365),ZA(365)
      COMMON/COMPRES/INC,AMINF3D,AME3D,SINP,COSP,GAMMA,GAM1,GAM2,GAM3,
     1GAM4,AMFS3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
      ITC=0
      IF(LINEAR.EQ.1)GO TO 15

      IF(INT3)1,1,2
    1 THETAS=THX(S)
      DSDTH=-0.5*SIN(THETAS)
      GO TO 3

```

```
C THETA(S) FOR ESTIMATED S
    2 TEST=S+XV(1)/CH
      IF(TEST.GT.1.) GO TO 7
      THETAS=THX(TEST)
      GO TO 4
    7 THETAS=6.

C FIND S AND DS/D(THETA) AT S
    4 CALL CSI(TH,STH,FSTH,INT4,THETAS,SX1,DSDTH)
      TEST1=S+SATT-SX1
      IF(ABS(TEST1).LT.0.00001) GO TO 3

C IMPROVE ESTIMATE FOR S AND EVALUATE THETA(S).
      THETAS=THETAS+TEST1/DSDTH
      ITC=ITC+1
      IF(ITC.LT.20)GO TO 4

      WRITE(2,5)
    5 FORMAT(40HONON-CONVERGENCE IN S TO THETA PROCEDURE)
      RETURN

C FIND U AND DU/D(THETA) AT THETA(S)
    3 CALL CSI(THXV,UM,FUTH,L,THETAS,U,DUDTH)
   15 AME2D=AMINF3D*U
      AME3D=(AME2D**2*(1.+AMFS3D)+(AMINF3D*SINP)**2)/(1.+AMFS3D*COSP**2)
      AME3D=SQRT(AME3D)
      RATIO=(1.+.5*(GAMMA-1.)*AME3D**2)/(1.+AMFS3D)
      DSCDSI=RATIO**GAM1
      IF(LINEAR.EQ.1)GO TO 20
      DUDS=DUDTH/DSDTH*DSCDSI
   20 X=XTH(THETAS)*CH

      IF(ILP.EQ.1)RETURN
      CALL CSI(TH,ZA,FZTH,INT4,THETAS,ROT,DZDTH)
      DXDTH=ABS(.5*SIN(THETAS))
      IF(DXDTH.GT.1.0E-05)GO TO 6
      ANGLE=3.141592654/2.
      RETURN
    6 ASLOPE=DZDTH/DXDTH
      ANGLE=ATAN(ASLOPE)
      RETURN
      END



      SUBROUTINE XSCPPNT  (INTV)

C PRINTS OUT TABLE OF VELOCITY DATA.

      COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
     1SXV(365),SXVINC(365),FSVSINC(365),L,SATT,INT3,CH,ISP

      DIMENSION S(365)

      IF(INT3.EQ.0)GO TO 6
      DO 5 N=1,L
      S(N)=SXV(N)*CH
    5 CONTINUE
    6 CONTINUE
```

```
      IF(INT3.EQ.0.AND.INTV.LE.2)WRITE(2,1)(XV(N),UM(N),N=1,L)
    1 FORMAT(1H0,4X,2HXV,8X,1HU/(1H ,2(F8.4,2X)))

      IF(INT3.EQ.0.AND.INTV.EQ.3)WRITE(2,2)(XV(N),CPUM(N),UM(N),N=1,L)
    2 FORMAT(1H0,4X,2HXV,7X,2HCP,9X,1HU/(1H ,3(F8.4,2X)))

      IF(INT3.EQ.1.AND.INTV.LE.2)WRITE(2,3)(XV(N),SXV(N),SXVINC(N),
     1UM(N),THXV(N),FUTH(N),FSVSINC(N),N=1,L)
    3 FORMAT(1H0,7X2HXV,14X3HSXV,11X6HSXVINC,13X1HU,13X4HTHXV,12X4HFUTH,
     111X7HFSVSINC/(1H ,7E16.8))

      IF(INT3.EQ.1.AND.INTV.EQ.3)WRITE(2,4)(XV(N),SXV(N),SXVINC(N),
     1CPUM(N),UM(N),N=1,L)
    4 FORMAT(1H0,6X2HXV,14X3HSXV,13X6HSXVINC,11X2HCP,14X1HU/
     1(1H ,5E16.8))

      RETURN
      END
```

## APPENDIX E

## SAMPLE CASE

The sample case consists of the computation of the boundary layer on the upper surface of a wing swept at $35^{\circ}$ with the airfoil section shown in figure 2 subject to the suction distribution given in figure 1. This airfoil which is nominally 13% thick was designed specifically for LFC use by Pfenninger, Allison, and Bobbitt using the inverse method in reference 6 to design the airfoil and the analysis method in reference 7 to modify the lower surface. The sample case free stream Reynolds number is $11 \times 10^{6}$, based on the chord measured perpendicularly to the leading edge. The free stream Mach number is 0.885 which gives a Mach number normal to the wing leading edge of 0.725, the same as the design value. The suction distribution shown in figure 1 maintains laminar flow over the entire wing surface according to the criterions which were previously discussed. It should be noted however that no attempt was made to optimize this suction distribution; hence, it is expected that these suction levels can be reduced thereby reducing the skin-friction drag.

The input for the sample case is listed below. The program prints this input as well as some computed quantities and that information is also listed below. A sample of the output is then shown with both the print out at a typical boundary-layer station and the boundary-layer profiles given. Figures 3 gives the distributions for this sample case of the x and y skin-friction coefficients along the surface from the leading to trailing edge. This sample case required a total of 18 seconds and $76_8$ K storage for execution on the CDC CYBER 175 computer.

```
   50  100.00001     .05          .01        .05        1.
    1
    7
-3.          .4
-3.5         .5
-4.          .6
-4.5         .7
-5.          .8
-5.5         .9
-6.          10.
    0 .885062   1.4
SUCTION, TRANSITION ANAYLSIS OF YAWED WING LAMINAR BOUNDARY LAYER
    11.
    0  161 .0003
  -.10000000E+01   0.
  -.99949851E+00    31847586E-04
  -.99801039E+00   .12412008E-03
  -.99555564E+00   .26996347E-03
  -.99213940E+00   .46162454E-03
  -.98776384E+00   .69008430E-03
  -.98242976E+00   .94451567E-03
  -.97613759E+00   .12111269E-02
  -.96888912E+00   .14722551E-02
  -.96068937E+00   .17070801E-02
  -.95154673E+00   .18927079E-02
  -.94147283E+00   .20041255E-02
  -.93048302E+00   .20136525E-02
  -.91859803E+00   .18915196E-02
  -.90584324E+00   .16074394E-02
  -.89224840E+00   .11289977E-02
  -.87785050E+00   .42313630E-03
  -.86268915E+00  -.53879543E-03
  -.84679335E+00  -.17910643E-02
  -.83019369E+00  -.34066194E-02
  -.81298151E+00  -.54978826E-02
  -.79534249E+00  -.81457877E-02
  -.77750733E+00  -.11330604E-01
  -.75967546E+00  -.14932555E-01
  -.74197277E+00  -.18770622E-01
  -.72442886E+00  -.22651897E-01
  -.70699860E+00  -.26438144E-01
  -.68963086E+00  -.30058774E-01
  -.67229757E+00  -.33468083E-01
  -.65497395E+00  -.36620239E-01
  -.63762323E+00  -.39484150E-01
  -.62021563E+00  -.42054396E-01
  -.60273999E+00  -.44333053E-01
  -.58519312E+00  -.46316717E-01
  -.56756606E+00  -.47999708E-01
  -.54984185E+00  -.49388548E-01
  -.53200957E+00  -.50511498E-01
  -.51408335E+00  -.51409030E-01
  -.49610193E+00  -.52109325E-01
  -.47810716E+00  -.52619291E-01
  -.46013100E+00  -.52937205E-01
  -.44219988E+00  -.53063103E-01
  -.42433954E+00  -.52998773E-01
  -.40657596E+00  -.52746910E-01
  -.38893588E+00  -.52311457E-01
  -.37144931E+00  -.51698406E-01
```

| | |
|---|---|
| -.35415496E+00 | -.50912247E-01 |
| -.33709961E+00 | -.49944234E-01 |
| -.32032395E+00 | -.48766969E-01 |
| -.30385496E+00 | -.47342658E-01 |
| -.28770446E+00 | -.45621039E-01 |
| -.27184737E+00 | -.43542764E-01 |
| -.25621317E+00 | -.41076078E-01 |
| -.24071830E+00 | -.38241165E-01 |
| -.22529209E+00 | -.35098316E-01 |
| -.20987996E+00 | -.31739388E-01 |
| -.19445512E+00 | -.28295190E-01 |
| -.17905534E+00 | -.24921795E-01 |
| -.16378959E+00 | -.21744095E-01 |
| -.14879038E+00 | -.18825569E-01 |
| -.13417989E+00 | -.16188476E-01 |
| -.12006868E+00 | -.13830033E-01 |
| -.10655276E+00 | -.11724098E-01 |
| -.93700365E-01 | -.98299269E-02 |
| -.81558093E-01 | -.81188513E-02 |
| -.70180912E-01 | -.65672286E-02 |
| -.59617866E-01 | -.51298876E-02 |
| -.49891094E-01 | -.37593524E-02 |
| -.41009359E-01 | -.24200189E-02 |
| -.32976423E-01 | -.10881966E-02 |
| -.25799979E-01 | .25606339E-03 |
| -.19479093E-01 | .16331177E-02 |
| -.14012376E-01 | .30512413E-02 |
| -.93981660E-02 | .45168636E-02 |
| -.56452706E-02 | .60128731E-02 |
| -.28150782E-02 | .75456025E-02 |
| -.94968242E-03 | .91967362E-02 |
| -.30485964E-04 | .11058310E-01 |
| 0. | .13243320E-01 |
| .65030247E-03 | .15829109E-01 |
| .17762539E-02 | .18647723E-01 |
| .34231107E-02 | .21490743E-01 |
| .56829827E-02 | .24332496E-01 |
| .85635736E-02 | .27169898E-01 |
| .12071072E-01 | .29979690E-01 |
| .16211803E-01 | .32745574E-01 |
| .20988300E-01 | .35449598E-01 |
| .26405806E-01 | .38073872E-01 |
| .32471242E-01 | .40603093E-01 |
| .39194110E-01 | .43025607E-01 |
| .46584525E-01 | .45336855E-01 |
| .54649490E-01 | .47539130E-01 |
| .63390359E-01 | .49640495E-01 |
| .72800014E-01 | .51651464E-01 |
| .82864580E-01 | .53580058E-01 |
| .93566769E-01 | .55431923E-01 |
| .10488595E+00 | .57209614E-01 |
| .11680199E+00 | .58912451E-01 |
| .12929459E+00 | .60540566E-01 |
| .14234126E+00 | .62092606E-01 |
| .15592027E+00 | .63566014E-01 |
| .17000928E+00 | .64958730E-01 |
| .18458558E+00 | .66268100E-01 |
| .19962635E+00 | .67492208E-01 |
| .21510730E+00 | .68629410E-01 |
| .23100353E+00 | .69677285E-01 |

