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TRANSEP: A Program for High Lift Separated Flow About Airfoils

Leland A. Carlson

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Leland A. Carlson
Texas A & M University
College Station, Texas

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INTRODUCTION

In the design and analysis of high performance airfoils, aerodynamicists would like not only to compute cruise behavior, but also to predict airfoil pressure distributions at high lift, high angle-of-attack conditions. Since such situations are characterized by large regions of separated flow and are dominated by strong viscous interaction effects, inviscid methods are not applicable. Furthermore, subsonic-transonic analysis and design computer codes (ref. 1 and 2) typically only include the effects of weak viscous interaction and fail to give acceptable answers whenever the length of the separated zone exceeds a few percent of the airfoil chord.

However, Barnwell (ref. 3) recently demonstrated that the direct-inverse technique could be successfully applied to the low speed high lift case. By specifying the separation point, he was able to obtain excellent agreement with experimental data by solving the linear equation with direct nonlinear boundary conditions (airfoil ordinates specified) upstream of separation and inverse boundary conditions (pressure specified) downstream of separation. Thus, the question arose--could similar results be obtained using the full potential equation coupled with viscous interaction and letting the separation point and pressure level be determined as part of the solution?

This report will describe a flow model and computer program, called TRANSEP, which can be used to determine the flowfield about a low speed single element airfoil at high angle-of-attack, high lift conditions with massive boundary layer separation. Since the program is a modification of the TRANDES code (ref. 2), which includes weak viscous interaction, it can also be used for subsonic-transonic airfoil analysis and design.

FLOW MODEL AND SOLUTION METHOD

As indicated previously, the present approach is based upon the direct-inverse method as developed in the TRANDES program and its ability to use either the displacement surface (airfoil ordinate plus displacement thickness) or pressure as the airfoil boundary condition. For the low speed high angle-of-attack case, the airfoil lower surface only experiences weak viscous interaction. The lower surface boundary layer, however, frequently has a long laminar run before transitioning to fully turbulent flow. Thus, the model needs to include an initial laminar boundary layer in its viscous interaction section. On the upper surface the boundary layer is also initially laminar, but it quickly becomes turbulent in character followed by boundary layer separation and a separated zone which can extend over as much as three-fourths of the airfoil surface. Fortunately, however, the separated region at low freestream velocities is characterized by an approximately constant pressure level. Consequently, the low speed massive separation problem has been modeled as shown on Figure 1.

To obtain the inviscid portion of the flowfield, the exact perturbation potential equation is solved iteratively using a rotated finite difference scheme and column relaxation. To include viscous effects, the basic approach is to calculate a boundary layer displacement thickness for weak interaction regions and to use it to correct the location of the displacement surface (i.e., airfoil ordinate plus displacement thickness, δ^*). For the strongly interacting separated zone, the pressure is specified and the location of the displacement surface is computed by integrating the surface-tangency conditions, with the initial conditions specified by the displacement surface slope and ordinate at the interface between the two regions. At present, the location and slopes of the displacement surface are updated every ten relaxation cycles.

On the lower surface of the airfoil, the flowfield is determined using direct boundary conditions (airfoil specified) including the effects of weak viscous interaction. On the upper surface, the flowfield is also computed directly with viscous interaction up to the separation point, which is determined as part of the solution. Downstream of separation, inverse boundary conditions are used, and the pressure is assumed to be constant in the separated zone. Studies with this model have shown that the separated-zone pressure, which has to be computed as part of the solution, must be determined by conditions at both the separation point and at the trailing edge and not just on conditions in the vicinity of separation. This result is in agreement with the conclusion of Gross (ref. 4) that conditions at the downstream end of the separation bubble partially determine bubble pressure.

In the present formulation, the pressure coefficient for the constant pressure separated zone is computed by the equation

$$C_{p,sep} = \frac{-2(\phi_{ITE} - \phi_{sep})}{X_{ITE} - X_{sep}} \tag{1}$$

as illustrated on Figure 2. Here ϕ_{ITE} and ϕ_{sep} are the perturbation potentials at the trailing edge and the turbulent boundary layer separation point, respectively. Note that equation (1) is a small-perturbation approximation for $C_{p,sep}$; and while this form probably introduces some error into the overall problem, its usage has been found to be simple, accurate, and adequate.

In principle, the separated region and wake probably should be accurately modeled with respect to physical phenomena and details. This approach has been taken by other investigators (ref. 4-7) and would typically introduce a large number of computational points to model the wake region. In the present model, however, the wake region contains very few computational points due to the coordinate stretching. Thus, it is treated very simply in that it is assumed to be inviscid with a constant pressure-trailing edge formed by the upper and lower displacement surfaces. As will be discussed later, this simplistic approach yields results which agree well with experimental data. In fact, numerical experiments with the present model indicate that the results for the pressure distribution and aerodynamic coefficients are primarily dependent upon obtaining accurate predictions for the location of the separation point and the magnitude of the separated pressure. Apparently, the details of the wake region are of secondary importance. Finally, as shown on Figure 2, the airfoil circulation, Γ, is modeled as the difference in the perturbation potentials at the airfoil trailing edge, i.e., $\Gamma = \phi_u - \phi_L$, and not as $(\phi_{ITE} - \phi_L)$.

In the present TRANSEP code the turbulent boundary layer is computed using the Nash-Macdonald method (ref. 8) in the same manner as in the original TRANDES program (ref. 2). For the laminar portion, the boundary layer is computed using a compressible Thwaites method which is a slightly modified version of a NASA Langley code originally developed by Grumman Aerospace Corporation. These integral methods are efficient and reliable and yield excellent predictions for displacement thickness values (ref. 9). Internally, the transition point is determined from a Granville type correlation (ref. 10) based upon the difference between the local momentum-thickness Reynolds number and the value at the laminar instability point combined with the pressure gradient history. Sometimes, particularly on the upper surface at high angles of attack, laminar separation is predicted upstream of the transition point. In these cases, the local momentum-thickness Reynolds number is compared to an empirical correlation in order to determine if the laminar bubble is long or short. If the estimate indicates that the bubble is long, the calculation proceeds, but a warning is printed which indicates that the results are probably in error. If the bubble is short, its length is assumed to be one horizontal Δx grid width (about 3% of chord) and the turbulent-flow computation is initiated at the next downstream grid point. As will be demonstrated, this very simple model and approach usually yield adequate results.

The calculation procedure used in TRANSEP is the same iterative successive-column-relaxation scheme used in the basic TRANDES program except that the separation point and separated pressure level are permitted to vary. A convergence history for a typical case is shown on Figure 3. Initially, some oscillation occurs on each grid, but, as can be seen, the values quickly converge. Normally four hundred iterative cycles are performed on both the medium and fine grids. Also, the location of the separation point is held fixed on the fine grid (typically 97 x 49 with 130 points on the airfoil) at the x/c location computed on the medium grid (49 x 25 with 66 points on the airfoil).

TYPICAL RESULTS

In the development of the present model and program, the NACA 4412 and GA(W)-2 airfoils were primarily used as test cases due to the excellent experimental pressure distributions available for these airfoils (ref. 11-12). Some typical results for these cases are shown on Figures 4 and 5. In both cases, the lower-surface boundary layer remained entirely laminar, although results with an all-turbulent lower surface boundary layer showed no significant differences. On the upper surface, transition with a short separation bubble occurred near the leading edge. As can be seen on the figures, comparison with experimental data is good with respect to C_p, separation point location, separated pressure level, and C_L.

Figures 6 and 7 show comparisons with experiment for these airfoils of C_L versus angle of attack at typical Reynolds numbers. Again, at least up to C_{Lmax}, the TRANSEP results are sufficiently accurate for engineering usage.

Another aerodynamic coefficient which would be desirable to predict theoretically is drag and, in general, its prediction for extensively separated flow is difficult. The present investigation has revealed that C_p integration (called CDWAVE in the code) is totally wrong and that the Squire-Young approach (ref. 13) evaluated at the trailing edge is consistently too high. The latter is expected since the boundary layer is not accurately computed in the separation zone. On the other hand, the present investigation has shown that when the Squire-Young formula is evaluated at separation the results are better.

The best method, however, seems to be empirical. Thus, the present

TRANSEP code utilizes Squire-Young evaluated at separation but with the reference length being the distance to separation instead of the chord. Results using this technique are shown on Figure 8.

Extensive investigations with the present model have shown that the theoretical results are primarily dependent upon the accurate prediction of the upper surface separation-point location. In the Nash-Macdonald integral method, separation is assumed to occur when a parameter, SEP, defined as

$$SEP = -\frac{\theta}{q}\frac{dq}{ds} \tag{2}$$

exceeds a specific value, SP. Here θ is the local momentum thickness, and q is the local boundary layer edge velocity. Obviously, agreement between the theoretical and experimental values requires an appropriate selection of the value for SP in order to obtain the correct separation point.

Theoretically, in the Nash-Macdonald method, separation occurs whenever the displacement-momentum thickness ratio, δ^*/θ, exceeds three. At low speeds and low angles of attack, this value usually corresponds to an SP of about 0.0055. In ref. 1, however, it was found that at transonic speeds, an SP value of 0.0040 was more appropriate. Interestingly, the present study indicates that accurate results can only be obtained at high angles of attack by making SP a function of angle of attack, α, Reynolds number, RN, and the low angle of attack lift curve slope, $C_{L_{\alpha_o}}$. The present best estimate for this correlation is:

For $\alpha \leq 15.3^{o}$

$$\text{Use:} \quad SP = -7.14352 \times 10^{-5} \alpha + (0.0142857\, C_{L_{\alpha_o}} + 0.004714337)$$

$$\text{If:} \quad SP > 0.0055, \text{ set } SP = 0.0055$$

For $\alpha > 15.3^{o}$

$$\text{Use:} \quad SP = 3.6213784 \times 10^{-3} + 0.0142875\, C_{L_{\alpha_o}} + (-8.4074 \times 10^{-11}\, RN + 2.1707 \times 10^{-4})\, (\alpha - 15.3)$$

where the angle of attack, α, is always in degrees.

This formula should be viewed strictly as an empirical attempt to force the correct separation point behavior into the Nash-Macdonald approach as it is formulated in a finite difference grid. Thus, the user should anticipate further empirical modification of it if his experience so dictates. This alteration should not be viewed as a criticism of the Nash-Macdonald method. Nevertheless, it should lead to reasonable results for the flow about low-speed airfoils up to C_{Lmax}, and sometimes even beyond C_{Lmax}.

PROGRAM USAGE

The program is written in FORTRAN IV programming language for use on IBM, AMDAHL, CDC, and similar computers. In nonoverlay mode it requires less than 256,000 bytes on an IBM machine. Some modification to formats, etc., may be required to run the program on different computer systems. The changes necessary to convert the TRANDES code, as given in Appendix C of NASA CR-2821, to the present TRANSEP version are listed in Appendix A.

INPUT

The input deck setup is identical to that of TRANDES. However, some of the variables have been redefined for the massive separation case, and a few new variables have been added to NAMELISTS FINP and IINP. The definitions for these new input variables are as follows:

XIBDLY - The x-location at which upper surface transition is assumed to occur. The turbulent boundary layer calculation starts at the next grid point. The relationship to percent chord is:

$$XIBDLY = (\%chord - 50.0)/100.0$$

Used only if ILAM = 0. Ignored if ILAM = 1. Default -0.44.

XLSEP - When IMASS = 0, location at which the trailing edge correction procedure begins. Between XLSEP and the trailing edge the pressure distribution and the displacement surface is modified. Used in this fashion only if ITEUPC and/or ITELWC equal 1. When IMASS = 1, set to a number forward of expected separation point. Default 0.50.

XLBDLY - The x-location at which lower surface transition is assumed to occur. Same relationship to chord is XIBDLY. Used only if ILAM = 0. Ignored if ILAM = 1. Default - 0.44.

RLAX - Relaxation parameter for separated pressure level. Sometimes needed to enhance convergence. It is used only when ITACT = 1. IMASS = 1. Default 1.0.

RADUS - Leading edge nose radius, $r_{LE/c}$. Used only if ILAM =1. Default 0.035.

CLALP - Low angle of attack lift curve slope. Used only if IMASS = 1. Default 0.10966.

ILAM - Boundary layer parameter. If zero, boundary layer is all turbulent. If one, boundary layer is laminar-turbulent with natural transition. Default 0.

IPRT1 - Print parameter. If one, perturbation potential values printed at the completion of each grid. Default 0.

IPRT2 - Print parameter. If one, x and y velocities at each grid point printed at the completion of each grid. Values printed as part of Mach Chart. Default 0.

IMASS - Massive separation parameter. It should be one for massive separation cases and zero for all others. To utilize, ITACT must be 1. Default 0.

OUTPUT

The program output for each grid in the massive separation mode is

1. Heading
2. Coordinate System. It is printed as I,X(I) followed by J,Y(J).
3. Mach number, angle of attack and location where direct calculation stops
4. Case number
5. Case type callouts, i.e.,
   - Inviscid analysis case
   - With viscous interaction
   - Massive separation
6. Input data in namelists FINP and IINP
7. Airfoil ordinates in direct region

   X - horizontal ordinate, where -0.5 is leading edge and 0.5 is the trailing edge

   YU - Upper surface ordinate

   YL - Lower surface ordinate

   Upper Slope - Upper surface slope

   Lower Slope - Lower surface slope
8. Iteration history at ten-cycle intervals

   CIR - Circulation

   DPM - Maximum ϕ correction (absolute value) in the last relaxation cycle, with the corresponding (I,J) grid location

   NSSP - Number of supersonic points

   DELTAY or DELSTAR - δ* at the trailing edge for massive separation, should go to a constant if solution is converging. Only changes after first fifty cycles on each grid.

Separation point and separated C_p are printed.

9. Laminar Boundary Layer Values (every LP cycles)

X - Horizontal ordinate

CF - Skin Friction Coefficient (the $.1 \times 10^{11}$ value is an arbitrary initial value and should be ignored)

D-STAR - δ^*/c, non-dimensional boundary layer displacement thickness

D-THETA - Θ /c, non-dimensional momentum thickness

H - δ^*/c, shape factor

RE-THETA - Reynolds number based on Θ

RE-STAR - Reynolds number based on δ^*

TM - $\Theta^2 \frac{du}{dx} / \nu$ Pressure gradient parameter

10. Laminar Flow Messages

   a. SEPARATION OCCURRED AT X = __; gives x location where laminar separation occurred

   b. SHORT BUBBLE FORMED? TRANSITION TO TURBULENT FLOW ASSUMED, X = __

   c. LONG BUBBLE? LAMINAR STALL MAY OCCUR, X = __ BOUNDARY LAYER CALCULATION WILL BE CONTINUED AS TURBULENT BUT ACCURACY OF RESULTS IS QUESTIONABLE

   d. BOUNDARY LAYER CONCULATION COMPLETED? NEITHER SEPARATION NOR TRANSITION WAS DETECTED

11. Turbulent Boundary Layer Values

X - Horizontal ordinates

M - Local Mach Number

DELS - δ^*, displacement thickness

THETA - Θ, momentum thickness

SEP - parameter used to determine if separation occurs

H - shape factor

PI - $\frac{\delta^*}{\tau_W} \frac{dp}{dx}$, pressure gradient parameter

TAU - $\tau_W/\rho u^2$, non-dimensional wall shear force

CF, D-STAR, D-THETA, H, RE-THETA, RE-STAR, TM (see 9)

12. Lower Surface Flow Messages

a. BOUNDARY LAYER CALCULATION COMPLETED?

b. NEITHER SEPARATION NOR TRANSITION WAS DETECTED

13. Upper surface flow message gives separation point and C_p for separated region

14. 1st group - x - horizontal ordinates

YU, YL, location of the surface ordinates in the computational plane

2nd group - x - horizontal ordinates

YU, YL, slopes of upper and lower surfaces in physical plane

repeat 8) thru 14) until convergence

15. Final Boundary Layer Results

YUORIG - Original airfoil upper surface ordinates

DU - Upper surface displacement thickness

SLU - Slope of upper displacement surface

YLORIG - Original airfoil lower surface ordinates

DL - Lower surface displacement thickness

SLL - Slope of lower displacement surface

16. Pressure distribution on airfoil

17. Displacement surface ordinates and slopes in physical plane

18. Mach chart, numbers printed are Mach number multiplied by 100. Velocities (U,V) may also be printed.

19. Wave drag coefficient

20. Plot of Results

    U - Upper surface C_p

    L - Lower surface C_p

    T - Upper displacement surface

    B - Lower displacement surface

    CLCIR - Lift coefficient from circulation

    CL - Lift coefficient from integration of C_p

    C_D - CDWAVE + CDF

    CMLE - Moment coefficient about leading edge

    CDF - Drag coefficient by modified Squire-Young

    CMC4 - Moment coefficient about quarter chord

    NOTE: For low speed massive separation, ignore CDWAVE and CD. Use CDF only.

