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Ajay Kumar and R. A. Graves, Jr.

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Langley Research Center
Hampton, Virginia 23665

A VECTORIZED CODE FOR CALCULATING LAMINAR AND TURBULENT HYPERSONIC FLOWS ABOUT BLUNT AXISYMMETRIC BODIES AT ZERO AND SMALL ANGLES OF ATTACK

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SUMMARY

This report is a user's guide for a computer code which calculates the laminar and turbulent hypersonic flows about blunt axisymmetric bodies, such as spherically blunted cones, hyperboloids, etc., at zero and small angles of attack. The code is written in STAR FORTRAN language for the CDC-STAR-100 computer. Time-dependent viscous-shock-layer-type equations are used to describe the flow field. These equations are solved by an explicit, two-step, time-asymptotic finite-difference method. For the turbulent flow, a two-layer, eddy-viscosity model is used. The code provides complete flow-field properties including shock location, surface pressure distribution, surface heating rates, and skin-friction coefficients. This report contains descriptions of the input and output, the listing of the program, and a sample flow-field solution.

INTRODUCTION

This report is a user's guide for a computer code which calculates the laminar and turbulent hypersonic flows about blunt axisymmetric bodies, such as spherically blunted cones, hyperboloids, etc., at zero and small angles of attack. Time-dependent viscous-shock-layer-type equations are used to describe the flow field bounded by the body, shock wave, and outflow boundaries as shown in figure 1. The equations are put in the conservative form as:

$$\frac{\partial U}{\partial t} + \frac{\partial M}{\partial s} + \frac{\partial N}{\partial n} + Q = 0 \qquad (1)$$

Two independent variable transformations are applied to the governing equations. The first transformation maps the computational domain into a rectangular region in which the body and the shock wave are made boundary mesh lines. The second transformation further maps the rectangular region into another plane to allow higher resolution near the surface, which is desirable for resolving the viscous flow. A time-asymptotic, two-step finite-difference method is used to solve the governing equations. Solutions are obtained only in the planes of symmetry of the flow field, i.e. the windward and leeward planes. The code given in this report considers the flow of a perfect gas only. For the turbulent flow, a two-layer, eddy-viscosity model is used. The details of the governing equations, eddy-viscosity model, and the method of solution are given in references 1 and 2.

The code is written in STAR FORTRAN language for the CDC-STAR-100 computer. The present method of solution works very efficiently on this computer. The results of the code include shock location, surface pressure distribution,

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*Research Associate Professor, Department of Mechanical Engineering and Mechanics, Old Dominion University, Norfolk, Virginia 23508

surface heating rate and skin friction, and detailed flow properties at all the grid points of the flow field. Since it is not necessary to solve the flow in two planes at zero angle of attack, a separate program listing is given for the zero angle-of-attack case for solving the flow only in one plane of the flow field.

The program listing for the angle-of-attack case is given in appendix A, the program listing for the zero angle-of-attack case is given in appendix B, and a sample input and output are given in appendixes C and D, respectively.

CODE STRUCTURE

The code has a main program which simply calls either BCON or BHYP depending upon whether the body is a spherically blunted cone or a hyperboloid. All the inputs are made in BCON or BHYP. These subroutines then calculate the body geometry and starting solution at all the grid points. Calculations for the time step and the finite differencing for the predictor and corrector steps are also performed in these subroutines.

Subroutine SHOCK calculates the flow properties immediately behind the shock by using the shock relations and updates the shock shape. Subroutine DERV calculates the normal derivatives of the velocities and enthalpy. These are required for calculating the transport terms in the governing equations. Subroutine VEC2 calculates the flow vectors U, M, N, and Q of equation (1) at the mesh points on the axis of symmetry of the body and subroutine VEC1 calculates at the remaining mesh points in the flow field. Eddy viscosity is calculated in subroutine EDDY which is called after every 25 time steps instead of every time step to save on computing time. Subroutine VEC4 calculates the physical flow quantities such as velocities, density, etc., at the mesh points on the axis of symmetry of the body and subroutine VEC3 performs these calculations at the remaining mesh points. For the turbulent flow, subroutine VEC5 is called in place of VEC3. In the case of zero angle of attack, VEC4 is eliminated and the physical flow quantities at the body axis are also calculated in either VEC3 or VEC5 depending upon whether the flow is laminar or turbulent. The boundary conditions on the body surface are applied in subroutine BOUND.

Finally, subroutine BCON or BHYP prints the surface quantities, shock shape, and drag coefficients after every 500 time steps. At this time, the convergence of the solution is also checked. The convergence criterion used in these codes is that the surface heating rates should not change by more than 1 percent over 500 time steps. The detailed flow-field properties are printed at all the mesh points after every 5000 time steps and after the solution is converged.

PROGRAM INPUT

The program is set up for 15 mesh points in the tangential direction in each plane and 101 mesh points in the normal direction. It uses the properties of air under perfect gas assumption. Sutherland's viscosity law is used to calculate the viscosity. The symbolic program name and a brief description of each input parameter are given.

NBODY	Parameter used to choose the type of body. NBODY = 1 for spherically blunted cone and NBODY = 2 for hyperboloid. Rest of the input parameters are prescribed in subroutine BCON for NBODY = 1 and in subroutine BHYP for NBODY = 2.
CC	Artificial damping coefficient of the order of 0.001.
FM	Free-stream Mach number.
TF	Free-stream temperature in ^oK.
PF	Free-stream pressure in N/m^2.
THC	Half-body angle in radians.
TW	Wall temperature in ^oK.
RN	Body-nose radius in m.
ALPHA	Angle of attack in radians.
DY	Mesh spacing in the tangential direction nondimensionalized with nose radius. For spherically blunted cones, it should be so chosen that the juncture point lies approximately in the middle of two mesh points.
BETA	Stretching factor greater than 1. The value of BETA has to be chosen such that the viscous region near the surface is properly resolved. To help the user in choosing the value of BETA, the distances of the first mesh point away from the body are given below as a percentage of shock-layer thickness for various BETA. With no stretching, this distance will be 1 percent for 101 mesh points in the normal direction.

BETA	Distance of first mesh point away from the body as percentage of the shock-layer thickness.
2.0	0.8262
1.5	0.6742
1.2	0.444
1.1	0.295
1.05	0.1845
1.02	0.093
1.01	0.05418
1.005	0.0308
1.002	0.01429
1.001	0.0079

FDT Time-step parameter equal to 1 or less. It determines what fraction of CFL time step be used to march the solution in time. For low Reynolds numbers and turbulent flows, FDT may have to be much less than 1.

THESH Initial shock angle in radians between the body surface and shock. For large angle bodies, it can be taken as zero but for bodies with half angle less than 20°, where the free-stream Mach number normal to shock may approach 1 for THESH = 0, a suitable small value should be prescribed for THESH.

LTURB Number of time steps up to which the flow remains laminar. Since the starting solution is obtained by linear interpolation between the body and the shock values, LTURB should be large enough (4000 or so) so that reasonable flow profiles are established before the turbulence is turned on.

LMAX Maximum number of time steps. The code will stop after LMAX time steps even though the solution may not have converged.

CRIT Convergence criterion.

NT Number of mesh points in the tangential direction up to which the flow is laminar. The flow becomes fully turbulent for NT + 1. NT is an input only for the zero angle-of-attack code. For the angle-of-attack code, the flow is assumed fully turbulent at all mesh points.

PROGRAM OUTPUT

The first quantities to be output are the geometry parameters for the body. These quantities are:

Y Distance measured along the body surface nondimensionalized with nose radius, R_n.

THE Local body angle in radians.

R Local body radius normal to axis nondimensionalized with R_n.

CUR Local body curvature nondimensionalized with R_n.

The complete starting solution is then printed at each grid point in the flow field. The details of the quantities printed in it will be given later.

The code prints gross flow quantities after every 500 time steps. These quantities are:

Y Distance along the body nondimensionalized with R_n.

S Shock standoff distance nondimensionalized with R_n.

US Shock speed nondimensionalized with free-stream velocity, V_∞.

CH Surface heating rate nondimensionalized with $\rho_\infty V_\infty^3/2$ where ρ_∞ is the free-stream density.

CF Skin friction coefficient nondimensionalized with $\rho_\infty V_\infty^2/2$.

PW Surface pressure nondimensionalized with $\rho_\infty V_\infty^2$.

CDP Local pressure drag coefficient.

CDF Local skin friction drag coefficient (only for zero angle of attack).

The code prints detailed flow quantities at each grid point after every 500 time steps and after the solution is converged. The same quantities are printed in the starting solution also. These quantities are:

ZN Distance normal to body nondimensionalized with R_n.

U Tangential velocity nondimensionalized with V_∞.

V Normal velocity nondimensionalized with V_∞.

WP Crossflow velocity derivative with respect to crossflow direction nondimensionalized with V_∞ (only for angle of attack).

P Pressure nondimensionalized with $\rho_\infty V_\infty^2$.

RO Density nondimensionalized with ρ_∞.

T Temperature nondimensionalized with free-stream temperature, T_∞.

H Total enthalpy nondimensionalized with V_∞^2.

VIST Eddy viscosity nondimensionalized with laminar viscosity.

GENERAL DISCUSSION

The code presented in this report calculates the hypersonic flow of a perfect gas past axisymmetric bodies at zero and small angles of attack. No-slip and no-mass flux boundary conditions are used at the surface. The flow-field solution for the sample input conditions, given in appendix C, required 7500 time steps for the zero angle of attack and 10 000 time steps for 5° angle of attack. It took about 5 minutes for the zero angle-of-attack case and about 15 minutes for the 5° angle-of-attack case.

The code works well over a wide range of input conditions and body angles. With suitable modifications, it has been used for the flow with low Reynolds numbers (ref. 3) as well as for the flow with massive surface blowing (ref. 4). Recently, the code has been made operational for calculating the aerothermal environment of the Jovian entry probe (ref. 5) in which the solutions are obtained for radiating and reacting flow under chemical equilibrium and massive ablation injection. The code also works well for bodies with ablated nose shapes.