```
.24729015E+00    .70633622E-01
.26394148E+00    .71496477E-01
.28093148E+00    .72263780E-01
.29823373E+00    .72933771E-01
.31582111E+00    .73504814E-01
.33366624E+00    .73975007E-01
.35174169E+00    .74342909E-01
.37001929E+00    .74607337E-01
.38847050E+00    .74766964E-01
.40706648E+00    .74820395E-01
.42577831E+00    .74766077E-01
.44457722E+00    .74602366E-01
.46343471E+00    .74328132E-01
.48232163E+00    .73942521E-01
.50120859E+00    .73444124E-01
.52006676E+00    .72830944E-01
.53886823E+00    .72101315E-01
.55758506E+00    .71254024E-01
.57618947E+00    .70287556E-01
.59465437E+00    .69199941E-01
.61295386E+00    .67989380E-01
.63106267E+00    .66654380E-01
.64895640E+00    .65193370E-01
.66661201E+00    .63604700E-01
.68400827E+00    .61887390E-01
.70112508E+00    .60041747E-01
.71794282E+00    .58068930E-01
.73444279E+00    .55970045E-01
.75060817E+00    .53746808E-01
.76642334E+00    .51401998E-01
.78187389E+00    .48938602E-01
.79694800E+00    .46359398E-01
.81163818E+00    .43667964E-01
.82594255E+00    .40870923E-01
.83986486E+00    .37981892E-01
.85341131E+00    .35025549E-01
.86658457E+00    .32040020E-01
.87937576E+00    .29074464E-01
.89175958E+00    .26181554E-01
.90369481E+00    .23408008E-01
.91513138E+00    .20787988E-01
.92601800E+00    .18343501E-01
.93630612E+00    .16087736E-01
.94595079E+00    .14028140E-01
.95491055E+00    .12167975E-01
.96314744E+00    .10507215E-01
.97062697E+00    .90435138E-02
.97731771E+00    .77726876E-02
.98319142E+00    .66888839E-02
.98822326E+00    .57854833E-02
.99239108E+00    .50559986E-02
.99567448E+00    .44944613E-02
.99805372E+00    .40957510E-02
.99950735E+00    .38562107E-02
.99999989E+00    .37758884E-02
    2
    3     2     00.0
UPPER SURFACE CALCULATION USING LFC 13.0 PCT THICK AIRFOIL DESIGNED BY ALLISON
35.        0.
    1     2
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11000000.
    1    83
0.                    .0874
     .65030247E-03    .23873709E+00
     .17762539E-02    .38790788E+00
     .34231107E-02    .52032364E+00
     .56829827E-02    .62806334E+00
     .85635736E-02    .72061834E+00
     .12071072E-01    .79895459E+00
     .16211803E-01    .86597527E+00
     .20988300E-01    .92548157E+00
     .26405806E-01    .97710088E+00
     .32471242E-01    .10228194E+01
     .39194110E-01    .10597190E+01
     .46584525E-01    .10882274E+01
     .54649490E-01    .11065774E+01
     .63390359E-01    .11171721E+01
     .72800014E-01    .11213306E+01
     .82864580E-01    .11220805E+01
     .93566769E-01    .11198619E+01
     .10488595E+00    .11172711E+01
     .11680199E+00    .11129790E+01
     .12929459E+00    .11088448E+01
     .14234126E+00    .11042433E+01
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     .17000928E+00    .10955684E+01
     .18458558E+00    .10915309E+01
     .19962635E+00    .10871666E+01
     .21510730E+00    .10834096E+01
     .23100353E+00    .10794909E+01
     .24729015E+00    .10760506E+01
     .26394148E+00    .10724985E+01
     .28093148E+00    .10693639E+01
     .29823373E+00    .10660479E+01
     .31582111E+00    .10631555E+01
     .33366624E+00    .10599941E+01
     .35174169E+00    .10570151E+01
     .37001929E+00    .10537295E+01
     .38847050E+00    .10506558E+01
     .40706648E+00    .10474622E+01
     .42577831E+00    .10447203E+01
     .44457722E+00    .10419195E+01
     .46343471E+00    .10393716E+01
     .48232163E+00    .10367261E+01
     .50120859E+00    .10343536E+01
     .52006676E+00    .10315352E+01
     .53886823E+00    .10282740E+01
     .55758506E+00    .10243370E+01
     .57618947E+00    .10202960E+01
     .59465437E+00    .10156384E+01
     .61295386E+00    .10104312E+01
     .63106267E+00    .10044108E+01
     .64895640E+00    .99778119E+00
     .66661201E+00    .99003184E+00
     .68400827E+00    .98131448E+00
     .70112508E+00    .97149016E+00
     .71794282E+00    .96091147E+00
     .73444279E+00    .94919644E+00
     .75060817E+00    .93645976E+00
     .76642334E+00    .92251687E+00
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| | |
|---|---|
| .78187389E+00 | .90744695E+00 |
| .79694800E+00 | .89071752E+00 |
| .81163818E+00 | .87208368E+00 |
| .82594255E+00 | .85100503E+00 |
| .83986486E+00 | .82766929E+00 |
| .85341131E+00 | .80254672E+00 |
| .86658457E+00 | .77704167E+00 |
| .87937576E+00 | .75258171E+00 |
| .89175958E+00 | .73053494E+00 |
| .90369481E+00 | .71139979E+00 |
| .91513138E+00 | .69503462E+00 |
| .92601800E+00 | .68087085E+00 |
| .93630612E+00 | .66848451E+00 |
| .94595079E+00 | .65746154E+00 |
| .95491055E+00 | .64759166E+00 |
| .96314744E+00 | .63855472E+00 |
| .97062697E+00 | .63021027E+00 |
| .97731771E+00 | .62231996E+00 |
| .98319142E+00 | .61464968E+00 |
| .98822326E+00 | .60678732E+00 |
| .99239108E+00 | .59839268E+00 |
| .99567448E+00 | .58878023E+00 |
| .99805372E+00 | .57681908E+00 |
| .99950735E+00 | .55847992E+00 |
| .99999989E+00 | .55516708E+00 |

96.1 -.00001549

7

## INPUT + SOME COMPUTED QUANTITIES

ITS= 50 J= 100 TOL= .00001 DZ= .05000 DS= .01000 USTEP= .05000 AF= 1.00000

IBLC=1 DISCONTINUOUS SUCTION OR INJECTION GIVEN BELOW

SUCTION OR INJECTION VELOCITY S LOCATION MSLAX= 7

| WWALL(MS) | SDS(MS) |
|---|---|
| -3.00000 | .40000 |
| -3.50000 | .50000 |
| -4.00000 | .60000 |
| -4.50000 | .70000 |
| -5.00000 | .80000 |
| -5.50000 | .90000 |
| -6.00000 | 10.00000 |