A sample case input and output is provided in Appendix B to aid potential users and for program checkout. It should be noted that Appendix B only presents results for a medium grid (49 x 25) calculation. Fine grid results for the same case are shown on Figure 5.

CONCLUDING REMARKS

Some comment should be made concerning the accuracy and applicability of the present method. Based upon extensive comparisons with experimental data, the TRANSEP method should yield accurate massive separation aerodynamic coefficients for airfoils at low speeds at Reynolds numbers above 1×10^6. Such results can be obtained on either the medium (default 49 x 25) or fine grids (97 x 49 normally). It should also yield reasonable pressure distribution estimates, transition points, and separation locations. Due to the finite mesh size used in the finite difference formulation, the separation point is probably at best only accurate to three percent chord. Consequently, at very high lift coefficients the overall program accuracy may be somewhat less. Obviously, the current TRANSEP code is primarily limited by the ability of its boundary layer techniques to predict separation.

In conclusion, the user should note that TRANSEP retains all the features of TRANDES. Thus, it can also be used for the design and analysis of high speed and transonic airfoils.

APPENDIX A

Changes to Convert TRANDES Code As

Defined in NASA CR-2821 to TRANSEP

```
  PAGE 19, CHANGE LINES 1 THRU 4 TO THE FOLLOWING
C ***************************  T R A N S E P  *************************
C ***********************************************************************
C ***** A FORTRAN PROGRAM FOR COMPUTING THE FLOW ABOUT AIRFOILS ********
C ***** AT LOW SPEEDS UNDER HIGH LIFT, MASSIVE SEPARATED FLOW    ********
C ***** CONDITIONS.  TRANSEP IS A MODIFIED VERSION OF TRANDES    ********
C ***** DISCUSSED IN NASA CR-2821.  THUS, IT CAN ALSO BE USED    ********
C ***** FOR TRANSONIC AIRFOIL ANALYSIS AND/OR DESIGN.            ********
C ***** LELAND A. CARLSON, AEROSPACE ENGINEERING DEPARTMENT      ********
C ***** TEXAS A&M UNIVERSITY, COLLEGE STATION, TEXAS, 77843      ********
C ***** JANUARY 1980 ***************************************************
C ***********************************************************************

  PAGE 19, INSERT AFTER LINE 5 THE FOLLOWING
      DIMENSION UVEL(99),VVEL(99)

  PAGE 19, INSERT AFTER LINE 25 THE FOLLOWING
     2,LBDLY,XLBDLY
      COMMON/IPT2/IMASS
      COMMON/SETCPS/CPSPO,RLAX
      COMMON/IPT3/ISIDE,ILAM,RADUS

  PAGE 19, INSERT AFTER LINE 27 THE FOLLOWING
     3,XLBDLY,RLAX,RADUS,CLALP

  PAGE 19, INSERT AFTER LINE 29 THE FOLLOWING
     2,IMASS,ILAM
     2,IPRT1,IPRT2

  PAGE 19, INSERT AFTER LINE 30 THE FOLLOWING
      CPSPO=0.0

  PAGE 20, INSERT AFTER LINE 45 THE FOLLOWING
      IPRT1=0
      IPRT2=0
      ILAM=0
      RADUS=0.035

  PAGE 20, INSERT AFTER LINE 54 THE FOLLOWING
      XLBDLY=-.44

  PAGE 20, INSERT AFTER LINE 57 THE FOLLOWING
      RLAX=1.0
      CLALP= 0.10966

  PAGE 20, INSERT AFTER LINE 70 THE FOLLOWING
      IMASS=0

  PAGE 21, INSERT AFTER LINE 111 THE FOLLOWING
      IF(IMASS.EQ.1) PRINT 6005
 6005 FORMAT(1H ,3X,'AND MASSIVE SEPARATION')
      IF(IMASS.EQ.0)GO TO 6000
      SPP=0.0
      ALPNU=0.0
      ALPT=ALPDEG
      IF(ALPDEG.LE.15.3) GO TO 6006
      ALPNU=ALPT-15.3
      ALPT=15.3
 6006 SP=-7.14352E-05*ALPT+(0.0142857*CLALP+0.004714337)
```

```
      IF(ALPDEG.LE.15.3) GO TO 6008
      SPP=(-8.4074E-11*RN+2.1707E-04)*ALPNU
      SP=SP+SPP
 6008 CONTINUE
      IF(SP.GT.0.0055) SP=0.0055
      IF(SP.LT.0.004) SP=0.004
      PRINT 6007,SP
 6007 FORMAT(1H ,3X,'SP PARAMETER VALUE IS CALCULATED TO BE ',F10.5)
 6000 CONTINUE
```

PAGE 22, INSERT AFTER LINE 138 THE FOLLOWING

```
      IF(IMASS.EQ.1) GO TO 5001
      GO TO 5002
 5001 IF(MHALF.GT.2.OR.ITER.GT.50) GO TO 5002
      GO TO 9
 5002 IF(I1.GT.ITE) GO TO 9
```

PAGE 22, INSERT AFTER LINE 144 THE FOLLOWING

```
      IF(IMASS.EQ.0) GO TO 1441
      JB2=JB-1
      DO 1442 J=JB2,JMAX1
      IF(YU(ITE).GT.E(J).AND.YU(ITE).LE.E(J+1)) GO TO 1443
 1442 CONTINUE
 1443 JA=J+1
      IF(JA.LE.JB) JA=JB+1
      PHITE=P(ITE,JA-1)+(P(ITE,JA)-P(ITE,JA-1))*(YU(ITE)-E(JA-1))/DE
 1441 CONTINUE
```

PAGE 23, INSERT AFTER LINE 192 THE FOLLOWING

```
      IF(IMASS.EQ.1)DELTAY=YU(ITE)-YUORIG(ITE)
      IF(IMASS.EQ.1) GO TO 5003
```

PAGE 23, REPLACE LINE 194 WITH THE FOLLOWING

```
 5003 IF(ITER/10*10.EQ.ITER)
```

PAGE 24, INSERT AFTER LINE 210 THE FOLLOWING

```
      IF(MHALF.EQ.2.AND.ITER.LE.50 ) GO TO 9006
      IF(ITER/10*10.EQ.ITER.AND.IMASS.EQ.1) CALL SHAPE
      IF(IMASS.EQ.0) GO TO 9006
      DO 9112 I=I1,ITE
      IF(YU(I).GE.0.0) GO TO 9112
      YU(I)=YU(I-1)
      SLU(I)=0.0
 9112 CONTINUE
```

PAGE 24, INSERT AFTER LINE 225 THE FOLLOWING

```
      IF(IPRT1.EQ.0) GO TO 3776
```

PAGE 24, REPLACE LINES 226 THRU 232 WITH THE FOLLOWING

```
      DO 18 JJ=1,JMAX
      J=JMAX+1-JJ
      PRINT 19,J
   19 FORMAT(1H ,'ROW  ',I5)
      PRINT 20,(P(I,J),I=1,IMAX)
   20 FORMAT(1H ,10E11.3)
   18 CONTINUE
```

PAGE 25, REPLACE LINES 233 AND 234 WITH THE FOLLOWING

```
      PRINT 19,JB
      PRINT 20,(PB(I),I=1,IMAX)
```

PAGE 25, INSERT AFTER LINE 234 THE FOLLOWING

```
3776 CONTINUE
```

PAGE 25, INSERT AFTER LINE 247 THE FOLLOWING

```
      IF(IMASS.EQ.1) CALL SHAPE
```

PAGE 26, INSERT AFTER LINE 276 THE FOLLOWING

```
      NMACH=2
      JL=2
      JU=JMAX1
      JDUM=JMAX-2
      IF(JDUM.LE.43) GO TO 513
      NMACH=1
      JU=JB
  513 CONTINUE
      PRINT 514
  514 FORMAT(//,38X,'MACH CHART IN COMPUTATIONAL
     1PLANE-FREE STREAM FROM TOP',/)
      PRINT 515,IMAX1
  515 FORMAT(3X,'I=2,',I2,' TOP TO BOTTOM',/)
      PRINT 516,JL,JU
  516 FORMAT(3X,'J=',I2,1H,,I2,' LEFT TO RIGHT'/)
```

PAGE 26, INSERT AFTER LINE 283 THE FOLLOWING

```
      UVEL(J)=U
      VVEL(J)=V
```

PAGE 26, REPLACE LINE 285 WITH THE FOLLOWING

```
      PRINT 28,(IONIC(J),J=JL,JU)
```

PAGE 26, INSERT AFTER LINE 285 THE FOLLOWING

```
      IF(IPRT2.EQ.0) GO TO 500
      PRINT 2878,(UVEL(J),J=JL,JU )
      PRINT 2878,(VVEL(J),J=JL,JU )
 2878 FORMAT(1H ,15F8.1)
```

PAGE 26, INSERT AFTER LINE 288 THE FOLLOWING

```
      UVEL(J)=0.0
      VVEL(J)=0.0
```

PAGE 26, INSERT AFTER LINE 301 THE FOLLOWING

```
      UVEL(J)=U
      VVEL(J)=V
```

PAGE 27, INSERT AFTER LINE 316 THE FOLLOWING

```
      UVEL(J)=U
      VVEL(J)=V
```

PAGE 27, REPLACE LINE 318 WITH THE FOLLOWING

```
      PRINT 28,(IONIC(J),J=JL,JU)
```

PAGE 27, INSERT AFTER LINE 318 THE FOLLOWING

```
      IF(IPRT2.EQ.0) GO TO 502
      PRINT 2878,(UVEL(J),J=JL,JU )
      PRINT 2878,(VVEL(J),J=JL,JU )
```