REFERENCES

1. Kumar, A.; and Graves, R. A., Jr.: Numerical Solution of the Viscous Hypersonic Flow Past Blunted Cones at Angle of Attack. AIAA Paper No. 77-172, January 1977.

2. Kumar, A.; and Graves, R. A., Jr.: Turbulent Viscous Shock Layer Solution for Jovian Entry at Small Angles of Attack. AIAA Paper No. 78-187, January 1978.

3. Kumar, A.: Low Reynolds Number Flow Past a Blunt Axisymmetric Body at Angle of Attack. AIAA J., Vol. 15, No. 8, August 1977, pp. 1212-1214.

4. Kumar A.; Graves, R. A., Jr.; and Tiwari, S. N.: Laminar and Turbulent Flows over a Spherically Blunted Cone with Massive Surface Blowing. AIAA J., Vol. 17, No. 12, December 1979, pp. 1326-1331.

5. Kumar, A.; Graves, R. A., Jr.; Weilmuenster, K. J.; and Tiwari, S. N.: Laminar and Turbulent Flow Solutions with Radiation and Ablation Injection for Jovian Entry. AIAA Paper No. 80-288, January 1980.

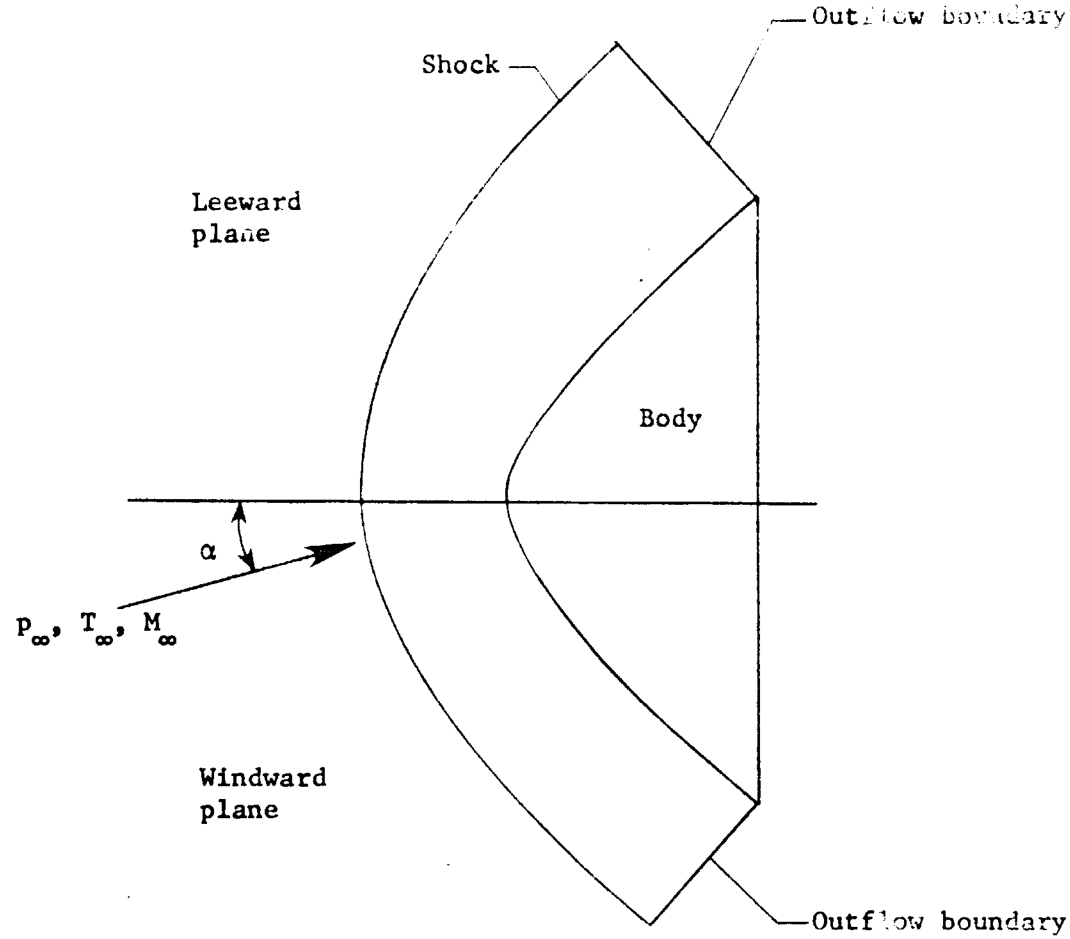

Figure 1. - Physical flow model.

