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

James E. Carter

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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

ORIGINAL PAGE IS
OF POOR QUALITY
The 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
- \(W = \Psi^* \sin \Psi\)
- \(w\) 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 = \( \frac{\delta^*}{\nu} \frac{\partial u^*}{\partial x^*} \)
\( \mu \) 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°. 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**

<table>
<thead>
<tr>
<th>Read Order</th>
<th>Variables</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ITS, J, TOL, DZ, DS, USTEP, (WF)</td>
<td>2I5,5F10.5</td>
</tr>
<tr>
<td>2</td>
<td>IBLC</td>
<td>I5</td>
</tr>
<tr>
<td>3</td>
<td>MSMAX (Skip if IBLC = 0)</td>
<td>I5</td>
</tr>
<tr>
<td>4</td>
<td>WWALL(MS), SDS(MS)</td>
<td>2F10.5</td>
</tr>
<tr>
<td></td>
<td>(MS = 1, MMAX)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>INC, AMINF3D, GAMMA</td>
<td>I5,2F10.2</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>8A10</td>
</tr>
<tr>
<td>7</td>
<td>INT3, CH</td>
<td>I5, F10.5</td>
</tr>
<tr>
<td>8</td>
<td>ISY, INT4, RHO (Skip if INT3 = 0)</td>
<td>2I5,F10.5</td>
</tr>
<tr>
<td>9</td>
<td>XA(N), ZA(N) (INT4 pairs of values)</td>
<td>2E16.8</td>
</tr>
<tr>
<td>10</td>
<td>ISP</td>
<td>I5</td>
</tr>
<tr>
<td>11</td>
<td>IFPT, INT1, NLLST, DX</td>
<td>3I5,2F10.5</td>
</tr>
<tr>
<td>12</td>
<td>OPX(N), N = 2, NLLSTPL (Skip if IFPT ≠ 2)</td>
<td>8F10.5</td>
</tr>
<tr>
<td>13</td>
<td>C</td>
<td>8A10</td>
</tr>
<tr>
<td>14</td>
<td>PSI, DTRIP</td>
<td>8F10.5</td>
</tr>
<tr>
<td>15</td>
<td>INTRL, IFR</td>
<td>2I5</td>
</tr>
<tr>
<td>16</td>
<td>RNL(I), I = 1, INTRL</td>
<td>8F10.5</td>
</tr>
<tr>
<td>17</td>
<td>INTV, L</td>
<td>2I5</td>
</tr>
<tr>
<td>18</td>
<td>XV(I), UM(I), I = 2, LF1</td>
<td>2E16.8</td>
</tr>
<tr>
<td>19</td>
<td>MGRAD, XV(I) (if INC = 0)</td>
<td>2F10.5</td>
</tr>
<tr>
<td>20</td>
<td>VGRAD, XV(I) (if INC = 1)</td>
<td>2F10.5</td>
</tr>
</tbody>
</table>

*Input which has been added to original Beasley program is underlined.*
The definitions of these input variables are as follows:

**ITL**
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 \( \frac{U^i}{\sqrt{\frac{U^2}{\infty}} \sqrt{\frac{C_{\infty}^2}{V^i}}} \). 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
AKINF3D  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, ...(INT1 + 1), 2(INT1) + 1, 3(INT1) + 1, ..., 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 = \( \frac{Q*_{INL} \sec \psi}{V*_{\infty}} \)
2. Data Reynolds number = \( \frac{Q*_{INL}}{V*_{\infty}} \)
3. Data Reynolds number = \( \frac{Q*_{INL} \cos \psi}{V*_{\infty}} \)
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.

<table>
<thead>
<tr>
<th>RNL</th>
<th>Reynolds number.</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTV</td>
<td></td>
</tr>
<tr>
<td>= 1:</td>
<td>Velocity data is given as ( U ).</td>
</tr>
<tr>
<td>= 2:</td>
<td>Velocity data is given as ( U \sec \psi ).</td>
</tr>
<tr>
<td>= 3:</td>
<td>Velocity data is given as ( C_p ).</td>
</tr>
</tbody>
</table>

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 \( M_{en} \). 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 \( \frac{dM_{en}}{dx} \). |
VGRAD Velocity gradient (nondimensional) at the attachment line in a plane perpendicular to the leading edge = $\frac{dU'}{dn} = \frac{dU}{dx} \sec \psi$

XY(l) 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 \( \frac{\delta_* u^*}{\frac{\gamma}{\gamma-1} M_e \rho_o} \)
THXV Value of \( \theta \) at the points where the velocity data is prescribed, \( \tau \).
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  
\[
U = \frac{a^* u^*}{a^* e^*} = \frac{M_e}{M_\infty^*}.
\]

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

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

**DELTAl**  
Scaled displacement thickness  
\[
 \delta_* \sqrt{\frac{U_{Re_*}}{x}} \left( \frac{\delta_*}{L^*} \right).
\]

**THETAl**  
Scaled momentum thickness  
\[
 \frac{\theta}{L^*} \sqrt{\frac{U_{Re_*}}{x}} \left( \frac{\theta}{L^*} \right).
\]

**(DU/DZ)Z=0**  
Scaled skin-friction coefficient in \( x \) direction  
\[
\frac{2\gamma-1}{2\gamma-1} \left( \frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2} \right) \left( \frac{\partial u}{\partial z} \right)_{z=0}.
\]

**(DV/DZ)Z=0**  
Scaled skin-friction coefficient in \( y \) direction  
\[
\frac{3\gamma-1}{2(\gamma-1)} \left( \frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_\infty^2} \right) \left( \frac{\partial v}{\partial z} \right)_{z=0}.
\]

**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

δ*/L*

THETA1/C

θ/L*

CFX Skin-friction coefficient x direction =

\[ \frac{\tau^*}{\rho^*Q^*} = \frac{2U^{3/2}}{\sqrt{xRe^*_x}} \frac{Du_D}{|z|=0}. \]

CFY Skin-friction coefficient in y direction =

\[ \frac{\tau^*}{\rho^*Q^*} = 2 \sin\psi \frac{U}{xRe^*_x} \frac{DV_D}{|z|=0}. \]

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 = \[ X = Re^*_x \int_0^\infty \frac{C}{Q^*} d(z*/L^*). \]

RTHETA Reynolds number based on momentum thickness = \[ \frac{u^*\theta}{\nu^*_\text{min}}. \]

where \( \nu^*_\text{min} \) is the minimum of \( \nu^*_\text{or} \nu^* \).

RTHETACRIT Critical momentum thickness Reynolds number from Stuart (ref. 2) for prediction of instability in the Tollmien-Schlichting sense.

LAM2 Pressure gradient parameter, \[ \lambda^*_2 = \frac{\theta^*}{\nu^*_\text{min}} \frac{du^*_e}{dx^*}. \]
\[
= (\text{THETA})^2 \left( \frac{1 + \gamma - 1 M_e^2}{1 + \gamma - 1 M_e^2} \right)^{3/2} \left( \frac{1 + \gamma - 1 M_e^2 \cos^2 \psi}{1 + \gamma - 1 M_e^2 U^2} \right)^{3/2} \frac{x}{U} \frac{dU}{dx}
\]

**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 \( \lambda_2 = \frac{x^t}{x^t - x_c^t} \)

**Z**  
Transformed coordinate normal to surface, \( z \).

**ZCOMP**  
Scaled coordinate normal to surface = \( U \Re_\infty \frac{z^*}{x^*} \)

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

**U**  
Velocity tangent to surface in x direction = \( \frac{u^*}{v^*} = \frac{u}{U} \).

**V**  
Velocity tangent to surface in y direction = \( \frac{v^*}{v^*} = \frac{v}{V} \).

**STV**  
Velocity component in direction of inviscid streamline = \( \frac{u^*}{v^*} \). See Appendix C for further explanation.

**CFV**  
Velocity component perpendicular to direction of inviscid streamline (cross-flow component) = \( \frac{v^*}{v^*} \). See Appendix C for further explanation.

**T**  
Static temperature ratio = \( \frac{T^*}{T^*} \).

**RHOD**  
Density ratio = \( \frac{\rho^*}{\rho^*} \).
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 α, the weighting factor, varies from 0.5 to 1.0. With derivatives evaluated at the point \( x = (m + a)\Delta x, z = n\Delta z \) the following finite-difference approximations are given.

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

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

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

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 \( 0.5 \leq WF \leq 1.0 \). 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:

\[ \frac{\partial \rho^* u^*}{\partial x^*} + \frac{\partial \rho^* w^*}{\partial z^*} = 0 \]  \hspace{1cm} (B1)

\[ \rho^* u^* \frac{\partial u^*}{\partial x^*} + \rho^* w^* \frac{\partial u^*}{\partial z^*} = \rho^* u^* \frac{\partial e}{\partial x^*} + \frac{\partial}{\partial z^*} (\mu^* \frac{\partial u^*}{\partial z^*}) \]  \hspace{1cm} (B2)

\[ \rho^* u^* \frac{\partial v^*}{\partial x^*} + \rho^* v^* \frac{\partial v^*}{\partial z^*} = \frac{\partial}{\partial z^*} (\mu^* \frac{\partial v^*}{\partial z^*}) \]  \hspace{1cm} (B3)

The coordinate system is explained in figure B-1.

\[ \text{Figure B-1. Yawed wing coordinate system.} \]
The Stewartson transformation, which is given by

\[ x' = \int_{0}^{x} \frac{x^* p^* a^*}{p^* a^*} \, dx^* \quad (B4) \]

\[ z' = \int_{0}^{z} \frac{z^* a^*}{a^* p^*} \, dz^* \quad (B5) \]

\[ u' = \frac{a^*}{e^*} u \quad (B6) \]

\[ v' = \frac{a^* v^*}{e^*} \left( u' \frac{\partial z'}{\partial x^*} + \frac{\partial v^*}{\partial x^*} \right) \quad (B7) \]