INC= 0 AMINF3D= .88506200E+00 GAMMA= .14000000E+01
COMPRESSIBLE FLOW(INC=0). STEWARTSON TRANSFORMATION USED

B= SUCTION, TRANSITION ANAYLSIS OF YAWED WING LAMINAR BOUNDARY LAYER

INT3= 1 CH= 1.00000

ISY= 0 INT4= 161 RHO= .30000000E-03

ISP= 2

| N | XA(N) | ZA(N) | STH(N) | TH(N) | FSTH(N) | FZTH(N) |
|---|---|---|---|---|---|---|
| 1 | -.10000000E+01 | 0. | 0. | 0. | .50111779E+00 | .32173472E-01 |
| 2 | -.99949851E+00 | .31847586E-04 | .50250024E-03 | .44791689E-01 | .50053486E+00 | .30896018E-01 |
| 3 | -.99801039E+00 | .12412008E-03 | .19934782E-02 | .89239698E-01 | .49885677E+00 | .27769252E-01 |
| 4 | -.99555564E+00 | .26996347E-03 | .44525569E-02 | .13343103E+00 | .49617756E+00 | .23753057E-01 |
| 5 | -.99213940E+00 | .46162454E-03 | .78741690E-02 | .17755318E+00 | .49252242E+00 | .19015895E-01 |
| 6 | -.98774384E+00 | .69008430E-03 | .12255689E-01 | .22168803E+00 | .48789578E+00 | .13380916E-01 |
| 7 | -.98242976E+00 | .94451567E-03 | .17595834E-01 | .26588810E+00 | .48228894E+00 | .62548502E-02 |
| 8 | -.97613759E+00 | .12111269E-02 | .23893650E-01 | .31019135E+00 | .47571685E+00 | -.29233377E-02 |
| 9 | -.96888912E+00 | .14722551E-02 | .31146822E-01 | .35462076E+00 | .46826032E+00 | -.13534041E-01 |
| 10 | -.96068937E+00 | .17070801E-02 | .39349934E-01 | .39918326E+00 | .45999144E+00 | -.24866529E-01 |
| 11 | -.95154673E+00 | .18927079E-02 | .48494458E-01 | .44387709E+00 | .45095145E+00 | -.37038037E-01 |
| 12 | -.94147283E+00 | .20041255E-02 | .58568974E-01 | .48869631E+00 | .44119449E+00 | -.50473053E-01 |
| 13 | -.93048302E+00 | .20136525E-02 | .69558788E-01 | .53363052E+00 | .43080923E+00 | -.65055156E-01 |
| 14 | -.91859803E+00 | .18915196E-02 | .81444406E-01 | .57866035E+00 | .41985186E+00 | -.79336503E-01 |
| 15 | -.90584324E+00 | .16074394E-02 | .94202359E-01 | .62376263E+00 | .40840696E+00 | -.95048582E-01 |
| 16 | -.89224840E+00 | .11289977E-02 | .10780562E+00 | .66891206E+00 | .39661132E+00 | -.11195686E+00 |
| 17 | -.87785050E+00 | .42313630E-03 | .12222081E+00 | .71407250E+00 | .38434390E+00 | -.12591484E+00 |
| 18 | -.86268915E+00 | -.53879543E-03 | .13741264E+00 | .75921252E+00 | .37160033E+00 | -.13918686E+00 |
| 19 | -.84679335E+00 | -.17910643E-02 | .15335769E+00 | .80434018E+00 | .36033020E+00 | -.17340004E+00 |
| 20 | -.83019369E+00 | -.34066194E-02 | .17003578E+00 | .84946181E+00 | .35349896E+00 | -.23825012E+00 |
| 21 | -.81298151E+00 | -.54978826E-02 | .18737454E+00 | .89443053E+00 | .34999789E+00 | -.29910118E+00 |
| 22 | -.79534249E+00 | -.81457877E-02 | .20521120E+00 | .93888885E+00 | .34324588E+00 | -.31754039E+00 |
| 23 | -.77750733E+00 | -.11330604E-01 | .22332849E+00 | .98241574E+00 | .32699260E+00 | -.28678255E+00 |
| 24 | -.75967546E+00 | -.14932555E-01 | .24152051E+00 | .10247051E+01 | .29848221E+00 | -.21251590E+00 |
| 25 | -.74197277E+00 | -.18770622E-01 | .25963448E+00 | .10656385E+01 | .25772689E+00 | -.98651162E-01 |
| 26 | -.72442886E+00 | -.22651897E-01 | .27760259E+00 | .11053097E+01 | .21817852E+00 | .42156577E-02 |
| 27 | -.70699860E+00 | -.26438144E-01 | .29543934E+00 | .11439554E+01 | .18922205E+00 | .62915790E-01 |
| 28 | -.68963086E+00 | -.30058774E-01 | .31318046E+00 | .11817981E+01 | .16470331E+00 | .10557758E+00 |
| 29 | -.67229757E+00 | -.33468083E-01 | .33084586E+00 | .12189889E+01 | .13997178E+00 | .15613772E+00 |
| 30 | -.65497395E+00 | -.36620239E-01 | .34845392E+00 | .12556581E+01 | .11868597E+00 | .19804850E+00 |
| 31 | -.63762323E+00 | -.39484150E-01 | .36603941E+00 | .12919503E+01 | .10333859E+00 | .21134347E+00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | -.62021563E+00 | -.42054396E-01 | .38363574E+00 | .13279862E+01 | .89395340E-01 | .21558578E+00 |
| 33 | -.60273999E+00 | -.44333053E-01 | .40125931E+00 | .13638422E+01 | .74877456E-01 | .22400651E+00 |
| 34 | -.58519312E+00 | -.46316717E-01 | .41891795E+00 | .13995747E+01 | .60293012E-01 | .23544841E+00 |
| 35 | -.56756606E+00 | -.47999708E-01 | .43662517E+00 | .14352495E+01 | .47044849E-01 | .23547795E+00 |
| 36 | -.54984185E+00 | -.49388548E-01 | .45440371E+00 | .14709468E+01 | .34963908E-01 | .21307603E+00 |
| 37 | -.53200957E+00 | -.50511498E-01 | .47227132E+00 | .15067334E+01 | .22261026E-01 | .17584635E+00 |
| 38 | -.51408335E+00 | -.51409030E-01 | .49021999E+00 | .15426259E+01 | .74565128E-02 | .15054962E+00 |
| 39 | -.49610193E+00 | -.52109325E-01 | .50821504E+00 | .15785925E+01 | -.88200474E-02 | .14636346E+00 |
| 40 | -.47810716E+00 | -.52619291E-01 | .52621704E+00 | .16145960E+01 | -.25317508E-01 | .14875142E+00 |
| 41 | -.46013100E+00 | -.52937205E-01 | .54419601E+00 | .16506191E+01 | -.41694783E-01 | .14814728E+00 |
| 42 | -.44219988E+00 | -.53063103E-01 | .56212757E+00 | .16866556E+01 | -.58051121E-01 | .14653678E+00 |
| 43 | -.42433954E+00 | -.52998773E-01 | .57998803E+00 | .17227008E+01 | -.74375283E-01 | .14442997E+00 |
| 44 | -.40657596E+00 | -.52746910E-01 | .59775339E+00 | .17587491E+01 | -.90653840E-01 | .14163898E+00 |
| 45 | -.38893588E+00 | -.52311457E-01 | .61539885E+00 | .17947930E+01 | -.10691811E+00 | .13698397E+00 |
| 46 | -.37144931E+00 | -.51698406E-01 | .63289616E+00 | .18308179E+01 | -.12314691E+00 | .13235107E+00 |
| 47 | -.35415496E+00 | -.50912247E-01 | .65020837E+00 | .18667896E+01 | -.13864082E+00 | .13989655E+00 |
| 48 | -.33709961E+00 | -.49944234E-01 | .66729117E+00 | .19026549E+01 | -.15229757E+00 | .16593941E+00 |
| 49 | -.32032395E+00 | -.48766969E-01 | .68410809E+00 | .19383699E+01 | -.16401921E+00 | .19773849E+00 |
| 50 | -.30385496E+00 | -.47342658E-01 | .70063855E+00 | .19739162E+01 | -.17275822E+00 | .23993181E+00 |
| 51 | -.28770446E+00 | -.45621039E-01 | .71688055E+00 | .20093065E+01 | -.17676379E+00 | .29377813E+00 |
| 52 | -.27184737E+00 | -.43542764E-01 | .73287326E+00 | .20446349E+01 | -.18114075E+00 | .31254885E+00 |
| 53 | -.25621317E+00 | -.41076078E-01 | .74870085E+00 | .20801049E+01 | -.19402034E+00 | .27229653E+00 |
| 54 | -.24071830E+00 | -.38241165E-01 | .76445292E+00 | .21159663E+01 | -.21618465E+00 | .19858735E+00 |
| 55 | -.22529209E+00 | -.35098316E-01 | .78019603E+00 | .21524612E+01 | -.24620993E+00 | .10656384E+00 |
| 56 | -.20987996E+00 | -.31739388E-01 | .79596994E+00 | .21898198E+01 | -.28437954E+00 | -.60916689E-02 |
| 57 | -.19445512E+00 | -.28295190E-01 | .81177462E+00 | .22282329E+01 | -.32415783E+00 | -.11844793E+00 |
| 58 | -.17905534E+00 | -.24921795E-01 | .82753955E+00 | .22677560E+01 | -.35196274E+00 | -.18114870E+00 |
| 59 | -.16378959E+00 | -.21744095E-01 | .84313253E+00 | .23082709E+01 | -.36787320E+00 | -.19350055E+00 |
| 60 | -.14879038E+00 | -.18825569E-01 | .85841304E+00 | .23495871E+01 | -.37980706E+00 | -.18772202E+00 |
| 61 | -.13417989E+00 | -.16188476E-01 | .87325962E+00 | .23915213E+01 | -.39003707E+00 | -.17321463E+00 |
| 62 | -.12006868E+00 | -.13830033E-01 | .88756655E+00 | .24338981E+01 | -.39874262E+00 | -.14900946E+00 |
| 63 | -.10655276E+00 | -.11724098E-01 | .90124555E+00 | .24765565E+01 | -.40667076E+00 | -.11808695E+00 |
| 64 | -.93700365E-01 | -.98299269E-02 | .91423678E+00 | .25193945E+01 | -.41667485E+00 | -.10162480E+00 |
| 65 | -.81558093E-01 | -.81168513E-02 | .92649902E+00 | .25623616E+01 | -.42685364E+00 | -.89997475E-01 |
| 66 | -.70180912E-01 | -.65672286E-02 | .93798152E+00 | .26053574E+01 | -.43401209E+00 | -.59796374E-01 |
| 67 | -.59617866E-01 | -.51298876E-02 | .94864191E+00 | .26482700E+01 | -.44088378E+00 | -.32993237E-01 |
| 68 | -.49891094E-01 | -.37593524E-02 | .95846476E+00 | .26910658E+01 | -.44756218E+00 | -.13923951E-01 |
| 69 | -.41009359E-01 | -.24200189E-02 | .96744691E+00 | .27337567E+01 | -.45405627E+00 | -.28241099E-02 |
| 70 | -.32976423E-01 | -.10881966E-02 | .97558951E+00 | .27763781E+01 | -.45868464E+00 | .76451099E-02 |
| 71 | -.25799979E-01 | .25606339E-03 | .98289076E+00 | .28189476E+01 | -.46230833E+00 | .18782364E-01 |
| 72 | -.19479093E-01 | .16331177E-02 | .98935991E+00 | .28615434E+01 | -.45955485E+00 | .22951109E-01 |
| 73 | -.14012376E-01 | .30512413E-02 | .99500757E+00 | .29042885E+01 | -.47637959E+00 | .86508035E-02 |
| 74 | -.93981660E-02 | .45168636E-02 | .99984896E+00 | .29473994E+01 | -.40586238E+00 | .56950156E-01 |
| 75 | -.56452706E-02 | .60128731E-02 | .10038890E+01 | .29911809E+01 | -.66383977E+00 | -.21081667E+00 |
| 76 | -.28150782E-02 | .75456025E-02 | .10071076E+01 | .30354282E+01 | .39363588E+00 | .84623066E+00 |
| 77 | -.94968242E-03 | .91967362E-02 | .10095988E+01 | .30799491E+01 | -.31720972E+01 | -.28352684E+01 |
| 78 | -.30485964E-04 | .11058310E-01 | .10116749E+01 | .31305498E+01 | .98100103E+01 | .98799391E+01 |
| 79 | 0. | .13243320E-01 | .10138602E+01 | .31415926E+01 | -.97624314E+01 | -.97930177E+01 |
| 80 | .65030247E-03 | .15829109E-01 | .10165265E+01 | .31926002E+01 | .44997238E+01 | .43755797E+01 |
| 81 | .17762539E-02 | .18647723E-01 | .10195617E+01 | .32259089E+01 | -.83280561E+00 | -.10443279E+01 |
| 82 | .34231107E-02 | .21490743E-01 | .10228472E+01 | .32586742E+01 | .46048953E+00 | .15715571E+00 |
| 83 | .56829827E-02 | .24332496E-01 | .10264780E+01 | .32925069E+01 | .24217530E+00 | -.99432912E-01 |
| 84 | .85635736E-02 | .27169898E-01 | .10305213E+01 | .33269370E+01 | .35092796E+00 | -.36113883E-01 |
| 85 | .12071072E-01 | .29979690E-01 | .10350155E+01 | .33617740E+01 | .35762820E+00 | -.60431344E-01 |
| 86 | .16211803E-01 | .32745574E-01 | .10399950E+01 | .33969369E+01 | .37978023E+00 | -.64246047E-01 |
| 87 | .20988300E-01 | .35449598E-01 | .10454838E+01 | .34323627E+01 | .38825642E+00 | -.78570239E-01 |
| 88 | .26405806E-01 | .38073872E-01 | .10515035E+01 | .34680375E+01 | .39609700E+00 | -.88619119E-01 |
| 89 | .32471242E-01 | .40603093E-01 | .10580751E+01 | .35039677E+01 | .40090680E+00 | -.97861165E-01 |
| 90 | .39194110E-01 | .43025607E-01 | .10652211E+01 | .35401759E+01 | .40543066E+00 | -.10002185E+00 |
| 91 | .46584525E-01 | .45336855E-01 | .10729645E+01 | .35766854E+01 | .40866529E+00 | -.96097988E-01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 92 | .54649490E-01 | .47539130E-01 | .10813248E+01 | .36135040E+01 | .41021616E+00 | -.86971573E-01 |
| 93 | .63390359E-01 | .49640495E-01 | .10903147E+01 | .36506193E+01 | .40953865E+00 | -.74966759E-01 |
| 94 | .72800014E-01 | .51651464E-01 | .10999368E+01 | .36879940E+01 | .40579625E+00 | -.66195307E-01 |
| 95 | .82864580E-01 | .53580058E-01 | .11101845E+01 | .37255800E+01 | .39988071E+00 | -.59560685E-01 |
| 96 | .93566769E-01 | .55431923E-01 | .11210457E+01 | .37633322E+01 | .39213607E+00 | -.55300456E-01 |
| 97 | .10488595E+00 | .57209614E-01 | .11325036E+01 | .38012078E+01 | .38264489E+00 | -.55333350E-01 |
| 98 | .11680199E+00 | .58912451E-01 | .11445407E+01 | .38391772E+01 | .37251213E+00 | -.53619618E-01 |
| 99 | .12929459E+00 | .60540566E-01 | .11571390E+01 | .38772186E+01 | .36129141E+00 | -.53700182E-01 |
| 100 | .14234126E+00 | .62092606E-01 | .11702776E+01 | .39153107E+01 | .34918489E+00 | -.55318726E-01 |
| 101 | .15592027E+00 | .63566014E-01 | .11839364E+01 | .39534397E+01 | .33653901E+00 | -.55932065E-01 |
| 102 | .17000928E+00 | .64958730E-01 | .11980940E+01 | .39915949E+01 | .32315816E+00 | -.57797936E-01 |
| 103 | .18458558E+00 | .66268100E-01 | .12127290E+01 | .40297680E+01 | .30930183E+00 | -.58824747E-01 |
| 104 | .19962635E+00 | .67492208E-01 | .12278195E+01 | .40679534E+01 | .29492942E+00 | -.59535293E-01 |
| 105 | .21510730E+00 | .68629410E-01 | .12433422E+01 | .41061443E+01 | .27998482E+00 | -.61287016E-01 |
| 106 | .23100353E+00 | .69677285E-01 | .12592729E+01 | .41443347E+01 | .26461428E+00 | -.62730174E-01 |
| 107 | .24729015E+00 | .70633622E-01 | .12755876E+01 | .41825207E+01 | .24883327E+00 | -.63930238E-01 |
| 108 | .26394148E+00 | .71496477E-01 | .12922613E+01 | .42206982E+01 | .23264426E+00 | -.65457350E-01 |
| 109 | .28093148E+00 | .72263780E-01 | .13092686E+01 | .42588638E+01 | .21611368E+00 | -.66663787E-01 |
| 110 | .29823373E+00 | .72933771E-01 | .13265838E+01 | .42970146E+01 | .19925629E+00 | -.67730966E-01 |
| 111 | .31582111E+00 | .73504814E-01 | .13441804E+01 | .43351470E+01 | .18208682E+00 | -.69280376E-01 |
| 112 | .33366624E+00 | .73975007E-01 | .13620318E+01 | .43732582E+01 | .16466938E+00 | -.70319668E-01 |
| 113 | .35174169E+00 | .74342909E-01 | .13801110E+01 | .44113458E+01 | .14701586E+00 | -.71187926E-01 |
| 114 | .37001929E+00 | .74607337E-01 | .13983905E+01 | .44494067E+01 | .12915243E+00 | -.72282816E-01 |
| 115 | .38847050E+00 | .74766964E-01 | .14168424E+01 | .44874376E+01 | .11111756E+00 | -.73398549E-01 |
| 116 | .40706648E+00 | .74820395E-01 | .14354384E+01 | .45254348E+01 | .92943746E-01 | -.74665006E-01 |
| 117 | .42577831E+00 | .74766077E-01 | .14541503E+01 | .45633949E+01 | .74669133E-01 | -.76157692E-01 |
| 118 | .44457722E+00 | .74602366E-01 | .14729500E+01 | .46013152E+01 | .56321026E-01 | -.77159936E-01 |
| 119 | .46343471E+00 | .74328132E-01 | .14918094E+01 | .46391931E+01 | .37922950E-01 | -.77911728E-01 |
| 120 | .48232163E+00 | .73942521E-01 | .15107003E+01 | .46770249E+01 | .19523290E-01 | -.79217196E-01 |
| 121 | .50120859E+00 | .73444124E-01 | .15295938E+01 | .47148062E+01 | .11736873E-02 | -.81149154E-01 |
| 122 | .52006676E+00 | .72830944E-01 | .15484620E+01 | .47525333E+01 | -.17114945E-01 | -.82713933E-01 |
| 123 | .53886823E+00 | .72101315E-01 | .15672776E+01 | .47902039E+01 | -.35323467E-01 | -.83862451E-01 |
| 124 | .55758506E+00 | .71254024E-01 | .15860136E+01 | .48278152E+01 | -.53389022E-01 | -.85376542E-01 |
| 125 | .57618947E+00 | .70287556E-01 | .16046431E+01 | .48653639E+01 | -.71257763E-01 | -.87387123E-01 |
| 126 | .59465437E+00 | .69199941E-01 | .16231400E+01 | .49028471E+01 | -.88929047E-01 | -.89165067E-01 |
| 127 | .61295386E+00 | .67989360E-01 | .16414795E+01 | .49402637E+01 | -.10637988E+00 | -.90670838E-01 |
| 128 | .63106267E+00 | .66654380E-01 | .16596374E+01 | .49776129E+01 | -.12355276E+00 | -.92291250E-01 |
| 129 | .64895640E+00 | .65193370E-01 | .16775907E+01 | .50148944E+01 | -.14040413E+00 | -.94060864E-01 |
| 130 | .66661201E+00 | .63604700E-01 | .16953177E+01 | .50521099E+01 | -.15696773E+00 | -.95211826E-01 |
| 131 | .68400827E+00 | .61887390E-01 | .17127985E+01 | .50892639E+01 | -.17329268E+00 | -.95177467E-01 |
| 132 | .70112508E+00 | .60041747E-01 | .17300145E+01 | .51263623E+01 | -.18934896E+00 | -.94337128E-01 |
| 133 | .71794282E+00 | .58068930E-01 | .17469476E+01 | .51634111E+01 | -.20499500E+00 | -.93775425E-01 |
| 134 | .73444279E+00 | .55970045E-01 | .17635805E+01 | .52004176E+01 | -.22032887E+00 | -.92423400E-01 |
| 135 | .75060817E+00 | .53746808E-01 | .17798980E+01 | .52373928E+01 | -.23542224E+00 | -.89832354E-01 |
| 136 | .76642334E+00 | .51401998E-01 | .17958861E+01 | .52743500E+01 | -.25015210E+00 | -.86935811E-01 |
| 137 | .78187389E+00 | .48938602E-01 | .18115318E+01 | .53113053E+01 | -.26446544E+00 | -.83923312E-01 |
| 138 | .79694800E+00 | .46359398E-01 | .18268249E+01 | .53482817E+01 | -.27855743E+00 | -.79564263E-01 |
| 139 | .81163818E+00 | .43667964E-01 | .18417596E+01 | .53853144E+01 | -.29281553E+00 | -.72007053E-01 |
| 140 | .82594255E+00 | .40870923E-01 | .18563349E+01 | .54224567E+01 | -.30808405E+00 | -.57759680E-01 |
| 141 | .83986486E+00 | .37981892E-01 | .18705538E+01 | .54597830E+01 | -.32520606E+00 | -.34308039E-01 |
| 142 | .85341131E+00 | .35025549E-01 | .18844191E+01 | .54973854E+01 | -.34469663E+00 | -.94922772E-03 |
| 143 | .86658457E+00 | .32040020E-01 | .18979264E+01 | .55353595E+01 | -.36575816E+00 | .37944419E-01 |
| 144 | .87937576E+00 | .29074464E-01 | .19110569E+01 | .55737833E+01 | -.38650216E+00 | .74894659E-01 |
| 145 | .89175958E+00 | .26181554E-01 | .19237741E+01 | .56126983E+01 | -.40494928E+00 | .10288684E+00 |
| 146 | .90369481E+00 | .23408008E-01 | .19360274E+01 | .56521034E+01 | -.42019222E+00 | .11904058E+00 |
| 147 | .91513138E+00 | .20787988E-01 | .19477602E+01 | .56919679E+01 | -.43292318E+00 | .12663041E+00 |
| 148 | .92601800E+00 | .18343501E-01 | .19589179E+01 | .57322514E+01 | -.44393462E+00 | .12912308E+00 |
| 149 | .93630612E+00 | .16087736E-01 | .19694504E+01 | .57729144E+01 | -.45375165E+00 | .12887117E+00 |
| 150 | .94595079E+00 | .14028140E-01 | .19793126E+01 | .58139218E+01 | -.46255089E+00 | .12672351E+00 |
| 151 | .95491055E+00 | .12167975E-01 | .19884634E+01 | .58552417E+01 | -.47042290E+00 | .12315822E+00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 152 | .96314744E+00 | .10507215E-01 | .19968660E+01 | .58968467E+01 | -.47748836E+00 | .11885666E+00 |
| 153 | .97062697E+00 | .90435138E-02 | .20044874E+01 | .59387135E+01 | -.48375500E+00 | .11398418E+00 |
| 154 | .97731771E+00 | .77726876E-02 | .20112978E+01 | .59808220E+01 | -.48918689E+00 | .10846374E+00 |
| 155 | .98319142E+00 | .66888839E-02 | .20172707E+01 | .60231575E+01 | -.49388107E+00 | .10295459E+00 |
| 156 | .98822326E+00 | .57854833E-02 | .20223830E+01 | .60657156E+01 | -.49787831E+00 | .97865495E-01 |
| 157 | .99239108E+00 | .50559986E-02 | .20266141E+01 | .61085051E+01 | -.50114070E+00 | .93213510E-01 |
| 158 | .99567448E+00 | .44944613E-02 | .20299452E+01 | .61515529E+01 | -.50366509E+00 | .89031168E-01 |
| 159 | .99805372E+00 | .40957510E-02 | .20323576E+01 | .61949233E+01 | -.50536356E+00 | .85486714E-01 |
| 160 | .99950735E+00 | .38562107E-02 | .20338309E+01 | .62387902E+01 | -.50650594E+00 | .82489585E-01 |
| 161 | .99999989E+00 | .37758884E-02 | .20343299E+01 | .62831853E+01 | -.50636002E+00 | .81016105E-01 |