APPENDIX A

LISTING FOR ANGLE-OF-ATTACK CODE

```
      PROGRAM BBODY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     TIME-DEPENDENT FINITE-DIFFERENCE METHOD FOR CALCULATING THE LAMINAR
C     AND TURBULENT HYPERSONIC FLOWS ABOUT BLUNT AXISYMMETRIC BODIES AT
C     SMALL ANGLE OF ATTACK.  LOCAL TIME STEP IS USED TO MARCH THE
C     SOLUTION IN TIME.
C     REFERENCE AIAA PAPER NO. 77-172 (KUMAR AND GRAVES).
C     NBODY=1 FOR SPHERE-CONE.  CALL BCON.
C
C     NBODY=2 FOR HYPERBOLOID.  CALL BHYP.
C
      NBODY=1
      IF(NBODY.EQ.1)CALL BCON
      IF(NBODY.EQ.2) CALL BHYP
      STOP
      END
```

```
      SUBROUTINE BCON
      DIMENSION CP1(15),CP2(15),CDP1(15),CDP2(15),CDP(15)
      DIMENSION Y(29),THE(29),R(29),CH(29),TEMP1(29),TEMP2(101),Z(101),
     1TZ(101),TZ1(101),GM(5)
      DIMENSION TAU(29,5),TAM(29,5),TAN1(29,5),TAN2(29,5),TAQ(29,5),
     1TAU1(29,5),CF(29)
      DIMENSION TE8(29),TE9(29),TE10(29)
      COMMON/F /THE1(101,29),THE2(101,29),VAIR(101,29),DT(101,29)
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
      COMMON/F4/XX,ZZ,FM,BETA,SIGT
      COMMON/F5/S(29),SS(29),G(29),CUR(29),US(29),DS(29),VS(29),VN(29)
      COMMON/F6/INT(29),TIMP(29),TEMP(29),TE(29),TE1(29),TE2(29),TE3(29)
     1,TE4(29),TE5(29),TE6(29),TE7(29)
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F11/DU(101,29),DSH(101,29),DWP(101,29),A6(101,29),
     1A7(101,29),A8(101,29)
      COMMON/F12/TZ2(101,29),Z1(101,29),TZ3(101,29),TZ4(101,29)
      COMMON/F13/AU1(101,29,5),AU2(101,29,5)
      COMMON/F14/AU(101,29,5),AM(101,29,5),AN(101,29,5),AQ(101,29,5)
      COMMON/F15/AUO(101,4),AMO(101,2,4),ANO(101,4),AQO(101,4)
      COMMON/F16/HTNF,RE1,RE2
      VIS(1,1;2929)=0.
      VIST(1,1;2929)=0.
      AU(1,1,1;14645)=0.
      AM(1,1,1;14645)=0.
      AN(1,1,1;14645)=0.
      AQ(1,1,1;14645)=0.
      AU1(1,1,1;14645)=0.
      AU2(1,1,1;14645)=0.
      CH(1;29)=0.
C     CONSTANTS AND FREESTREAM CONDITIONS
      PI=4.*ATAN(1.)
      GAMA=1.4
      RGAS=287.
      SIG=.72
      CP=GAMA*RGAS/(GAMA-1.)
      SIGT=.9
      CC=.001
      FM=10.3
      TF=46.26
```

```
      PF=100.77
      ROF=PF/TF/RGAS
      ALPHA=5.*PI/180.
      THC=45.*PI/180.
      TW=330.6
      TW=TW/TF
      RN=.03175
      DY=.185
      BETA=1.1
      FDT=1.
      THESH=2.*PI/180.
      VF=FM*(GAMA*RGAS*TF)**.5
      VISF=1.458/10.**6*TF**1.5/(TF+110.)
      RE=VF*ROF*RN/VISF
C     LMAX IS THE MAXIMUM NUMBER OF TIME STEPS AFTER WHICH THE PROGRAM
C     WILL STOP EVEN THOUGH THE SOLUTION MAY NOT BE CONVERGED.
      LMAX=20000
      LTURB=25000
C     FOR LAMINAR FLOW, CALL VEC3 AND FOR TURBULENT FLOW, CALL VEC5
C     LTURB IS THE NUMBER OF ITERATIONS UP TO WHICH THE FLOW REMAINS
C     LAMINAR.
C     CONVERGENCE CRITERION.
      CRIT=.01
      DO 5 I=1,5
 5    GM(I)=(-1.)**I
      GM1=1./GAMA/FM**2
      GM2=2.*GAMA/(1.+GAMA)
      GM3=CP*TF/VF**2
      GM4=SIN(ALPHA)
      GM5=110./TF
      GM6=1.+GM5
      GM7=(GAMA-1.)/(GAMA+1.)
      GM8=(1.+GAMA)/(2.*GAMA*FM**2)
      GM9=(GAMA-1.)/GAMA
      GM10=TW*GM3/GAMA
      HINF=.995*(.5+GM3)
      RE1=SQRT(RE)
      RE2=0.0168*RE
C     MESH SIZES AND VECTOR LENGTHS
      N1=15
      N11=2*N1-1
      N12=N1+1
      N14=N1-1
      N15=N11-1
      N50=N1-2
      N51=N11-2
      N13=N1+3
      N17=N1+4
      N52=N1-3
      N53=N11-3
      N16=N1+2
```

```
      M1=101
      M11=M1-1
      M50=M1-2
      M51=M1-3
      M52=M1-4
      NXM=N11*M1
      NXM1=NXM-M11
      NXM2=NXM-1
      NXM3=NXM-2
      NXM4=NXM-M1
      NXM5=N14*M1
      NXM6=N51*M1-2
      NXM61=N51*M1-1
      NXM7=NXM-3*M1+1
      NXM8=NXM-M1-1
      NXM9=NXM-4*M1+1
      NXM10=5*NXM
      NXMM=NXM-2*M1+1
      NXMM1=5*NXM8
      NXMM2=NXM-2*M1-4
      NXMM3=NXM-4*M1-2
C     STEP SIZES
      DZ=-1./M11
      XX=2.*DY
      ZZ=2.*DZ
      Y(1;N1)=Q8VINTL(0.,DY;Y(1;N1))
      Z(1;M1)=Q8VINTL(1.,DZ;Z(1;M1))
      A1=PI/2.-THC
      YM=DY*N14
      RB=((YM-A1)*SIN(THC)+COS(THC))*RN
C     NJ1 IS THE MESH POINT UPSTREAM OF JUNTURE POINT.
      NJ=A1/DY
      NJ1=NJ+1
      NJ2=NJ+N1
      NJ3=NJ+N14
      NJ11=NJ1-1
      NJ12=NJ1-2
      NJ21=NJ2-1
      NJ22=NJ2-2
C     INITIAL SHOCK SHAPE AND SHOCK SLOPE.
      S(1;N11)=.17
      DO 15 N=3,N1
   15 S(N)=S(N-1)+DY*SIN(THESH)
      SS(1)=(S(2)-S(N12))/XX
      DO 16 N=2,NJ
   16 SS(N)=(S(N+1)-S(N-1))/XX
      SS(N12)=(S(N16)-S(1))/XX
      DO 17 N=NJ1,N1
   17 SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      DO 18 N=N16,NJ3
   18 SS(N)=(S(N+1)-S(N-1))/XX
```

```
      DO 19 N=NJ2,N11
 19   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
C      BODY GEOMETRY.
      DO 10 N=1,N1
      IF(Y(N).GT.A1)GO TO 11
      THE(N)=PI/2.-Y(N)
      CUR(N)=1.
      R(N)=COS(THE(N))
      GO TO 10
 11   THE(N)=THC
      CUR(N)=0.
      R(N)=COS(THC)+(Y(N)-A1)*SIN(THC)
 10   CONTINUE
      Y(N12;N14)=Y(2;N14)
      R(N12;N14)=R(2;N14)
      THE(N12;N14)=THE(2;N14)
      CUR(N12;N14)=CUR(2;N14)
      DO 20 N=1,N1
      VS(N)=COS(THE(N)-ALPHA)
 20   VN(N)=SIN(ALPHA-THE(N))
      DO 25 N=N12,N11
      VS(N)=COS(ALPHA+THE(N))
 25   VN(N)=-SIN(ALPHA+THE(N))
      DO 35 N=1,N11
      S1(1,N;M1)=S(N)
      CUR1(1,N;M1)=CUR(N)
      R1(1,N;M1)=R(N)
 35   THE1(1,N;M1)=THE(N)
      THEC(1,1;NXM)=VCOS(THE1(1,1;NXM);THEC(1,1;NXM))
      THES(1,1;NXM)=VSIN(THE1(1,1;NXM);THES(1,1;NXM))
      B1=(BETA+1.)/(BETA-1.)
      B2=2.*BETA/ALOG(B1)
      XL1=   -B2/(BETA**2-1.)
      XL=-2.*B2/(BETA**2-1.)/SIG/RE
      TZ(1;M1)=B1**(Z(1;M1))
      TZ1(1;M1)=BETA*(TZ(1;M1)-1.)/(TZ(1;M1)+1.)
      DO 30 N=1,N11
 30   Z1(1,N;M1)=TZ1(1;M1)
      ZN(1,1;NXM)=S1(1,1;NXM)*(1.-Z1(1,1;NXM))
      EMDA(1,1;NXM)=1.+ZN(1,1;NXM)*CUR1(1,1;NXM)
      BT(1,1;NXM)=R1(1,1;NXM)+ZN(1,1;NXM)*THEC(1,1;NXM)
      TZ2(1,1;NXM)=BETA**2-Z1(1,1;NXM)**2
      TZ3(1,1;NXM)=2.*Z1(1,1;NXM)/TZ2(1,1;NXM)
      TZ4(1,1;NXM)=B2/TZ2(1,1;NXM)
      INT(1;N11)=Q8VINTL (1,M1;INT(1;N11))
C     CALCULATION OF THE STARTING SOLUTION.
      DO 40 N=1,N1
 40   TEMP(N)=SIN(THE(N)-ALPHA)**2*(.9+.1*(N-1)/N1)
      DO 45 N=N12,N11
 45   TEMP(N)=SIN(THE(N)+ALPHA)**2*(.9+.1*(N-N1)/N1)