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:

\[ \frac{\partial u'}{\partial x'} + \frac{\partial v'}{\partial z'} = 0 \quad (B8) \]

\[ u' \frac{\partial u'}{\partial x'} + w' \frac{\partial u'}{\partial z'} = \left[ 1 + \frac{Y-1}{2} \frac{M_{x}^2}{1 + \frac{Y-1}{2} M_{x}^2 \cos^2 \psi \left( 1 - \frac{v^*}{Q_{x}^2 \sin^2 \psi} \right)} \right] \frac{u'}{e^*} \frac{\partial u'}{\partial x'} + v^* \frac{\partial^2 u'}{\partial z'^2} \quad (B9) \]

\[ u' \frac{\partial v'}{\partial x'} + w' \frac{\partial v'}{\partial z'} = v^* \frac{\partial^2 v'}{\partial z'^2} \quad (B10) \]
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

$$
u \frac{\partial u'}{\partial x'} + \nu' \frac{\partial u'}{\partial z'} = \frac{u'}{\nu_\infty} \frac{e}{\partial x'} + \nu_\infty^* \frac{\partial^2 u'}{\partial z'^2}$$

(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

$$
x = \frac{x'}{L^*}
\frac{z = \left(\frac{U'x'}{\nu_\infty^*}\right)^{1/2} z'}{z'}
U = \frac{U'}{Q_\infty^*}
\frac{v = \frac{V'}{Q_\infty^*}}{v}
u = \frac{v^*}{V'}
\frac{w = \left(\frac{U'x'}{\nu_\infty^*}\right)^{1/2} w'}{w'}
$$

(B12)

to equations (B8), (B11), and (B10), respectively, and obtained
The surface boundary conditions including suction are given as

\[ u = v = 0 \quad (B16) \]

The edge conditions are

\[ z = 0, \quad u = v = 0 \]

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

\[ M_e^2 = \frac{M_e^2 \left[ U^2 \left( 1 + \frac{Y-1}{2} M_e^2 \right) + \sin^2 \psi \right]}{1 + \frac{Y-1}{2} M_e^2 \cos^2 \psi} \] (B18)

The scaled, non-dimensional suction velocity, \( \frac{w^* \sqrt{Re}}{Q_{\infty}} \), 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:
The momentum and displacement thicknesses are given by

\[
\delta^* \left/ D^* \right. = \left( \frac{v^*}{L^*} \right) _e \sqrt{ \frac{x}{U \text{Re}_c} } \left( \frac{1 + \frac{\gamma - 1}{2} M^2_e}{1 + \frac{\gamma - 1}{2} M^2_\infty} \right)^{\gamma + 1} \left( 2(\gamma - 1) \right) \int z_e u dz
\]  

where the subscript \( e \) denotes the edge of the boundary layer. The local skin-friction coefficients are
\[ C_{fx} = 2U \sqrt{ \frac{U}{x \text{Re}_\infty} \left( \frac{1 + \frac{\gamma-1}{2} \frac{M_e^2}{\text{Re}_\infty}}{1 + \frac{\gamma-1}{2} M_e^2} \right)^{\frac{2\gamma-1}{\gamma-1}} \right) } \frac{\partial u}{\partial z} \bigg|_{z=0} \] (B27)

\[ C_{fy} = 2 \sin \psi \sqrt{ \frac{U}{x \text{Re}_\infty} \left( \frac{1 + \frac{\gamma-1}{2} \frac{M_e^2}{\text{Re}_\infty}}{1 + \frac{\gamma-1}{2} M_e^2} \right)^{\frac{3\gamma-1}{2(\gamma-1)}} \right) } \frac{\partial \psi}{\partial z} \bigg|_{z=0} \] (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:

\[ u_s^* = u^* \cos \phi + v^* \sin \phi \quad (C1) \]

\[ u_c^* = v^* \cos \phi - u^* \sin \phi \quad (C2) \]

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

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

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

Note that at the boundary-layer edge

\[ \frac{u_s^*}{Q_{\infty}^*} = \left[ u^2 \left( \frac{1 + \frac{\gamma - 1}{2} M_{\infty}^2}{1 + \frac{\gamma - 1}{2} M_e^2} \right) + \sin^2 \psi \right]^{1/2} \quad (C5) \]

\[ u_c^* = 0 \quad (C6) \]
Figure C-1. Resolution of velocity components.
APPENDIX D

PROGRAM LISTING

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

C MASTER LAMINAR BOUNDARY LAYER

COMMON/GENMXX(365), XA(365)
DIMENSION XAHLD(365), ZAHLD(365)
COMMON/OPLIST/OPX(200), OPB(200)
COMMON/COMPRE8/INC, AMINS(8), AME(8), BINS, CINS, GAMMA, GAM1, GAM2, GAM3,
1 GAM4, AMPS(8), RATIO, SCOMP, ZCOMP(170), T(170), RHOD(170)
REAL MGRID
DIMENSION S(2), R(8), C(8)
DIMENSION UM(170), UH2H(170), VM2H(170)
DIMENSION WALL(15), SO(15)
DIMENSION VCFX2(200), VCFY2(200), HSCOMP(200), LABEL(8)
1, LAB(8), INFO(30)
REAL KMAX(10)

PI=3.14159265
DTM=0.17453292
CALL PSEUDO
CALL LEROY

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

CALL JPARAMS(INFO)
ENCOD(RO, QT, LAB(1)) INFO(1), INFO(23), INFO(22)
025 FORMAT(A7,3X,2A10,50X)
24 READ(1,6) ITJ, J, TOL, Z, DS, USTEP, WF
6 FORMAT(2I5P5F10.5)

WRITE(2,103)
103 FORMAT(1H1/1X65(2H**)=//
14X,KINPUT + SOME COMPUTED QUANTITIES*
2/1X65(2H**)=/) WRITE(2,400) ITJ, J, TOL, Z, DS, USTEP, WF
400 FORMAT(5H INPUTS, 15, 2X, 2H23, 15, 2X, HMTOL, 10.5, 2X, 3HDZ, 10.5, 2X,
13HDZ, 10.5, 2X, 6HSTEP, 10.5, 2X, 3HWF, 10.5)

C READ LAMINAR 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(15)
IF (IBLC.EQ.0) GO TO 78