PAGE 27, INSERT AFTER LINE 328 THE FOLLOWING

```
      UVEL(J)=U
      VVEL(J)=V
```

PAGE 27, REPLACE LINE 330 WITH THE FOLLOWING

```
      PRINT 28,(IONIC(J),J=JL,JU)

 PAGE 27, INSERT AFTER LINE 330 THE FOLLOWING
      IF(IPRT2.EQ.0) GO TO 510
      PRINT 2878,(UVEL(J),J=JL,JU  )
      PRINT 2878,(VVEL(J),J=JL,JU  )

 PAGE 27, INSERT AFTER LINE 332 THE FOLLOWING
      IF(NMACH.EQ.2) GO TO 519
      NMACH=NMACH+1
      JL=JB
      JU=JMAX1
      JDUM=JU-JL-42
      IF(JDUM.GT.0) JU=JL+42
      GO TO 513
 519  CONTINUE

 PAGE 29, INSERT AFTER LINE 400 THE FOLLOWING
      IF(IMASS.EQ.1.AND.MHALF.EQ.3) MITER=400

 PAGE 30, INSERT AFTER LINE 443 THE FOLLOWING
     2,LBDLY,XLBDLY

 PAGE 30, INSERT AFTER LINE 450 THE FOLLOWING
      LBDLY=ILE-1
 218  LBDLY=LBDLY+1
      IF(X(LBDLY).LT.XLBDLY) GO TO 218

 PAGE 33, CHANGE LINE 555 TO THE FOLLOWING
      IF(I.LT.LBDLY) GO TO 37

 PAGE 35, INSERT AFTER LINE 606 THE FOLLOWING
      INTEGER SEPMK

 PAGE 35, INSERT AFTER LINE 620 THE FOLLOWING
     2,LBDLY,XLBDLY
      COMMON/IPT2/IMASS
      COMMON/FIX/MHALF
      COMMON/SETCPS/CPSPO,RLAX
      COMMON/IPT3/ISIDE,ILAM,RADUS

 PAGE 35, INSERT AFTER LINE 625 THE FOLLOWING
      IF(MHALF.EQ.2.AND.ITER.LE.50) LSPOLD=ITE
      IF(MHALF.GT.2.AND.ITER.LE.50) LSPOLD=LSPOLD*2-1

 PAGE 35, INSERT AFTER LINE 638 THE FOLLOWING
      JB2=JB-2
      DO 3010 J=JB2,JMAX1
      IF(YU(ITE).GT.E(J).AND.YU(ITE).LE.E(J+1)) GO TO 3011
3010  CONTINUE
3011  JA=J+1
      IF(JA.LE.JB)JA=JB+1
      PHITE=P(ITE,JA-1)+(P(ITE,JA)-P(ITE,JA-1))*(YU(ITE)-E(JA-1))/DE

 PAGE 36, INSERT AFTER LINE 641 THE FOLLOWING
5061  CONTINUE

 PAGE 36, INSERT AFTER LINE 650 THE FOLLOWING
      IF(IMASS.EQ.1) LSEP=ITE

 PAGE 36, DELETE LINES 652 THRU 655
```

```
PAGE 36, REPLACE LINE 663 WITH THE FOLLOWING
      EM(J)=1.E-03

PAGE 36, INSERT AFTER LINE 673 THE FOLLOWING
      DSS(ILE)=SLOWER(ILE)
      IF(ISIDE.EQ.1)DSS(ILE)=SUPPER(ILE)

PAGE 37, INSERT AFTER LINE 683 THE FOLLOWING
      IF(ISIDE.EQ.1) ISTART=IBDLY
      IF(ISIDE.EQ.2) ISTART=LBDLY
C     ILAM=1
      IF(ILAM.EQ.0) GO TO 5060
      CALL THWAIT(THETA,HH,UE,DSS,DUDS,ISTART)
      IF(ISIDE.EQ.1) IBDLY=ISTART
      IF(ISIDE.EQ.2) LBDLY=ISTART
      IF(ISTART.GE.ITE) THET2=THETA
      IF(ISTART.GE.ITE) GO TO 202
 5060 CONTINUE
      IF(ITER/LP*LP.EQ.ITER) PRINT 1,RN
    1 FORMAT(1H0,10X,'BOUNDARY LAYER ANALYSIS FOR REYNOLDS NO. OF ',E10.
     13,//,5X,'X',9X,'M',8X,'DELS',4X,'THETA',3X,'SEP',
     210X,'H',9X,'PI',5X,'TAU')

PAGE 37, INSERT AFTER LINE 691 THE FOLLOWING
      IF(ILAM.EQ.1)THET1=THETA

PAGE 37, INSERT AFTER LINE 704 THE FOLLOWING
      IF(TAU.LT.1.E-06)TAU=1.E-06

PAGE 37, INSERT AFTER LINE 707 THE FOLLOWING
      IF(SEP.GT.1.0) SEP=1.0

PAGE 37, INSERT AFTER LINE 708 THE FOLLOWING
      IF(ISIDE.EQ.1.AND.IMASS.EQ.1) GO TO 3005

PAGE 37, INSERT AFTER LINE 709 THE FOLLOWING
      GO TO 3006
 3005 IF(X(J+1).LT.XLSEP) SEP=SP
 3006 CONTINUE

PAGE 38, INSERT AFTER LINE 741 THE FOLLOWING
      IF(IMASS.EQ.1) GO TO 3001
      GO TO 3004
 3001 IF(ISIDE.EQ.2)GO TO 3004
      IF(J.NE.LSPOLD) GO TO 3015
      EMSTR=EM(LSPOLD)
      USTR=UE(LSPOLD)
      HSTR=HH
      TSTR=THT/(X(LSPOLD)+0.50)
 3015 CONTINUE
      IF(SEPMK.EQ.1) GO TO 3004
      IF(SEPR.GT.SP) LSEP=J
      IF(LSEP.LT.ITE) SEPMK=1
 3004 CONTINUE

PAGE 38, INSERT AFTER LINE 755 THE FOLLOWING
      IF(IMASS.EQ.1) GO TO 3002
 3002 CONTINUE

PAGE 38, INSERT AFTER LINE 758 THE FOLLOWING
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      IF(IMASS.EQ.1) GO TO 440

 PAGE 39, INSERT AFTER LINE 761 THE FOLLOWING
 440  CONTINUE

 PAGE 43, INSERT AFTER LINE 924 THE FOLLOWING
      IF(IMASS.EQ.0) GO TO 3007
      IF(MHALF.EQ.4) LSEP=LSPOLD
      IF(LSEP.GT.LSPOLD)LSEP=LSPOLD
      IF(LSEP.GE.(ITE-1)) GO TO 3008
      I1=LSEP
      I11=I1-1
      X1=X(I1)-0.001
      X2=0.5
      JB2=JB-2
      DO 3012 J=JB2,JMAX1
      IF(YU(I1).GT.E(J).AND.YU(I1).LE.E(J+1)) GO TO 3013
3012  CONTINUE
3013  JA=J+1
      IF(JA.LE.JB) JA=JB+1
      PHSEP=P(I1,JA-1)+(P(I1,JA)-P(I1,JA-1))*(YU(I1)-E(JA-1))/DE
      CPU(LSEP)=-2.*(PHITE-PHSEP)/(X(ITE)-X(LSEP))
      CPU(LSEP)=CPSPO+RLAX*(CPU(LSEP)-CPSPO)
      CPSPO=CPU(LSEP)
      DO 3009 J=LSEP,ITE
3009  CPU(J)=CPU(LSEP)
      PRINT 6152,X(LSEP),CPU(LSEP)
6152  FORMAT(' ',2X,'SEPARATION AT ',F10.5,5X,'SEPARATED CP IS ',F10.5)
      LSPOLD=LSEP
      RETURN
3008  I1=ITE+1
      I11=I1-1
      X1=0.5
      X2=10000.0
3007  CONTINUE

 PAGE 43, INSERT AFTER LINE 945 THE FOLLOWING
     2,LBDLY,XLBDLY

 PAGE 52, INSERT AFTER LINE 1292 THE FOLLOWING
      IF(D(J).EQ.0.0) GO TO 21

 PAGE 62, INSERT AFTER LINE 1647 THE FOLLOWING
      COMMON/IPT2/IMASS

 PAGE 63, INSERT AFTER LINE 1722 THE FOLLOWING
      IF(IMASS.EQ.1) GO TO 3600

 PAGE 66, INSERT AFTER LINE 1805 THE FOLLOWING
      COMMON/IPT2/IMASS

 PAGE 68, INSERT AFTER LINE 1876 THE FOLLOWING
      ITMP1=I1
      ITMP11=I11
      IF(IMASS.EQ.1)I1=ITE+1
      IF(IMASS.EQ.1)I11=ITE

 PAGE 69, INSERT AFTER LINE 1939 THE FOLLOWING
      I1=ITMP1
      I11=ITMP11
```

```
PAGE 70, INSERT AFTER LINE 1956 THE FOLLOWING
      COMMON/IPT2/IMASS

PAGE 70, INSERT AFTER LINE 1957 THE FOLLOWING
      DIMENSION PTEMP(99)
      IMARK=0
      IF(IMASS.EQ.0) TO TO 100
      JB2=JB-1
      DO 101 J=JB2,JMAX1
      IF(YU(ITE).GT.E(J).AND.YU(ITE).LE.E(J+1)) GO TO 102
101   CONTINUE
102   JA=J+1
      IF(JA.LE.JB)JA=JB+1
      STE=S4+2./PI*ATAN((0.5-X4)/A2)
      QUAN1=STE-S4
      F=PI*A2*0.5*(1.+TAN(PI2*QUAN1)**2)
      F=1./F
      JAM1=JA-1
      DO 103 J=JB,JAM1
      IMARK=1
C     PTEMP(J)=P(ITE,J)
      P(ITE,J)=0.5/F*CPU(I1)+(4.*P(ITE+1,J)-P(ITE+2,J))/(2.*DS)
     1 +(STE-S(ITE))*(-2.*P(ITE+1, ,J)+P(ITE+2,J))/(DS*DS)
      P(ITE,J)=P(ITE,J)/(1.5/DS-(STE-S(ITE))/(DS*DS))
      P1(J)=P(ITE,J)
      P2(J)=-P(ITE+1,J)+2.*P1(J)
103   CONTINUE
100   CONTINUE

PAGE 71, INSERT AFTER LINE 2017 THE FOLLOWING
C     IF(IMARK.EQ.0) GO TO 105
C     DO 104 J=JB,JAM1
C 104 P(ITE,J)=PTEMP(J)
C 105 CONTINUE

PAGE 72, INSERT AFTER LINE 2039 THE FOLLOWING
      COMMON/IPT2/IMASS
      IF(I1.GE.ITE) RETURN

PAGE 72, INSERT AFTER LINE 2040 THE FOLLOWING
      IF(IMASS.EQ.1) GO TO 100

PAGE 72, INSERT AFTER LINE 2041 THE FOLLOWING
100   CONTINUE

PAGE 74, INSERT AFTER LINE 2107 THE FOLLOWING
      IF(IMASS.EQ.0) GO TO 1000
      RETURN
1000  CONTINUE

PAGE 84, INSERT AFTER LINE 2518 THE FOLLOWING
      SUBROUTINE THWAIT(THETA,HH,UE,DSS,DUDS,ISTART)
C ***** THIS SUBROUTINE IS BASED UPON A NASA LANGLEY  *****************
C ***** PROGRAM ORIGINALLY DEVELOPED BY THE GRUMMAN   *****************
C ***** AEROSPACE CORPORATION ******************************************
      REAL M
      COMMON CPU(99),CPL(99),E(99),DU1(99),DU2(99),DL1(99),DL2(99),D(99)
     1,FF(99),FFP12(99),FFM12(99),FFM1(99),FFM32(99),
     1P1(99),P2(99),PB(99),P(99,99),RS(99),S(99),SUP(99),SUB(99),TEMP(99
     2),X(99),Y(99),YU(99),YL(99),SLU(99),SLL(99),
     3A1,A2,AI2,ALP,CIR,EPS,EPSS,DE,DS,DP,DPM,F,FP12,FM12,FM32,M,QI,QI2,
```

```
4W,X1,X2,VVJB,VVJB1,AAJB1,AAJB,QQJB,QQJB1,UUJB,VVJBP1,QQJBP1,AAJBP1
5,Q,QQ,UUJB1,PI,PI2,A22,A11,X4,S4
 COMMON I,ITE,ITE1,ILE,ILE1,I1,I11,ICON,IMAX,IMAX1,INV,JB,JA1,JB1,
1JMAX,JCON,JMAX1,NSSP,IW
 COMMON/NASH/RN,IBDLY,ITACT,YUORIG(99),YLORIG(99),SUPPER(99),SLOWER
1(99),DEL(99),DUPOLD(99),DLWOLD(99),CDF
 COMMON/DELTA/ITER
 COMMON/IPT1/XIBDLY,RDEL,RDELFN,RCPB,SP,XSEP,CONV,CPB,XMON,XLSEP,
1 MITER,LP,ITEUPC,ITELWC,XPC
2,LBDLY,XLBDLY
 COMMON/IPT2/IMASS
 COMMON/FIX/MHALF
 COMMON/SETCPS/CPSPO,RLAX
 COMMON/IPT3/ISIDE,ILAM,RADUS
 DIMENSION UE(99),DSS(99),DUDS(99)
 DIMENSION TWM(29),TWL(29),TWH(29),UBAR(500)
 DIMENSION HP(29),HPP(29),HPPP(29),PL(29),PPL(29),PPPL(29)
 F1(YY,Y1,Y2,Y3,DB)=YY+DB*(Y1+.5*DB*(Y2+DB*Y3/3.))
 F2(A1,A2,DS)=.5*DS*(A1+A2)
 DATA TWL/0.500,0.463,0.404,0.382,0.359,0.333,0.313,
1         0.291,0.268,0.244,0.220,0.208,0.195,0.182,0.168,
2         0.153,0.138,0.130,0.122,0.113,0.104,0.095,0.085,
3         0.072,0.056,0.038,0.027,0.015,0.000/
 DATA TWH/2.00,2.07,2.18,2.23,2.28,2.34,2.39,2.44,2.49,
1    2.55,2.61,2.64,2.67,2.71,2.75,2.81,2.87,2.90,2.94,2.99,
2    3.04,3.09,3.15,3.22,3.30,3.39,3.44,3.49,3.55/
 DATA TWM/-0.25,-0.20,-0.14,-0.12,-0.10,-0.080,-0.064,
1    -0.048,-0.032,-0.016,0.0,0.008,0.016,0.024,0.032,0.040,
2    0.048,0.052,0.056,0.060,0.064,0.068,0.072,
3    0.076,0.080,0.084,0.086,0.088,0.090/
 DATA MM /0/
 IBUB=0
 IF(MM.NE.0) GO TO 2
 CALL FIT2 (29,TWM,TWH,HP,HPP,HPPP,3,3,0.,0.)
 CALL FIT2 (29,TWM,TWL,PL,PPL,PPPL,3,3,0.,0.)
 MM        = 1
 RE=RN
 AMACH=M
 R=1.0
 OMEG=1.0
 RCVF=0.89
C        RADUS=0.035
       2 CONTINUE
 KTRAN= 0
 SINT= 0.
 VAL       = .2
 UBARSB= 0.
 IF(ITER/LP*LP.EQ.ITER)PRINT 100
 TRAT      = SQRT(.5*RADUS/RE)*(1.+.2*AMACH**2)**(-.75)
 DELTA1= 0.64474*TRAT
 DELTA2= 0.29478*TRAT
 H= 2.187
 TM= -0.08695
 RD1= 0.
 RD2= 0.
 CFV=1.E+10
 N=ILE-1
 T1        = 0.
 R1        = 1.
 XSURF=-0.50
 DUDS(ILE)=UE(ILE)/DSS(ILE)
```

```
      SLG=DSS(ILE)
      IF(ISIDE.EQ.1)GO TO 1001
      DO 1002 J=ILE,ITE
      IF(CPL(J+1).LT.CPL(J))GO TO 1003
 1002 CONTINUE
 1003 IF(J.EQ.ILE)GO TO 1001
      N=J
      XSURF=X(N)
      SLG=DSS(N+1)
 1001 CONTINUE
      IF(ITER/LP*LP.EQ.ITER)PRINT 101,XSURF,CFV,DELTA1,DELTA2,H,RD2,
     1 RD1,TM
    5 DELTP1= DELTA1
      DELTP2= DELTA2
      U=UE(N+1)
      UP=DUDS(N+1)
      T2     = U**2*((1.+.2*AMACH**2*(U**2-1)))**2.5
      UBAR(N+1)= U
      TMO      = TM
      UBAR5A= UBAR5B
      QQQ= SQRT(1.+VAL*AMACH**2*(1.-UBAR(N+1)**2))
      FMACH= AMACH*UBAR(N+1)/QQQ
      TRAT= 1.+VAL*FMACH**2
      UBAR5B= UBAR(N+1)**5/TRAT**(1.5)*R**2
      SINT=SINT+F2(UBAR5A,UBAR5B,DSS(N+1))
      TTT= 0.45*SINT/UBAR(N+1)**6*TRAT**3/R**2
      TM       = -UP*TTT/SQRT(TRAT)
      IF(TM.GT.0.090) GO TO 19
      DO 6 J=1,28
      IF(TWM(J+1).GT.TM) GO TO 60
    6 CONTINUE
   60 DB=TM-TWM(J)
      TL=F1      (TWL(J),PL(J),PPL(J),PPPL(J),DB)
      HINC=F1    (TWH(J),HP(J),HPP(J),HPPP(J),DB)
      IF(HINC.LT.1.0) HINC= 1.0
      IF(TL.LT.0.) TL= 0.
      H= TRAT*(HINC+1.)-1.
      DELTA2   = SQRT(TTT/RE)*(1.+.2*AMACH**2)**(-.75)
      DELTA1= H *DELTA2
      RD2      = RE*UBAR(N+1)*DELTA2*QQQ**3.
      RD1= H *RD2
      CFV=2.*TL/RD2
      DEL(N+1)=DELTA1
      N= N+1
      SM=SLG
      SLG=SLG+DSS(N+1)
      IF(ITER/LP*LP.EQ.ITER)PRINT 101,X(N),CFV,DELTA1,DELTA2,H,RD2,RD1,
     1 TM
   14 IF(KTRAN.GT.0) GO TO 15
      RD2TR= 217.-11787.*TM+366762*TM**2-4380632.*TM**3
     1    +10453860.*TM**4
      IF(RD2.LT.RD2TR) GO TO 21
      KTRAN= 1
      KT=1
      IF(ITER/LP*LP.EQ.ITER)PRINT 33,X(N)
   33 FORMAT(3X,'INSTABILITY DETECTED AT X=',F10.5)
      UNSTM= -TM
      RD2UNS= RD2
      SSHF= 0.
      SUNST= SM
      GO TO 21
```

```
   15 SSHF=SSHF-F2(TMO,TM,DSS(N))/(SM-SUNST)
      RD2TR= RD2UNS+914.+27250.*SSHF+328333*SSHF**2
      IF(RD2.GT.RD2TR) GO TO 25
      GO TO 21
   19 IBUB=1
      IF(ITER/LP*LP.NE.ITER)GO TO 27
      WRITE(6,102)X(N)
      IF(RD2.GT.135.)WRITE(6,107)X(N)
      IF(RD2.LT.135.)WRITE(6,108)X(N)
      GO TO 27
   21 IF(N-ITE)5,28,28
   25 IF(ITER/LP*LP.EQ.ITER)PRINT 106,X(N)
   27 THETA=DELTA2
      HH=H
      ISTART=N
      IF(IBUB.EQ.1)ISTART=N+1
      RETURN
   28 IF(ITER/LP*LP.EQ.ITER)PRINT 109
      THETA=DELTA2
      HH=H
      ISTART=N
      RETURN
  100 FORMAT(12X,'X',13X,'CF',11X,'D-STAR',9X,'D-THETA',10X,'H',12X,
     1        'RE-THETA',7X,'RE-STAR',10X,'TM'/)
  101 FORMAT(4X,8E15.4)
  102 FORMAT(/10X,'SEPARATION OCCURRED AT X= ',F10.5)
C 103 FORMAT(/10X,*FINAL LAMINAR BOUNDARY LAYER PROFILES*/)
C 104 FORMAT(/10X,*Y*,19X,*VEL. RATIO*,10X,*STRESS*/)
C 105 FORMAT(3(10X,F10.5))
  106 FORMAT(/10X,'TRANSITION OCCURS AT X= ',F10.5)
  107 FORMAT( 10X,'SHORT BUBBLE FORMED?',
     1 'TRANSITION TO TURBULENT FLOW IS ASSUMED, X=',F10.5/)
  108 FORMAT( 10X,'LONG BUBBLE? LAMINAR STALL MAY OCCUR, X=',F10.5,
     1 /10X,'BOUNDARY LAYER CALCULATION WILL BE CONTINUED ',
     2 'AS TURBULENT BUT ACCURACY OF RESULTS IS QUESTIONABLE'/)
  109 FORMAT(//10X,'BOUNDARY LAYER CALCULATION COMPLETED?',
     1   /10X,'NEITHER SEPARATION NOR TRANSITION WAS DETECTED'/)
C 110 FORMAT(//10X,*SPECIFIED SEPARATION POINT REACHED, X=*,F10.5,
C    1   /10X,*NO TURBULENT CALCULATION WILL BE PERFORMED*)
      END
      SUBROUTINE FIT2(N,X,F,FP,FPP,FPPP,K1,KN,END1,ENDN)
C     IMPLICIT REAL*4 (A-H,O-Z)
      DIMENSION X(1),F(1),FP(1),FPP(1),FPPP(1)
      NM1=N-1
      IF (N.LT.3) X(N+1)=X(N)+1.0
      IF (N.LT.3) F(N+1)=F(N)
      DX2=X(2)-X(1)
      GO TO (1,2,3),K1
    1 FP(1)=0.5
      FPPP(1)=3.*((F(2)-F(1))/DX2-END1)/DX2
      GO TO 4
    2 FP(1)=0.0
      FPPP(1)=END1
      GO TO 4
    3 FP(1)=-1.0
      FPPP(1)=-DX2*END1
    4 DO 5 I=2,NM1
      IP       = I+1
      IM       = I-1
      DX1=X(I)-X(IM )
      DX2=X(IP )-X(I)
```

```
      FP(I)=.5*DX2/(DX1+DX2-.5*DX1*FP(IM ))
    5 FPPP(I)=(6.*(F(IP )-F(I))/DX2-6.*(F(I)-F(IM ))/DX1-DX1*FPPP(IM ))
     1*FP(I)/DX2
      DX1=X(N)-X(NM1)
      FP(N)=0.0
      GO TO (6,7,8),KN
    6 FPPP(N)=(6.*(ENDN-(F(N)-F(NM1))/DX1)/DX1-FPPP(NM1))/(2.-FP(NM1))
      GO TO 9
    7 FPPP(N)=ENDN
      GO TO 9
    8 FPPP(N)=(ENDN*DX1+FPPP(NM1))/(1.+FP(NM1))
    9 FPP(N)=FPPP(N)
      DO 10 II=1,NM1
      I=N-II
      IP      = I+1
      DX2=X(IP )-X(I)
      FPP(I)=FPPP(I)-FP(I)*FPP(IP )
      FPPP(I)=(FPP(IP )-FPP(I))/DX2
   10 FP(I)=(F(IP )-F(I))/DX2-DX2*(FPP(IP )+2.*FPP(I))/6.
      FPPP(N)=FPPP(NM1)
      DX1=X(N)-X(NM1)
      FP(N)=(F(N)-F(NM1))/DX1+DX1*(FPP(NM1)+2.*FPP(N))/6.
      RETURN
      END
```