      P(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);P(1,1;NXM))
```

```
      TEMP(1;N11)=0.
      U(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);U(1,1;NXM))
      V(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);V(1,1;NXM))
      WP(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);WP(1,1;NXM))
      TEMP(1;N11)=T*
      T(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);T(1,1;NXM))
      TE5(1;N11)=SS(1;N11)/(1.+S(1;N11)*CUR(1;N11))
      TE6(1;N11)=1.+TE5(1;N11)*TE5(1;N11)
      TE6(1;N11)=VSQRT(TE6(1;N11);TE6(1;N11))
      TE7(1;N11)=-(VN(1;N11)-VS(1;N11)*TE5(1;N11))/TE6(1;N11)
      TEMP(1;N11)=(TE7(1;N11)*TE7(1;N11)/GM8-GM7)*GM1
      P(M1,1;NXM1)=Q8VSCATR(TEMP(1;N11),INT(1;N11);P(M1,1;NXM1))
      TEMP(1;N11)=TEMP(1;N11)/GM1
      TE(1;N11)=(TEMP(1;N11)+GM7)/(1.+TEMP(1;N11)*GM7)
      TE1(1;N11)=(1.-1./TE(1;N11))*TE7(1;N11)/TE6(1;N11)
      TE2(1;N11)=VS(1;N11)-TE1(1;N11)*TE5(1;N11)
      TE3(1;N11)=VN(1;N11)+TE1(1;N11)
      TE4(1;N11)=TEMP(1;N11)/TE(1;N11)
      U(M1,1;NXM1)=Q8VSCATR(TE2(1;N11),INT(1;N11);U(M1,1;NXM1))
      V(M1,1;NXM1)=Q8VSCATR(TE3(1;N11),INT(1;N11);V(M1,1;NXM1))
      T(M1,1;NXM1)=Q8VSCATR(TE4(1;N11),INT(1;N11);T(M1,1;NXM1))
      DO 61 N=2,N1
      DDEL=-(S(N)-S(N+N14))/2.
61    WP(M1,N)=-GM4-TE1(N)*DDEL/BT(M1,N)
      DO 65 N=N12,N11
      DDEL=(S(N-N14)-S(N))/2.
65    WP(M1,N)=GM4-TE1(N)*DDEL/BT(M1,N)
      WP(M1,1)=-U(M1,1)
      DO 50 N=1,N11
      DXU=(U(M1,N)-U(1,N))/M11
      DXV=(V(M1,N)-V(1,N))/M11
      DXP=(P(M1,N)-P(1,N))/M11
      DXT=(T(M1,N)-T(1,N))/M11
      DXWP=(WP(M1,N)-WP(1,N))/M11
      U(1,N;M11)=Q8VINTL(U(1,N),DXU;U(1,N;M11))
      V(1,N;M11)=Q8VINTL(V(1,N),DXV;V(1,N;M11))
      P(1,N;M11)=Q8VINTL(P(1,N),DXP;P(1,N;M11))
      T(1,N;M11)=Q8VINTL(T(1,N),DXT;T(1,N;M11))
50    WP(1,N;M11)=Q8VINTL(WP(1,N),DXWP;WP(1,N;M11))
      RO(1,1;NXM)=P(1,1;NXM)/T(1,1;NXM)/GM1
      SH(1,1;NXM)=T(1,1;NXM)*GM3
      H(1,1;NXM)=SH(1,1;NXM)+(U(1,1;NXM)**2+V(1,1;NXM)**2)/2.
      TV2(1,1;NXM)=VSQRT(T(1,1;NXM);TV2(1,1;NXM))
      VIS(1,1;NXM)=T(1,1;NXM)*TV2(1,1;NXM)*GM6/(T(1,1;NXM)+GM5)
      WRITE (6,399) ALPHA,RE,FM
399   FORMAT(/,1X,'ALPHA',F8.5,5X,'REYN NO.',F15.3,5X,'MACH NO.',F8.3,/)
      WRITE(6,435)(Y(N),THE(N),R(N),CUR(N),N=1,N11)
435   FORMAT(2X,'Y=',F10.5,5X,'THE=',F10.5,5X,'R=',F10.5,5X,'CUR=',F10.5
     1)
      DO 60 N=1,N11,2
      WRITE(6,421)N,Y(N)
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      WRITE(6,430)
      WRITE(6,440)(            Z1(M,N),U(M,N),V(M,N),WP(M,N),P(M,N),RO(M,N
     1),T(M,N),H(M,N),M=1,M1)
 60   CONTINUE
 430  FORMAT(/,           6X,'Z1',9X,'U',9X,'V',8X,'WP',9X,'P',8X,'RO',
     19X,'T',9X,'H')
 440  FORMAT(1X,8F10.5)
      DM=-1./4./M11
      TEMP2(1;M11)=Q8VINTL(1.+DM,DM;TEMP2(1;M11))
      AU1(1,1,1;NXM10)=1.
      TE8(1;N51)=1.
      TE9(1;N51)=0.
      TE10(1;N51)=GM10
      L=1
C     MARCHING IN TIME STARTS HERE.
 1    CONTINUE
      MM=1
C     LOCAL TIME STEP CALCULATION.
      VAIR(1,1;NXM2)=GAMA*P(1,1;NXM2)/RO(1,1;NXM2)
      VAIR(1,1;NXM2)=VSQRT(VAIR(1,1;NXM2);VAIR(1,1;NXM2))
      DT(1,1;NXM2)=FOT*(ZN(2,1;NXM2)-ZN(1,1;NXM2))/(VABS(V(1,1;NXM2);
     1THE2(1,1;NXM2))+VAIR(1,1;NXM2))
      DO 70 N=1,N11
 70   DT(1,N;M11)=DT(1,N;M11)*TEMP2(1;M11)
      TIMP(1;N11)=Q8VGATHR(DT(M11,1;NXM1),INT(1;N11);TIMP(1;N11))
      DT(M1,1;NXM1)=Q8VSCATR(TIMP(1;N11),INT(1;N11);DT(M1,1;NXM1))
C     PREDICTOR STEP.
      SS(1)=(S(2)-S(N12))/XX
      DO 74 N=2,NJ
 74   SS(N)=(S(N+1)-S(N-1))/XX
      SS(N12)=(S(N16)-S(1))/XX
      DO 75 N=NJ1,N1
 75   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      DO 76 N=N16,NJ3
 76   SS(N)=(S(N+1)-S(N-1))/XX
       DO 77 N=NJ2,N11
 77   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 110 I=1,5
      AU1(2,2,I;NXM6)=AU(2,2,I;NXM6)-DT(2,2;NXM6)*((AM(2,3,I;NXM6)-AM(2,
     12,I;NXM6))/DY+(AN(3,2,I;NXM6)-AN(2,2,I;NXM6))/DZ+AQ(2,2,I;NXM6))
      AU1(2,N1,I;M50)=AU(2,N1,I;M50)-DT(2,N1;M50)*((AM(2,N1,I;M50)-AM(2,
     1N14,I;M50))/DY+(AN(3,N1,I;M50)-AN(2,N1,I;M50))/DZ+AQ(2,N1,I;M50))
      AU1(2,N11,I;M50)=AU(2,N11,I;M50)-DT(2,N11;M50)*((AM(2,N11,I;M50)-
     1AM(2,N15,I;M50))/DY+(AN(3,N11,I;M50)-AN(2,N11,I;M50))/DZ+AQ(2,N11,
     2I;M50))
      AU1(2,NJ1,I;M50)=AU(2,NJ1,I;M50)+DT(2,NJ1;M50)*((4.*AM(2,NJ11,I;
     1M50)-3.*AM(2,NJ1,I;M50)-AM(2,NJ12,I;M50))/XX-(AN(3,NJ1,I;M50)-
     2AN(2,NJ1,I;M50))/DZ-AQ(2,NJ1,I;M50))
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```
      AU1(2,NJ2,I;M50)=AU(2,NJ2,I;M50)+DT(2,NJ2;M50)*((4.*AM(2,NJ21,I;
     1M50)-3.*AM(2,NJ2,I;M50)-AM(2,NJ22,I;M50))/XX-(AN(3,NJ2,I;M50)-AN(
     22,NJ2,I;M50))/DZ-AQ(2,NJ2,I;M50))
      TAU(1,I;N11)=Q8VGATHR(AU(M1,1,I;NXM1),INT(1;N11);TAU(1,I;N11))
      TAM(1,I;N11)=Q8VGATHR(AM(M1,1,I;NXM1),INT(1;N11);TAM(1,I;N11))
      TAN1(1,I;N11)=Q8VGATHR(AN(M1,1,I;NXM1),INT(1;N11);TAN1(1,I;N11))
      TAN2(1,I;N11)=Q8VGATHR(AN(M11,1,I;NXM1),INT(1;N11);TAN2(1,I;N11))
      TAQ(1,I;N11)=Q8VGATHR(AQ(M1,1,I;NXM1),INT(1;N11);TAQ(1,I;N11))
      TAU1(2,I;N15)=TAU(2,I;N15)-TIMP(2;N15)*((TAM(3,I;N15)-TAM(2,I;N15)
     1)/DY+(TAN1(2,I;N15)-TAN2(2,I;N15))/DZ+TAQ(2,I;N15))
      TAU1(N1,I)=TAU(N1,I)-TIMP(N1)*((TAM(N1,I)-TAM(N14,I))/DY+(TAN1(N1,
     1I)-TAN2(N1,I))/DZ+TAQ(N1,I))
      TAU1(N11,I)=TAU(N11,I)-TIMP(N11)*((TAM(N11,I)-TAM(N15,I))/DY+(TAN1
     1(N11,I)-TAN2(N11,I))/DZ+TAQ(N11,I))
      TAU1(NJ1,I)=TAU(NJ1,I)+TIMP(NJ1)*((4.*TAM(NJ11,I)-3.*TAM(NJ1,I)-
     1TAM(NJ12,I))/XX-(TAN1(NJ1,I)-TAN2(NJ1,I))/DZ-TAQ(NJ1,I))
      TAU1(NJ2,I)=TAU(NJ2,I)+TIMP(NJ2)*((4.*TAM(NJ21,I)-3.*TAM(NJ2,I)-
     1TAM(NJ22,I))/XX-(TAN1(NJ2,I)-TAN2(NJ2,I))/DZ-TAQ(NJ2,I))
  110 AU1(M1,2,I;NXMM)=Q8VSCATR(TAU1(2,I;N15),INT(1;N15);AU1(M1,2,I;
     1NXMM))
      CALL VEC2
      DO 150 I=1,4
      AU1(2,1,I;M50)=AU0(2,I;M50)-DT(2,1;M50)*((AM0(2,2,I;M50)-AM0(2,1,I
     1;M50))/DY+(AN0(3,I;M50)-AN0(2,I;M50))/DZ+AQ0(2,I;M50))
  150 AU1(M1,1,I)=AU0(M1,I)-DT(M1,1)*((AM0(M1,2,I)-AM0(M1,1,I))/DY+(AN0(
     1M1,I)-AN0(M1',I))/DZ+AQ0(M1,I))
      AU1(1,3,1;NXM7)=Q8VSCATR(TE8(1;N51),INT(1;N51);AU1(1,3,1;NXM7))
      AU1(1,3,2;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,2;NXM7))