C READ SUCTION OR INJECTION VELOCITY PARAMETER, MWall(M8)= WS*8RGT(DL/NU
77 FORMAT(15)
```

ORIGINAL PAGE IS OF POOR QUALITY
C) WHICH IS ALLOWED TO CHANGE DISCONTINUOUSLY AT SDS(HS) LOCATIONS, A
C TOTAL OF HS MAX LOCATIONS ARE PERMITTED,
READ(1,77)HS MAX
READ(1,502)(WWALL(HS),SDS(HS),HS MAX)
WRITE(2,78)
79 FORMAT(* IBLC1 DISCONTINUOUS SUCTION OR INJECTION GIVEN BELOW*)
WRITE(2,80) HS MAX
80 FORMAT(* X29HDSUCTION OR INJECTION VEL CHY, 5X10HS LOCATION, 
15XHSMAX=15*)
WRITE(2,81)(WWALL(HS),SDS(HS),HS MAX)
GO TO 82
81 FORMAT(* 29HSUCTN OR INJECTION VELOCITY LOCATION 
15X6HSMAX=15)
82 CONTINUE
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 BS, INC, AMINF3D, GAMMA
85 FORMAT(15,2F10,2)
IF(INC.EQ.1) AMINF3D=0,
PRINT 86, INC, AMINF3D, GAMMA
86 FORMAT(* INC=1, AMINF3D=E16.8, GAMMA=E16.8)
IF(INC.EQ.1) GO TO 87
PRINT 87
87 FORMAT(* COMPRESSIBLE FLOW (INC=1), STEWARTSON TRANSFORMATION USED 
1*)
GO TO 90
88 FORMAT(* INCOMPRESSIBLE FLOW (INC=0), STEWARTSON TRANSFORMATION USED 
1*)
CONTINUE
C CONSTANTS NEEDED FOR COMPRESSIBLE FLOW CALCULATION
C GM1=GYAMMA=1,
GP1=GYAMMA=1,
GAM1=(3.*GYAMMA=1)/(2.*GM1)
GAM2=GP1/(2.*GM1)
GAM3=GAMMA/GAM1
GAM4=(2.*GYAMMA=1)/(GAMMA=1)
AMF83D=5*GM1*AMINF3D**2
C READ MAIN TITLE (COLS 1->72)
74 READ(1,151)B
151 FORMAT(BA10)
WRITE(2,420)B
420 FORMAT(1HO,3HM,,BA10)
C READ GEOMETRY PARAMETER AND CHORD LENGTH
C IF INT300 VELOCITY DATA WILL BE GIVEN AT INTERVALS MEASURED AROUND THE 
C AEROFOIL SURFACE AND NO GEOMETRICAL DATA IS REQUIRED
C READ(1,72)INT3,CH
72 FORMAT(15,F10.5)
WRITE(2,401)INT3,CH
401 FORMAT(1HO,SHINT3*,15,2X,3HM,,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 ISYM=0 AEROFOIL IS CHAMFERED, IF ISYM1 AEROFOIL IS SYMMETRICAL.
76 READ(1,100)ISy,int4,rho
100 FORMAT(2f10.5)
WRITE(2,400)ISy,int4,rho
400 FORMAT(1H0,4HISy=15,2X,5HINT4,15,2X,4HRHO,16,E8)
rho=rho/ch
C READ (INT4) PAIRS OF X AND Z
N1=(INT4-1)*ISy+1
K2=(INT4-1)*ISy+INT4
READ(1,510)(XAML,N),ZAML(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=*P)
IF(ISP,eq,0.2)go to 107
DO 105 N=1,int4
INT4=INT4+1
X=INT4+1
XAML=XAML(N)
ZAML=ZAML(N)
GO TO 110
107 DO 109 N=1,int4
109 XAML=XAML(N)
ZAML=ZAML(N)
C CONTINUE

C CALCULATE DISTANCES AROUND SURFACE CORRESPONDING TO DISTANCES
C ALONG CHORD LINE.
C CALL GEOMETRY(ISY,RHO,CH)
C WRITE(2,403)(XAML(N),ZAML(N),STH(N),TH(N),FST(N),FT(N),N=N1,N2)
403 FORMAT(1H0,4HXAML),15,2X,ZAML,STH,TH,FS,FT,N=N1,N2)
2(1X,15,E16.8)
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, FULL P/O AT EVERY
C NTH STANDARD O/P STEP,DX, IN Z DIRECTION EVERY INT1 POINT IS PRINTED.
75 READ(1,106)IFPT,inti,nlist,dx
NLIST=nlist+1
106 FORMAT(3I5,2F10.5)
404 FORMAT(1H0,4HIFPT),15,2X,NLIST,15,2X,DHX,16,E8)
404 FORMAT(1H0,4HIFPT),15,2X,NLIST,15,2X,DHX,16,E8)
IF(IFPT,NE,2)GO TO 310
C READ LIST OF OUTPUT POINTS
READ (1,501)(OPX(N),N=2,NLIST1)
501 FORMAT(AF10,5)
WRITE(2,405)(OPX(N),N=2,NLIST1)
405 FORMAT(1H0,6HDFX(N)/(1H ,8(F10.5,2X))
310 CONTINUE
C READ TITLE
73 READ(1,511)C
WRITE(2,421)C
421 FORMAT(1H0,6HPSI,18X,4HDFR)
C READ ANGLE OF SHEAR (IN DEGREES) AND TRIPWIRE DIAMETER.
READ(1,501)PSI, DTRIP
WRITE(2,404)PSI, DTRIP
404 FORMAT(1H0,6HPSI,18X,4HDFR)
PSI=PSI*DTRIP
COS=2*COS(PSI)
SIN=2*SIN(PSI)
C READ NUMBER OF VALUES OF REYNOLDS NUMBER AND DEFINITION PARAMETER
C IFR=1, RN=DL*SEC(PSI)/NU, IFR=2, RN=DL/NU, IFR=3, RN=DL*COS(PSI)/NU
READ(1,100)INTVL, IFR
READ(1,501)(RN(N),N=1,INTVL)
WRITE(2,407)INTVL, IFR
407 FORMAT(1H0,6HINTV,18X,4HDFR)
WRITE(2,403)(RN(N),N=1,INTVL)
403 FORMAT(1H0,6HINTV,18X,4HDFR)
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)INTVL, 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 IOUT=O
WRITE(2,409)INTVL, L
409 FORMAT(1H0,5HINTV,12,2X,2HL,13)
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 (HEN)*)
WRITE(2,410)(XV(I),UM(I),I=2,LP1)
IF(INC.EQ.1) GO TO 505
AMINFR=0
DO 504 I=2,LP1
504 UM(I)=UM(I)*AMINFR
505 CONTINUE
410 FORMAT(1H0,4X1HI,3X5HXV(I),5X5HUM(I)/(1X,15,2F10.5))
UM(I)=0.0
C CONVERT VELOCITY DATA TO U.
IF(INY,NE,1) CALL VELOCJS (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.
C IF (INC,EQ,1) GO TO 422
C FLOW IS COMPRESSIBLE, READ IN MGRAD,DMIN/DSCOMP, THEN COMPUTE VIA THE
C STEWARTSON TRANSFORMATION THE TRANSFORMED INCOMPRESSIBLE VELOCITY
C GRADIENT, VGRAD, WHERE
C VGRAD = {UPRIME/ON)/DISING, 
C = VGRAD/AMINF3D/DSCOMP/DSINC*SEC(PI)
C READ(1,501) MGRAD, XV(1)
IF(IS,EQ,2) GO TO 113
XV(1)=XV(1)
113 WRITE(2,428) MGRAD
428 FORMAT(* MGRAD==EE6.8)
426 RATIO1 = (1 + AMP30/COSP)**2
VGRAD=VGRAD/AMINF3D*RATIO1/GAM1/COSP
GO TO 427
422 READ(1,501) VGRAD, XV(1)
427 WRITE(2,411) VGRAD, XV(1)
411 FORMAT(* MGRAD, XV(1)
IF(VGRAD.GT,0.) GO TO 122
11 IF(ISY,FG,9.OR.0NT3.FQ.0) GO TO 14
C READ DATA FOR S/R TO COMPUTE (DU/DX)AL.  
C READ(1,501) ALPHA, B1, B3
WRITE(2,412) ALPHA, B1, B3
412 FORMAT(* ALPHA, B1, B3)
411 GO TO 13
14 WRITE(2,312)
312 FORMAT(* MGRAD**2/6.6, B1, B3**2/F16.6)
GO TO 21
C COMPUTE VELOCITY GRADIENT AT ATTACHMENT LINE
13 CALL VGRADAT(ALPHA, RHO, B1, B3, 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, B1, B3, CH, XV(1), CHV(1), CHAT)
PRINT 511, 8ATT
511 FORMAT(* NON-DIMENSIONAL DISTANCE FROM LOWER SURFACE TRAILING EDGE
15 (IF UPPER SURFACE IS TO BE COMPUTED, ISP=2), OR FROM UPPER SURFACE
20 TRAILING EDGE (IF LOWER SURFACE IS TO BE COMPUTED, ISP=0) TO
30 ATTACHMENT LINE = BATT/CH ==E16.8/)
IF (INC, EQ, 1) GO TO 508
C FLOW IS COMPRESSIBLE, USE THE STEWARTSON TRANSFORMATION IN
C S/R SINCRS TO TRANSFORM THE ACTUAL SURFACE DISTANCE, S, INTO AN
C EQUIVALENT INCOMPRESSIBLE DISTANCE, SINC
C CALL SINCRS(LP1, SXV, SXVINC, UM, DSCOSI1, DSCOSI2)