APPENDIX B

Sample Case Input and Output

SAMPLE CASE INPUT DATA

```
 NACA 4412 51ST RUN. MASSIVE SEPERATION
&FINP  M=0.15,ALP=15.3,RN=6.3+06,XIBDLY=-0.47,SP=0.00425,XPC=0.4,
  RLAX=0.90,RADUS=0.0158, CONV=1.E-06,XLSEP=0.0,CLALP=0.095,&END
&IINP  NHALF=2,ITACT=1,ILAM=1,IMASS=1,&END
 87
 0.0       0.0       0.000481  0.008083  0.001509  0.010787  0.002913  0.013454
 0.004641  0.016057  0.006628  0.018567  0.008806  0.020960  0.019911  0.030350
 0.031450  0.037756  0.043229  0.044071  0.055172  0.049642  0.067237  0.054647
 0.079399  0.059195  0.091640  0.063353  0.103947  0.067173  0.116310  0.070688
 0.128721  0.073928  0.141174  0.076913  0.153664  0.079661  0.166185  0.082187
 0.178735  0.084503  0.191308  0.086618  0.203903  0.088542  0.216516  0.090282
 0.229146  0.091845  0.241788  0.093238  0.254442  0.094466  0.267106  0.095533
 0.279776  0.096445  0.292453  0.097206  0.305134  0.097818  0.317818  0.098287
 0.330504  0.098614  0.343189  0.098803  0.355874  0.098858  0.368556  0.098780
 0.381235  0.098572  0.393910  0.098236  0.406477  0.097781  0.418945  0.097241
 0.431410  0.096625  0.443872  0.095932  0.456331  0.095166  0.468785  0.094327
 0.481235  0.093417  0.493680  0.092439  0.506121  0.091392  0.518556  0.090278
 0.530986  0.089100  0.543410  0.087856  0.555829  0.086550  0.568242  0.085181
 0.580648  0.083751  0.593048  0.082261  0.605442  0.080711  0.617829  0.079102
 0.630209  0.077435  0.642581  0.075711  0.654947  0.073930  0.667305  0.072092
 0.679656  0.070199  0.691999  0.068250  0.704334  0.066246  0.716661  0.064188
 0.728980  0.062075  0.741291  0.059909  0.753593  0.057688  0.765887  0.055414
 0.778171  0.053087  0.790448  0.050706  0.802714  0.048272  0.814972  0.045784
 0.827220  0.043243  0.839459  0.040649  0.851688  0.038001  0.863908  0.035300
 0.876117  0.032544  0.888315  0.029735  0.900504  0.026871  0.912681  0.023952
 0.924848  0.020979  0.937004  0.017950  0.949148  0.014865  0.961281  0.011724
 0.973402  0.008526  0.985511  0.005271  0.997607  0.001958
      0.0       1.0       0.0       0.0
 90
 0.0       0.0       0.000752 -0.002575  0.001940 -0.005006  0.003538 -0.007281
 0.005509 -0.009390  0.007803 -0.011325  0.010359 -0.013085  0.013111 -0.014668
 0.015984 -0.016079  0.029504 -0.020772  0.042591 -0.023633  0.055437 -0.025555
 0.068118 -0.026884  0.080678 -0.027799  0.093141 -0.028408  0.105525 -0.028780
 0.117843 -0.028963  0.130105 -0.028995  0.142319 -0.028903  0.154491 -0.028707
 0.166626 -0.028427  0.178730 -0.028075  0.190805 -0.027665  0.202857 -0.027206
 0.214887 -0.026707  0.226898 -0.026176  0.238894 -0.025620  0.250876 -0.025045
 0.262847 -0.024457  0.274809 -0.023859  0.286763 -0.023258  0.298711 -0.022657
 0.310655 -0.022060  0.322596 -0.021470  0.334536 -0.020891  0.346475 -0.020325
 0.358416 -0.019776  0.370358 -0.019246  0.382304 -0.018738  0.394254 -0.018254
 0.406312 -0.017790  0.418469 -0.017319  0.430628 -0.016838  0.442791 -0.016349
 0.454958 -0.015854  0.467129 -0.015353  0.479304 -0.014849  0.491483 -0.014343
 0.503668 -0.013837  0.515857 -0.013331  0.528052 -0.012828  0.540253 -0.012327
 0.552459 -0.011830  0.564671 -0.011339  0.576890 -0.010853  0.589115 -0.010375
 0.601346 -0.009904  0.613584 -0.009442  0.625829 -0.008989  0.638081 -0.008546
 0.650341 -0.008114  0.662608 -0.007692  0.674882 -0.007283  0.687164 -0.006885
 0.699454 -0.006499  0.711751 -0.006127  0.724057 -0.005767  0.736372 -0.005421
 0.748694 -0.005089  0.761026 -0.004770  0.773366 -0.004465  0.785715 -0.004174
 0.798073 -0.003897  0.810440 -0.003635  0.822816 -0.003386  0.835203 -0.003151
 0.847598 -0.002930  0.860004 -0.002723  0.872420 -0.002529  0.884846 -0.002348
 0.897283 -0.002181  0.909730 -0.002026  0.922188 -0.001884  0.934658 -0.001753
 0.947138 -0.001634  0.959631 -0.001526  0.972135 -0.001429  0.984651 -0.001342
 0.997179 -0.001264  0.999834 -0.001249
      0.0      -1.0       0.0       0.0
```

```
NACA 4412 51ST RUN, MASSIVE SEPERATION

                         X-Y GRID SYSTEM

   2 -0.1410E 01    3 -0.4900E 00    4 -0.3706E 00    5 -0.2485E 00    6 -0.1247E 00    7  0.0
   8  0.1247E 00    9  0.2485E 00   10  0.3706E 00   11  0.4900E 00   12  0.1410E 01
   2 -0.4261E 00    3 -0.1420E 00    4 -0.2303E-07    5  0.1420E 00    6  0.4261E 00
   MACH NO. IS 0.150 ANGLE OF ATTACK IS     15.300 DEGREES
        DIRECT SOLUTION TO      0.50
                         CASE NUMBER   100
   INVISCID ANALYSIS CASE
   WITH VISCOUS INTERACTION
   AND MASSIVE SEPARATION
   SP PARAMETER VALUE IS CALCULATED TO BE     0.00498
 &FINP
 M= 0.14999998    ,W=  1.6999998    ,X1= 0.50000000    ,X2=  10000.000    ,ALP= 0.26703525    ,EPS= 0.0         ,EPSS=
 0.39999998    ,X4= 0.48999995    ,S4=  2.0000000    ,CONV= 0.99999943E-06,A1= 0.24599999    ,A2= 0.14999998    ,A3=  3.8
699999
 RN=  6300000.0    ,XIBDLY=-0.46999997    ,CIR= 0.0          ,CDCORR= 0.0           ,RDEL= 0.25000000    ,RDELFN= 0.12500
000
 SP= 0.49785152E-02,XSEP= 0.44000000    ,RCPB= 0.19999999    ,CPB= 0.39999998    ,XMON= 0.46999997    ,XLSEP= 0.0
  ,XPC=
 0.39999998    ,XLBDLY=-0.44000000    ,RLAX= 0.89999998    ,RADUS= 0.15799999E-01,CLALP= 0.94999969E-01
 &END
 &IINP
 IMAX=          13,JMAX=           7,IKASE=        100,INV=           0,MITER=        800,NHALF=           2,ITACT=          1
,ISKP2=
           0,ISKP3=            0,ISKP4=            0,ITERP=            0,IREAD=           0,LP=        1000,ITEUPC=          0,ITE
LWC=
           0,IMASS=            1,ILAM=             1,IPRT1=            0,IPRT2=           0
 &END
                      AIRFOIL COORDINATES
    X        YU        YL       UPPER SLOPE LOWER SLOPE
 -0.49000   0.02216  -0.01286   0.98021  -0.64270
 -0.37058   0.07410  -0.02900   0.24890   0.00219
 -0.24852   0.09419  -0.02502   0.09358   0.04866
 -0.12470   0.09869  -0.01903  -0.01674   0.04269
  0.0       0.09192  -0.01399  -0.08421   0.04152
  0.12470   0.07818  -0.00903  -0.13492   0.03668
  0.24852   0.05861  -0.00509  -0.18095   0.02642
  0.37058   0.03380  -0.00256  -0.22597   0.01526
  0.49000   0.00405  -0.00131  -0.27323   0.00631
ITERATION  10 CIR =  0.23673 DPM =  0.01788384 AT 12  3 NSSP =    0 DELTAY OR DELSTAR =  0.0064
ITERATION  20 CIR =  0.40489 DPM =  0.01465756 AT 12  3 NSSP =    0 DELTAY OR DELSTAR =  0.0064
ITERATION  30 CIR =  0.54029 DPM =  0.01221043 AT 12  3 NSSP =    0 DELTAY OR DELSTAR =  0.0064
ITERATION  40 CIR =  0.65274 DPM =  0.01024419 AT 12  3 NSSP =    0 DELTAY OR DELSTAR =  0.0064
ITERATION  50 CIR =  0.74703 DPM =  0.00862175 AT 12  3 NSSP =    0 DELTAY OR DELSTAR =  0.0064
 CP BY CENTRAL DIFFERENCES
X           CPU          CPL
    -0.490     -4.034      1.005
    -0.371     -2.849      0.377
    -0.249     -1.763      0.330
    -0.125     -1.232      0.327
     0.0       -0.841      0.305
     0.125     -0.555      0.291
     0.249     -0.266      0.273
     0.371      0.545      0.244
     0.490     -0.471      0.118

     1.410      0.029      0.031
```

X	YU	YL	SLU	SLL
-0.49000	0.02216	-0.01286	0.98021	-0.64270
-0.37058	0.07410	-0.02900	0.24890	0.00219
-0.24852	0.09419	-0.02502	0.09358	0.04866
-0.12470	0.09869	-0.01903	-0.01674	0.04269
0.0	0.09192	-0.01399	-0.08421	0.04152
0.12470	0.07818	-0.00903	-0.13492	0.03668
0.24852	0.05861	-0.00509	-0.18095	0.02642
0.37058	0.03380	-0.00256	-0.22597	0.01526
0.49000	0.00405	-0.00131	-0.27323	0.00631

MACH CHART IN COMPUTATIONALTIONAL PLANE-FREE STREAM FROM TOP

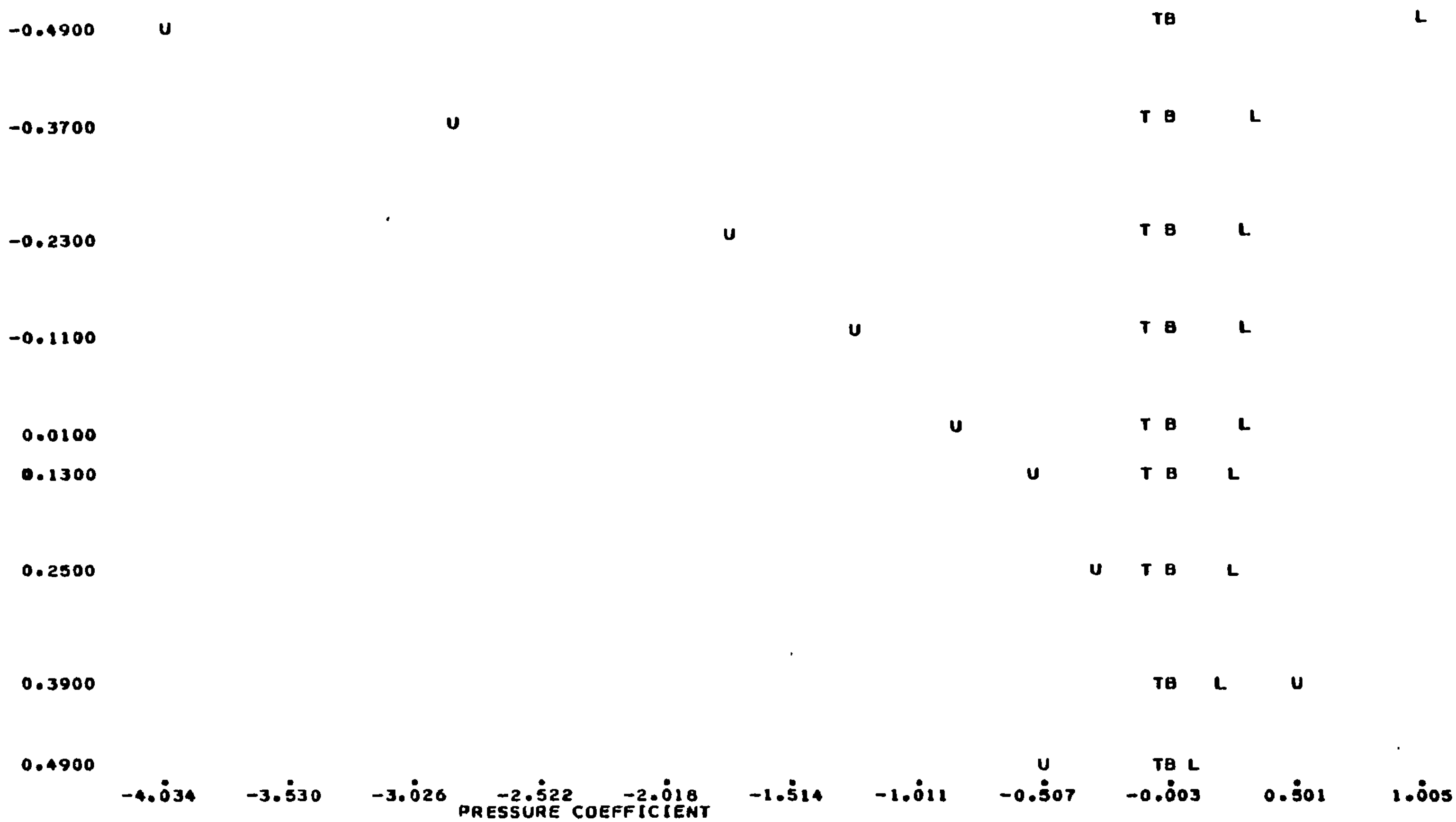
I=2.12 TOP TO BOTTOM

J= 2. 6 LEFT TO RIGHT

15	15	15	15	16
7	2	0	28	25
12	11	0	25	19
12	12	0	23	19
12	12	0	21	18
12	12	0	20	17
13	12	0	18	17
13	12	0	16	16
13	13	0	15	15
11	12	0	10	14
14	14	14	14	14