      AU1(1,3,3;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,3;NXM7))
      AU1(1,3,4;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,4;NXM7))
      AU1(1,3,5;NXM7)=Q8VSCATR(TE10(1;N51),INT(1;N51);AU1(1,3,5;NXM7))
      IF(L.GT.LTURB)GO TO 154
      CALL VEC3
      GO TO 155
  154 CALL VEC5
  155 CONTINUE
      CALL VEC4
      CALL BOUND
C     CORRECTOR STEP.
      DO 160 I=1,5
  160 AU2(2,2,I;NXM8)=AU(2,2,I;NXM8)+AU1(2,2,I;NXM8)
      DO 170 I=1,4
  170 AU2(2,1,I;M11)=AU0(2,I;M11)+AU1(2,1,I;M11)
      MM=2
      SS(1)=(S(2)-S(N12))/XX
      DO 174 N=2,NJ
  174 SS(N)=(S(N+1)-S(N-1))/XX
      SS(N12)=(S(N16)-S(1))/XX
      DO 175 N=NJ1,N1
  175 SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      DO 176 N=N16,NJ3
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176   SS(N)=(S(N+1)-S(N-1))/XX
      DO 177 N=NJ2,N11
177   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 180 I=1,5
      AU1(2,2,I;NXM8)=0.5*(AU2(2,2,I;NXM8)-DT(2,2;NXM8)*((AM(2,2,I;NXM8)
     1-AM(2,1,I;NXM8))/DY+(AN(2,2,I;NXM8)-AN(1,2,I;NXM8))/DZ+AQ(2,2,I;
     2NXM8)))
      AU1(2,NJ1,I;M11)=0.5*(AU2(2,NJ1,I;M11)+DT(2,NJ1;M11)*((4.*AM(2,NJ1
     11,I;M11)-3.*AM(2,NJ1,I;M11)-AM(2,NJ12,I;M11))/XX-(AN(2,NJ1,I;M11)-
     2AN(1,NJ1,I;M11))/DZ-AQ(2,NJ1,I;M11)))
      AU1(2,NJ2,I;M11)=0.5*(AU2(2,NJ2,I;M11)+DT(2,NJ2;M11)*((4.*AM(2,NJ2
     11,I;M11)-3.*AM(2,NJ2,I;M11)-AM(2,NJ22,I;M11))/XX-(AN(2,NJ2,I;M11)-
     2AN(1,NJ2,I;M11))/DZ-AQ(2,NJ2,I;M11)))
      AM(1,1,I;M1)=GM(I)    *AM(1,1,I;M1)
180   AU1(2,N12,I;M11)=.5*(AU2(2,N12,I;M11)-DT(2,N12;M11)*((AM(2,N12,I;
     1M11)-AM(2,1,I;M11))/DY+(AN(2,N12,I;M11)-AN(1,N12,I;M11))/DZ+AQ(2,
     2N12,I;M11)))
      WP(1,N12;M1)=-WP(1,N12;M1)
      U(1,N12;M1)=-U(1,N12;M1)
      CALL VEC2
      DO 190 I=1,4
190   AU1(2,1,I;M11)=.5*(AU2(2,1,I;M11)-DT(2,1;M11)*((AMO(2,1,I;M11)-AMO
     1(2,2,I;M11))/DY+(ANO(2,I;M11)-ANO(1,I;M11))/DZ+AQO(2,I;M11)))
C     FOURTH ODER DAMPING.  CC IS THE DAMPING COEFFICIENT.
      DO 200 I=1,5
      AU2(3,2,I;NXMM2)=AU(5,2,I;NXMM2)+AU(1,2,I;NXMM2)-4.*(AU(4,2,I;NXMM
     12)+AU(2,2,I;NXMM2))+6.*AU(3,2,I;NXMM2)
      TE1(1;N51)=Q8VGATHR(AU(1,2,I;NXM7),INT(1;N51);TE1(1;N51))
      TE2(1;N51)=Q8VGATHR(AU(2,2,I;NXM7),INT(1;N51);TE2(1;N51))
      TE3(1;N51)=Q8VGATHR(AU(3,2,I;NXM7),INT(1;N51);TE3(1;N51))
      TE4(1;N51)=Q8VGATHR(AU(4,2,I;NXM7),INT(1;N51);TE4(1;N51))
      TE5(1;N51)=TE4(1;N51)-TE1(1;N51)-3.*(TE3(1;N51)-TE2(1;N51))
      AU2(2,2,I;NXM7)=Q8VSCATR(TE5(1;N51),INT(1;N51);AU2(2,2,I;NXM7))
      TE1(1;N51)=Q8VGATHR(AU(M51,2,I;NXM7),INT(1;N51);TE1(1;N51))
      TE2(1;N51)=Q8VGATHR(AU(M50,2,I;NXM7),INT(1;N51);TE2(1;N51))
      TE3(1;N51)=Q8VGATHR(AU(M11,2,I;NXM7),INT(1;N51);TE3(1;N51))
      TE4(1;N51)=Q8VGATHR(AU(M1,2,I;NXM7),INT(1;N51);TE4(1;N51))
      TE5(1;N51)=TE1(1;N51)-TE4(1;N51)-3.*(TE2(1;N51)-TE3(1;N51))
200   AU2(M11,2,I;NXM7)=Q8VSCATR(TE5(1;N51),INT(1;N51);AU2(M11,2,I;NXM7)
     1)
      DO 210 I=1,4
      AU2(3,1,I;M52)=AUO(5,I;M52)+AUO(1,I;M52)-4.*(AUO(4,I;M52)+AUO(2,I;
     2M52))+6.*AUO(3,I;M52)
      AU2(2,1,I)=AUO(4,I)-AUO(1,I)-3.*(AUO(3,I)-AUO(2,I))
210   AU2(M11,1,I)=AUO(M51,I)-AUO(M1,I)-3.*(AUO(M50,I)-AUO(M11,I))
      DO 220 I=1,5
      AN(2,3,I;NXMM3)=AU1(2,3,I;NXMM3)-CC*(AU(2,5,I;NXMM3)+AU(2,1,I;NXM
     1M3)-4.*(AU(2,4,I;NXMM3)+AU(2,2,I;NXMM3))+6.*AU(2,3,I;NXMM3)+AU2(2,
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     23,I;NXMM3))
      TE1(1;N53)=Q8VGATHR(AU1(M1,2,I;NXM9),INT(1;N53);TE1(1;N53))
      AN(M1,2,I;NXM9)=Q8VSCATR(TE1(1;N53),INT(1;N53);AN(M1,2,I;NXM9))
      AN(2,N1,I;M50)=AU1(2,N1,I;M50)
      AN(2,N14,I;M50)=AU1(2,N14,I;M50)-CC*(AU(2,N52,I;M50)-AU(2,N1,I;M
     150)-3.*(AU(2,N50,I;M50)-AU(2,N14,I;M50))+AU2(2,N14,I;M50))
      AN(2,N15,I;M50)=AU1(2,N15,I;M50)-CC*(AU(2,N53,I;M50)-AU(2,N11,I;M
     150)-3.*(AU(2,N51,I;M50)-AU(2,N15,I;M50))+AU2(2,N15,I;M50))
      AN(2,2,I;M50)=AU1(2,2,I;M50)-CC*(AU(2,4,I;M50)-GM(I)    *AU(2,N12,
     1I;M50)-4.*(AU(2,3,I;M50)+AU(2,1,I;M50))+6.*AU(2,2,I;M50)+AU2(2,2,I
     2;M50))
      AN(2,N12,I;M50)=AU1(2,N12,I;M50)-CC*(AU(2,N13,I;M50)-GM(I)    *AU(
     12,2,I;M50)-4.*(AU(2,N16,I;M50)-GM(I)    *AU(2,1,I;M50))+6.*AU(2,N12
     2,I;M50)+AU2(2,N12,I;M50))
      AN(2,N16,I;M50)=AU1(2,N16,I;M50)-CC*(AU(2,N17,I;M50)-GM(I)    *AU(
     12,1,I;M50)-4.*(AU(2,N13,I;M50)+AU(2,N12,I;M50))+6.*AU(2,N16,I;M50)
     2+AU2(2,N16,I;M50))
 220  AU1(2,2,I;NXM6)=AN(2,2,I;NXM6)
      AU(2,N12,2;M50)=-AU(2,N12,2;M50)
      AU(2,N16,2;M50)=-AU(2,N16,2;M50)
      DO 230 I=1,4
      II=I
      IF(I.EQ.4)II=5
 230  AU1(2,1,I;M50)=AU1(2,1,I;M50)-CC*(AU(2,3,II;M50)+AU(2,N16,II;M50)-
     14.*(AU(2,2,II;M50)+AU(2,N12,II;M50))+6.*AU0(2,I;M50)+AU2(2,1,I;
     2M50))
      AU1(1,3,1;NXM7)=Q8VSCATR(TE8(1;N51),INT(1;N51);AU1(1,3,1;NXM7))
      AU1(1,3,2;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,2;NXM7))
      AU1(1,3,3;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,3;NXM7))
      AU1(1,3,4;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,4;NXM7))
      AU1(1,3,5;NXM7)=Q8VSCATR(TE10(1;N51),INT(1;N51);AU1(1,3,5;NXM7))
      IF(L.GT.LTURB)GO TO 231
      CALL VEC3
      GO TO 232
 231  CALL VEC5
 232  CONTINUE
      CALL VEC4
      CALL BOUND
C     EDDY VISCOSITY CALCULATION.
      IF(L.LT.LTURB)GO TO 235
      LL=L/25
      LL=LL*25
      IF(LL.NE.L)GO TO 450
      CALL DERV
      CALL EDDY
 235  CONTINUE
      LL=L/500
      LL=LL*500
      IF(LL.NE.L)GO TO 450
C     SURFACE HEATING RATE AND SKIN FRICTION COEFFICIENT CALCULATIONS.
      WRITE(6,400) L
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      WRITE(6,405)
      TE(1;N11)=CH(1;N11)
      DO 250 N=1,N11
      DSH1=(4.*SH(2,N)-3.*SH(1,N)-SH(3,N))/ZZ/S(N)
      CH(N)=VIS(1,N)*DSH1*XL
      DU1=(4.*U(2,N)-3.*U(1,N)-U(3,N))/ZZ/S(N)*XL1
      CF(N)=2.*VIS(1,N)*(DU1-U(1,N)*CUR(N)/EMDA(1,N))/RE
  250 WRITE(6,420) Y(N),S(N),US(N),CH(N),CF(N),PW(N)
C     THE CODE CALCULATES ONLY PRESSURE DRAG AT ANGLE OF ATTACK AS A
C     FUNCTION OF LOCAL BODY RADIUS NORMAL TO THE BODY AXIS.
      CP1(1)=PW(1)
      CP2(1)=0.
      CDP1(1)=0.
      CDP2(1)=0.
      DO 340 N=1,N14