GO TO 507
508 DO 506 X=1, LP1
506 SXVINC(N)=SXV(N)
507 GO TO 508
ORIGINAL PAGE IS OF POOR QUALITY
GO TO 509
C FROM SXVINC AND SXV(SXVINC) COMPUTE FVSINC FOR INTERPOLATION
FROM INCOMPRESSIBLE, TRANSFORMED (STEWARTSON) PLANE TO
COMPRESSIBLE, PHYSICAL PLANE
C
517 CALL CSG(SXVINC,SXV,FBSVINC,LPI,6SCDSI1,6SCDSI2)
509 CONTINUE
C WRITE MAIN AND SUB TITLES
WRITE(2,03)B,C
83 FORMAT(1H1,BA10/1H0,BA10)
WRITE(2,04)
414 FORMAT(1H0,31X,14H0=SEC(PSI)/NU)
416 FORMAT(1H0,31X,10H0=NU)
417 FORMAT(1H0,31X,14H0=CO. (PSI)/NU)
91 WRITE(2,02)GRAD
92 FORMAT(14H0=VELOCITY GRADIENT AT ATTACHMENT LINE= ,FB,2)
L=L+1
LP1=LP1+1
C FROM THE ETA AND U(THETA) COMPUTE FUTH FOR VELOCITY INTERPOLATIONS.
C CALL CSG(THXV,UM,FUTH,L,100D+VGRAD*COEP,(UM(L)=UM(L-1))/(THXV(L)=
THXV(L-1)))
C WRITE TABLE OF VELOCITY DATA
CALL XSCPPNT(INTV)
LIST=LIST+1
C COMPIL LIST OF OUTPUT POINTS IF REQUIRED.
IF(IFPT.NE.1)CALL PLIST(IFPT,LIST,SXV,SXVINC,L,DS,TNT3,CH,XV(1),
1DX,INC)
C IS WING SHEARED
IF(PSI,LT,.00001)GO TO 26
C GUESS AT VELOCITIES AT ATTACHMENT LINE
26 N=J
DO 9 N=2,J
UM1(N)=UM(1)/A
9 CONTINUE
C CONSTANT
A=0.5/(DZ*DZ)
C SET STEP COUNT
N=1
M=1
IFCON=0
C BOUNDARY CONDITIONS INCLUDING SUCTION OR INJECTION,
UM1(1)=UMG(1)+UM2(1)+VM2(1)=0.
HCONM1(1,1+AMFS3D*COSP**2)**(-1/2)/H3D(1)
W(1)=WALL(1)/SORT(VGRAD*COSP)*HCONM1
UM2(J+1)=UM2(J+1)=1.

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

CALL WUV(1,S(2))
ANGLE1=ANGLE2*5/PI
SCOMP=0.
ANES3=SORT((AMINS3D**2*STNP**2)/(1.+AMF3D*COSP**2))

C WRITE ATTACHMENT LINE PROFILES

C LEADING EDGE CONTAMINATION TEST

WRITE(2,104)
104 FORMAT(1H1/1X$4(2H=1//6X*6OUT$5(2H=))
CALL CONTAM(VGRAD,DTRIP,CH,STNP,THETA1,RATIO)
CALL PRINTX(V(1),0.,0.,VGRAD*COSP,J,DZ,T,N,1.,0.,0.,ANGLE2)

DO 18 NATR,INTRL
18 CONTINUE
B(1)=0.
SCOMP1=0.
U(1)=UM(1)
SZ=DZ
NEXTh=1
SNEXT=1.0
INTHOLD=0
LAST=0
IST=1
CFX1=0.
CPFX=0.
CPFX1=0.
CFV1=2.*STNP*(VGRAD*COSP/RNL(1))**5*DVN

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

C CALCULATE LENGTH OF NEXT STEP IN X DIRECTION

10 CALL SPLPLTH(SNEXT,B,INTHOLD,DZ,DS1,DSZ,NEXT,NLIST,LAST,
1FPT,LC,ILP,USTEP,DUDS,X,BH,ITC,ANGLE2,WP)

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 M=2,J
UM1(N)=UM1(N)
UM2(N)=UM2(N)
C VARIABLES INDEPENDENT OF N
UAVG*VF*(U(2),=VF)*(1)+
G=VF**2/4.*SH/(UAVG*DS1)*(U(2)-U(1)-1.*
CON1=1./DS**2
CON2=(1.,=VF)/VF
CON3=SH/(DS1*UAVG)
CON4=(1.,=VF)*SH/DS1
CON5=(1.,=VF)/VF**2
CON6=SH*DS2/(2.*VF*DS1*UAVG)
CON7=SH/DS1

C VARIABLES DEPENDENT ON N
DO 3 NM2,J
G1=M2*(UM2(N+1)-UM2(N-1))
AND(N)=CON2*M2(N-1)+UM2(N)
WNO=(1.,=VF)*Z/(2.*VF**2)*G2*(UM2(N)-UM2(N-1))
1=AND(N)*WNO=CON2=1.*WNO(N)
IF((VF,LT.,=011,AND(N)=.5*WNO(N))
RNO(N)=4.*VF*A0+CON2=N-1)*G*(UM2(N)+UM2(N+1))
CON(N)=1.0+CON2=(1.*VF)+(UFQ(N)*.5*UM2(N-1))
3 CONTINUE
C COMPLETE THE SPECIFICATION OF SURFACE SUCTION OR INJECTION VELOCITY, N.
IF(1,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 COMPUTE HM, UM AND VM PROFILES
CALL WUV(M$(2))
C COMPUTE SKIN FRICTION Drag, BASED ON REYNOLDS NUMBER DEFINITION, IFR=2
C AND THE FIRST VALUE IN REYNOLDS NUMBER ARRAY, RNL(1).
C CFXIAUX/(.5*RHOINF*QINF**2) 481
C CFYeTAUX/(.5*RHOINF*QINF**2) 482
C CDFX = SKIN FRICTION DRAG COEFFICIENT IN DIRECTION PERPENDICULAR TO LE 483
C BASED ON CHORD MEASURED PERPENDICULAR TO LE 484
C CDFXINF = TOTAL SKIN FRICTION DRAG COEFFICIENT IN FREESTREAM DIRECTION 485
C BASED ON CHORD MEASURED PARALLEL TO FREESTREAM 486

IF(IFCON.EQ.1)GO TO 203 488
ICOUNT=ICOUNT+1 489
DCOMP=SCOMP=SCOMP1 490
CFX2=U(2)/(RN(1)/S(2))**2,DUDZ 491
CFY2=U(2)/(RN(1)/S(2))**2,DVDZ 492
DCDFX=5*DCOMP*(COS(ANGLE1)+CFX1+SCOMP*(CFX2,CFY2)) 493
VCF21=ICOUNT=1000,CF2 494
VCF22=ICOUNT=1000,CF2 495
HSCOMP=ICOUNT=SCOMP 496
C FDFX=SCOMP+DCOMP 497
C CDFXINF=SCOMP+DCOMP*5*SCOMP*SCOMP 498
203 CONTINUE 499

C HAS ITERATION CONVERGED 500
IF(IFCON.EQ.1)GO TO 239 501
C HAS STEP LENGTH BEEN HALVED TWICE ALREADY 502
IF(LC.EQ.2)GO TO 239 503
C HALVE STEP LENGTH AND TRY AGAIN 504
LC=LC+1 505
GO TO 10 506

238 IFCON=3 507
LAST=2 508
C DETERMINE IF PRINT OUT IS TO BE COMPLETE, PARTIAL OR SKIPPED 509
239 CALL IFPRINT(IFPRINT,ILP,LAST,JACKPOT) 510
IF(JACKPOT.EQ.0)GO TO 5 511
C COMPUTE CROSS-FLOW VELOCITIES 512
IF(PJJ.EQ.0.001) CALL CRSSFLW(J,02) 513
C WRITE BOUNDARY-LAYER CALCULATION RESULTS AS REQUIRED 514
CALL PRINT(X,S(2),U(2),DELTA1,THETA1,JACKPOT,P51,AMINF) 515
C CALCULATE DIMENSIONALISING FACTORS 516
CALL DIINSION(S(2),U(2),COSB,DELTA1,THETA1,ILP,CF2,CFY2,CFDFX, 517
C RELAMINARISATION TEST 518
IF(KMAX.INTNL,GT.=0.5)CALL RELAM(U,S,BIN,COSB,KMAX) 519
C IS PRINT-OUT COMPLETE 520
IF(JACKPOT.EQ.2)GO TO 5 521
C CROSS-FLOW INSTABILITY TEST 522
IF(PJJ.EQ.0.001) 523
1 CALL INSTAB(COSB,B(2),U(2),AM3D,AMINF3D) 524
C VISCOUS INSTABILITY TEST 525
50 CALL TRANS(B(2),U(2),AM3D,AMINF3D) 526

ORIGINAL PAGE IS
OF POOR QUALITY
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(L1P,EQ,1)GO TO 47

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

C REPLACE U(N=2), U(N=1) AND V(N=1) PROFILES WITH THOSE STORED AT START
C OF LAST STEP
47 DO 48 N=2,J
   UP1(N)=UP1M(N)
   U2(N)=UM2M(N)
   VM2(N)=VM2M(N)
48 CONTINUE
   GO TO 11

27 WRITE(2,19)
19 FORMAT(33HOLAMAR FLOW CALCULATED TO END OF DATA OR LAST POINT KE
       IQUESTED)
   GO TO 21
5 WRITE(2,20)
20 FORMAT(11HSEPARATION)

C READ CUE TO READ MORE DATA OR TO FINISH
21 READ(1,100)KUE
   WRITE(2,141)KUE
100 FORMAT(1H4H RUEmpI7) -
   C PLOT INSTRUCTIONS FOR X AND Y SKIN FRICTION DISTRIBUTIONS
C
NPTSN=COUNT
   HGT1=0.05 HGT1=1.45 HGT2=0.065 HGT3=0.05
   NP1=NPTS+1
   NP2=NPTS+2
   YORG=0.5 XORG=0.
   XSCALE=.2
   YPG=.5