WAVE CD = 0.169714

CHART 100



CPSTAR = -29.4074 CLCIR = 1.4041

CL = 1.4907 CD = 0.169714 CMLE = -0.3839 CDF = 0.0 CMC4 = -0.0112

```
NACA 4412 51ST RUN. MASSIVE SEPERATION

                         X-Y GRID SYSTEM

  2 -0.3872E 01     3 -0.1410E 01     4 -0.6471E 00     5 -0.4900E 00     6 -0.4307E 00     7 -0.3706E 00
  8 -0.3098E 00     9 -0.2485E 00    10 -0.1868E 00    11 -0.1247E 00    12 -0.6240E-01    13  0.0
 14  0.6240E-01    15  0.1247E 00    16  0.1868E 00    17  0.2485E 00    18  0.3098E 00    19  0.3706E 00
 20  0.4307E 00    21  0.4900E 00    22  0.6471E 00    23  0.1410E 01    24  0.3872E 01
  2 -0.9181E 00     3 -0.4261E 00     4 -0.2460E 00     5 -0.1420E 00     6 -0.6592E-01     7 -0.9213E-07
  8  0.6592E-01     9  0.1420E 00    10  0.2460E 00    11  0.4261E 00    12  0.9181E 00
  MACH NO. IS 0.150 ANGLE OF ATTACK IS    15.300 DEGREES
       DIRECT SOLUTION TO      0.50
                    CASE NUMBER    100
  INVISCID ANALYSIS CASE
  WITH VISCOUS INTERACTION
  AND MASSIVE SEPARATION
  SP PARAMETER VALUE IS CALCULATED TO BE    0.00498
 &FINP
 M= 0.14999998    .W=  1.6999998    .X1= 0.50000000    .X2=  10000.000    .ALP= 0.26703525    .EPS= 0.0           .EPSS=
  0.39999998    .X4= 0.48999995    .S4=  2.0000000    .CONV= 0.99999943E-06.A1= 0.24599999    .A2= 0.14999998    .A3=  3.8
699999
 RN=  6300000.0    .XIBDLY=-0.46999997    .CIR= 0.74703497    .CDCORR= 0.0             .RDEL= 0.25000000    .RDELFN= 0.12500
000
 SP= 0.49785152E-02,XSEP= 0.44000000    .RCPB= 0.19999999    .CPB= 0.39999998    .XMON= 0.46999997    .XLSEP= 0.0
  .XPC=
  0.39999998    .XLBDLY=-0.44000000    .RLAX= 0.89999998    .RADUS= 0.15799999E-01.CLALP= 0.94999969E-01
 &END
 &IINP
 IMAX=          25.JMAX=          13.IKASE=          100.INV=          0.MITER=          400.NHALF=          2.ITACT=
.ISKP2=
          0.ISKP3=          0.ISKP4=          0.ITERP=          0.IREAD=          0.LP=          1000.ITEUPC=          0.ITE
 LWC=
          0.IMASS=          1.ILAM=          1.IPRT1=          0.IPRT2=          0
 &END
                         AIRFOIL COORDINATES
     X        YU         YL      UPPER SLOPE LOWER SLOPE
  -0.49000   0.02216  -0.01286   0.98021  -0.64270
  -0.43067   0.05546  -0.02699   0.38622  -0.08421
  -0.37058   0.07410  -0.02900   0.24890   0.00219
  -0.30982   0.08644  -0.02769   0.16175   0.03592
  -0.24852   0.09419  -0.02502   0.09358   0.04866
  -0.18677   0.09813  -0.02193   0.03544   0.04963
  -0.12470   0.09869  -0.01903  -0.01674   0.04269
  -0.06240   0.09629  -0.01656  -0.05562   0.04025
   0.0       0.09192  -0.01399  -0.08421   0.04152
   0.06240   0.08583  -0.01143  -0.11045   0.04007
   0.12470   0.07818  -0.00903  -0.13492   0.03668
   0.18677   0.06908  -0.00690  -0.15826   0.03197
   0.24852   0.05861  -0.00509  -0.18095   0.02642
   0.30982   0.04684  -0.00365  -0.20333   0.02069
   0.37058   0.03380  -0.00256  -0.22597   0.01526
   0.43067   0.01953  -0.00179  -0.24908   0.01035
   0.49000   0.00405  -0.00131  -0.27323   0.00631
ITERATION  10 CIR =  0.80321 DPM =  0.00382394 AT 24  6 NSSP =   0 DELTAY OR DELSTAR =  0.0064
ITERATION  20 CIR =  0.83499 DPM =  0.00253958 AT 24  6 NSSP =   0 DELTAY OR DELSTAR =  0.0064
ITERATION  30 CIR =  0.85831 DPM =  0.00207573 AT 24  6 NSSP =   0 DELTAY OR DELSTAR =  0.0064
ITERATION  40 CIR =  0.87775 DPM =  0.00182289 AT 23  6 NSSP =   0 DELTAY OR DELSTAR =  0.0064
ITERATION  50 CIR =  0.89464 DPM =  0.00168610 AT 22  6 NSSP =   0 DELTAY OR DELSTAR =  0.0064
  SEPARATION AT    0.37058     SEPARATED CP IS    0.26520
ITERATION  60 CIR =  0.91781 DPM =  0.00202775 AT 21  6 NSSP =   0 DELTAY OR DELSTAR =  0.0548
  SEPARATION AT    0.24852     SEPARATED CP IS   -0.06477
ITERATION  70 CIR =  0.91161 DPM =  0.00149947 AT 13  6 NSSP =   0 DELTAY OR DELSTAR =  0.1001
  SEPARATION AT    0.24852     SEPARATED CP IS   -0.07667
ITERATION  80 CIR =  0.91409 DPM =  0.00119740 AT 12  6 NSSP =   0 DELTAY OR DELSTAR =  0.1177
  SEPARATION AT    0.24852     SEPARATED CP IS   -0.07555
```

```
ITERATION  90 CIR =  0.91772 DPM =  0.00100952 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1173
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.07964
ITERATION 100 CIR =  0.92098 DPM =  0.00088352 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1197
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.08479
ITERATION 110 CIR =  0.92273 DPM =  0.00078338 AT 14  6 NSSP =    0 DELTAY OR DELSTAR =  0.1218
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.09480
ITERATION 120 CIR =  0.92406 DPM =  0.00068170 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.09909
ITERATION 130 CIR =  0.92549 DPM =  0.00059229 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1295
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.10197
ITERATION 140 CIR =  0.92687 DPM =  0.00051624 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.10453
ITERATION 150 CIR =  0.92811 DPM =  0.00045222 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.10675
ITERATION 160 CIR =  0.92923 DPM =  0.00039721 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.10869
ITERATION 170 CIR =  0.93024 DPM =  0.00034946 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1294
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11038
ITERATION 180 CIR =  0.93113 DPM =  0.00030833 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11185
ITERATION 190 CIR =  0.93194 DPM =  0.00027061 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11312
ITERATION 200 CIR =  0.93265 DPM =  0.00023812 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11423
ITERATION 210 CIR =  0.93329 DPM =  0.00020945 AT 14  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293

  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11519
ITERATION 220 CIR =  0.93386 DPM =  0.00018471 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1293
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11603
ITERATION 230 CIR =  0.93438 DPM =  0.00016278 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11679
ITERATION 240 CIR =  0.93484 DPM =  0.00014341 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11745
ITERATION 250 CIR =  0.93525 DPM =  0.00012672 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11802
ITERATION 260 CIR =  0.93561 DPM =  0.00011182 AT 14  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11853
ITERATION 270 CIR =  0.93594 DPM =  0.00009835 AT 12  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11897
ITERATION 280 CIR =  0.93623 DPM =  0.00008726 AT 14  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11935
ITERATION 290 CIR =  0.93649 DPM =  0.00007701 AT 15  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.11971
ITERATION 300 CIR =  0.93672 DPM =  0.00006837 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1292
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12000
ITERATION 310 CIR =  0.93693 DPM =  0.00006020 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12027
ITERATION 320 CIR =  0.93713 DPM =  0.00005347 AT 14  6 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12053
ITERATION 330 CIR =  0.93729 DPM =  0.00007772 AT 24  5 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12075
ITERATION 340 CIR =  0.93743 DPM =  0.00004196 AT 14  5 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12093
ITERATION 350 CIR =  0.93756 DPM =  0.00003690 AT  2  6 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12110
ITERATION 360 CIR =  0.93768 DPM =  0.00003266 AT 14  6 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12124
ITERATION 370 CIR =  0.93778 DPM =  0.00002897 AT 16  5 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12134
ITERATION 380 CIR =  0.93787 DPM =  0.00002575 AT 16  6 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12147
ITERATION 390 CIR =  0.93796 DPM =  0.00002259 AT 13  6 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12158
ITERATION 400 CIR =  0.93803 DPM =  0.00002056 AT 22  3 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT     0.24852      SEPARATED CP IS    -0.12168
```

BOUNDARY LAYER ANALYSIS FOR REYNOLDS NUMBER OF 0.630E 07

X	YUORIG	DU	SLU	YLORIG	DL	SLL
-0.49000	0.02216	0.0	0.98021	-0.01286	0.0	-0.64270
-0.43067	0.05546	0.00012	0.34321	-0.02699	0.00005	-0.08421
-0.37058	0.07410	0.00026	0.26224	-0.02900	0.00012	0.00219
-0.30982	0.08644	0.00046	0.16257	-0.02769	0.00020	0.03592
-0.24852	0.09419	0.00069	0.09818	-0.02502	0.00025	0.04866
-0.18677	0.09813	0.00096	0.03992	-0.02193	0.00028	0.04963
-0.12470	0.09869	0.00128	-0.01115	-0.01903	0.00031	0.04269
-0.06240	0.09629	0.00168	-0.04920	-0.01656	0.00033	0.04025
0.0	0.09192	0.00216	-0.07494	-0.01399	0.00035	0.04152
0.06240	0.08583	0.00287	-0.09601	-0.01143	0.00037	0.04007
0.12470	0.07818	0.00400	-0.11273	-0.00903	0.00039	0.03668
0.18677	0.06908	0.00548	-0.13360	-0.00690	0.00040	0.03197
0.24852	0.05861	0.00709	-0.10159	-0.00509	0.00041	0.02642
0.30982	0.04684	0.00970	-0.10519	-0.00365	0.00041	0.02069
0.37058	0.03380	0.01499	-0.10034	-0.00256	0.00041	0.01526
0.43067	0.01953	0.02307	-0.07188	-0.00179	0.00038	0.01035
0.49000	0.00405	0.03109	0.17174	-0.00131	0.00035	0.00642

CP BY CENTRAL DIFFERENCES

X	CPU	CPL
-0.490	-5.579	0.738
-0.431	-3.487	0.919
-0.371	-2.760	0.741
-0.310	-2.351	0.660
-0.249	-2.000	0.606
-0.187	-1.724	0.565
-0.125	-1.451	0.525
-0.062	-1.188	0.484
0.0	-0.965	0.449
0.062	-0.776	0.419
0.125	-0.608	0.390
0.187	-0.401	0.361
0.249	-0.122	0.329
0.310	-0.122	0.293
0.371	-0.122	0.251
0.431	-0.122	0.201
0.490	-0.122	0.083
0.647	0.050	0.053
1.410	0.033	0.033
3.872	0.022	0.022

X	YU	YL	SLU	SLL
-0.49000	0.02216	-0.01286	0.98021	-0.64270
-0.43067	0.05559	-0.02704	0.34321	-0.08421
-0.37058	0.07437	-0.02912	0.26224	0.00219
-0.30982	0.08690	-0.02788	0.16257	0.03592
-0.24852	0.09489	-0.02526	0.09818	0.04866
-0.18677	0.09909	-0.02222	0.03992	0.04963
-0.12470	0.09997	-0.01934	-0.01115	0.04269
-0.06240	0.09797	-0.01689	-0.04920	0.04025
0.0	0.09409	-0.01434	-0.07494	0.04152
0.06240	0.08871	-0.01180	-0.09601	0.04007
0.12470	0.08220	-0.00942	-0.11273	0.03668
0.18677	0.07461	-0.00730	-0.13360	0.03197
0.24852	0.06720	-0.00550	-0.10159	0.02642
0.30982	0.06039	-0.00406	-0.10519	0.02069
0.37058	0.05417	-0.00296	-0.10034	0.01526
0.43067	0.04900	-0.00217	-0.07188	0.01035
0.49000	0.05221	-0.00166	0.17174	0.00642

MACH CHART IN COMPUTATIONALTIONAL PLANE-FREE STREAM FROM TOP

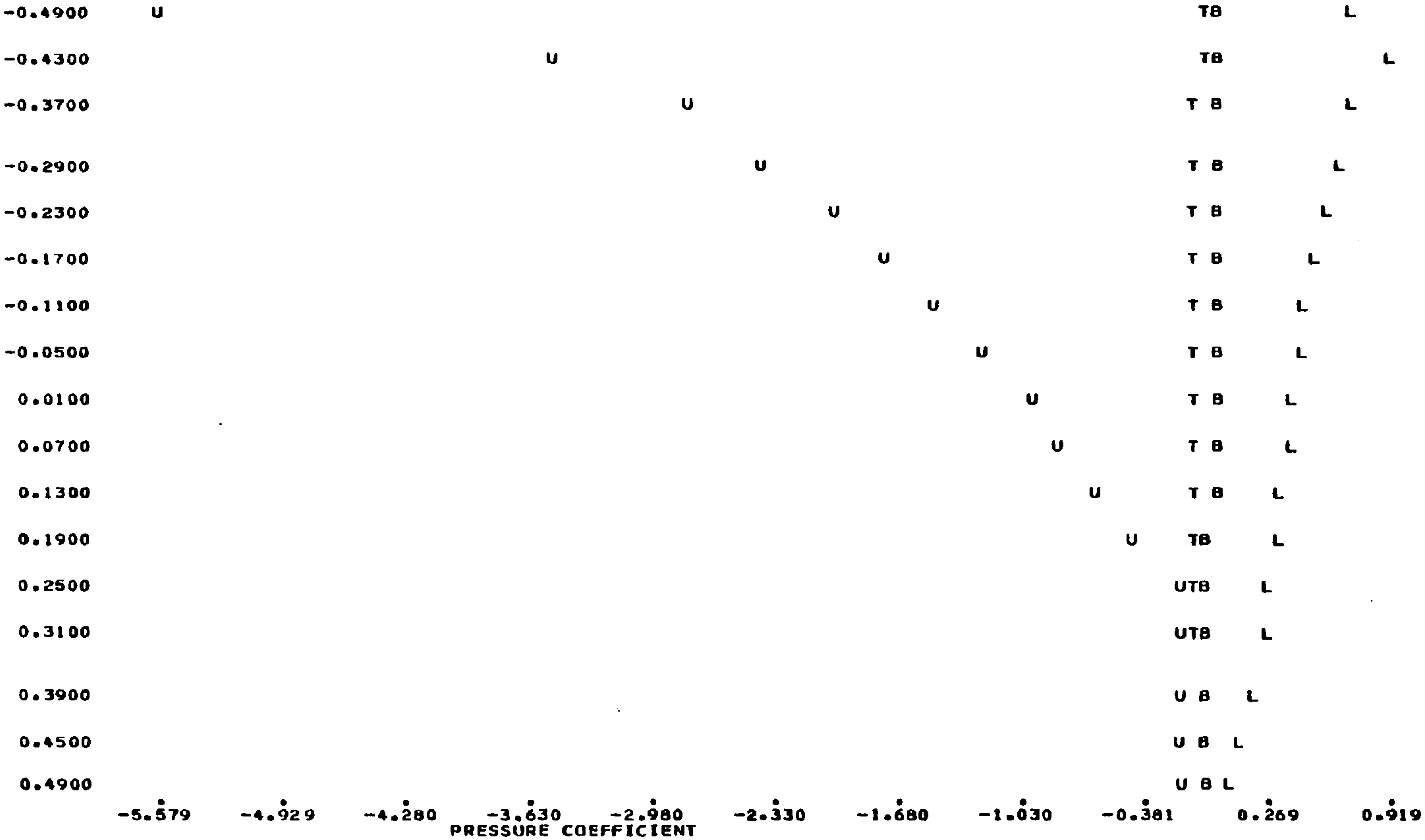
```
 I=2.24 TOP TO BOTTOM

 J= 2.12 LEFT TO RIGHT

15 15 15 15 15 15 15 15 15 15 15
14 14 14 14 15 15 15 15 15 16 16
12 12 13 13 14 17 19 19 18 18 17
11  9  7  5  4  0 33 28 26 22 19
12 11  9  8  5  0 30 26 23 20 17
12 11  9  8  7  0  0 26 23 20 17
12 11 10  9  8  0  0 25 23 20 17
12 11 10  9  9  0  0 24 22 20 17
12 11 10 10  9  0  0 24 22 20 17
12 11 10 10 10  0  0 22 21 19 17
12 11 11 10 10  0  0 21 20 19 17
12 11 11 11 11  0  0 20 20 18 17
13 12 11 11 11  0  0 19 19 18 17
13 12 11 11 11  0  0 18 18 18 17
13 12 12 12 12  0  0 17 17 17 17

13 12 12 12 12  0  0 17 17 17 16
13 12 12 12 12  0 16 16 16 16 16
13 12 12 13 13  0 15 15 16 16 16
13 13 13 13 13  0 14 15 15 16 16
12 12 12 13 13  0 13 14 16 16 17
13 13 13 14 14 14 14 14 15 15 16
14 14 14 14 14 14 14 14 14 14 15
14 14 14 14 14 14 14 14 14 14 14
                        WAVE CD =    0.207096
```