      CP1(N+1)=(PW(N+1)+PW(N+N1))/2.
      CP2(N+1)=(PW(N+1)-PW(N+N1))/2.
      CDP1(N+1)=CDP1(N)+.5*DY*(CP1(N)*R(N)*SIN(THE(N))+CP1(N+1)*R(N+1)*
     1SIN(THE(N+1)))
  340 CDP2(N+1)=CDP2(N)+.5*DY*(CP2(N)*R(N)*COS(THE(N))+CP2(N+1)*R(N+1)*
     1COS(THE(N+1)))
      CDP(1)=2.*PW(1)
      DO 350 N=2,N1
  350 CDP(N)=(4.*COS(ALPHA)*CDP1(N)-8.*SIN(ALPHA)*CDP2(N)/PI)/R(N)**2
      WRITE(6,460)(R(N),CDP(N),N=1,N1)
  460 FORMAT(2X,'BODY RADIUS R=',F12.5,10X,'PRESSURE DRAG=',F12.5)
C     CONVERGENCE CHECK. CONVERGENCE CRITERION IS THAT OVER 500 TIME STEPS,
C     THE HEATING RATES SHOULD NOT CHANGE BY MORE THAN  1 PERCENT.
      TE1(1;N11)=CH(1;N11)-TE(1;N11)
      TE1(1;N11)=VABS(TE1(1;N11);TE1(1;N11))
      TE2(1;N11)=CRIT*CH(1;N11)
      II=Q8SGE(TE1(1;N11),TE2(1;N11))
      IF(II.EQ.N11)GO TO 261
      LL=L/5000
      LL=LL*5000
      IF(LL.NE.L)GO TO 450
  261 CONTINUE
      DO 260 N=1,N11
      WRITE(6,421)N,Y(N)
      WRITE(6,431)
      WRITE(6,445)(ZN(M,N),U(M,N),V(M,N),WP(M,N),P(M,N),RO(M,N),T(M,N),
     1H(M,N),VIST(M,N),M=1,M1)
  260 CONTINUE
      IF(II.EQ.N11)GO TO 551
  400 FORMAT(//,10X,'NO.OF ITERATIONS=',I5)
  405 FORMAT(/,1X,'DIST.ALONG BODY',5X,'SHOCK STANDOFF DIST.',5X,'SHOCK
     1SPEED',5X,'STANTON NO.',5X,'SKIN FRICTION',5X,'WALL PR.')
  420 FORMAT(5X,F10.5,10X,F10.5,10X,F10.5,6X,F12.8,6X,F11.7,6X,F10.5)
  421 FORMAT(/,5X,'BODY STATION NO.=',I3,5X,'DIST. ALONG BODY=',F10.5,/)
  431 FORMAT(/,6X,'ZN',9X,'U',9X,'V',8X,'WP',9X,'P',8X,'RO',9X,'T',9X,
     1'H',8X,'VIST')
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      NXM8=NXM-2*M1-1
      NXM9=NXM-4*M1+1
      NXM10=4*NXM
      NXMM=NXM-2*M1+1
      NXMM2=NXM-2*M1-4
      NXMM3=NXM-4*M1-2
C     STEP SIZES
      DZ=-1./M11
      XX=2.*DY
      ZZ=2.*DZ
      Y(1;N1)=Q8VINTL(0.,DY;Y(1;N1))
      Z(1;M1)=Q8VINTL(1.,DZ;Z(1;M1))
      A1=PI/2.-THC
      YM=DY*N14
      RB=((YM-A1)*SIN(THC)+COS(THC))*RN
C     NJ1 IS THE MESH POINT UPSTREAM OF JUNTURE POINT.
      NJ=A1/DY
      NJ1=NJ+1
      NJ2=NJ-1
      NJ3=NJ1+1
C     INITIAL SHOCK SHAPE AND SHOCK SLOPE.
      S(1;NJ1)=.17
      DO 17 N=NJ3,N1
 17    S(N)=S(N-1)+DY*SIN(THESH)
C      BODY GEOMETRY.
       DO 10 N=1,N1
      IF(Y(N).GT.A1)GO TO 11
      THE(N)=PI/2.-Y(N)
      CUR(N)=1.
      R(N)=COS(THE(N))
      GO TO 10
 11   THE(N)=THC
      CUR(N)=0.
      R(N)=COS(THC)+(Y(N)-A1)*SIN(THC)
 10   CONTINUE
      DO 20 N=1,N1
      VS(N)=COS(THE(N))
 20   VN(N)=-SIN(THE(N))
      DO 35 N=1,N1
      S1(1,N;M1)=S(N)
      CUR1(1,N;M1)=CUR(N)
      R1(1,N;M1)=R(N)
 35   THE1(1,N;M1)=THE(N)
      THEC(1,1;NXM)=VCOS(THE1(1,1;NXM);THEC(1,1;NXM))
      THES(1,1;NXM)=VSIN(THE1(1,1;NXM);THES(1,1;NXM))
      INT(1;N1)=Q8VINTL (1,M1;INT(1;N1))
C     CALCULATION OF THE STARTING SOLUTION.
      DO 40 N=1,N1
 40   TEMP(N)=SIN(THE(N))**2*(.9+.1*(N-1)/N1)
      P(1,1;NXM)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );P(1,1;NXM))
      TEMP(1;N1)=0.
```

```
449   FORMAT(1X,9F10.5)
450   L=L+1
      IF(L.LE.LMAX)GO TO 1
551   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BHYP
      DIMENSION CP1(15),CP2(15),CDP1(15),CDP2(15),CDP(15)
      DIMENSION Y(29),THE(29),R(29),CH(29),TEMP1(29),TEMP2(101),Z(101),
     1TZ(101),TZ1(101),GM(5)
      DIMENSION TAU(29,5),TAM(29,5),TAN1(29,5),TAN2(29,5),TAQ(29,5),
     1TAU1(29,5),CF(29)
      DIMENSION TE8(29),TE9(29),TE10(29)
      COMMON/F /THE1(101,29),THE2(101,29),VAIR(101,29),DT(101,29)
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
      COMMON/F4/XX,ZZ,FM,BETA,SIGT
      COMMON/F5/S(29),SS(29),G(29),CUR(29),US(29),DS(29),VS(29),VN(29)
      COMMON/F6/INT(29),TIMP(29),TEMP(29),TE(29),TE1(29),TE2(29),TE3(29)
     1,TE4(29),TE5(29),TE6(29),TE7(29)
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F11/DU(101,29),DSH(101,29),DWP(101,29),A6(101,29),
     1A7(101,29),A8(101,29)
      COMMON/F12/TZ2(101,29),Z1(101,29),TZ3(101,29),TZ4(101,29)
      COMMON/F13/AU1(101,29,5),AU2(101,29,5)
      COMMON/F14/AU(101,29,5),AM(101,29,5),AN(101,29,5),AQ(101,29,5)
      COMMON/F15/AU0(101,4),AM0(101,2,4),AN0(101,4),AQ0(101,4)
      COMMON/F16/HINF,RE1,RE2
      VIS(1,1;2929)=0.
      VIST(1,1;2929)=0.
      AU(1,1,1;14645)=0.
      AM(1,1,1;14645)=0.
      AN(1,1,1;14645)=0.
      AQ(1,1,1;14645)=0.
      AU1(1,1,1;14645)=0.
      AU2(1,1,1;14645)=0.
      CH(1;29)=0.
C     CONSTANTS AND FREESTREAM CONDITIONS
      PI=4.*ATAN(1.)
      GAMA=1.4
      RGAS=287.
      SIG=.72
      CP=GAMA*RGAS/(GAMA-1.)
      SIGT=.9
      CC=.001
      FM=10.3
      TF=46.26
```

```
      PF=100.77
      ROF=PF/TF/RGAS
      ALPHA=5.*PI/180.
      THC=45.*PI/180.
      TW=330.6
      TW=TW/TF
      RN=.03175
      DY=.185
      BETA=1.1
      FDT=1.
      THESH=2.*PI/180.
      VF=FM*(GAMA*RGAS*TF)**.5
      VISF=1.458/10.**6*TF**1.5/(TF+110.)
      RE=VF*ROF*RN/VISF
C     LMAX IS THE MAXIMUM NUMBER OF TIME STEPS AFTER WHICH THE PROGRAM
C     WILL STOP EVEN THOUGH THE SOLUTION MAY NOT BE CONVERGED.
      LMAX=20000
      LTURB=25000
C     FOR LAMINAR FLOW, CALL VEC3 AND FOR TURBULENT FLOW, CALL VEC5
C     LTURB IS THE NUMBER OF ITERATIONS UP TO WHICH THE FLOW REMAINS
C     LAMINAR.
C     CONVERGENCE CRITERION.
      CRIT=.01
      DO 5 I=1,5
 5    GM(I)=(-1.)**I
      GM1=1./GAMA/FM**2
      GM2=2.*GAMA/(1.+GAMA)
      GM3=CP*TF/VF**2
      GM4=SIN(ALPHA)
      GM5=110./TF
      GM6=1.+GM5
      GM7=(GAMA-1.)/(GAMA+1.)
      GM8=(1.+GAMA)/(2.*GAMA*FM**2)
      GM9=(GAMA-1.)/GAMA
      GM10=TW*GM3/GAMA
      HINF=.995*(.5+GM3)
      RE1=SQRT(RE)
      RE2=0.0168*RE
C     MESH SIZES AND VECTOR LENGTHS
      N1=15
      N11=2*N1-1
      N12=N1+1
      N14=N1-1
      N15=N11-1
      N50=N1-2
      N51=N11-2
      N13=N1+3
      N17=N1+4
      N52=N1-3
      N53=N11-3
      N16=N1+2
```

```
      M1=101
      M11=M1-1
      M50=M1-2
      M51=M1-3
      M52=M1-4
      NXM=N11*M1
      NXM1=NXM-M11
      NXM2=NXM-1
      NXM3=NXM-2
      NXM4=NXM-M1
      NXM5=N14*M1
      NXM6=N51*M1-2
      NXM61=N51*M1-1
      NXM7=NXM-3*M1+1
      NXM8=NXM-M1-1
      NXM9=NXM-4*M1+1
      NXM10=5*NXM
      NXMM=NXM-2*M1+1