IFPT= 3 INT1= 2 NLIST= 0 DX= 0.00000

C= UPPER SURFACE CALCULATION USING LFC 13.0 PCT THICK AIRFOIL DESIGNED BY ALLISON

PSI= 35.00000 DTRIP= 0.00000

INTRL= 1 IFR= 2

RNL(I)
11000000.0

INTV= 1 L= 83

FLOW IS COMPRESSIBLE AND THE FOLLOWING UM(I) IS THE MACH NO. DISTRIBUTION NORMAL TO THE LEADING EDGE (MEN)

| I | XV(I) | UM(I) |
|---|---|---|
| 2 | 0.00000 | .08740 |
| 3 | .00065 | .23874 |
| 4 | .00178 | .38791 |
| 5 | .00342 | .52032 |
| 6 | .00568 | .62806 |
| 7 | .00856 | .72062 |
| 8 | .01207 | .79895 |
| 9 | .01621 | .86598 |
| 10 | .02099 | .92548 |
| 11 | .02641 | .97710 |
| 12 | .03247 | 1.02282 |
| 13 | .03919 | 1.05972 |
| 14 | .04658 | 1.08823 |
| 15 | .05465 | 1.10658 |
| 16 | .06339 | 1.11717 |
| 17 | .07280 | 1.12133 |
| 18 | .08286 | 1.12208 |
| 19 | .09357 | 1.11986 |
| 20 | .10489 | 1.11727 |
| 21 | .11680 | 1.11298 |
| 22 | .12929 | 1.10884 |
| 23 | .14234 | 1.10424 |
| 24 | .15592 | 1.10000 |
| 25 | .17001 | 1.09557 |
| 26 | .18459 | 1.09153 |
| 27 | .19963 | 1.08717 |
| 28 | .21511 | 1.08341 |
| 29 | .23100 | 1.07949 |
| 30 | .24729 | 1.07605 |
| 31 | .26394 | 1.07250 |
| 32 | .28093 | 1.06936 |
| 33 | .29823 | 1.06605 |
| 34 | .31582 | 1.06316 |
| 35 | .33367 | 1.05999 |
| 36 | .35174 | 1.05702 |
| 37 | .37002 | 1.05373 |
| 38 | .38847 | 1.05066 |
| 39 | .40707 | 1.04746 |
| 40 | .42578 | 1.04472 |
| 41 | .44458 | 1.04192 |

| | | |
|---|---|---|
| 42 | .46343 | 1.03937 |
| 43 | .48232 | 1.03673 |
| 44 | .50121 | 1.03435 |
| 45 | .52007 | 1.03154 |
| 46 | .53887 | 1.02827 |
| 47 | .55759 | 1.02434 |
| 48 | .57619 | 1.02030 |
| 49 | .59465 | 1.01564 |
| 50 | .61295 | 1.01043 |
| 51 | .63106 | 1.00441 |
| 52 | .64896 | .99778 |
| 53 | .66661 | .99003 |
| 54 | .68401 | .98131 |
| 55 | .70113 | .97149 |
| 56 | .71794 | .96091 |
| 57 | .73444 | .94920 |
| 58 | .75061 | .93646 |
| 59 | .76642 | .92252 |
| 60 | .78187 | .90745 |
| 61 | .79695 | .89072 |
| 62 | .81164 | .87208 |
| 63 | .82594 | .85101 |
| 64 | .83986 | .82767 |
| 65 | .85341 | .80255 |
| 66 | .86658 | .77704 |
| 67 | .87938 | .75258 |
| 68 | .89176 | .73053 |
| 69 | .90369 | .71140 |
| 70 | .91513 | .69503 |
| 71 | .92602 | .68087 |
| 72 | .93631 | .66848 |
| 73 | .94595 | .65746 |
| 74 | .95491 | .64759 |
| 75 | .96315 | .63855 |
| 76 | .97063 | .63021 |
| 77 | .97732 | .62232 |
| 78 | .98319 | .61465 |
| 79 | .98822 | .60679 |
| 80 | .99239 | .59839 |
| 81 | .99567 | .58878 |
| 82 | .99805 | .57682 |
| 83 | .99951 | .55848 |
| 84 | 1.00000 | .55517 |