CHART 100



CPSTAR = -29.4074 CLCIR = 1.8761

CL = 1.7893 CD = 0.221758 CMLE = -0.5022 CDF = 0.014662 CMC4 = -0.0549

```
NACA 4412 51ST RUN, MASSIVE SEPERATION

                         X-Y GRID SYSTEM

    2 -0.8027E 01     3 -0.3872E 01     4 -0.2276E 01     5 -0.1410E 01     6 -0.9115E 00     7 -0.6471E 00
    8 -0.5317E 00     9 -0.4900E 00    10 -0.4604E 00    11 -0.4307E 00    12 -0.4007E 00    13 -0.3706E 00
   14 -0.3403E 00    15 -0.3098E 00    16 -0.2792E 00    17 -0.2485E 00    18 -0.2177E 00    19 -0.1868E 00
   20 -0.1558E 00    21 -0.1247E 00    22 -0.9357E-01    23 -0.6240E-01    24 -0.3121E-01    25  0.0
   26  0.3121E-01    27  0.6240E-01    28  0.9357E-01    29  0.1247E 00    30  0.1558E 00    31  0.1868E 00
   32  0.2177E 00    33  0.2485E 00    34  0.2792E 00    35  0.3098E 00    36  0.3403E 00    37  0.3706E 00
   38  0.4007E 00    39  0.4307E 00    40  0.4604E 00    41  0.4900E 00    42  0.5317E 00    43  0.6471E 00
   44  0.9115E 00    45  0.1410E 01    46  0.2276E 01    47  0.3872E 01    48  0.8027E 01
    2 -0.1869E 01     3 -0.9181E 00     4 -0.5939E 00     5 -0.4261E 00     6 -0.3206E 00     7 -0.2460E 00
    8 -0.1888E 00     9 -0.1420E 00    10 -0.1019E 00    11 -0.6592E-01    12 -0.3239E-01    13 -0.9213E-07
   14  0.3239E-01    15  0.6592E-01    16  0.1019E 00    17  0.1420E 00    18  0.1888E 00    19  0.2460E 00
   20  0.3206E 00    21  0.4261E 00    22  0.5939E 00    23  0.9181E 00    24  0.1869E 01
    MACH NO. IS 0.150 ANGLE OF ATTACK IS     15.300 DEGREES
           DIRECT SOLUTION TO      0.25
                         CASE NUMBER    100
    INVISCID ANALYSIS CASE
    WITH VISCOUS INTERACTION
    AND MASSIVE SEPARATION
    SP PARAMETER VALUE IS CALCULATED TO BE     0.00498
 &FINP
 M= 0.14999998    ,W=  1.6999998    ,X1= 0.24751765    ,X2= 0.50000000    ,ALP= 0.26703525    ,EPS= 0.0          ,EPSS=
  0.39999998    ,X4= 0.48999995    ,S4=  2.0000000    ,CONV= 0.99999943E-06,A1= 0.24599999    ,A2= 0.14999998    ,A3=  3.8
699999   ,
 RN=  6300000.0    ,XIBDLY=-0.46999997    ,CIR= 0.93803447    ,CDCORR= 0.0           ,RDEL= 0.25000000    ,RDELFN= 0.12500
000    ,
 SP= 0.49785152E-02,XSEP= 0.44000000    ,RCPB= 0.19999999    ,CPB= 0.39999998    ,XMON= 0.46999997    ,XLSEP= 0.0
  ,XPC=
  0.39999998    ,XLBDLY=-0.44000000    ,RLAX= 0.89999998    ,RADUS= 0.15799999E-01,CLALP= 0.94999969E-01
 &END
 &IINP
 IMAX=          49,JMAX=          25,IKASE=         100,INV=           0,MITER=         400,NHALF=           2,ITACT=           1
,ISKP2=
           0,ISKP3=           0,ISKP4=           0,ITERP=           0,IREAD=           0,LP=         1000,ITEUPC=           0,ITE
LWC=
           0,IMASS=           1,ILAM=            1,IPRT1=           0,IPRT2=           0
 &END
                    AIRFOIL COORDINATES
     X          YU          YL        UPPER SLOPE LOWER SLOPE
  -0.49000    0.02216    -0.01286    0.98021    -0.64270
  -0.46044    0.03887    -0.02307    0.66171    -0.19498
  -0.43067    0.05559    -0.02704    0.34321    -0.08421
  -0.40072    0.06498    -0.02808    0.30272    -0.04101
  -0.37058    0.07437    -0.02912    0.26224     0.00219
  -0.34028    0.08064    -0.02850    0.21240     0.01905
  -0.30982    0.08690    -0.02788    0.16257     0.03592
  -0.27923    0.09089    -0.02657    0.13038     0.04229
  -0.24852    0.09489    -0.02526    0.09818     0.04866

  -0.21769    0.09699    -0.02374    0.06905     0.04914
  -0.18677    0.09909    -0.02222    0.03992     0.04963
  -0.15577    0.09953    -0.02078    0.01439     0.04616
  -0.12470    0.09997    -0.01934   -0.01115     0.04269
  -0.09357    0.09997    -0.01812   -0.03017     0.04147
  -0.06240    0.09797    -0.01689   -0.04920     0.04025
  -0.03121    0.09603    -0.01562   -0.06207     0.04089
   0.0        0.09409    -0.01434   -0.07494     0.04152
   0.03121    0.09140    -0.01307   -0.08548     0.04079
   0.06240    0.08871    -0.01190   -0.09601     0.04007
   0.09357    0.08546    -0.01061   -0.10437     0.03837
   0.12470    0.08220    -0.00942   -0.11273     0.03668
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  0.15577   0.07841  -0.00836  -0.12317   0.03433
  0.18677   0.07461  -0.00730  -0.13360   0.03197
  0.21769   0.07090  -0.00640  -0.11759   0.02920
  0.24852   0.06720  -0.00550  -0.10159   0.02642
  0.27923   0.06380  -0.00478  -0.10339   0.02356
  0.30982   0.06039  -0.00406  -0.10519   0.02069
  0.34028   0.05728  -0.00351  -0.10276   0.01798
  0.37058   0.05417  -0.00296  -0.10034   0.01526
  0.40072   0.05158  -0.00257  -0.08611   0.01280
  0.43067   0.04900  -0.00217  -0.07188   0.01035
  0.46044   0.05061  -0.00192   0.04993   0.00838
  0.49000   0.05221  -0.00166   0.17174   0.00642
ITERATION  10 CIR =  0.93756 DPM =  0.00099355 AT 38  2 NSSP =    0 DELTAY OR DELSTAR =  0.1291
ITERATION  20 CIR =  0.93585 DPM =  0.00026560 AT 48 11 NSSP =    0 DELTAY OR DELSTAR =  0.1291
ITERATION  30 CIR =  0.93406 DPM =  0.00017205 AT 48 13 NSSP =    0 DELTAY OR DELSTAR =  0.1291
ITERATION  40 CIR =  0.93238 DPM =  0.00019312 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.1291
ITERATION  50 CIR =  0.93085 DPM =  0.00014520 AT 47 12 NSSP =    0 DELTAY OR DELSTAR =  0.1291
  SEPARATION AT    0.18677     SEPARATED CP IS    -0.18315
ITERATION  60 CIR =  0.92598 DPM =  0.00040728 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.1428
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.22767
ITERATION  70 CIR =  0.91776 DPM =  0.00054908 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.1638
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.19578
ITERATION  80 CIR =  0.91185 DPM =  0.00043064 AT 47 12 NSSP =    0 DELTAY OR DELSTAR =  0.2002
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18704
ITERATION  90 CIR =  0.90699 DPM =  0.00042599 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.2011
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18510
ITERATION 100 CIR =  0.90266 DPM =  0.00028467 AT 47 12 NSSP =    0 DELTAY OR DELSTAR =  0.2041
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18468
ITERATION 110 CIR =  0.89876 DPM =  0.00027609 AT 46 12 NSSP =    0 DELTAY OR DELSTAR =  0.2052
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18447
ITERATION 120 CIR =  0.89525 DPM =  0.00032365 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.2058
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18419
ITERATION 130 CIR =  0.89206 DPM =  0.00022912 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.2060
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18382
ITERATION 140 CIR =  0.88916 DPM =  0.00040609 AT 48 11 NSSP =    0 DELTAY OR DELSTAR =  0.2061
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18341
ITERATION 150 CIR =  0.88651 DPM =  0.00017834 AT 47 12 NSSP =    0 DELTAY OR DELSTAR =  0.2061
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18300
ITERATION 160 CIR =  0.88406 DPM =  0.00023943 AT 48 10 NSSP =    0 DELTAY OR DELSTAR =  0.2061
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18259
ITERATION 170 CIR =  0.88180 DPM =  0.00017607 AT 46 11 NSSP =    0 DELTAY OR DELSTAR =  0.2060
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18220
ITERATION 180 CIR =  0.87970 DPM =  0.00025922 AT 48 11 NSSP =    0 DELTAY OR DELSTAR =  0.2059
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18182
ITERATION 190 CIR =  0.87775 DPM =  0.00022250 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.2058
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18145
ITERATION 200 CIR =  0.87592 DPM =  0.00014019 AT 46 12 NSSP =    0 DELTAY OR DELSTAR =  0.2057
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18110
ITERATION 210 CIR =  0.87421 DPM =  0.00021975 AT 48 13 NSSP =    0 DELTAY OR DELSTAR =  0.2056

  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18078
ITERATION 220 CIR =  0.87260 DPM =  0.00018585 AT 48  8 NSSP =    0 DELTAY OR DELSTAR =  0.2055
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18047
ITERATION 230 CIR =  0.87105 DPM =  0.00017825 AT 48 13 NSSP =    0 DELTAY OR DELSTAR =  0.2053
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.18015
ITERATION 240 CIR =  0.86964 DPM =  0.00012803 AT 46  9 NSSP =    0 DELTAY OR DELSTAR =  0.2052
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.17987
ITERATION 250 CIR =  0.86828 DPM =  0.00025523 AT  2 11 NSSP =    0 DELTAY OR DELSTAR =  0.2051
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.17960
ITERATION 260 CIR =  0.86699 DPM =  0.00015891 AT 48 10 NSSP =    0 DELTAY OR DELSTAR =  0.2050
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.17935
ITERATION 270 CIR =  0.86576 DPM =  0.00013804 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.2049
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.17909
ITERATION 280 CIR =  0.86459 DPM =  0.00023842 AT 48 12 NSSP =    0 DELTAY OR DELSTAR =  0.2048
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.17884
ITERATION 290 CIR =  0.86348 DPM =  0.00016278 AT 48  9 NSSP =    0 DELTAY OR DELSTAR =  0.2047
  SEPARATION AT    0.15577     SEPARATED CP IS    -0.17861
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ITERATION 300 CIR =  0.86241 DPM =  0.00013393 AT 47 12 NSSP =     0 DELTAY OR DELSTAR =  0.2046
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17837
ITERATION 310 CIR =  0.86139 DPM =  0.00010097 AT 48 13 NSSP =     0 DELTAY OR DELSTAR =  0.2045
  SEPARATION AT     0.'5577      SEPARATED CP IS   -0.17814
ITERATION 320 CIR =  0.86041 DPM =  0.00009310 AT 46  6 NSSP =     0 DELTAY OR DELSTAR =  0.2044
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17792
ITERATION 330 CIR =  0.85948 DPM =  0.00010669 AT 45 12 NSSP =     0 DELTAY OR DELSTAR =  0.2044
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17771
ITERATION 340 CIR =  0.85858 DPM =  0.00010043 AT 47 12 NSSP =     0 DELTAY OR DELSTAR =  0.2043
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17752
ITERATION 350 CIR =  0.85772 DPM =  0.00010085 AT 46 10 NSSP =     0 DELTAY OR DELSTAR =  0.2042
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17732
ITERATION 360 CIR =  0.85689 DPM =  0.00008178 AT 46 12 NSSP =     0 DELTAY OR DELSTAR =  0.2042
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17714
ITERATION 370 CIR =  0.85609 DPM =  0.00008178 AT 48  8 NSSP =     0 DELTAY OR DELSTAR =  0.2041
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17694
ITERATION 380 CIR =  0.85533 DPM =  0.00021237 AT 48 11 NSSP =     0 DELTAY OR DELSTAR =  0.2040
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17676
ITERATION 390 CIR =  0.85458 DPM =  0.00013477 AT 47  8 NSSP =     0 DELTAY OR DELSTAR =  0.2040
  SEPARATION AT     0.18577      SEPARATED CP IS   -0.17656
ITERATION 400 CIR =  0.85387 DPM =  0.00009191 AT 46 12 NSSP =     0 DELTAY OR DELSTAR =  0.2039
  SEPARATION AT     0.15577      SEPARATED CP IS   -0.17638
BOUNDARY LAYER ANALYSIS FOR REYNOLDS NUMBER OF   0.630E 07
```

X	YUORIG	DU	SLU	YLORIG	DL	SLL
-0.49000	0.02216	0.0	0.98021	-0.01286	0.0	-0.64270
-0.46044	0.04221	0.00008	0.66171	-0.02307	0.00004	-0.19498
-0.43067	0.05546	0.0001[illegible]	0.39439	-0.02699	0.00009	-0.08421
-0.40072	0.06577	0.00020	0.30808	-0.02862	0.00013	-0.04101
-0.37058	0.07410	0.00030	0.25285	-0.02900	0.00016	0.00219
-0.34028	0.08091	0.00041	0.20558	-0.02860	0.00018	0.01905
-0.30982	0.08644	0.00053	0.16560	-0.02769	0.00020	0.03592
-0.27923	0.09083	0.00065	0.13002	-0.02645	0.00022	0.04229
-0.24852	0.09419	0.00078	0.09783	-0.02502	0.00024	0.04866
-0.21769	0.09661	0.00091	0.06820	-0.02348	0.00026	0.04914
-0.18677	0.09813	0.00107	0.04059	-0.02193	0.00028	0.04963
-0.15577	0.09881	0.00125	0.01495	-0.02043	0.00029	0.04616
-0.12470	0.09869	0.00145	-0.00995	-0.01903	0.00030	0.04269
-0.09357	0.09778	0.00169	-0.03116	-0.01779	0.00031	0.04147
-0.06240	0.09629	0.00197	-0.04625	-0.01656	0.00032	0.04025
-0.03121	0.09433	0.00229	-0.05872	-0.01528	0.00033	0.04089
0.0	0.09192	0.00268	-0.07046	-0.01399	0.00034	0.04152
0.03121	0.08908	0.00315	-0.08062	-0.01270	0.00035	0.04079
0.06240	0.08583	0.00381	-0.08279	-0.01143	0.00036	0.04007
0.09357	0.08220	0.00493	-0.07841	-0.01020	0.00037	0.03837
0.12470	0.07818	0.00641	-0.08891	-0.00903	0.00038	0.03668
0.15577	0.07381	0.00757	-0.06505	-0.00793	0.00039	0.03433
0.18677	0.06908	0.00805	-0.03691	-0.00690	0.00039	0.03197
0.21769	0.06401	0.00813	-0.01495	-0.00595	0.00040	0.02920
0.24852	0.05861	0.00813	0.00005	-0.00509	0.00040	0.02642
0.27923	0.05288	0.00813	0.00941	-0.00433	0.00040	0.02356
0.30982	0.04684	0.00813	0.01415	-0.00365	0.00040	0.02069
0.34028	0.04047	0.00813	0.01417	-0.00306	0.00040	0.01798
0.37058	0.03380	0.00833	0.00799	-0.00256	0.00040	0.01526
0.40072	0.02682	0.00992	-0.00822	-0.00214	0.00039	0.01280
0.43067	0.01953	0.01430	-0.03926	-0.00179	0.00037	0.01035
0.46044	0.01194	0.01988	-0.06677	-0.00152	0.00034	0.00838
0.49000	0.00405	0.02544	0.32109	-0.00131	0.00030	0.00730

CP BY CENTRAL DIFFERENCES

X	CPU	CPL
-0.490	-4.548	0.647
-0.460	-4.753	1.003
-0.431	-3.897	0.919
-0.401	-3.121	0.831
-0.371	-2.703	0.760
-0.340	-2.434	0.705
-0.310	-2.217	0.662
-0.279	-2.031	0.627
-0.249	-1.865	0.598
-0.218	-1.713	0.573
-0.187	-1.568	0.551
-0.156	-1.428	0.530
-0.125	-1.289	0.508
-0.094	-1.146	0.486
-0.062	-1.010	0.464
-0.031	-0.889	0.444
0.0	-0.775	0.427
0.031	-0.660	0.411
0.062	-0.546	0.395
0.094	-0.462	0.379
0.125	-0.361	0.364
0.156	-0.176	0.348
0.187	-0.176	0.332
0.218	-0.176	0.315
0.249	-0.176	0.298
0.279	-0.176	0.279
0.310	-0.176	0.259
0.340	-0.176	0.237
0.371	-0.176	0.213
0.401	-0.176	0.185
0.431	-0.176	0.153
0.460	-0.176	0.112
0.490	-0.176	0.000
0.532	-0.012	-0.009
0.647	0.028	0.028
0.912	0.027	0.027
1.410	0.017	0.017
2.276	0.010	0.010
3.872	0.006	0.006
8.027	0.009	0.009