      NXMM1=5*NXMM
      NXMM2=NXM-2*M1-4
      NXMM3=NXM-4*M1-2
C     STEP SIZES
      DZ=-1./M11
      XX=2.*DY
      ZZ=2.*DZ
      Y(1;N1)=Q8VINTL(0.,DY;Y(1;N1))
      Z(1;M1)=Q8VINTL(1.,DZ;Z(1;M1))
C     INITIAL SHOCK SHAPE AND SHOCK SLOPE.
      S(1;N11)=.17
      DO 15 N=3,N1
   15 S(N)=S(N-1)+DY*SIN(THESH)
      SS(1)=(S(2)-S(N12))/XX
      DO 16 N=2,N14
   16 SS(N)=(S(N+1)-S(N-1))/XX
      SS(N12)=(S(N16)-S(1))/XX
      DO 17 N=N16,N15
   17 SS(N)=(S(N+1)-S(N-1))/XX
      DO 18 N=N1,N11,N14
   18 SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
C      BODY GEOMETRY.
      CUR(1)=1.
      THE(1)=PI/2.
      R(1)=0.
      A=1./TAN(THC)**2
      B=SQRT(A)
      DO 10 N=2,N1
      F1=DY*SQRT((B**2+R(N-1)**2)/(B**2+(1.+(A/B)**2)*R(N-1)**2))
      F2=DY*SQRT((B**2+(R(N-1)+F1/2.)**2)/(B**2+(1.+(A/B)**2)*
     1(R(N-1)+F1/2.)**2))
      F3=DY*SQRT((B**2+(R(N-1)+F2/2.)**2)/(B**2+(1.+(A/B)**2)
     1*(R(N-1)+F2/2.)**2))
```

```
      F4=DY*SQRT((B**2+(R(N-1)+F3)**2)/(B**2+(1.+(A/B)**2)*(R(N-1)+F3)
     1**2))
      R(N)=R(N-1)+(F1+2.*F2+2.*F3+F4)/6.
      X=A*SQRT(B**2+R(N)**2)/B
      CUR(N)=A**4*B**4/(A**4*R(N)**2+B**4*X**2)**1.5
      X=B*X/(A*SQRT(X**2-A**2))
10    THE(N)=ATAN(X)
      Y(N12;N14)=Y(2;N14)
      R(N12;N14)=R(2;N14)
      THE(N12;N14)=THE(2;N14)
      CUR(N12;N14)=CUR(2;N14)
      DO 20 N=1,N1
      VS(N)=COS(THE(N)-ALPHA)
20    VN(N)=SIN(ALPHA-THE(N))
      DO 25 N=N12,N11
      VS(N)=COS(ALPHA+THE(N))
25    VN(N)=-SIN(ALPHA+THE(N))
      DO 35 N=1,N11
      S1(1,N;M1)=S(N)
      CUR1(1,N;M1)=CUR(N)
      R1(1,N;M1)=R(N)
35    THE1(1,N;M1)=THE(N)
      THEC(1,1;NXM)=VCOS(THE1(1,1;NXM);THEC(1,1;NXM))
      THES(1,1;NXM)=VSIN(THE1(1,1;NXM);THES(1,1;NXM))
      B1=(BETA+1.)/(BETA-1.)
      B2=2.*BETA/ALOG(B1)
      XL1=    -B2/(BETA**2-1.)
      XL=-2.*B2/(BETA**2-1.)/SIG/RE
      TZ(1;M1)=B1**(Z(1;M1))
      TZ1(1;M1)=BETA*(TZ(1;M1)-1.)/(TZ(1;M1)+1.)
      DO 30 N=1,N11
30    Z1(1,N;M1)=TZ1(1;M1)
      ZN(1,1;NXM)=S1(1,1;NXM)*(1.-Z1(1,1;NXM))
      EMDA(1,1;NXM)=1.+ZN(1,1;NXM)*CUR1(1,1;NXM)
      BT(1,1;NXM)=R1(1,1;NXM)+ZN(1,1;NXM)*THEC(1,1;NXM)
      TZ2(1,1;NXM)=BETA**2-Z1(1,1;NXM)**2
      TZ3(1,1;NXM)=2.*Z1(1,1;NXM)/TZ2(1,1;NXM)
      TZ4(1,1;NXM)=B2/TZ2(1,1;NXM)
      INT(1;N11)=Q8VINTL (1,M1;INT(1;N11))
C     CALCULATION OF THE STARTING SOLUTION.
      DO 40 N=1,N1
40    TEMP(N)=SIN(THE(N)-ALPHA)**2*(.9+.1*(N-1)/N1)
      DO 45 N=N12,N11
45    TEMP(N)=SIN(THE(N)+ALPHA)**2*(.9+.1*(N-N1)/N1)
      P(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);P(1,1;NXM))
      TEMP(1;N11)=0.
      U(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);U(1,1;NXM))
      V(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);V(1,1;NXM))
      WP(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);WP(1,1;NXM))
      TEMP(1;N11)=TW
      T(1,1;NXM)=Q8VSCATR(TEMP(1;N11),INT(1;N11);T(1,1;NXM))
```

```
      TE5(1;N11)=SS(1;N11)/(1.+S(1;N11)*CUR(1;N11))
      TE6(1;N11)=1.+TE5(1;N11)*TE5(1;N11)
      TE6(1;N11)=VSQRT(TE6(1;N11);TE6(1;N11))
      TE7(1;N11)=-(VN(1;N11)-VS(1;N11)*TE5(1;N11))/TE6(1;N11)
      TEMP(1;N11)=(TE7(1;N11)*TE7(1;N11)/GM8-GM7)*GM1
      P(M1,1;NXM1)=Q8VSCATR(TEMP(1;N11),INT(1;N11);P(M1,1;NXM1))
      TEMP(1;N11)=TEMP(1;N11)/GM1
      TE(1;N11)=(TEMP(1;N11)+GM7)/(1.+TEMP(1;N11)*GM2)
      TE1(1;N11)=(1.-1./TE(1;N11))*TE7(1;N11)/TE6(1;N11)
      TE2(1;N11)=VS(1;N11)-TE1(1;N11)*TE5(1;N11)
      TE3(1;N11)=VN(1;N11)+TE1(1;N11)
      TE4(1;N11)=TEMP(1;N11)/TE(1;N11)
      U(M1,1;NXM1)=Q8VSCATR(TE2(1;N11),INT(1;N11);U(M1,1;NXM1))
      V(M1,1;NXM1)=Q8VSCATR(TE3(1;N11),INT(1;N11);V(M1,1;NXM1))
      T(M1,1;NXM1)=Q8VSCATR(TE4(1;N11),INT(1;N11);T(M1,1;NXM1))
      DO 61 N=2,N1
      DDEL=-(S(N)-S(N+N14))/2.
61    WP(M1,N)=-GM4-TE1(N)*DDEL/BT(M1,N)
      DO 65 N=N12,N11
      DDEL=(S(N-N14)-S(N))/2.
65    WP(M1,N)=GM4-TE1(N)*DDEL/BT(M1,N)
      WP(M1,1)=-U(M1,1)
      DO 50 N=1,N11
      DXU=(U(M1,N)-U(1,N))/M11
      DXV=(V(M1,N)-V(1,N))/M11
      DXP=(P(M1,N)-P(1,N))/M11
      DXT=(T(M1,N)-T(1,N))/M11
      DXWP=(WP(M1,N)-WP(1,N))/M11
      U(1,N;M11)=Q8VINTL(U(1,N),DXU;U(1,N;M11))
      V(1,N;M11)=Q8VINTL(V(1,N),DXV;V(1,N;M11))
      P(1,N;M11)=Q8VINTL(P(1,N),DXP;P(1,N;M11))
      T(1,N;M11)=Q8VINTL(T(1,N),DXT;T(1,N;M11))
50    WP(1,N;M11)=Q8VINTL(WP(1,N),DXWP;WP(1,N;M11))
      RO(1,1;NXM)=P(1,1;NXM)/T(1,1;NXM)/GM1
      SH(1,1;NXM)=T(1,1;NXM)*GM3
      H(1,1;NXM)=SH(1,1;NXM)+(U(1,1;NXM)**2+V(1,1;NXM)**2)/2.
      TV2(1,1;NXM)=VSQRT(T(1,1;NXM);TV2(1,1;NXM))
      VIS(1,1;NXM)=T(1,1;NXM)*TV2(1,1;NXM)*GM6/(T(1,1;NXM)+GM5)
      WRITE (6,399) ALPHA,RE,FM
399   FORMAT(/,1X,'ALPHA',F8.5,5X,'REYN NO.',F15.3,5X,'MACH NO.',F8.3,/)
      WRITE(6,435)(Y(N),THE(N),R(N),CUR(N),N=1,N11)
435   FORMAT(2X,'Y=',F10.5,5X,'THE=',F10.5,5X,'R=',F10.5,5X,'CUR=',F10.5
     1)
      DO 60 N=1,N11,2
      WRITE(6,421)N,Y(N)
      WRITE(6,430)
      WRITE(6,440)(            Z1(M,N),U(M,N),V(M,N),WP(M,N),P(M,N),RO(M,N
     1),T(M,N),H(M,N),M=1,M1)
60    CONTINUE
430   FORMAT(/,              6X,'Z1',9X,'U',9X,'V',8X,'WP',9X,'P',8X,'RO',
     19X,'T',9X,'H')
```

```
440   FORMAT(1X,8F10.5)
      DM=-1./4./M11
      TEMP2(1;M11)=Q8VINTL(1.+DM,DM;TEMP2(1;M11))
      AU1(1,1,1;NXM10)=1.
      TE8(1;N51)=1.
      TE9(1;N51)=0.
      TE10(1;N51)=GM10
      L=1
C     MARCHING IN TIME STARTS HERE.
 1    CONTINUE
      MM=1
C     LOCAL TIME STEP CALCULATION.
      VAIR(1,1;NXM2)=GAMA*P(1,1;NXM2)/RO(1,1;NXM2)
      VAIR(1,1;NXM2)=VSQRT(VAIR(1,1;NXM2);VAIR(1,1;NXM2))
      DT(1,1;NXM2)=FDT*(ZN(2,1;NXM2)-ZN(1,1;NXM2))/(VABS(V(1,1;NXM2);
     1THF2(1,1;NXM2))+VAIR(1,1;NXM2))
      DO 70 N=1,N11
 70   DT(1,N;M11)=DT(1,N;M11)*TEMP2(1;M11)
      TIMP(1;N11)=Q8VGATHR(DT(M11,1;NXM1),INT(1;N11);TIMP(1;N11))
      DT(M1,1;NXM1)=Q8VSCATR(TIMP(1;N11),INT(1;N11);DT(M1,1;NXM1))
C     PREDICTOR STEP.
      SS(1)=(S(2)-S(N12))/XX
      DO 74 N=2,N14
 74   SS(N)=(S(N+1)-S(N-1))/XX
      SS(N12)=(S(N16)-S(1))/XX
      DO 75 N=N1,N11,N14
 75   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      DO 76 N=N16,N15