   YDP=.5
   XDP=.5 XTICM=1.
   YDP=.5 YTCM=1.
   ORG=0.
   CALL BSCL(VCFX2,YPG,NPTS,1,1.,=1,ORG)
   YSCALE=VCFY2(NP2)=VCFX2(NP2)
   VCFX2(NPSTS+1)=VCFY2(NPSTS+1)=YORG
   VCFX2(NPSTS+2)=VCFY2(NPSTS+2)=YSCALE
   HSCOMP(NPSTS+1)=XORG
   HSCOMP(NPSTS+2)=XSCALE
   CALL AXES(0.,0.,0.,0.,90.,=1,YPG,VCFX2(NP1),VCFX2(NP2),YTIC,YDV,1H,HGT1,600

36
SUBROUTINE SINCFRS(J, SXV, SXVINC, UMY, Q, CD5II, DSCD512)

DIMENSION SXV(1), SXVINC(I), UMY(1)

C USE STEWART'S TRANSFORMATION TO CONVERT SXV, THE PHYSICAL DISTANCE AROUND THE AIRFOIL AT WHICH MACH NO. 1 IS GIVEN, TO SKVINC, AN INCOMPRESSIBLE COORDINATE.

GM = GAMMA / (1 + AMF30 * COS2)

SYVINC(1) = 0,

CON = (AMEN**(-GAM1) + AMEN1**(-GAM2)) ** GAM4

FACIN = AMF30

DO 10 N = 2, J

AME2 = AME1 * AMINF3D**2 * (UM(N-1)**2 * FACT * BIND**2) / DENOMR

AME1Z = 1.5 * GM1 * AME1Z1

10 SXVINC(N) = 0.5 * CON * (AME2**(GAM1) * AME1Z**(GAMII) * SXV(N) + SXVINC(N-1))

AME1Z1 = 1.5 * GM1 * AME1Z1

CALL ENCODE(80,423,LABFL(1))

AMINF3D = AMINF3D**2

STOP

END
SUBROUTINE WIJV(M,$)
C COMPUTES W, U AND V PROFILES.
COMMON/SCDSIR/IT$,TOL,IFCON,RS,DR1,DRZ,*F,SH,UMGH,A0,CON3,CON6,
1CON7,G,AN(170),RDG(170),AN(170),BNG(170),BN(170),CN(170),DDO(170)
2,DR(170),RD1,DNG(170),DNY(170),UM1(170),UMG(170),WH(170),WM1(170),
3HNO(170),U4(4),AND(170)
COMMON/RESULTS/WH1(170),UM2(170),V1(170),V2(170),DELTA1,THETA1,NO,DUDZ
1,NUMZ
COMMON/COMPRESS/INC,AMINF30,AHE30,SINF,CONP,GAMMA1,GAM1,GAM2,GAM3,
1GAM4,AFPS30;RATIO;SCOMP;ZCOMP(170),T(170),BNOD(170)
DIMENSION UP(170),V(170)
!
C EVALUATION OF W
11 DO 2 N=2,J
IF(M,NE,1)GO TO 1
C AT ATTACHMENT LINE
WH(N)=WH(N-1)=0.5*DF*(UM1(N)+UM1(N-1))
GO TO 2
C AT X(=1/2)
1 FACT=AND/CON6*(2*N*(1+0.5*DF)/DF*(UMG(N)+UMG(N-1))
1=UMG(N)+UMG(N-1)+G
IF(WF,LT,.501) GO TO 50
WH(N)=WH(N-1)+(1-WF)/WF*(WH(N-1)+WH(N)+G)
GO TO 2
50 WH(N)=WH(N-1)+WH(N)-G
2 CONTINUE
!
C EVALUATION OF UM,N
DO 4 N=2,J
IF(M,NE,1)GO TO 3
AN(N)=0.5*WH(N)/DZ+2*AO
BN(N)=UM1(N)-G*AO
CN(N)=AN(N)+2*AO
DN(N)=1
GO TO 4
3 IF(WF,LT,.501) GO TO 51
AN(N)=2*N*DF/ND*(WF=WH(N)+(1-WF)*WH(N-1)+N=1)*G*UMG(N)
1+AND(N)
DN(N)=AND(N)+CON3*(1+0.5*DF)*(1-WF)*AND(N)*UMG(N)-5/DZ*(1-
1*WF)*(UM2(N+1)+UM2(N-1)+UMG(N)+CON3*UMG(N))
GO TO 52
51 AN(N)= AND+25/DZ*WH(N)+(N=1)*G*UMG(N)+AND(N)

I

\[ R, 1)N(N)\alpha DNO(N) + 0.5*CON3*U
\]

\[ U\text{M}2(N) \times U\text{M}G(N) - 25/DZ*(U\text{M}2(N+1) = U\text{M}2(N-1)) \]

\[ K = H(N) \]

\[ R(N) = AN(N) + 0.5*CON3\]

\[ FACT = CON3*KF*(3*N**WF)*U(2)*UMG(N) \]

IF(KF, LT, .75) GO TO 4

DN(N) = DN(N)*FACT

CONTINUE

LP(J) = BN(J)

DO 5 K = 3, J

NB = K + 3

UP(N-1) = RT(N=1) = AN(N=1) = CN(N)/UP(N)

CONTINUE

Y(J) = DN(J) = AN(J)

DO 6 K = 3, J

NL = K + 3

Y(N+1) = DN(N+1) = AN(N+1) = Y(N)/UP(N)

CONTINUE

UMG(2) = Y(2)/UP(2)

DO 7 N = 3, J

UMG(N) = (Y(N) = CN(N) = UMG(N-1))/UP(N)

CONTINUE

COUNT NUMBER OF ITERATIONS

NO = NO + 1

IF(NO, LT, 3) GO TO 22

IF(TOL, GT, ABS(UMG(2))/DZ) GO TO 8

CHECK NUMBER OF ITERATIONS

IF(NO, GE, IT) GO TO 12

STORE U NEAREST SURFACE FOR CONVERGENCE CHECK

UMG = UMG(2)

IF(M, LT, 1) GO TO 11

DO 37 N = 2, J

UMG(N) = UMG(N)

CONTINUE

GO TO 11

ITERATION HAS NOT CONVERGED

IFCON = 2

RETURN

ITERATION HAS CONVERGED

IFCON = 1

EVALUATION OF VM,N

DO 16 N = 2, J

IF(M, LT, 1) GO TO 21

BND(N) = 4*AO

DND(N) = 0

GO TO 16

PND(N) = RND(N) + KF*CON*UMG(N)
IF(WF.LT..50t) GO TO 53
FACTn.S/DZ*(1.-WF)
* (W
F*WM1(AL))+(1.-WF)* WMi(N))
GO TO 54
53 FACTn.25/DZ*UM(N)
54 DND(N)*DND(N)*CND7*WF*VM2(N)*UMG(N) = (VM2(N+1) - VM2(N=1)) *(FACT*(1.-
1/F)/WF*(N=1)*G*UMG(N))

16 CONTINUE
UP(J) = RND(J)
DO 17 K = 3, J
NJ = K + 3
UP(J) = RND(N-1) - AN(N-1) * CN(N)/UP(N)
17 CONTINUE
Y(J) = RND(J) - AN(J)
DO 18 K = 3, J
NJ = K + 3
Y(N-1) = RND(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-1) = AN(N-1) * VM2(N-1)/UP(N)
19 CONTINUE
DO 23 NJ = 1, J
C STORE W PROFILE FOR POSSIBLE PRINTING OUT.
W*M(N)*M(N+1) = VM(N)*VM(N+1)
C U PROFILE AT END OF STEP BECOMES PROFILE AT START OF NEXT STEP.
UM(N) = VM(N)
UM2(N) = UMG(N)
M(N) = VM(N)
23 CONTINUE
C COMPUTE TEMPERATURE RATIO, T(N)*T/T-INF AND DENSITY RATIO,
RHOD(N)*RHOD/RHODINF, AND THE COMPRESSIBLE (ACTUAL) NORMAL
COORDINATE, ZCOMP(N)=Z/C
C
IF(M,GT.1) GO TO 25
U(2) = 0.
RATIO = (1.+AHFS3*D*COSP**2)
25 ZCONM = RATIO**GAM1
DELMR = RATIO**GAM2
RHOCON = RATIO**GAM3
CFCON = RATIO**GAM4
CFCONY = RATIO**GAM1
UCON = RATIO**GAM5*U(2)
ZCOMP(1) = 0.
JP1 = 1
DO 26 N = 1, JP1
URATIO = UCON*UM2(N)
VRATIO = VINP*VM2(N)
T(N) = U*URATIO**2 - VRATIO**2
RHOD(N) = RHODCON/T(N)
IF (N,EQ.1) GO TO 26
IF (N,NE.1) GO TO 26
ZCOMP(N) = ZCOMP(N)+S*(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-UH2(N))*((3+18))
THETA1=THETA1+(UH2(N)*((1-UH2(N)))*((3+18))
IS=IS
IF(UH2(N),GE,1.0=TOL,=OZ)GO TO 41
IF(N,L,T,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.
DU/DZ=2.0*UMZ(2)=0,5*UMZ(3)/DZ=CFCONX
DV/DZ=2.0*UMZ(2)=0,5*VH2(3)/DZ=CFCONY
RETURN
END

FUNCTION THX(X)
C TRANSFORMS X TO THETA
ARG=2.0*ABS(X)-1.
IF(ARG,LE,1.0)GO TO 2
WRITE(2,5)X
3 FORMAT(///* ERROR NO. 2 DETECTED BY ACOSIN IN FUNCTION THX///
1= X=EI6.6,** ARG=EI6.6/**
IF(ARG,GT,1.0,AND,ARG,LT,1.000001) ARG=1,
2 THX=ACOS(ARG)
IF(X,0.0,GO TO 1
THX=2*3.1831853=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 C86(X,Y,F,NOP,Fl,Fi)  
C GENERATES SECOND DERIVATIVES FOR USB IN C81 CURIC SPLINE  
DIMENSION X(1),Y(1),F(1),E(365),G(365)  
N2=NOP+1  
DO 1 N=2,N2  
E(N)=2*(X(N+1)-X(N))  
F(N)=6*(Y(N+1)-Y(N))/(X(N+1)-X(N))+6*(Y(N)-Y(N-1))/(X(N)-X(N-1))  
1 CONTINUE  
N=1  
N=N2  
E(1)=2*(X(2)-X(1))  
F(1)=6*(Y(2)-Y(1))/(X(2)-X(1))+6*E(1)  
E(NOP)=2*(X(NOP)-X(NOP-1))  