X	YU	YL	SLU	SLL
-0.49000	0.02216	-0.01286	0.98021	-0.64270
-0.46044	0.04231	-0.02311	0.66171	-0.19498
-0.43067	0.05560	-0.02708	0.39439	-0.08421
-0.40072	0.06597	-0.02875	0.30808	-0.04101
-0.37058	0.07441	-0.02915	0.25285	0.00219
-0.34028	0.08133	-0.02877	0.20558	0.01905
-0.30982	0.08697	-0.02789	0.16560	0.03592
-0.27923	0.09148	-0.02667	0.13002	0.04229
-0.24852	0.09497	-0.02526	0.09783	0.04866
-0.21769	0.09753	-0.02374	0.06820	0.04914
-0.18677	0.09920	-0.02221	0.04059	0.04963
-0.15577	0.10006	-0.02072	0.01495	0.04616
-0.12470	0.10014	-0.01934	-0.00995	0.04269
-0.09357	0.09948	-0.01810	-0.03116	0.04147
-0.06240	0.09826	-0.01688	-0.04625	0.04025
-0.03121	0.09662	-0.01562	-0.05872	0.04089
0.0	0.09460	-0.01433	-0.07046	0.04152

0.03121	0.09224	-0.01305	-0.08062	0.04079
0.06240	0.08965	-0.01179	-0.08279	0.04007
0.09357	0.08714	-0.01058	-0.07841	0.03837
0.12470	0.08462	-0.00941	-0.08891	0.03668
0.15577	0.08220	-0.00831	-0.06505	0.03433
0.18677	0.08061	-0.00729	-0.03691	0.03197
0.21769	0.07980	-0.00635	-0.01495	0.02920
0.24852	0.07957	-0.00549	0.00005	0.02642
0.27923	0.07972	-0.00473	0.00941	0.02356
0.30982	0.08008	-0.00405	0.01415	0.02069
0.34028	0.08051	-0.00346	0.01417	0.01798
0.37058	0.08084	-0.00296	0.00799	0.01526
0.40072	0.08084	-0.00253	-0.00822	0.01280
0.43067	0.08014	-0.00217	-0.03926	0.01035
0.46044	0.07866	-0.00186	-0.06677	0.00838
0.49000	0.08332	-0.00161	0.32109	0.00730

MACH CHART IN COMPUTATIONALTIONAL PLANE-FREE STREAM FROM TOP

I=2.48 TOP TO BOTTOM

J= 2.24 LEFT TO RIGHT

15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
14	14	14	14	15	15	15	15	15	15	15	15	15	15	15	15	15	16	15	15	15	15	15
14	14	14	14	14	14	14	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
14	14	14	14	14	14	14	14	14	15	15	15	15	15	15	15	15	15	15	15	15	16	15
13	13	13	13	13	14	14	14	14	14	15	15	15	15	16	16	16	16	16	16	16	16	16
13	13	12	12	12	12	12	13	13	14	14	15	17	18	18	18	18	18	18	18	17	17	16
13	12	12	11	10	10	10	9	9	10	13	22	26	24	23	22	22	21	20	19	18	17	16
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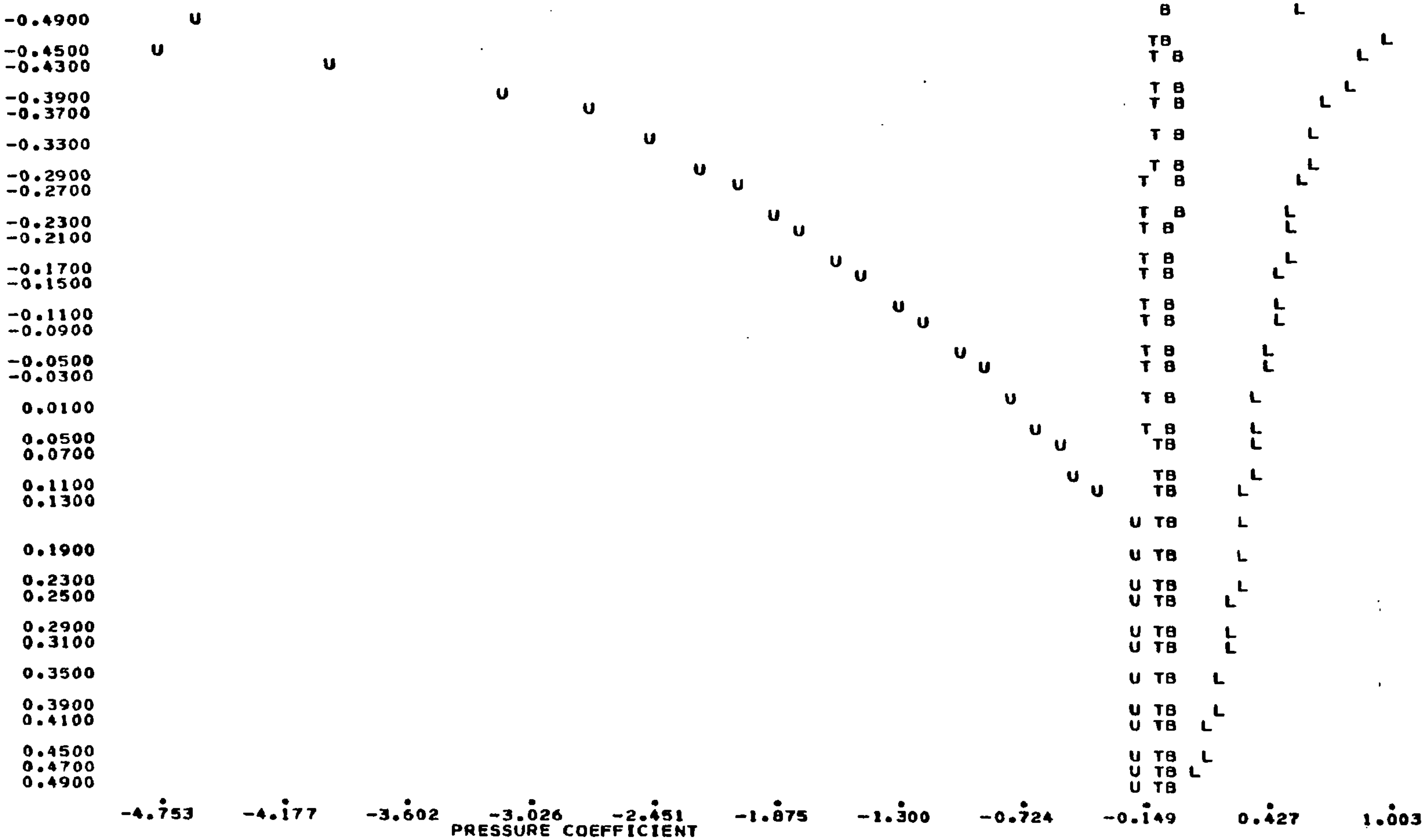
CHART 100



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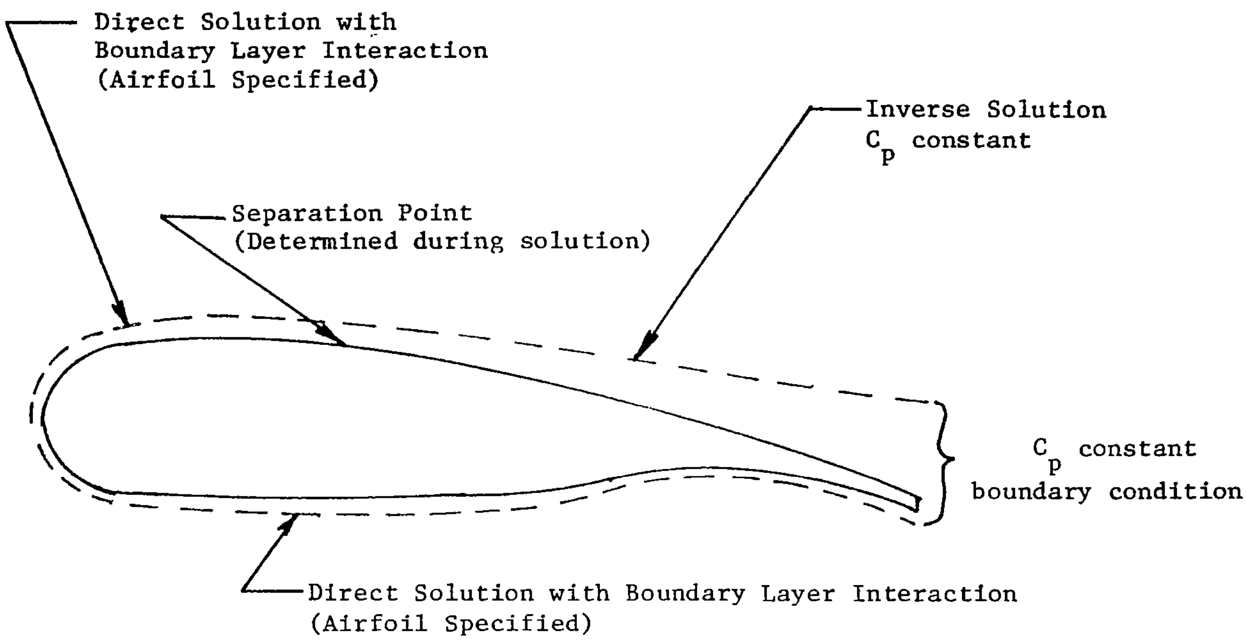
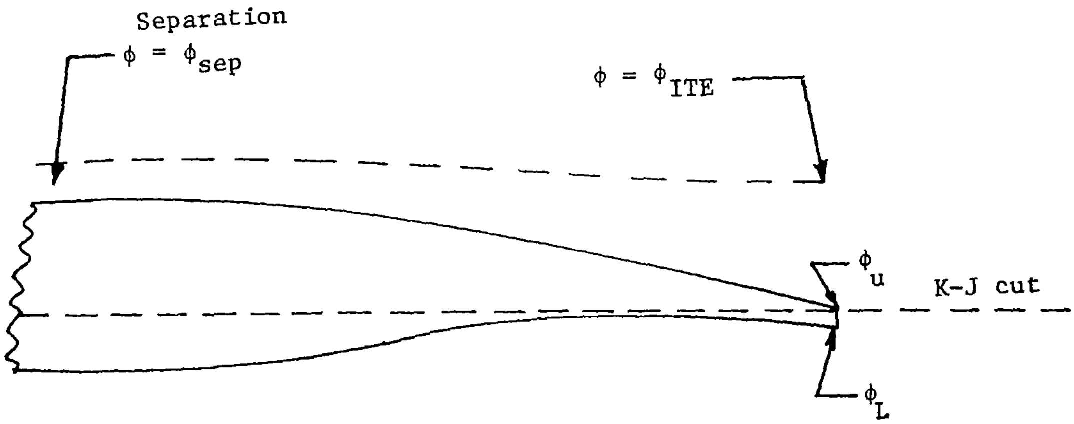


Figure 1. Problem Formulation.

$$C_{p_{sep}} = -2\frac{(\phi_{ITE} - \phi_{sep})}{X_{ITE} - X_{sep}}$$



$$\Gamma = \phi_u - \phi_L$$

Figure 2. $C_{p_{sep}}$ and Γ Formulation.

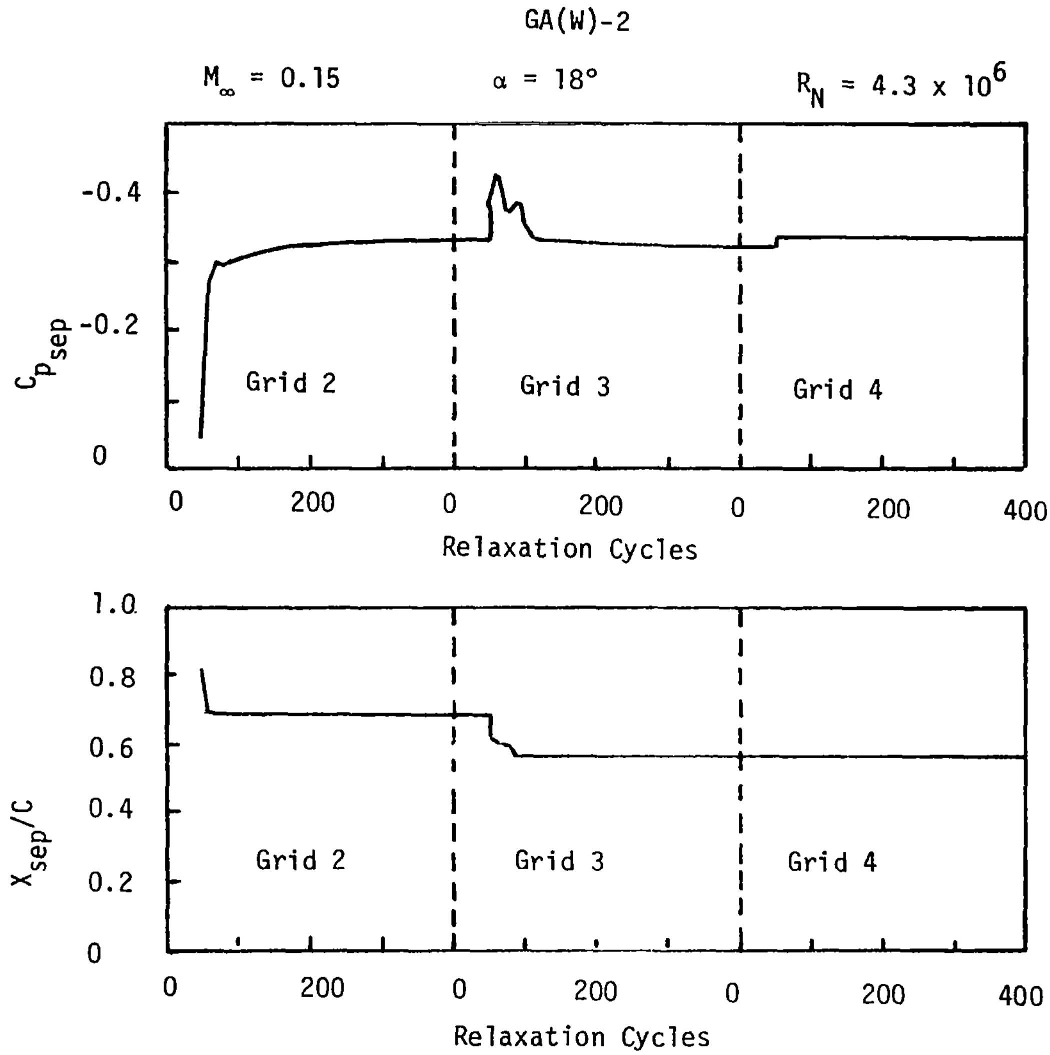


Figure 3. Separation Point and Pressure Behavior During Relaxation Process.

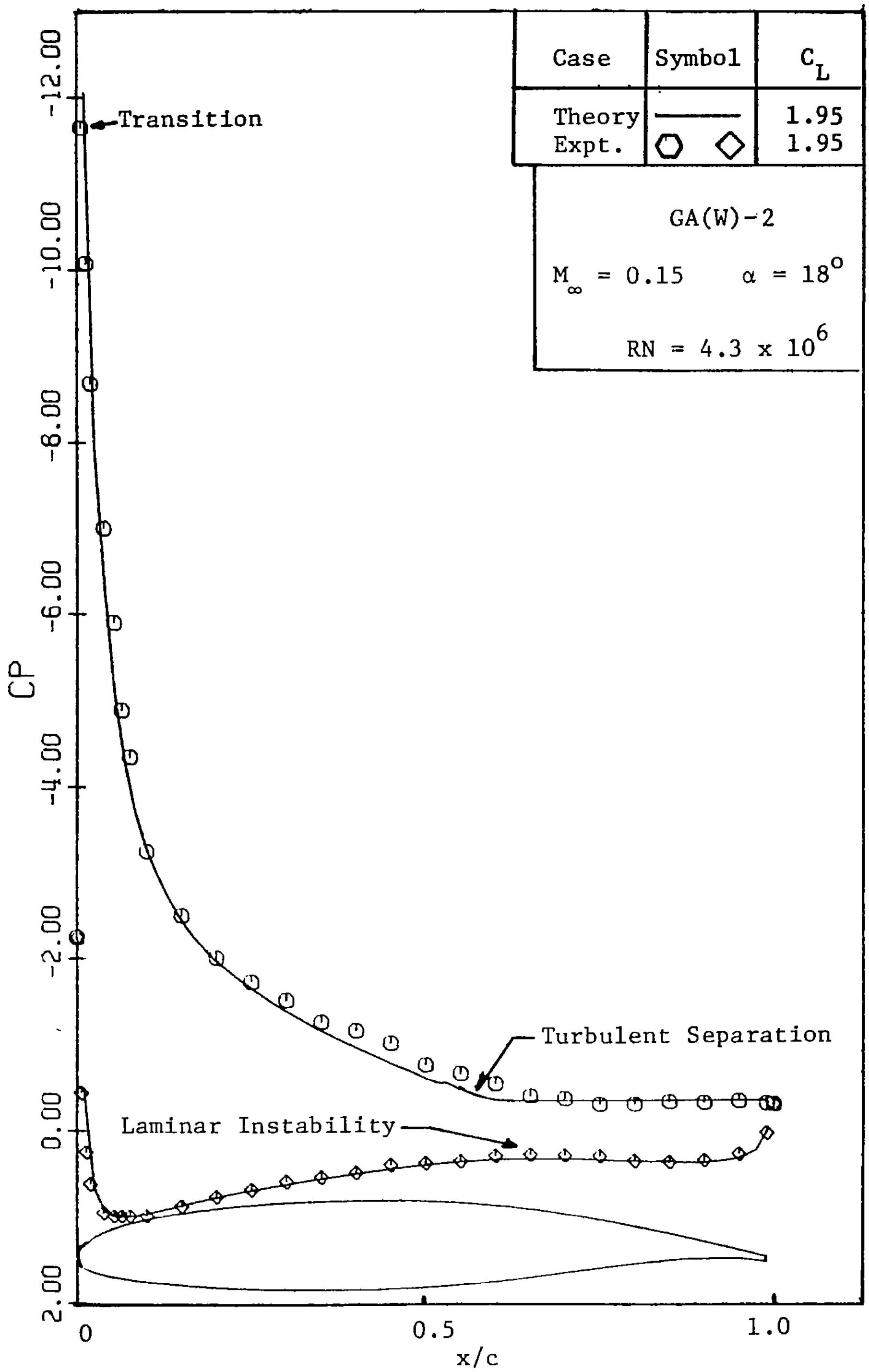


Figure 4. Theoretical and Experimental Pressure Distribution Comparisons - Laminar Turbulent Case.