MGRAD= .96100000E+02

VGRAD= 88.86677 XV(1)= -.15490000E-04

NON-DIMENSIONAL DISTANCE FROM LOWER SURFACE TRAILING EDGE (IF UPPER SURFACE IS TO BE COMPUTED,ISP=2), OR FROM UPPER SURFACE TRAILING EDGE (IF LOWER SURFACE IS TO BE COMPUTED,ISP=0) TO ATTACHMENT LINE = SATT/CH = .10122849E+01

SUCTION, TRANSITION ANAYLSIS OF YAWED WING LAMINAR BOUNDARY LAYER

UPPER SURFACE CALCULATION USING LFC 13.0 PCT THICK AIRFOIL DESIGNED BY ALLISON

REYNOLDS NUMBER DEFINED BY RN= QL/NU

VELOCITY GRADIENT AT ATTACHMENT LINE= 88.87

| XV | SXV | SXVINC | U | THXV | FUTH | FSVSINC |
|---|---|---|---|---|---|---|
| -.15490000E-04 | 0. | 0. | 0. | .31337212E+01 | -.55420016E+03 | .48872162E+00 |
| 0. | .15752780E-02 | .23424970E-02 | .98750144E-01 | .31415926E+01 | -.53428647E+03 | .42655150E+01 |
| .65030247E-03 | .42415860E-02 | .62192537E-02 | .26974053E+00 | .31926002E+01 | .23762412E+03 | .96822370E+01 |
| .17762539E-02 | .72767716E-02 | .10392972E-01 | .43428328E+00 | .32259089E+01 | -.77211587E+02 | .15393367E+02 |
| .34231107E-02 | .10562331E-01 | .14553619E-01 | .58789513E+00 | .32586742E+01 | -.20594967E+02 | .18691375E+02 |
| .56829827E-02 | .14193113E-01 | .18744973E-01 | .70962638E+00 | .32925069E+01 | -.15834746E+02 | .19853854E+02 |
| .85635736E-02 | .18236460E-01 | .23001526E-01 | .81420097E+00 | .33269370E+01 | -.14688648E+02 | .20707975E+02 |
| .12071072E-01 | .22730621E-01 | .27331671E-01 | .90271031E+00 | .33617740E+01 | -.11474979E+02 | .20245174E+02 |
| .16211803E-01 | .27710155E-01 | .31751697E-01 | .97843458E+00 | .33969369E+01 | -.58201738E+01 | .19972623E+02 |
| .20988300E-01 | .33198932E-01 | .36267064E-01 | .10456656E+01 | .34323627E+01 | -.87130013E+01 | .19386995E+02 |
| .26405806E-01 | .39218582E-01 | .40883799E-01 | .11039914E+01 | .34680375E+01 | -.37298538E+01 | .18524631E+02 |
| .32471242E-01 | .45790224E-01 | .45612246E-01 | .11556472E+01 | .35039677E+01 | -.94093239E+01 | .16890399E+02 |
| .39194110E-01 | .52936238E-01 | .50474526E-01 | .11973387E+01 | .35401759E+01 | -.62364750E+01 | .13917680E+02 |
| .46584525E-01 | .60679629E-01 | .55510011E-01 | .12295493E+01 | .35766854E+01 | -.10063672E+02 | .10098084E+02 |
| .54649490E-01 | .69039873E-01 | .60770159E-01 | .12502824E+01 | .36135040E+01 | -.57377098E+01 | .59939008E+01 |
| .63390359E-01 | .78029785E-01 | .66311190E-01 | .12622529E+01 | .36506193E+01 | -.60506556E+01 | .28560408E+01 |
| .72800014E-01 | .87651927E-01 | .72179618E-01 | .12669515E+01 | .36879940E+01 | -.17787177E+01 | .84040489E+00 |
| .82864580E-01 | .97899608E-01 | .78407598E-01 | .12677988E+01 | .37255800E+01 | -.33581957E+01 | -.38653665E+00 |
| .93566769E-01 | .10876[illegible]83E+00 | .85015415E-01 | .12652920E+01 | .37633322E+01 | .10385002E+01 | -.86353184E+00 |
| .10488595E+00 | .12021876E+00 | .92010310E-01 | .12623648E+01 | .38012078E+01 | -.25245897E+01 | -.11248056E+01 |
| .11680199E+00 | .13225585E+00 | .99395050E-01 | .12575153E+01 | .38391772E+01 | .10800788E+01 | -.13383794E+01 |
| .12929459E+00 | .14485410E+00 | .10717067E+00 | .12528442E+01 | .38772186E+01 | -.10185685E+01 | -.12528907E+01 |
| .14234126E+00 | .15799276E+00 | .11533043E+00 | .12476451E+01 | .39153107E+01 | .83533909E+00 | -.12183368E+01 |
| .15592027E+00 | .17165148E+00 | .12386661E+00 | .12428504E+01 | .39534397E+01 | -.63239775E+00 | -.11235067E+01 |
| .17000928E+00 | .18580915E+00 | .13276919E+00 | .12378437E+01 | .39915949E+01 | .83347303E+00 | -.10383524E+01 |
| .18458558E+00 | .20044415E+00 | .14202715E+00 | .12332818E+01 | .40297680E+01 | -.85928899E+00 | -.99640772E+00 |
| .19962635E+00 | .21553465E+00 | .15163000E+00 | .12283508E+01 | .40679534E+01 | .10900608E+01 | -.91968892E+00 |
| .21510730E+00 | .23105731E+00 | .16156444E+00 | .12241059E+01 | .41061443E+01 | -.67517301E+00 | -.82590170E+00 |
| .23100353E+00 | .24698804E+00 | .17181512E+00 | .12196783E+01 | .41443347E+01 | .85883321E+00 | -.77047765E+00 |
| .24729015E+00 | .26330271E+00 | .18236710E+00 | .12157912E+01 | .41825207E+01 | -.53824485E+00 | -.70243044E+00 |
| .26394148E+00 | .27997638E+00 | .19320410E+00 | .12117778E+01 | .42206982E+01 | .77063884E+00 | -.65064811E+00 |
| .28093148E+00 | .29698370E+00 | .20430964E+00 | .12082361E+01 | .42588638E+01 | -.60670235E+00 | -.61141382E+00 |
| .29823373E+00 | .31429892E+00 | .21566712E+00 | .12044895E+01 | .42970146E+01 | .80574190E+00 | -.57069493E+00 |
| .31582111E+00 | .33189557E+00 | .22725910E+00 | .12012215E+01 | .43351470E+01 | -.64926208E+00 | -.53822616E+00 |
| .33366624E+00 | .34974689E+00 | .23906834E+00 | .11976495E+01 | .43732582E+01 | .52852724E+00 | -.53889906E+00 |
| .35174169E+00 | .36782608E+00 | .25107928E+00 | .11942837E+01 | .44113458E+01 | -.62184462E+00 | -.53699290E+00 |
| .37001929E+00 | .38610560E+00 | .26327600E+00 | .11905714E+01 | .44494067E+01 | .51477603E+00 | -.53696724E+00 |
| .38847050E+00 | .40455750E+00 | .27564187E+00 | .11870985E+01 | .44874376E+01 | -.45655307E+00 | -.52007479E+00 |
| .40706648E+00 | .42315355E+00 | .28815824E+00 | .11834902E+01 | .45254348E+01 | .73604711E+00 | -.48168090E+00 |
| .42577831E+00 | .44186546E+00 | .30080407E+00 | .11803922E+01 | .45633949E+01 | -.37820850E+00 | -.43770923E+00 |
| .44457722E+00 | .46066508E+00 | .31355757E+00 | .11772277E+01 | .46013152E+01 | .48551510E+00 | -.42091507E+00 |
| .46343471E+00 | .47952457E+00 | .32639863E+00 | .11743489E+01 | .46391931E+01 | -.38432104E+00 | -.40566627E+00 |
| .48232163E+00 | .49841542E+00 | .33930681E+00 | .11713599E+01 | .46770249E+01 | .57514408E+00 | -.38275657E+00 |
| .50120859E+00 | .51730896E+00 | .35226112E+00 | .11686793E+01 | .47148062E+01 | -.63751488E+00 | -.38539697E+00 |
| .52006676E+00 | .53617710E+00 | .36524386E+00 | .11654948E+01 | .47525333E+01 | -.16405357E+00 | -.45891693E+00 |
| .53886823E+00 | .55499272E+00 | .37824415E+00 | .11618101E+01 | .47902039E+01 | -.84030328E+00 | -.54968420E+00 |
| .55758506E+00 | .57372872E+00 | .39125284E+00 | .11573619E+01 | .48278152E+01 | .26493143E+00 | -.59825187E+00 |
| .57618947E+00 | .59235821E+00 | .40425768E+00 | .11527961E+01 | .48653639E+01 | -.75050807E+00 | -.63783034E+00 |
| .59465437E+00 | .61085512E+00 | .41724606E+00 | .11475336E+01 | .49028471E+01 | -.26983529E+00 | -.72549192E+00 |
| .61295386E+00 | .62919460E+00 | .43020976E+00 | .11416502E+01 | .49402637E+01 | -.86923061E+00 | -.82122558E+00 |
| .63106267E+00 | .64735256E+00 | .44314223E+00 | .11348480E+01 | .49776129E+01 | -.24722417E+00 | -.91195931E+00 |
| .64895640E+00 | .66530583E+00 | .45603754E+00 | .11273574E+01 | .50148944E+01 | -.11639346E+01 | -.10254652E+01 |
| .66661201E+00 | .68303277E+00 | .46889274E+00 | .11186017E+01 | .50521099E+01 | -.63073359E+00 | -.11669328E+01 |
| .68400827E+00 | .70051359E+00 | .48170843E+00 | .11087522E+01 | .50892639E+01 | -.11259269E+01 | -.12978885E+01 |
| .70112508E+00 | .71772962E+00 | .49448499E+00 | .10976521E+01 | .51263623E+01 | -.37810235E+00 | -.14003652E+01 |
| .71794282E+00 | .73466267E+00 | .50722029E+00 | .10856996E+01 | .51634111E+01 | -.11497006E+01 | -.14988521E+01 |
| .73444279E+00 | .75129560E+00 | .51991214E+00 | .10724632E+01 | .52004176E+01 | -.70481692E+00 | -.16160421E+01 |
| .75060817E+00 | .76761315E+00 | .53256074E+00 | .10580725E+01 | .52373928E+01 | -.11439815E+01 | -.17236511E+01 |
| .76642334E+00 | .78360120E+00 | .54516646E+00 | .10423189E+01 | .52743500E+01 | -.73552152E+00 | -.18241676E+01 |
| .78187389E+00 | .79924689E+00 | .55773000E+00 | .10252920E+01 | .53113053E+01 | -.15117698E+01 | -.19421706E+01 |
| .79694800E+00 | .81454007E+00 | .57025624E+00 | .10063900E+01 | .53482817E+01 | -.14052404E+01 | -.20941106E+01 |
| .81163818E+00 | .82947476E+00 | .58275773E+00 | .98533626E+00 | .53853144E+01 | -.21617014E+01 | -.22712023E+01 |
| .82594255E+00 | .84405003E+00 | .59525518E+00 | .96152024E+00 | .54224567E+01 | -.17080103E+01 | -.24409912E+01 |
| .83986486E+00 | .85826894E+00 | .60777319E+00 | .93515402E+00 | .54597830E+01 | -.15075937E+01 | -.25400752E+01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| .85341131E+00 | .87213423E+00 | .62032907E+00 | .90476893E+00 | .54973854E+01 | -.36274643E-01 | -.25166513E+01 |
| .86658457E+00 | .88564156E+00 | .63291801E+00 | .87795168E+00 | .55353595E+01 | .10069617E+01 | -.23474140E+01 |
| .87937576E+00 | .89877203E+00 | .64549958E+00 | .85031524E+00 | .55737833E+01 | .22171591E+01 | -.20746105E+01 |
| .89175958E+00 | .91148926E+00 | .65799569E+00 | .82540538E+00 | .56126983E+01 | .23957133E+01 | -.17603860E+01 |
| .90369481E+00 | .92374251E+00 | .67030076E+00 | .80378526E+00 | .56521034E+01 | .22110082E+01 | -.14787284E+01 |
| .91513138E+00 | .93547536E+00 | .68230154E+00 | .78529484E+00 | .56919679E+01 | .16069547E+01 | -.12625374E+01 |
| .92601800E+00 | .94663304E+00 | .69389219E+00 | .76929170E+00 | .57322514E+01 | .13325073E+01 | -.11081800E+01 |
| .93630612E+00 | .95716556E+00 | .70497925E+00 | .75529682E+00 | .57729144E+01 | .93745432E+00 | -.99978978E+00 |
| .94595079E+00 | .96702769E+00 | .71548067E+00 | .74284235E+00 | .58139218E+01 | .86366277E+00 | -.92395321E+00 |
| .95491055E+00 | .97617851E+00 | .72532377E+00 | .73169073E+00 | .58552417E+01 | .54022237E+00 | -.87723200E+00 |
| .96314744E+00 | .98458116E+00 | .73444417E+00 | .72148021E+00 | .58968467E+01 | .51747931E+00 | -.85871627E+00 |
| .97062697E+00 | .99220256E+00 | .74278481E+00 | .71205212E+00 | .59387135E+01 | .29789328E+00 | -.86547699E+00 |
| .97731771E+00 | .99901292E+00 | .75029460E+00 | .70313714E+00 | .59808220E+01 | .21790824E+00 | -.90871914E+00 |
| .98319142E+00 | .10049858E+01 | .75692841E+00 | .69447076E+00 | .60231575E+01 | -.17248033E+00 | -.10220340E+01 |
| .98822326E+00 | .10100981E+01 | .76264689E+00 | .68558736E+00 | .60657156E+01 | -.96659261E-01 | -.12143433E+01 |
| .99239108E+00 | .10143293E+01 | .76741467E+00 | .67610256E+00 | .61085051E+01 | -.12554519E+01 | -.16693182E+01 |
| .99567448E+00 | .10176603E+01 | .77119850E+00 | .66524179E+00 | .61515529E+01 | .83323844E+00 | -.21916816E+01 |
| .99805372E+00 | .10200727E+01 | .77396493E+00 | .65172731E+00 | .61949233E+01 | -.10279694E+02 | -.53732532E+01 |
| .99950735E+00 | .10215460E+01 | .77567658E+00 | .63100655E+00 | .62387902E+01 | .18075375E+02 | -.80131082E+01 |
| .99999989E+00 | .10220449E+01 | .77626160E+00 | .62726349E+00 | .62825220E+01 | -.90376876E+01 | -.20621022E+01 |