F(NOP)=6*(Y(NOP)-Y(NOP-1))/(X(NOP)-X(NOP-1))+6*F  
DO 5 N=1,N2  
G(N)=X(N)/E(N-1)  
E(N)=G(N)*E(N-1)  
F(N)=G(N)*F(N-1)  
5 CONTINUE  
RETURN  
END  

SUBROUTINE CBSI(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)12,13,12  
12 CONTINUE  
RETURN  
END  

A1=0.5*F(N-1)*(X(N)+XI)/(X(N)+XI)/(X(N)-X(N-1))  
A2=0.5*F(N-1)*(X(N)+XI)/(X(N)+XI)/(X(N)-X(N-1))  
C1=(1/NOP)(X(N)+XI)+(N-1)/NOP  
C2=(1/NOP)(X(N)+XI)+(N-1)/NOP  
YX=A1+B1+C1+D1*(XI-X(N))  
RETURN  
END
SUBROUTINE CONTAM(VGRAD,DTTRIP,CH,COSP,SNP,THETA1,RATIO)

C TEST FOR CONTAMINATION AT ATTACHMENT LINE

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

WRITE(2,18)
1A 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=SNP*THETA/NUEDGE
IF(IR,JG,1)RNL(N)
IF(IR,JG,2)RNL(N)/COSP
RTHETA=SNP+SORT(RN/VGRAD)*THETA1/RATIO**1,5
WRITE(2,11)RTHETA
IF(RTHETA=100,1,2,3)
WRITE(2,12)
GO TO 1

3 IF(RTHETA=200,1,4,5
4 IF(DTRIP=00001116,6,6)
WRITE(2,13)DCRIT
IF(DCRIT=DTTRIP)7,16,16
WRITE(2,14)
GO TO 1

16 WRITE(2,17)
GO TO 1

5 WRITE(2,14)
CONTINUE
RETURN

10 FORMAT(18H REYNOLDS NUMBER, ,F10,0)
11 FORMAT(1H+,32X,THETA1,F6,1)
12 FORMAT(1H+,67X,TURBULENT CONTAMINATION AT A1,L)
13 FORMAT(1H+,5X,6HDCRIT,F8,4)
14 FORMAT(1H+,67X,TURBULENT CONTAMINATION AT A1,L)
15 FORMAT(1H+,67X,TURBULENT CONTAMINATION AT TRIP WIRE)
17 FORMAT(1H+,67X,TURBULENT CONTAMINATION POSSIBLE AT A1,L)
END

SUBROUTINE CRSFLKH (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,DUZ
COMMON/CROSSV/VV(170),CV(170),50T,CDT,CVM
COMMON/COMPRS/INC,AMIN50,AMESD,SNP,COSP,GAMMA,GAM1,GAM2,GAM3,
1GAM4,AMFS3D,RATIO,SCOMP,ZCOMP(170),T(170),RHOD(170)
C VELOCITY AT EDGE OF BOUNDARY LAYER
SVJ=5ORT(1.0/2/RATIO+SNP**2)

C CALCULATE SIN(THETA) WHERE THETA IS ANGLE BETWEEN FLOW AT EDGE OF
C BOUNDARY LAYER AND THE PERPENDICULAR TO THE LEADING EDGE.
SIN=SNP/SVJ
COST=5ORT(1.0-SIN**2)
SDT=0.0
CDT=0.0
IS=1
CVM=0.0
SV(1)=SV(1)=0.0
DO 1 N=2,J

C VELOCITY COMPONENT IN DIRECTION OF FLOW AT EDGE OF BOUNDARY LAYER
SV(N)=(UM2(N)*COST+H)/SORT(RATIO)*X2(N)*SIN*SNP/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)=I+SNP*(VM2(N)+UM2(N))/SORT(RATIO)
C CROSS FLOW DISPLACEMENT THICKNESS
CDT=CDT+.5*(CV(N)+CV(N-1))*(ZCOMP(N)=ZCOMP(N-1))
IS=15
IF(ARS(CV(N))=CVM11.1.2
2 CVM=ARS(CV(N))
1 CONTINUE
CDT=ARS(CDT)
SNZ=ZCOMP(J)=SDT
RETURN
END

SUBROUTINE DIMENSION(S, U, COSP, DELTA1, THETA1, ILP, CFX2, CFY2, CFOX,
1 CDFXINF)
C CALCULATES DIMENSIONALISING FACTOR AND DIMENSIONAL B,L, THICKNESSES,
COMMON/TEST/RNL(INL),INRL,IFR
DO 1 N=1,INRL

C SCALE REYNOLDS NUMBER TO STANDARD FORM,
IF(IFR.EQ,1)RN=RN(RNL(N))
IF(IFR.EQ,2)RN=RN(RNL(N))/COSP
IF(IFR.EQ,3)RN=RN(RNL(N))/COSP**2
D5SORT(S(U=US*COSP))
D1=0+DELTA1
D2=0+THETA1
IF(ILP.EQ,0)GO TO 4
WRITE(2,3)RNL(N);N,01,02
3 FORMAT((X,17HREYNOLDS NUMBER=,F10.0,2X,23H(DIMENSIONAL Z)/CHORD) )
1,F8.6,H2.0Z,2X,10HDELTA1/CX ,F8.6,2X,10HTHETA1/CX ,FR,6)
4 F9.6
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/S(365), TH(365), FSTH(365), INT4, FZTH(365)
DIMENSION SN(170), THD(170)

PI =3.14159265
INT4 INT4 = 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, INT4
   XA(N) = XA(2*INT4-N)
   ZA(N) = ZA(2*INT4-N)
103 CONTINUE

C TRANSFORM X TO THETA
102 N L = INT4 = INT4 = (I+1)
   DO 105 N = 2, N L
      TH(N) = THX(XA(N)/CH)
105 CONTINUE
   TH(1) = 0.
   IF (I .EQ. 0) GO TO 1
   TH(INT4) = PI
   INT4 = INT4 + INT4
   INT4 = INT4
1 TH = INT4 = 2*PI
   DO 105 N = 1, INT4
      ZA(N) = ZA(N)/CH
105 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)
RH0**2*(RH0**2)

10A 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 CSQF(STH,STH,FSTH,INTG,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 INSTAR(COSP,S,U,CH,RATIO,AME30,AKINF3)
C EVALUATES THE CROSS-FLOW REYNOLDS NUMBER, CH.
COMMON/TEST/RNL(10),INTRL,IFR
COMMON/CROSSV/BV(170),CV(170),SDT,COT,CVM
C CALCULATE CHI/SORT(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((AM3D,GT,MINF3D) FACT=1,
CROSS*SORT(COSP*S*CH/TI)*FACT
WRITE(2,3)
3 FORMAT(1X,30**** SHEEP INSTABILITY TEST ****)
DO 1 N=1,INTRL
C SCALE REYNOLDS NUMBER TO STANDARD FORM,
IF(IFR,EQ,1)RN=RN(L(N))
IF(IFR,EQ,2)RN=RN(L(N))/COSP
IF(IFR,EQ,3)RN=RN(L(N))/COSP**2
CHI*CORR*SORT(RN)
WRITE(2,4)RNL(
4 FORMAT(1H ,17REYNOLDS NUMBER: ,F11.0,2X,19CHI(DOWN-RANDALL): ,F7.2)
1,2)
1 CONTINUE
RETURN
END

SUBROUTINE PLIST(IFPT,NLIST,SXV,SXVINC,LDS,INT3,CH,XATT,DX,INC)
C PREPARE LIST OF POINTS WHERE FULL OUTPUT IS REQUIRED
COMMON/OPLIST/OPX(200),OP8(200)
DIMENSION BXY(1),DUMP(365),X(2),S(2),SXVINC(1)
IF(IFPT.EQ.1)301,302,303
301 CALL STHFRMX(NLIST,OPX,OP8,DUMP,D,INT3,CH,XATT,H)
DO 310 N=2,NLIST
OP8(N)=OP8(N)
310 CONTINUE
GO TO 303
302 NLIST=N-1
DO 306 N=1,NLIST
OPS(N)=SXVINC(N+1)
306 CONTINUE
GO TO 303
303 N=1
IF(INC.EQ,0) GO TO 308
308 X(2)=DX
CALL STHFRRMX (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
309 DO 311 N=1,L
OPS(N)=FLOT(N)*DX
IF(OPS(N),GT,SXVINC(L)) GO TO 307
311 NLIST=N

SUBROUTINE PRINT(X,B,U,DJ,J,DZ,INT1,JACKPOT,PBI,LC,ANGLE2)

COMMON/RESULTS/XM2(170),UH2(170),VM2(170),DELTA1,THETA1,NO,DUDZ

WRITE(2,11) X,S,SCOMP,U,AME3D,DU,NO
11 FORMAT(1H0,3HYM,12F9,6,4X,3HS

IF(ZEONIP,EQ,31) GO TO 7

GO TO 5

7 IF(PXI.LT,00001) GO TO 13

WRITE(2,15) BDT
15 FORMAT(1H0,36HSTREAM FLOW DISPLACEMENT THICKNESS

WRITE(2,16) CDT
16 FORMAT(1H0,36HCROSS FLOW DISPLACEMENT THICKNESS

WRITE(2,19) CVM
19 FORMAT(1H0,26HMAXX, CROSS FLOW VELOCITY

WRITE(2,21) H
21 FORMAT(4X1HZ,10X5HCMP,8X1HK,11X1HU,11X1HV,10X3HSTV,10X3HCFV,
19X1HT,9X1HROD)

17 N=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,1.OR.N,EQ,J)GO TO 3

GO TO 2

2 ZN=DZ-DZ

3 ZN=DZ-DZ

END