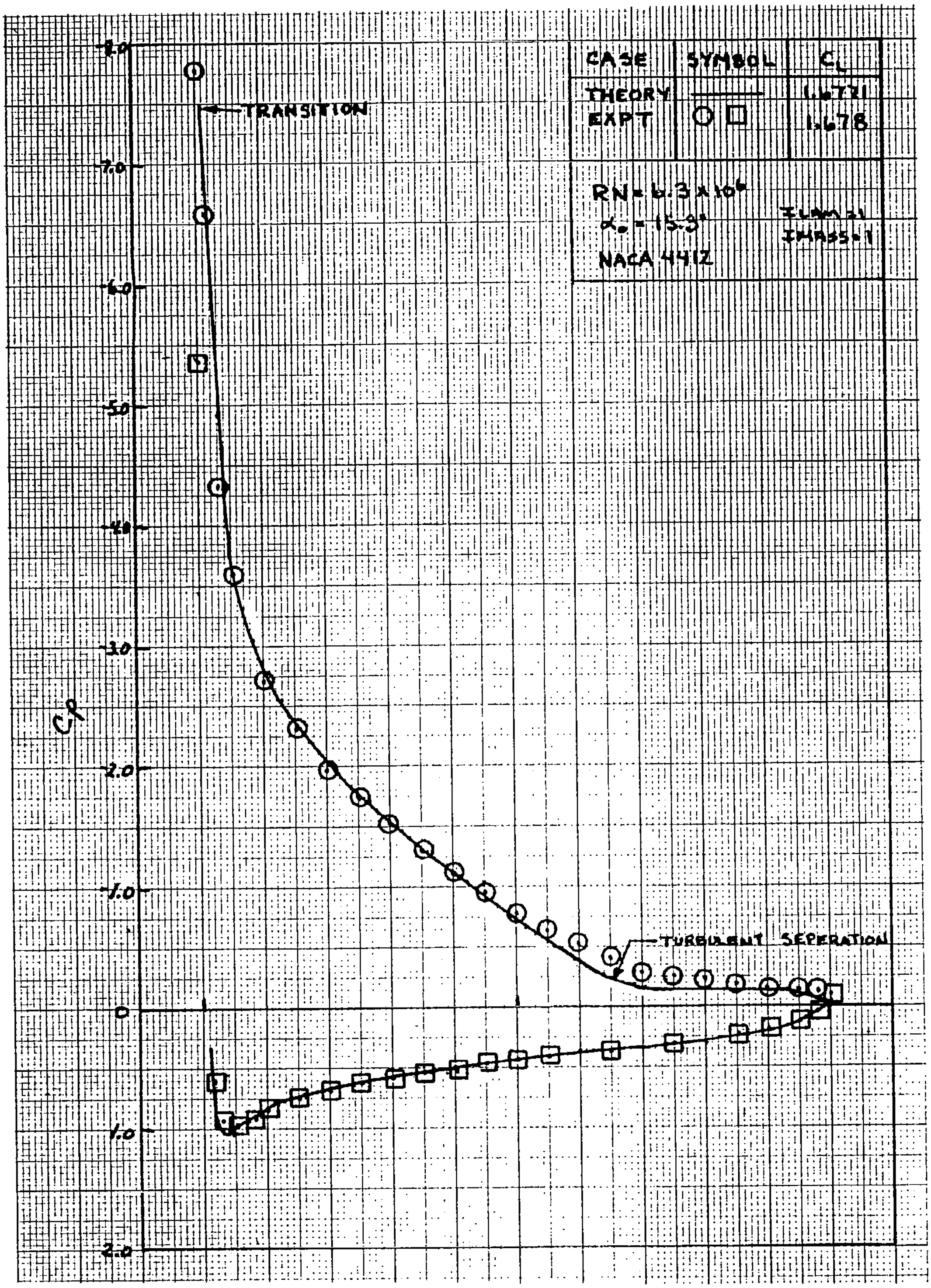


Figure 5. Theoretical and Experimental Pressure Distribution Comparisons - Fine Grid - Laminar Turbulent Case.

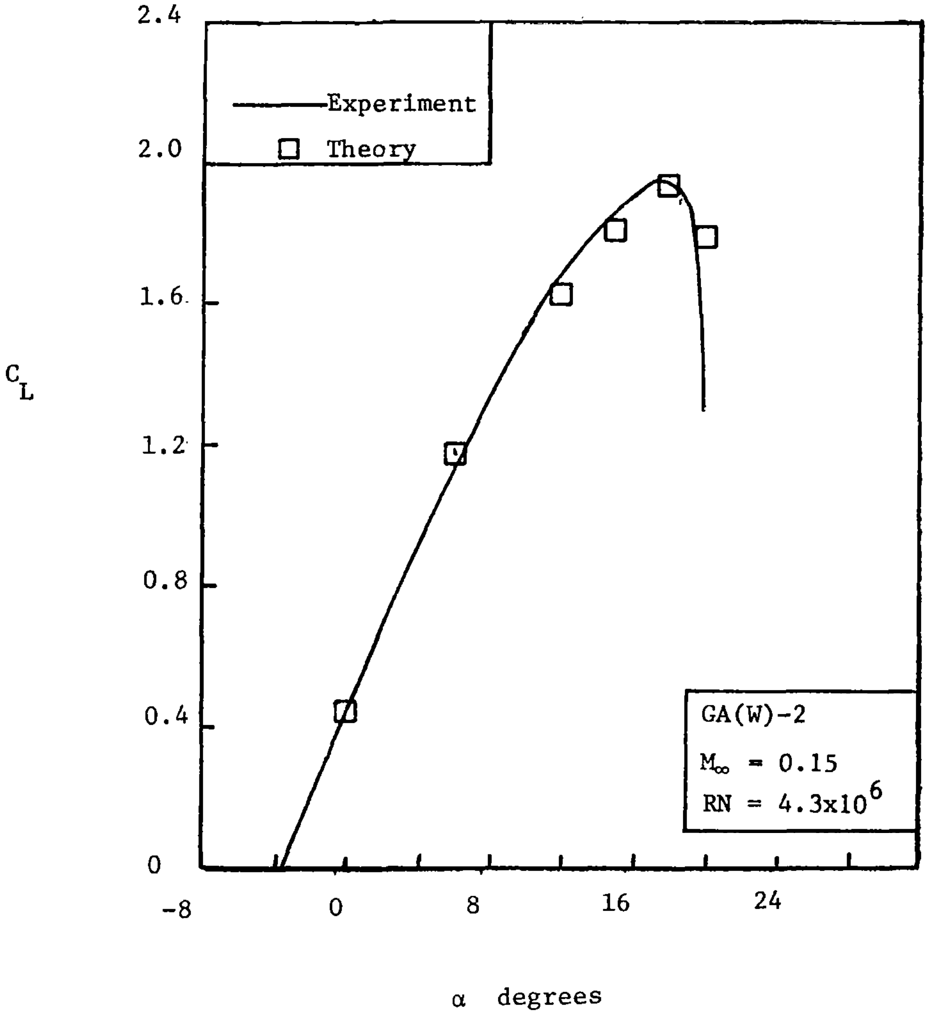


Figure 6. Comparison of C_L (α) with Experiment.

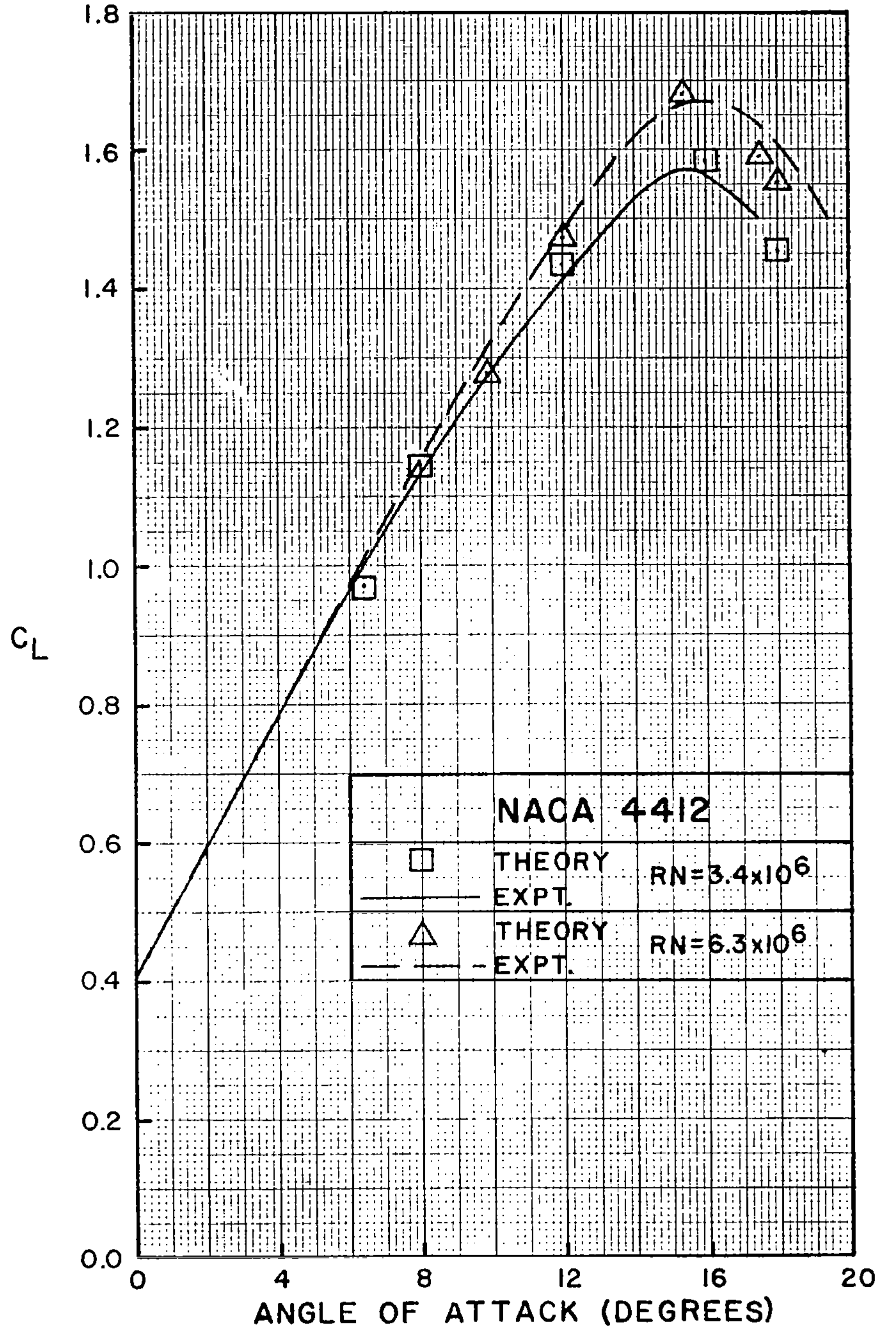


Figure 7. Comparison of C_L (α) with Experiment.

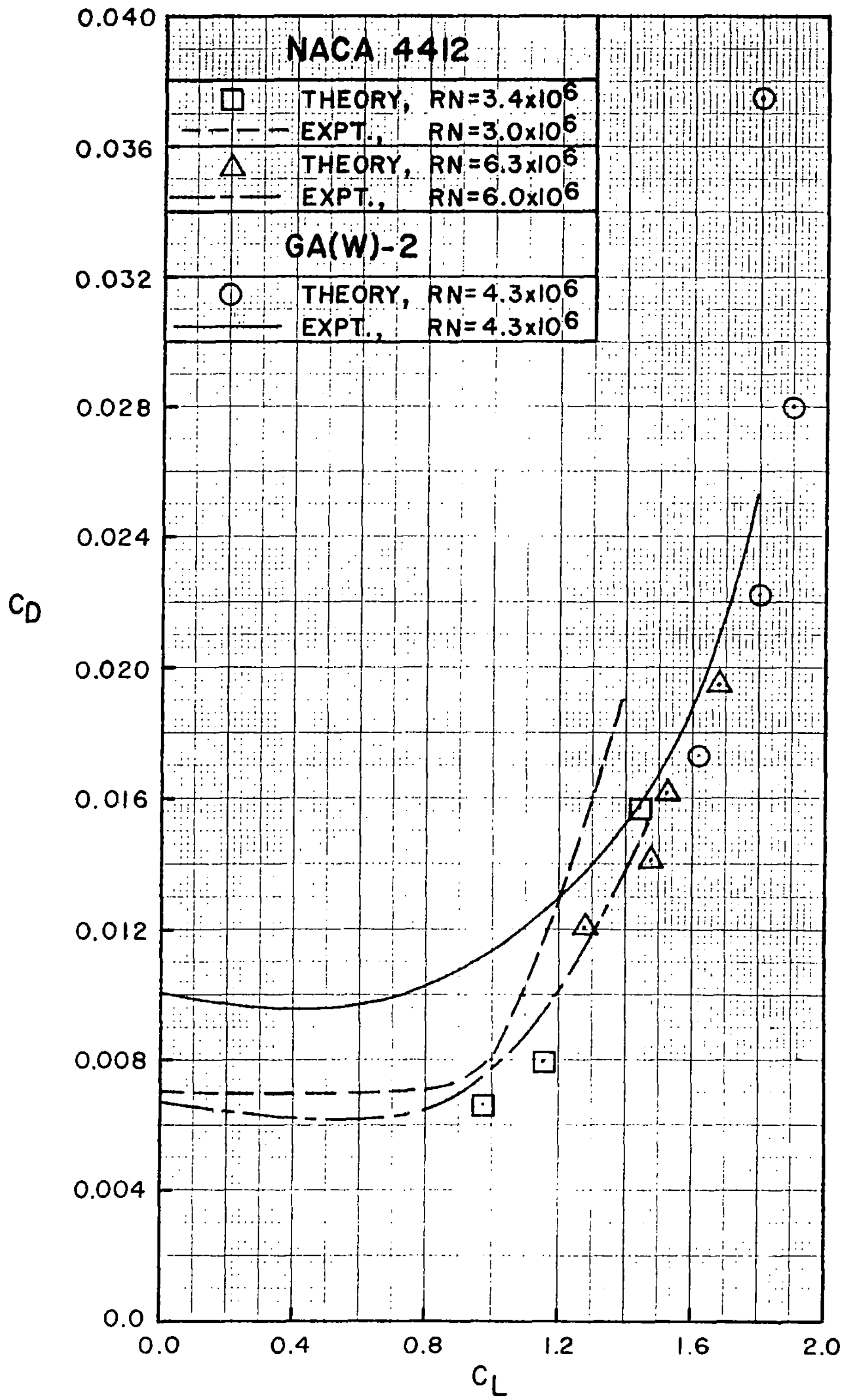


Figure 8. Comparison of Theoretical and Experimental Drag Coefficients.

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15. Supplementary Notes

Langley Technical Monitor: Joel L. Everhart
Topical Report

16. Abstract

A method and program called TRANSEP is presented that can be used for the analysis of the flow about a low speed airfoil under high lift, massive separation conditions. Since the present program is a modification of the direct-inverse TRANDES code, it can also be used for the design and analysis of transonic airfoils, including the effects of weak viscous interaction. Interations on program usage, program modifications to convert TRANDES to TRANSEP, and sample cases and results are given.

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