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OUTPUT

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*** LEADING-EDGE CONTAMINATION TEST ***

REYNOLDS NUMBER= 11000000.    RTHETA= 51.2    NO TURBULENT CONTAMINATION AT A.L.

X= -.000015   S= 0.000000   SCOMP= 0.000000   U= 0.000000   AME3D= .482902   DU/D(S/L)= 72.795397   12 ITERATIONS

DELTA1= .4750   THETA1= .1975   (DU/DZ)Z=0 =2.2046   (DV/DZ)Z=0 = .114E+01   AIRFOIL SLOPE= .900E+02

| Z | ZCOMP | W | U | V | STV | CFV | T | RHOD |
|---|---|---|---|---|---|---|---|---|
| 0.000000 | 0.000000 | -.289171 | 0.000000 | 0.000000 | | | 1.156667 | 1.226681 |
| .050000 | .038772 | -.290886 | .068570 | .038029 | | | 1.156592 | 1.226760 |
| .100000 | .077539 | -.295942 | .133679 | .075508 | | | 1.156373 | 1.226993 |
| .200000 | .155040 | -.315399 | .253793 | .148809 | | | 1.155526 | 1.227893 |
| .300000 | .232467 | -.346216 | .360975 | .219829 | | | 1.154176 | 1.229328 |
| .400000 | .309788 | -.387137 | .455969 | .288429 | | | 1.152379 | 1.231246 |
| .500000 | .386975 | -.436984 | .539592 | .354420 | | | 1.150193 | 1.233586 |
| .600000 | .464004 | -.494662 | .612708 | .417588 | | | 1.147679 | 1.236288 |
| .700000 | .540856 | -.559165 | .676205 | .477706 | | | 1.144905 | 1.239283 |
| .800000 | .617516 | -.629576 | .730973 | .534553 | | | 1.141939 | 1.242502 |
| .900000 | .693972 | -.705066 | .777888 | .587931 | | | 1.138851 | 1.245871 |
| 1.000000 | .770219 | -.784893 | .817799 | .637675 | | | 1.135709 | 1.249319 |
| 1.100000 | .846255 | -.868395 | .851513 | .683665 | | | 1.132576 | 1.252773 |
| 1.200000 | .922083 | -.954992 | .879790 | .725830 | | | 1.129513 | 1.256171 |
| 1.300000 | .997710 | -1.044177 | .903338 | .764155 | | | 1.126570 | 1.259453 |
| 1.400000 | 1.073145 | -1.135508 | .922805 | .798681 | | | 1.123789 | 1.262570 |
| 1.500000 | 1.148400 | -1.228608 | .938779 | .829501 | | | 1.121202 | 1.265482 |
| 1.600000 | 1.223488 | -1.323154 | .951790 | .856759 | | | 1.118833 | 1.268162 |
| 1.700000 | 1.298426 | -1.418874 | .962307 | .880639 | | | 1.116695 | 1.270590 |
| 1.800000 | 1.373227 | -1.515539 | .970743 | .901361 | | | 1.114792 | 1.272759 |
| 1.900000 | 1.447910 | -1.612959 | .977458 | .919169 | | | 1.113121 | 1.274670 |
| 2.000000 | 1.522487 | -1.710978 | .982761 | .934325 | | | 1.111673 | 1.276330 |
| 2.100000 | 1.596975 | -1.809469 | .986916 | .947097 | | | 1.110434 | 1.277754 |
| 2.200000 | 1.671386 | -1.908328 | .990145 | .957754 | | | 1.109388 | 1.278959 |
| 2.300000 | 1.745733 | -2.007471 | .992634 | .966560 | | | 1.108515 | 1.279967 |
| 2.400000 | 1.820026 | -2.106833 | .994537 | .973764 | | | 1.107794 | 1.280799 |
| 2.500000 | 1.894276 | -2.206362 | .995981 | .979600 | | | 1.107209 | 1.281479 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.600000 | 1.968490 | -2.306016 | .997066 | .984279 | 1.106733 | 1.282027 |
| 2.700000 | 2.042676 | -2.405765 | .997876 | .987994 | 1.106355 | 1.282465 |
| 2.800000 | 2.116839 | -2.505584 | .998474 | .990915 | 1.106057 | 1.282810 |
| 2.900000 | 2.190985 | -2.605454 | .998913 | .993188 | 1.105825 | 1.283080 |
| 3.000000 | 2.265117 | -2.705362 | .999232 | .994939 | 1.105646 | 1.283288 |
| 3.100000 | 2.339238 | -2.805298 | .999462 | .996274 | 1.105508 | 1.283447 |
| 3.200000 | 2.413351 | -2.905252 | .999626 | .997283 | 1.105405 | 1.283568 |
| 3.300000 | 2.487458 | -3.005221 | .999743 | .998037 | 1.105327 | 1.283658 |
| 3.400000 | 2.561561 | -3.105200 | .999824 | .998595 | 1.105270 | 1.283724 |
| 3.500000 | 2.635660 | -3.205185 | .999881 | .999004 | 1.105228 | 1.283773 |
| 3.600000 | 2.709757 | -3.305175 | .999920 | .999301 | 1.105197 | 1.283809 |
| 3.700000 | 2.783852 | -3.405169 | .999947 | .999514 | 1.105175 | 1.283834 |
| 3.800000 | 2.857946 | -3.505164 | .999965 | .999666 | 1.105160 | 1.283852 |
| 3.900000 | 2.932039 | -3.605161 | .999977 | .999772 | 1.105149 | 1.283865 |
| 4.000000 | 3.006131 | -3.705160 | .999985 | .999847 | 1.105141 | 1.283874 |
| 4.100000 | 3.080223 | -3.805158 | .999991 | .999898 | 1.105136 | 1.283880 |
| 4.200000 | 3.154315 | -3.905158 | .999994 | .999933 | 1.105132 | 1.283884 |
| 4.300000 | 3.228406 | -4.005157 | .999996 | .999956 | 1.105130 | 1.283887 |
| 4.400000 | 3.302497 | -4.105157 | .999998 | .999972 | 1.105128 | 1.283889 |
| 4.500000 | 3.376588 | -4.205137 | .999999 | .999983 | 1.105127 | 1.283890 |
| 4.600000 | 3.450680 | -4.305157 | .999999 | .999990 | 1.105126 | 1.283891 |
| 4.700000 | 3.524771 | -4.405156 | 1.000000 | .999994 | 1.105126 | 1.283892 |
| 4.800000 | 3.598862 | -4.505156 | 1.000000 | .999997 | 1.105125 | 1.283892 |
| 4.900000 | 3.672953 | -4.605156 | 1.000000 | .999999 | 1.105125 | 1.283892 |
| 4.950000 | 3.709998 | -4.655156 | 1.000000 | .999999 | 1.105125 | 1.283892 |