```
SUBROUTINE RELAM(U, B, BINP, COSP, KMAX)
C EVALUATES THE RE-LAMINARISATION PARAMETER, K.
C (HAS NOT BEEN MODIFIED FOR COMPRESSIBILITY)
C
DIMENSION U(N), B(2), A(2)
COMMON/TEST/RNL(N), INTRL, IFR
REAL KMAX(10)

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

DO 1 N = 1, 2
B(N) = SORT(U(N) ** 2 + BINP ** 2)
1 CONTINUE

DS#(2) = S(1)
D#U(2) = U(1)
RCOSP#K = (A(2) - A(1)) * DU / (DS#(A(2) - A(1)) ** 3)

DO 2 N = 1, INTRL
CAY = RCOSP#K / (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, 4) RNL(N), CAY, KMAX(N)
3 FORMAT(1H, 17HREYNOLDS NUMBER= , F10.0, 3X, SHK= , E10.3, 3X, HKMAX= , E10.3, 3X, HMAX= , E10.3)
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, INTLD, DS, DS1, DS2, NEXT, M, BST, LAST,

ORIGINAL PAGE IS
OF POOR QUALITY
```
C CALCULATES LENGTH OF NEXT STEP.

COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
18XV(365),3XVINC(365),FBSVINC(365),L,SATT,INT3,CH,ISP
COMMON/MPIST/OPX(200),OPS(200)
COMMON/COMPS/INC,AM1,F30,AM3D,SINC,CMSP,AMMA,AM1,AM2,AM3,
1GAM4,AMF3D,MAT,SCOMP,ZCOMP(170),T(170),RHOD(170)
DIMENSION U(41,62)

ILP=0
LINEAR=0

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

C HALF STEP LENGTH AFTER NONCONVERGENCE
1 IF((DS1,.GT.,.01)*DS)GO TO 11

C STEP LENGTH LESS THAN MINIMUM PERMITTED- END CALCULATION,
LAST=2
GO TO 6

11 D81=D81/2.0
LAST=0
GO TO 7

9 IF(SNEXT.LT.0.) GO TO 2
S(2)=SNEXT
D81=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.
D81=DSH

C STEP LENGTH IS HELD AT D8H FOR INTHOLD STEPS,
INTHOLD=INTHOLD+1
GO TO 7

C STANDARD STEP LENGTH
33 D81=DS

C CHECK RATIO (PROPOSED LENGTH OF NEXT STEP)/(LENGTH OF LAST STEP)
4 IF((DS1,.LT.,.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(TFFP,.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

50
C REPLACE PROPOSED VALUE WITH THAT OF NEXT LISTED OUTPUT POINT
S(2)=GP8(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)SNF(XMXP8(NEXT))

C IS PROPOSED VALUE OF X LESS THAN THAT OF LAST VELOCITY DATA POINT
10 IF (S(2),LT,XVINC(L),0,001*00) GO TO 44

C VALUES AT LAST VELOCITY DATA POINT
S(2)=XVINC(L)
U(M)=U(L)

C TS PROPOSED VALUE OF X LESS THAN THAT OF LAST VELOCITY DATA POINT
10 IF (S(2),LT,XVINC(L),0,001*00) GO TO 44

C VALUES AT LAST VELOCITY DATA POINT
S(2)=XVINC(L)
U(M)=U(L)

48 IF (INC,EQ,0) GO TO 46
SCOMP=S(2)
GO TO 47

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,FSVINC,L,S(2),SCOMP,ROT)

C FIND VELOCITY AT END OF PROPOSED STEP
47 CALL XNDFRMS(SCOMP,U(2),NUDS,X,ITC,ILP,ANGLE2,LINEAR,THETAS)

C DID NON-CONVERGENCE OCCUR IN SUBROUTINE XNDFRMS
IF(IITC,NE,20)GO TO 15

45 DS1=8(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,NE,1)NEXT=NEXT-1
ILP=0

C ITERATION TO FIND S FOR (U(1)+USTEP)
INT=0
S(2)=S(2)+D8*(1-USTEP/(U(2)-U(1))
IF(INC,EQ,0) GO TO 48
SCOMP=S(2)
GO TO 12

48 CALL CSI(SXVINC,SXV,FSVINC,L,S(2),SCOMP,ROT)
12 CALL XNDFRMS(SCOMP,U(2),NUDS,X,ITC,ILP,ANGLE2,LINEAR,THETAS)
IF(IITC,NE,20)GO TO 15
IF(ABS(U(2)-U(1)),LT,01*USTEP)GO TO 111
INT=INT+1
IF(INTC,NE,25)GO TO 24
S(2)=S(2)+(U(2)-U(1))/D8
IF(INC,ED,0) GO TO 48
SCOMP=S(2)
GO TO 12
15 WRITE(2,26)
20 FORMAT(1HO,1WNON=CONVERGENCE IN X AND U FROM S ROUTINE)
GO TO 120
20 IF(ABS(U(2)-U(1)),GT,USTEP) WRITE(2,3)
3 FORMAT(1HO,* 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 LINEMAR:
U(2)=U(1)+USTEP
DO 60 N=1,L
IF(U(2),LT,U(N))GO TO 65
IF(SXVIN(N),GT,.5)GO TO 63
60 CONTINUE
63 PRINT 66
66 FORMAT/* LEADING-EDGE LINEAR INTERPOLATION OF U(2) VS. S(2) TO
IF FIND S(2) FOR A GIVEN U(2) RESULTS IN S(2) GREATER THAN .5*)
STOP A66
65 FACT=(U(2)-UM(N=1))/(UM(N)-UM(N=1))
S(N)=S(N)+UM(N-1)+(SXVIN(N)=UM(N-1))*FACT
THETAS=THXV(N)=THXV(N-1)*FACT
DUDS=(U(2)-U(1))/(S(2)-S(1))
IF(INC,ED,0)GO TO 110
SCOMP=S(2)
GO TO 112
110 CALL CSI(SXVIN,SXV,FBVINC,L,S(2),SCOMP,ROT)
112 CALL XNDFRMS(SCOMP,U(2),DU08,X,ITC,JLP,ANGLE2,LINAR,THETAS)
111 LAST=0
C LENGTH OF NEXT STEP.
19 NSUM(S(2)=S(1))
C S LOCATION OF NEXT STEP
SHK=W*S(2)+(1.,-K)*S(1)
8 RETURN
END

SUBROUTINE STHFRMX(J,X,S,THXV,DSDT,TNT3,CH,XATT,BATT)
C FINDS S(N) AT POINTS X(N) FOR N=1(J) AND D8/DTHETA AT X(1)
C WHERE S IS MEASURED FROM THE ATTACHMENT LINE.
COMMON/SFX/BTH(365),TH(365),F8TH(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)
1 RETURN
52
IF(INT3.EQ.0) GO TO 2
CALL CS1(TH,STH,FSTH,THV(N),B(N),DBDTH)
IF(N,GT,1) GO TO 3
DODD=BDTH
GO TO 1
2 S(N)*X(N)/CH
GO TO 1
3 S(N)=S(N)=S(1)
1 CONTINUE
SAT=S(1)
S(1)=0.
RETURN
END

SUBROUTINE TRANS(SC,USM,THETA,UTWO,UDONE,IST,JACKPOT)
C ESTIMATES THE POSITIONS OF VISCOS TURBULENCE AND SUBSEQUENT
C TRANSITION,
C COMMON/TEST/RNL(10),INTRL,IFR
COMMON/SI/E/ROIS(17),AM(17),GRAN(13),AMT(13)
COMMON/CMPRES/I-N,C,AHINS3D,AHES3D,BINS,CP8P,GAMMA,GAM1,GAM2,GAM3,
1GM4,AHFS3D,RAI0,SCOMP,ZCOMP(170),T(170),RHOC(170)
COMMON/XSANDUM/XM(365),THXV(365),FUTH(365),XV(365),CPHM(365),
1SXV(365),SXVINC(365),FV8VINC(365),L,SATT,INT3,CH,ISP
DIMENSION SCTR(10),SCI(10),SUMM(10),RTCL(10),RDL(10),RTL(10),
1RTT(10),SICOMP(10)
B=(1./RATIO)**GAM1*80RT(1.+AHFS3D*CO8P**2)/(1.+AHFS3D*UTWO**2)**1
15 IF(IST,NE,1) GO TO 2
C ESTABLISH B Slot TO ZERO WHEN B/R IS ENTERED FOR FIRST TIME.
SC=0.,0.
SCOMPL=0.,0.
RAI0=0.,0.
DO 4 N=1,INTL
SCTR(N)=0.,0.
SCI(N)=0.,0.
SICOMP(N)=0.,0.
SUMM(N)=0.,0.
4 CONTINUE
1ST=0.

C EVALUATE (LAMBDA)*2 = BASED ON MINIMUM KINETIC VISCOITY COEFFICIENT.
C EITHER FREE STREAM OR EDGE VALUE
FACT=1./RATIO**1.5
IF(AHFS3D,GT,AHINS3D) FACT=1,
2 EM=EM+SC*USM*THETA**2/UTWO*FACT
WRITE(2,10)

ORIGINAL PAGE IS
OF POOR QUALITY
10 FORMAT(1X,'TRANSITION TEST (GRANVILLE) ***')
DO 3 N=1,INTRL
WRITE(2,11)RN(RNL(N))
11 FORMAT(1X,'REYNOLDS NUMBER= ',F10.0)
IF(SCTR(N),GT,0.,) GO TO 14
C SCALE REYNOLDS NUMBER TO STANDARD FORM.
IF(IFR.EQ.1)RN=RN(RNL(N))
IF(IFR.EQ.2)RN=RN(RNL(N))/COSP
IF(IFR.EQ.3)RN=RN(RNL(N))/COSP**2
C EVALUATE R2
C REYNOLDS NUMBER IS BASED ON MINIMUM KINEMATIC VISCOITY COEFFICIENT.
R0=SC(RN=SC(RNL(N))*COSP/RATIO)*THETA*FACT
WRITE(2,22) RD
22 FORMAT(1H,'#17HR1YNnLD5 NUMSER #FiO.A)
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 AM(RNL(J-1)+ROB(J)=ROB(J-1))*EM=AM(J,1,1)/AM(J)+AM(J-1)
RTC=10.**A
IF(RD,GT,RTC) GO TO 9
RTC(N)=RTC
RD(N)=RD
IF(JACKPTOT,EQ.3) GO TO 3
WRITE(2,110)RTC,EM
110 FORMAT(1H,'#4X/11HTHETACRIT=#F6.1,2X,AM #LAM=6.2,2X,14HNO INSTABIL
ITY)
GO TO 3
C INTERPOLATE FOR VALUES AT POINT OF INSTABILITY.
9 SCI(N)=SCL+(SC=SCL)*(RTCL(N)-RD(N))/(RN=RTC-RDL(N)+RTCL(N))
IF(2NC,EQ.0) GO TO 20
SCICOMP(N)=SCI(N)
GO TO 21
20 CALL C6I(SXVINC,8XV,F8VINC,+8CI(N),SCICOMP(N),ROT)
21 RTI(N)=RTCL(N)+RTC-RTCL(N)+(SCI(N)+SCL)/(SC=SCL)
EM=EML+(EM=EML)+(SCI(N)-SCL)/(SC=SCL)
SUM(N)=0.5*(EM+EMI)+(SC=SCI(N))
GO TO 8
140 DTM=0.5*(EM=RATIO*GAM1+EML=RATIOL*GAM1)*SC=8CL
SUM(M)=SUM(N)+DTM
C EVALUATE (R2)=R(N)
8 RTMRTI+RD=RTI(N)
C EVALUATE (LAMDA)=2 BAR
AMB=SUM(N)/(SCICOMP+8CLICOMP(N))
C FIND CRITICAL VALUE OF (R2)T=(R2)I FROM GRANVILLES CURVE.
  DO 15 K=2,13
    IF(AMT(K),GT,AMR) GO TO 16
    CONTINUE
    K=13
  16 RTMRTI=GRAN(K-1)+(AMR-AMT(K-1))*(GRAN(K)-GRAN(K-1))/
    (AMT(K)-AMR(K-1))
  14 WRITE (2,13)SCICOMP(N)
  13 FORMAT(1H+,72X,9HINSTABILITY AT 8/CE ,F6.4)
    IF(STR(N),GT,0.) GO TO 5
    IF(RTMRKI,GT,RTMRTI) GO TO 17
    WRITE (2,19)
  19 FORMAT(1H+,72X,13HNO TRANSITION)
    RTL(N)=RTMRTI-RTL(N)
    GO TO 100
  17 SCRN(N)=SCOMP+RTL(N)*(SCOMP-SCOMP)/RTMRKI-RTMRTI+RTL(N))
    WRITE (2,18)STR(N)
  18 FORMAT(1H+,72X,19HTRANSITION AT 8/CE ,F6.4)
    WRITE (2,101) RTL(N),RTMRTI,AMR