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X= -.000004   S=  .001119   SCOMP=  .000751   U=  .050400   AME3D=  .485054   DU/D(S/L)=  41.452912   4 ITERATIONS
DELTA1=  .4640  THETA1=  .1937  (DU/DZ)Z=0 =2.2748  (DV/DZ)Z=0 = .121E+01  AIRFOIL SLOPE= .894E+02
REYNOLDS NUMBER= 11000000.  (DIMENSIONAL Z)/CHORD=) .000045)Z  DELTA1/C= .000021  THETA1/C= .000009
CFX= .464E-03  CFY= .282E-02  CDFX= .178E-08  CDFXINF= .133E-05
*** RELAMINARISATION CHECK ***
REYNOLDS NUMBER= 11000000.  K= .238E-07  KMAX= .238E-07
*** SWEEP INSTABILITY TEST ***
REYNOLDS NUMBER= 11000000.  CHI(OWEN-RANDALL)=  6.27
*** TRANSITION TEST (GRANVILLE) ***
REYNOLDS NUMBER= 11000000.  RTHETA=  5.9

X= -.000000   S=  .002342   SCOMP=  .001575   U=  .098577   AME3D=  .491082   DU/D(S/L)=  39.030765   4 ITERATIONS
DELTA1=  .4721  THETA1=  .1966  (DU/DZ)Z=0 =2.2255  (DV/DZ)Z=0 = .121E+01  AIRFOIL SLOPE= .894E+02
REYNOLDS NUMBER= 11000000.  (DIMENSIONAL Z)/CHORD=) .000046)Z  DELTA1/C= .000022  THETA1/C= .000009
*** RELAMINARISATION CHECK ***
REYNOLDS NUMBER= 11000000.  K= .177E-06  KMAX= .177E-06
*** SWEEP INSTABILITY TEST ***
REYNOLDS NUMBER= 11000000.  CHI(OWEN-RANDALL)=  12.21
*** TRANSITION TEST (GRANVILLE) ***
REYNOLDS NUMBER= 11000000.  RTHETA=  12.1  RTHETCRIT=3219.6  LAM2= .065  NO INSTABILITY

X=  .000000   S=  .002387   SCOMP=  .001606   U=  .100483   AME3D=  .491399   DU/D(S/L)=  39.061186   4 ITERATIONS
DELTA1=  .4719  THETA1=  .1965  (DU/DZ)Z=0 =2.2269  (DV/DZ)Z=0 = .121E+01  AIRFOIL SLOPE= .900E+02
REYNOLDS NUMBER= 11000000.  (DIMENSIONAL Z)/CHORD=) .000046)Z  DELTA1/C= .000022  THETA1/C= .000009
CFX= .875E-03  CFY= .272E-02  CDFX= .397E-08  CDFXINF= .269E-05
*** RELAMINARISATION CHECK ***
REYNOLDS NUMBER= 11000000.  K= .182E-06  KMAX= .182E-06
*** SWEEP INSTABILITY TEST ***
REYNOLDS NUMBER= 11000000.  CHI(OWEN-RANDALL)=  12.44
*** TRANSITION TEST (GRANVILLE) ***
REYNOLDS NUMBER= 11000000.  RTHETA=  12.3
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X=  .102078   S=  .090273   SCOMP=  .117378   U= 1.263216   AME3D= 1.241560   DU/D(S/L)=   -.445287     8 ITERATIONS
DELTA1=  1.7127   THETA1=   .5225   (DU/DZ)Z=0 = .5546  (DV/DZ)Z=0 =  .545E+00  AIRFOIL SLOPE=  .871E+01
REYNOLDS NUMBER=  11000000.  (DIMENSIONAL Z)/CHORD=) .000081)Z  DELTA1/C=  .000138  THETA1/C=  .000042
CFX=  .158E-02  CFY=  .705E-03  CDFX=  .253E-03  CDFXINF=  .285E-03
*** SWEEP INSTABILITY TEST ***
REYNOLDS NUMBER=   11000000.  CHI(OWEN-RANDALL)=   69.72
*** TRANSITION TEST (GRANVILLE) ***
REYNOLDS NUMBER=  11000000.   RTHETA= 638.9 INSTABILITY AT S/C=  .0678  NO TRANSITION
INSTAB. RE. NO.= 455.2  RTC-RTI= 918.0  LAM2BAR=  .003

X=  .104886   S=  .092010   SCOMP=  .120219   U= 1.262365   AME3D= 1.240850   DU/D(S/L)=   -.541482     5 ITERATIONS
DELTA1=  1.7179   THETA1=   .5244   (DU/DZ)Z=0 = .5531  (DV/DZ)Z=0 =  .548E+00  AIRFOIL SLOPE=  .871E+01

STREAM FLOW DISPLACEMENT THICKNESS=   1.475369

CROSS FLOW DISPLACEMENT THICKNESS=    .075184

MAX, CROSS-FLOW VELOCITY=    .024473
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| Z | ZCOMP | W | U | V | STV | CFV | T | RHOD |
|---|---|---|---|---|---|---|---|---|
| 0.000000 | 0.000000 | -.744610 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 1.156667 | .562292 |
| .050000 | .094534 | -.743710 | .047259 | .043981 | .046639 | -.001693 | 1.156074 | .562580 |
| .100000 | .188974 | -.741084 | .092876 | .086355 | .091642 | -.003368 | 1.154378 | .563406 |
| .200000 | .377241 | -.731061 | .179397 | .166515 | .176959 | -.006653 | 1.148132 | .566471 |
| .300000 | .564224 | -.715326 | .259933 | .240932 | .256337 | -.009813 | 1.138758 | .571135 |
| .400000 | .749469 | -.694640 | .334792 | .310016 | .330103 | -.012796 | 1.126967 | .577110 |
| .500000 | .932634 | -.669743 | .404230 | .374142 | .398535 | -.015539 | 1.113376 | .584155 |
| .600000 | 1.113468 | -.641364 | .468467 | .433644 | .461877 | -.017985 | 1.098521 | .592054 |
| .700000 | 1.291803 | -.610216 | .527704 | .488822 | .520345 | -.020081 | 1.082869 | .600612 |
| .800000 | 1.467544 | -.576989 | .582127 | .539939 | .574143 | -.021788 | 1.066823 | .609646 |
| .900000 | 1.640653 | -.542346 | .631922 | .587230 | .623463 | -.023081 | 1.050729 | .618984 |
| 1.000000 | 1.811149 | -.506908 | .677275 | .630901 | .668498 | -.023950 | 1.034878 | .628465 |
| 1.100000 | 1.979090 | -.471249 | .718383 | .671139 | .709441 | -.024399 | 1.019510 | .637938 |
| 1.200000 | 2.144572 | -.435882 | .755452 | .708112 | .746492 | -.024449 | 1.004820 | .647264 |
| 1.300000 | 2.307718 | -.401256 | .788699 | .741978 | .779857 | -.024129 | .990954 | .656321 |
| 1.400000 | 2.468673 | -.367751 | .818353 | .772886 | .809748 | -.023482 | .978019 | .665001 |
| 1.500000 | 2.627594 | -.335678 | .844650 | .800982 | .836385 | -.022553 | .966084 | .673217 |
| 1.600000 | 2.784648 | -.305275 | .867835 | .826410 | .859994 | -.021394 | .955186 | .680898 |
| 1.700000 | 2.940005 | -.276715 | .888153 | .849315 | .880802 | -.020058 | .945330 | .687997 |
| 1.800000 | 3.093836 | -.250107 | .905852 | .869843 | .899037 | -.018597 | .936501 | .694483 |
| 1.900000 | 3.246304 | -.225505 | .921176 | .888145 | .914925 | -.017059 | .928661 | .700346 |
| 2.000000 | 3.397567 | -.202914 | .934363 | .904372 | .928687 | -.015489 | .921760 | .705590 |
| 2.100000 | 3.547774 | -.182295 | .945641 | .918678 | .940538 | -.013925 | .915734 | .710232 |
| 2.200000 | 3.697063 | -.163576 | .955226 | .931215 | .950682 | -.012401 | .910516 | .714303 |
| 2.300000 | 3.845560 | -.146660 | .963324 | .942138 | .959314 | -.010941 | .906032 | .717838 |
| 2.400000 | 3.993378 | -.131427 | .970122 | .951595 | .966615 | -.009568 | .902207 | .720881 |
| 2.500000 | 4.140619 | -.117747 | .975794 | .959734 | .972754 | -.008294 | .898968 | .723478 |
| 2.600000 | 4.287373 | -.105482 | .980497 | .966693 | .977884 | -.007129 | .896246 | .725676 |
| 2.700000 | 4.433720 | -.094490 | .984373 | .972606 | .982146 | -.006077 | .893973 | .727521 |
| 2.800000 | 4.579728 | -.084633 | .987548 | .977599 | .985665 | -.005138 | .892089 | .729058 |
| 2.900000 | 4.725455 | -.075776 | .990133 | .981788 | .988554 | -.004310 | .890537 | .730328 |
| 3.000000 | 4.870953 | -.067793 | .992225 | .985280 | .990911 | -.003587 | .889267 | .731371 |
| 3.100000 | 5.016262 | -.060566 | .993907 | .988172 | .992822 | -.002962 | .888235 | .732220 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3.200000 | 5.161419 | -.053985 | .995253 | .990553 | .994363 | -.002427 | .887402 | .732908 |
| 3.300000 | 5.306454 | -.047955 | .996321 | .992499 | .995598 | -.001974 | .886733 | .733461 |
| 3.400000 | 5.451391 | -.042388 | .997166 | .994081 | .996582 | -.001593 | .886200 | .733902 |
| 3.500000 | 5.596250 | -.037208 | .997829 | .995357 | .997361 | -.001276 | .885777 | .734253 |
| 3.600000 | 5.741047 | -.032349 | .998346 | .996382 | .997975 | -.001015 | .885443 | .734529 |
| 3.700000 | 5.885796 | -.027754 | .998748 | .997199 | .998455 | -.000800 | .885182 | .734746 |
| 3.800000 | 6.030507 | -.023374 | .999058 | .997846 | .998829 | -.000626 | .884979 | .734915 |
| 3.900000 | 6.175188 | -.019167 | .999296 | .998356 | .999118 | -.000486 | .884821 | .735046 |
| 4.000000 | 6.319847 | -.015101 | .999478 | .998755 | .999341 | -.000373 | .884700 | .735146 |
| 4.100000 | 6.464489 | -.011147 | .999616 | .999066 | .999512 | -.000284 | .884607 | .735223 |
| 4.200000 | 6.609117 | -.007281 | .999720 | .999306 | .999642 | -.000214 | .884537 | .735282 |
| 4.300000 | 6.753735 | -.003484 | .999798 | .999492 | .999740 | -.000158 | .884483 | .735327 |
| 4.400000 | 6.898345 | .000258 | .999857 | .999634 | .999815 | -.000115 | .884442 | .735361 |
| 4.500000 | 7.042950 | .003958 | .999901 | .999742 | .999871 | -.000082 | .884412 | .735386 |
| 4.600000 | 7.187550 | .007626 | .999933 | .999825 | .999913 | -.000056 | .884389 | .735405 |
| 4.700000 | 7.332147 | .011269 | .999958 | .999888 | .999944 | -.000036 | .884372 | .735419 |
| 4.800000 | 7.476741 | .014893 | .999976 | .999936 | .999968 | -.000021 | .884359 | .735430 |
| 4.900000 | 7.621334 | .018503 | .999990 | .999972 | .999986 | -.000009 | .884349 | .735438 |
| 4.950000 | 7.693630 | .020304 | .999995 | .999987 | .999994 | -.000004 | .884345 | .735442 |

REYNOLDS NUMBER= 11000000. (DIMENSIONAL Z)/CHORD=) .000081)Z DELTA1/C= .000140 THETA1/C= .000043
*** SWEEP INSTABILITY TEST ***
REYNOLDS NUMBER= 11000000. CHI(OWEN-RANDALL)= 67.32
*** TRANSITION TEST (GRANVILLE) ***
REYNOLDS NUMBER= 11000000. RTHETA= 647.2 INSTABILITY AT S/C= .0678 NO TRANSITION
INSTAB. RE. NO.= 455.2 RTC-RTI= 904.3 LAM2[illegible]= .002