  101 FORMAT(17H INSTAR, REF. NO.,F6.1,2X,8HRTE=RTI,F6.1,2X,BHLM2BAR=MF).
  13) CONTINUE
SCL=6C
SCOMP=8C
EM=EM
RATIO=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/1.392,1.464,1.573,1.71,1.84,2.016,2.224,2.456,2.713,2.956,
  13.155,3.310,3.493,3.57,3.676,3.734,3.767,AM/=06,05,04,03,
  2,02,01,0,0,01,02,03,04,05,06,07,08,09,10/GRAN/450,640,
  836,1030,504,506,706,836,1000,1199,1440,1720,2046,/
  AMT/=035,030,025,02,015,01,005,0,005,01,015,02,
  5,025/
END

SUBROUTINE VELOCTS (INTV,COSP)
C COMPUTES U FROM DATA
 COMMON/XSANDU/UM(365),THXV(365),FUTH(365),XV(365),CPUM(365),
  18XV(365),8XVINC(365),FV3INC(365),L,SATT,INT3,CH,ISP

ORIGIANAL PAGE IS OF POOR QUALITY
LP1=LP1+1
DO 1 N=2,LP1
IF(INV,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)=SORT(CDSP**2-CPUM(N))
1 CONTINUE
CPUM(1)=COSP**2
RETURN
END

SUBROUTINE VGRADAT(ALPHA,RHO,B1,B3,VGRAD,XV)
C ESTIMATES DU/DB AT ATTACHMENT LINE AND POSITION OF ATTACHMENT LINE.
INC=1
IF(ALPHA,LT,0.0)INC=-1
ALPHAF=INC*ALPHA
XATT=(TAN(A)*(1+B3)**2/((1+B1)**2+(TAN(A)*(1+B3)**2)
VGRAD=COS(A)*(1+B1)*(1+XATT)/(RHO+B*XATT)
XV=XATT*INC
RETURN
END

SUBROUTINE XNDFRMS(S,U,DUDB,X,ITC,ILP,ANGLE,LIN,THETAB)
C FINDS X(8) FROM 8 BY ITERATIVE METHOD, HENCE U(8) AND DUD/DB.
COMMON/SFX/RTH(365),TH(365),F8TH(365),INTG,F2TH(365)
COMMON/XBAND/UH(365),THX(365),FWTH(365),XV(365),CPUM(365),
1SXV(365),SXINC(365),F8V8INC(365),L,BATT,INT3,CH,18P
COMMON/GEOM/XA(365),ZA(365)
COMMON/COMPRF,INC,AMINF3D,AM3D,BINP,COSP,GAMA,GAM1,GAM2,GAM3,
1LGAU,AM3F3D,RATIO,SCOMP,ZCOMP(170),T(170),RHO2(170)
ITC=0
IF(LINAR,.EQ,1)GO TO 15
IF(INT3),1,2
1 THETAB=THX(8)
DS=THETA-0.5*BIN(THETAB)
GO TO 3

56
C. THETA(S) FOR ESTIMATED S
   1 TESTS+XV(1)/CH
   IF(TEST,GT,1.1) GO TO 7
   THETAS=THX(TEST)
   GO TO 4
   7 THETAS=6.

C FIND S AND DS/DTHETA AT S
   6 CALL CST(THX,STH,FSTH,INT4,THETAS,SX1,NSOTH)
   TERT1=S+SATT-SX1
   IF(ABS(TERT1),LT,0.0001) GO TO 3

C IMPROVE ESTIMATE FOR S AND EVALUATE THETA(S).
   THETAS=THETAS+TFST1/DSOTH
   TEC=TIC+1
   IF(TIC,LT,20) GO TO 7

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

C FIND U AND DU/DTHETA AT THETA(S)
   3 CALL CST(THX,UM,FUTH,U,UDOTH)
   15 AME2D=AMINF3D*U
       AME3D=(AME2D**2*(1.+AMEF83D)+(AMINF3D**2)**2)/(1.+AMEF83D**2)
       AME3D=AME3D**2/(1.+AMEF83D)
       DSCD5T=RATIO**GAM1
       IF(LINEAR,GT,1.0) GO TO 20
       DU=UDOTH/DSOTH*DSCD5T
   20 XMUTH(THETAS)*CH

   IF(ILP,EQ,1) RETURN
   CALL CST(TH,2A,FZTH,INT4,THETAS,ROT,DDOTH)
   DXOTH=ABS(5*Sin(THETAS))
   IF(DXOTH,GT,1.0E-05) GO TO 6
   ANGLE3=1.0592654/2.
   RETURN
   6 ASLOPE=DDOTH/DXOTH
   ANGLE=ATAN(ASLOPE)
   RETURN
   END

SUBROUTINE XSCPPNT (INTV)

C PRINTS OUT TABLE OF VELOCITY DATA.

COMMON/X8ANDU/UM(365), THXV(365), FUTH(365), XV(365), CPUK(365),
18XV(365), 8XVINC(365), F8V8INC(365), L, BATT, INT3, CH, ISP
DIMENSION S(365)

IF(INT3,EQ,0) GO TO 6
DO 5 N=1,L
   8(N)=8XV(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(1HX,2HX,6X,1HU/(1H,2F8.4,2X))
1792
1793
IF(INT3.EQ.0.AND.INTV.EQ.3)WRITE(2,2)(XV(N),CPUH(N),UM(N),N=1,L)
2 FORMAT(1HO,2X,2HXV,7X,2HC,9X,1HU/(1H,3(FF,4.2X)))
1794
1795
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(1HO,7HX2HXV,14X3H5XV,11X6HSXVINC,13X1MU,13X6HTH XV,12X4HFUTH,
111X7FSVSINC/(1H,7E16.8))
1800
1801
IF(INT3.EQ.1.AND.INTV.EQ.3)WRITE(2,4)(XV(N),SXV(N),SXVINC(N),
1CPUH(N),UM(N),N=1,L)
4 FORMAT(1HO,6X2HXV,14X3H5XV,13X6HSXVINC,11X2HCP,14X1HU/
1(1H,5E16.8))
1805
1806
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 768 K storage for execution on the CDC CYBER 175 computer.
### Suction, Transition Analysis of Yawed Wing Laminar Boundary Layer

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**Upper Surface Calculation Using LFC 15.0 Pct Thick Airfoil Designed by Allison**
### INPUT + SOME COMPUTED QUANTITIES

**Input Data**

- **N**: 50
- **J**: 100
- **TOL**: 0.0001
- **DZ**: 0.5000
- **DS**: 0.0100
- **USTEP**: 0.0500
- **F**: 1.0000

**Solution Method**

- **IRL**: DISCONTINUOUS SUCTION OR INJECTION GIVEN REL0

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**Computed Quantities**

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- **ANFIS**: 8.85062000E+00
- **GAMMA**: 1.4000000E+01

**Compressible Flow (C)**: STEWARTSON TRANSFORMATION USED

**Boundary Conditions**

- **Suction**: TRANSITION ANALYSIS OF YAWING LAMINAR-boundary-layer

**Input Parameters**

- **INTL**: 1
- **CM**: 1.0000

**Input File**

- **INB**: 0
- **INTM**: 1.0000

**Input File 2**

- **IBD**: 0
- **INTM**: 1.0000

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**Notes:**

- The table above contains various input and computed quantities for a compressible flow simulation, including suction and injection velocities, locations, and other related data. The specific parameters and values are detailed in the table format, providing a comprehensive overview of the solution process and computed results.
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SUCTION, TRANSITION ANALYSIS OF YAWED WING LAMINAR BOUNDARY LAYER
UPPER SURFACE CALCULATION USING LFC 13.1 PCT THICK AIRFOIL DESIGNED BY ALLISON
REYNOLDS NUMBER DEFINED BY RNA Q12445

3 VELCITY GRADIENT AT ATTACHMENT LINE = 0.8887
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### OUTPUT

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*** LEADING-EDGGE CONTAMINATION TEST ***
REYNOLDS NUMBER: 11000000, RTHETA = 91.2
NO TURBULENT CONTAMINATION AT ALL.

X   U   T   Z   Tp   Xp   fp   fU
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0.250000   0.250000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
0.500000   0.500000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
0.750000   0.750000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
1.000000   1.000000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
1.250000   1.250000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
1.500000   1.500000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
1.750000   1.750000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
2.000000   2.000000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
2.250000   2.250000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000
2.500000   2.500000   -2.04071   0.000000   0.000000   0.000000   0.000000   0.000000

12 ITERATIONS
```

---

The above table represents a series of data points likely related to aerodynamic or fluid dynamics tests, possibly involving airflow or pressure measurements. The table includes variables such as X, U, T, Z, Tp, Xp, fp, and fU, which could represent different parameters or conditions being measured or calculated in the test.
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**Relaminarisation Check**

- Reynolds Number: 11000000
- Nu = 0.000000
- Km = 0.000006
- Kmax = 0.000006

**Transversal Test (Granville)**

- Reynolds Number: 11000000
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- Km = 0.000000
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REFERENCES


7. Bauer, Frances; Garabedian, Paul; Korn, David; and Jameson, Anthony: Supercritical Wing Sections II. Springer-Verlag, 1975.
Figure 1. Suction distribution for sample case.
Figure 2. Airfoil and pressure distribution for sample case, $M_\infty = 0.725$. 
Figure 3. Upper surface skin-friction distributions for sample case.