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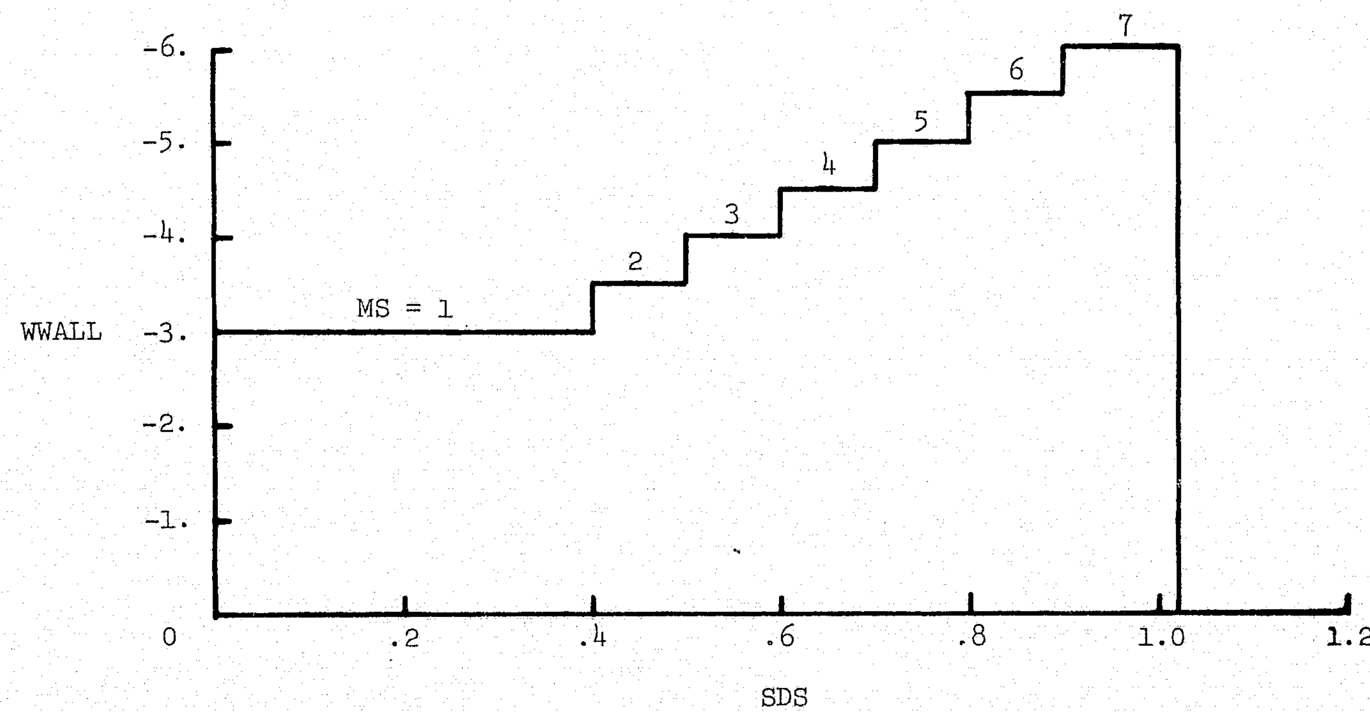



Figure 1. Suction distribution for sample case.

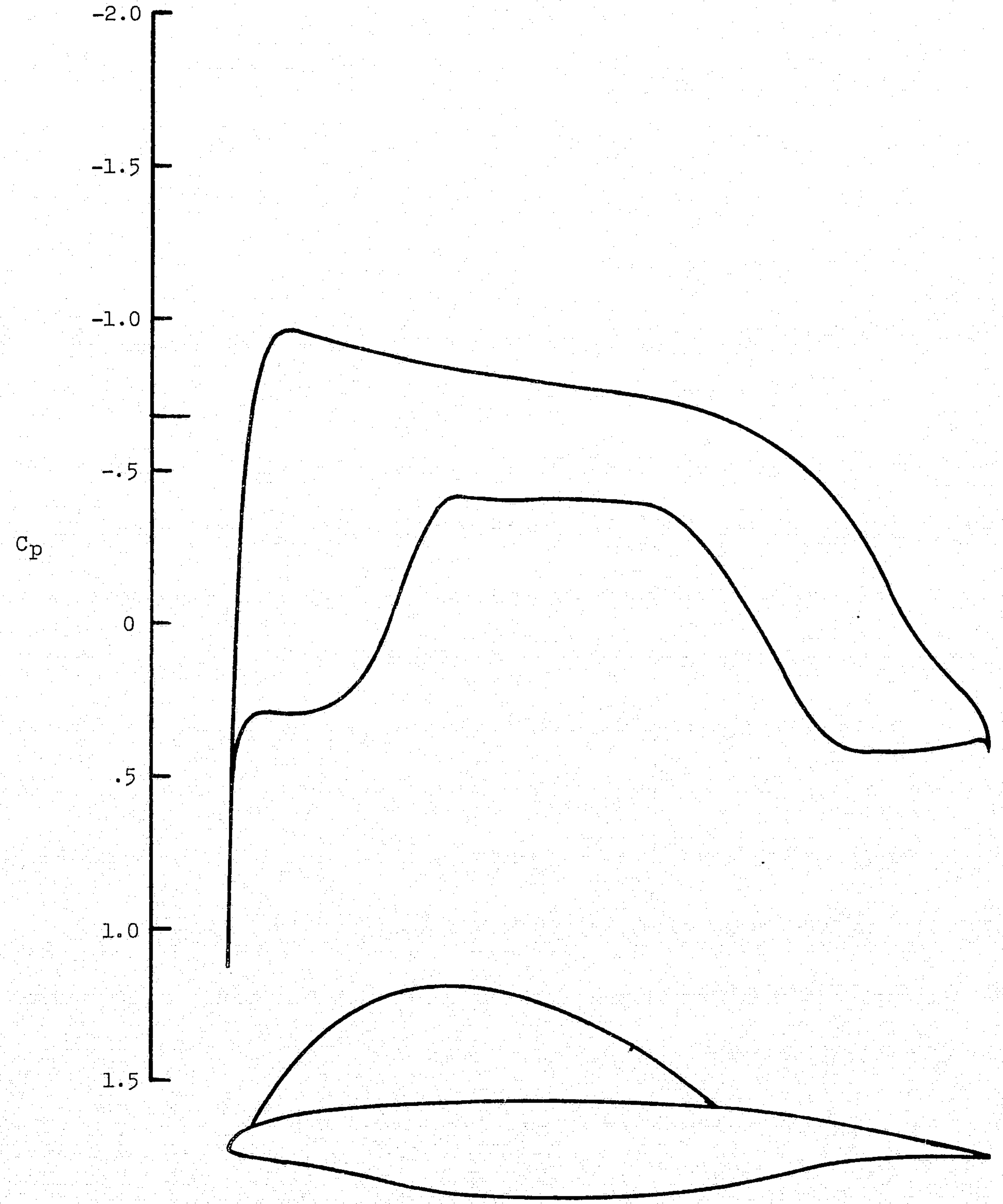
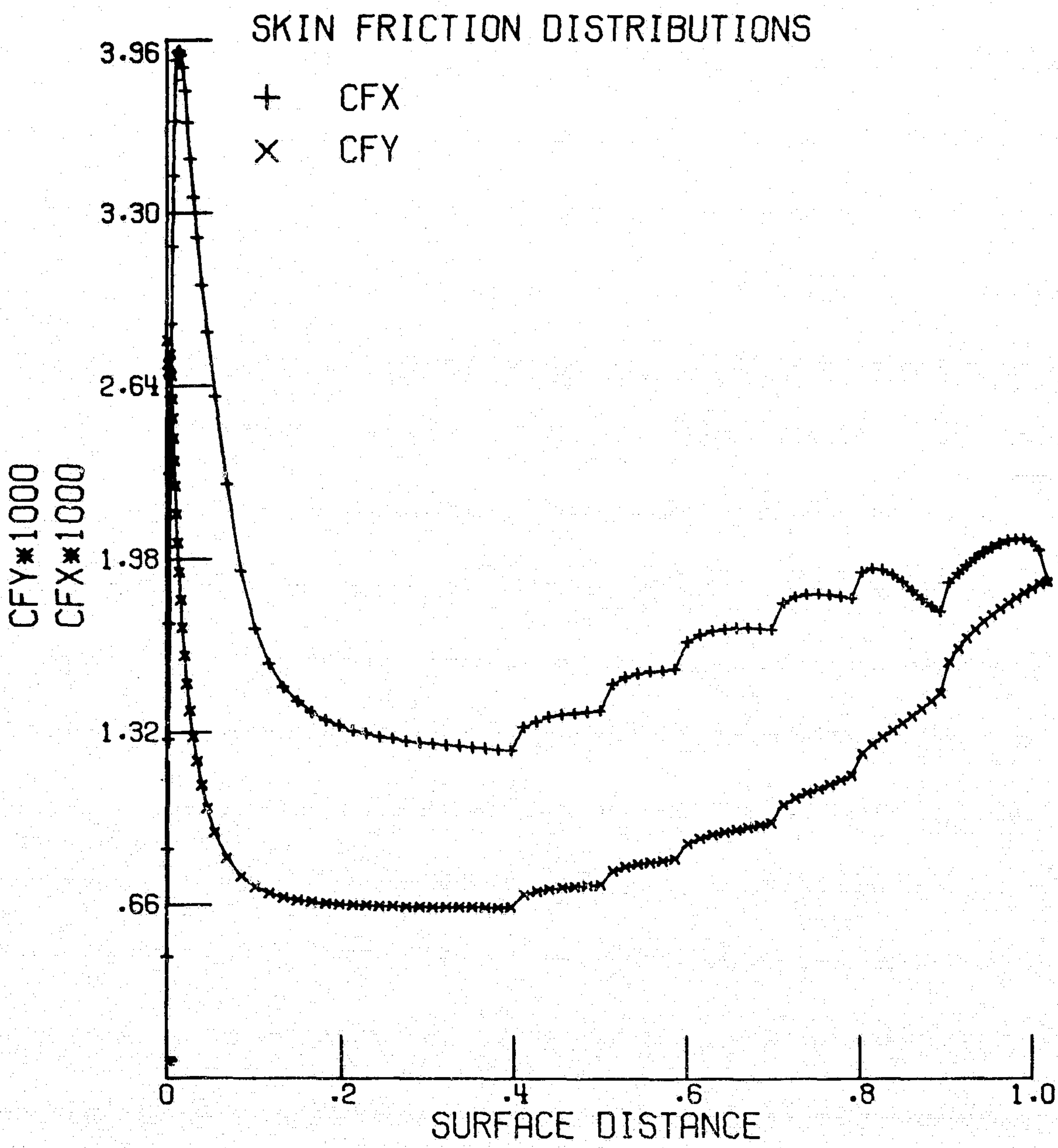



Figure 2. Airfoil and pressure distribution for sample case, $M_\infty = 0.725$.




AMINF3D= .885  PSI=35.0  RNL(1)= 1.10E+07
CDFX= .00168  CDFXINF= .00196
4ADYOGI  77/01/27. 12.01.35.

Figure 3. Upper surface skin-friction distributions for sample case.