 76   SS(N)=(S(N+1)-S(N-1))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 110 I=1,5
      AU1(2,2,I;NXM6)=AU(2,2,I;NXM6)-DT(2,2;NXM6)*((AM(2,3,I;NXM6)-AM(2,
     12,I;NXM6))/DY+(AN(3,2,I;NXM6)-AN(2,2,I;NXM6))/DZ+AQ(2,2,I;NXM6))
      AU1(2,N1,I;M50)=AU(2,N1,I;M50)-DT(2,N1;M50)*((AM(2,N1,I;M50)-AM(2,
     1N14,I;M50))/DY+(AN(3,N1,I;M50)-AN(2,N1,I;M50))/DZ+AQ(2,N1,I;M50))
      AU1(2,N11,I;M50)=AU(2,N11,I;M50)-DT(2,N11;M50)*((AM(2,N11,I;M50)-
     1AM(2,N15,I;M50))/DY+(AN(3,N11,I;M50)-AN(2,N11,I;M50))/DZ+AQ(2,N11,
     2I;M50))
      TAU(1,I;N11)=Q8VGATHR(AU(M1,1,I;NXM1),INT(1;N11);TAU(1,I;N11))
      TAM(1,I;N11)=Q8VGATHR(AM(M1,1,I;NXM1),INT(1;N11);TAM(1,I;N11))
      TAN1(1,I;N11)=Q8VGATHR(AN(M1,1,I;NXM1),INT(1;N11);TAN1(1,I;N11))
      TAN2(1,I;N11)=Q8VGATHR(AN(M11,1,I;NXM1),INT(1;N11);TAN2(1,I;N11))
      TAQ(1,I;N11)=Q8VGATHR(AQ(M1,1,I;NXM1),INT(1;N11);TAQ(1,I;N11))
      TAU1(2,I;N15)=TAU(2,I;N15)-TIMP(2;N15)*((TAM(3,I;N15)-TAM(2,I;N15)
     1)/DY+(TAN1(2,I;N15)-TAN2(2,I;N15))/DZ+TAQ(2,I;N15))
      TAU1(N1,I)=TAU(N1,I)-TIMP(N1)*((TAM(N1,I)-TAM(N14,I))/DY+(TAN1(N1,
     1I)-TAN2(N1,I))/DZ+TAQ(N1,I))
      TAU1(N11,I)=TAU(N11,I)-TIMP(N11)*((TAM(N11,I)-TAM(N15,I))/DY+(TAN1
     1(N11,I)-TAN2(N11,I))/DZ+TAQ(N11,I))
```

```
110   AU1(M1,2,I;NXMM)=Q8VSCATR(TAU1(2,I;N15),INT(1;N15);AU1(M1,2,I;
     1NXMM))
      CALL VEC2
      DO 150 I=1,4
      AU1(2,1,I;M50)=AU0(2,I;M50)-DT(2,1;M50)*((AM0(2,2,I;M50)-AM0(2,1,I
     1;M50))/DY+(AN0(3,I;M50)-AN0(2,I;M50))/DZ+AQ0(2,I;M50))
150   AU1(M1,1,I)=AU0(M1,I)-DT(M1,1)*((AM0(M1,2,I)-AM0(M1,1,I))/DY+(AN0(
     1M1,I)-AN0(M11,I))/DZ+AQ0(M1,I))
      AU1(1,3,1;NXM7)=Q8VSCATR(TE8(1;N51),INT(1;N51);AU1(1,3,1;NXM7))
      AU1(1,3,2;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,2;NXM7))
      AU1(1,3,3;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,3;NXM7))
      AU1(1,3,4;NXM7)=Q8VSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,4;NXM7))
      AU1(1,3,5;NXM7)=Q8VSCATR(TE10(1;N51),INT(1;N51);AU1(1,3,5;NXM7))
      IF(L.GT.LTURB)GO TO 154
      CALL VEC3
      GO TO 155
154   CALL VEC5
155   CONTINUE
      CALL VEC4
      CALL BOUND
C     CORRECTOR STEP.
      DO 160 I=1,5
160   AU2(2,2,I;NXM8)=AU(2,2,I;NXM8)+AU1(2,2,I;NXM8)
      DO 170 I=1,4
170   AU2(2,1,I;M11)=AU0(2,I;M11)+AU1(2,1,I;M11)
      MM=2
      SS(1)=(S(2)-S(N12))/XX
      DO 174 N=2,N14
174   SS(N)=(S(N+1)-S(N-1))/XX
      SS(N12)=(S(N16)-S(1))/XX
      DO 175 N=N1,N11,N14
175   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      DO 176 N=N16,N15
176   SS(N)=(S(N+1)-S(N-1))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 180 I=1,5
      AU1(2,2,I;NXM8)=0.5*(AU2(2,2,I;NXM8)-DT(2,2;NXM8)*((AM(2,2,I;NXM8)
     1-AM(2,1,I;NXM8))/DY+(AN(2,2,I;NXM8)-AN(1,2,I;NXM8))/DZ+AQ(2,2,I;
     2NXM8)))
      AM(1,1,I;M1)=GM(I)    *AM(1,1,I;M1)
180   AU1(2,N12,I;M11)=.5*(AU2(2,N12,I;M11)-DT(2,N12;M11)*((AM(2,N12,I;
     1M11)-AM(2,1,I;M11))/DY+(AN(2,N12,I;M11)-AN(1,N12,I;M11))/DZ+AQ(2,
     2N12,I;M11)))
      WP(1,N12;M1)=-WP(1,N12;M1)
      U(1,N12;M1)=-U(1,N12;M1)
      CALL VEC2
      DO 190 I=1,4
190   AU1(2,1,I;M11)=.5*(AU2(2,1,I;M11)-DT(2,1;M11)*((AM0(2,1,I;M11)-AM0
     1(2,2,I;M11))/DY+(AN0(2,I;M11)-AN0(1,I;M11))/DZ+AQ0(2,I;M11)))
```

```
C     FOURTH ODER DAMPING.  CC IS THE DAMPING COEFFICIENT.
      DO 200 I=1,5
      AU2(3,2,I;NXMM2)=AU(5,2,I;NXMM2)+AU(1,2,I;NXMM2)-4.*(AU(4,2,I;NXMM
     12)+AU(2,2,I;NXMM2))+6.*AU(3,2,I;NXMM2)
      TE1(1;N51)=Q8VGATHR(AU(1,2,I;NXM7),INT(1;N51);TE1(1;N51))
      TE2(1;N51)=Q8VGATHR(AU(2,2,I;NXM7),INT(1;N51);TE2(1;N51))
      TE3(1;N51)=Q8VGATHR(AU(3,2,I;NXM7),INT(1;N51);TE3(1;N51))
      TE4(1;N51)=Q8VGATHR(AU(4,2,I;NXM7),INT(1;N51);TE4(1;N51))
      TE5(1;N51)=TE4(1;N51)-TE1(1;N51)-3.*(TE3(1;N51)-TE2(1;N51))
      AU2(2,2,I;NXM7)=Q8VSCATR(TE5(1;N51),INT(1;N51);AU2(2,2,I;NXM7))
      TE1(1;N51)=Q8VGATHR(AU(M51,2,I;NXM7),INT(1;N51);TE1(1;N51))
      TE2(1;N51)=Q8VGATHR(AU(M50,2,I;NXM7),INT(1;N51);TE2(1;N51))
      TE3(1;N51)=Q8VGATHR(AU(M11,2,I;NXM7),INT(1;N51);TE3(1;N51))
      TE4(1;N51)=Q8VGATHR(AU(M1,2,I;NXM7),INT(1;N51);TE4(1;N51))
      TE5(1;N51)=TE1(1;N51)-TE4(1;N51)-3.*(TE2(1;N51)-TE3(1;N51))
  200 AU2(M11,2,I;NXM7)=Q8VSCATR(TE5(1;N51),INT(1;N51);AU2(M11,2,I;NXM7)
     1)
      DO 210 I=1,4
      AU2(3,1,I;M52)=AU0(5,I;M52)+AU0(1,I;M52)-4.*(AU0(4,I;M52)+AU0(2,I;
     2M52))+6.*AU0(3,I;M52)
      AU2(2,1,I)=AU0(4,I)-AU0(1,I)-3.*(AU0(3,I)-AU0(2,I))
  210 AU2(M11,1,I)=AU0(M51,I)-AU0(M1,I)-3.*(AU0(M50,I)-AU0(M11,I))
      DO 220 I=1,5
       AN(2,3,I;NXMM3)=AU1(2,3,I;NXMM3)-CC*(AU(2,5,I;NXMM3)+AU(2,1,I;NXM
     1M3)-4.*(AU(2,4,I;NXMM3)+AU(2,2,I;NXMM3))+6.*AU(2,3,I;NXMM3)+AU2(2,
     23,I;NXMM3))
      TE1(1;N53)=Q8VGATHR(AU1(M1,2,I;NXM9),INT(1;N53);TE1(1;N53))
      AN(M1,2,I;NXM9)=Q8VSCATR(TE1(1;N53),INT(1;N53);AN(M1,2,I;NXM9))
      AN(2,N1,I;M50)=AU1(2,N1,I;M50)
       AN(2,N14,I;M50)=AU1(2,N14,I;M50)-CC*(AU(2,N52,I;M50)-AU(2,N1,I;M
     150)-3.*(AU(2,N50,I;M50)-AU(2,N14,I;M50))+AU2(2,N14,I;M50))
       AN(2,N15,I;M50)=AU1(2,N15,I;M50)-CC*(AU(2,N53,I;M50)-AU(2,N11,I;M
     150)-3.*(AU(2,N51,I;M50)-AU(2,N15,I;M50))+AU2(2,N15,I;M50))
       AN(2,2,I;M50)=AU1(2,2,I;M50)-CC*(AU(2,4,I;M50)-GM(I)    *AU(2,N12,
     1I;M50)-4.*(AU(2,3,I;M50)+AU(2,1,I;M50))+6.*AU(2,2,I;M50)+AU2(2,2,I
     2;M50))
       AN(2,N12,I;M50)=AU1(2,N12,I;M50)-CC*(AU(2,N13,I;M50)-GM(I)    *AU(
     12,2,I;M50)-4.*(AU(2,N16,I;M50)-GM(I)    *AU(2,1,I;M50))+6.*AU(2,N12
     2,I;M50)+AU2(2,N12,I;M50))
       AN(2,N16,I;M50)=AU1(2,N16,I;M50)-CC*(AU(2,N17,I;M50)-GM(I)    *AU(
     12,1,I;M50)-4.*(AU(2,N13,I;M50)+AU(2,N12,I;M50))+6.*AU(2,N16,I;M50)
     2+AU2(2,N16,I;M50))
  220 AU1(2,2,I;NXM6)=AN(2,2,I;NXM6)
      AU(2,N12,2;M50)=-AU(2,N12,2;M50)
      AU(2,N16,2;M50)=-AU(2,N16,2;M50)
      DO 230 I=1,4
      II=I
      IF(I.EQ.4)II=5
  230 AU1(2,1,I;M50)=AU1(2,1,I;M50)-CC*(AU(2,3,II;M50)+AU(2,N16,II;M50)-
     14.*(AU(2,2,II;M50)+AU(2,N12,II;M50))+6.*AU0(2,I;M50)+AU2(2,1,I;
     2M50))
```

```
      AU1(1,3,1;NXM7)=QBVSCATR(TE8(1;N51),INT(1;N51);AU1(1,3,1;NXM7))
      AU1(1,3,2;NXM7)=QBVSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,2;NXM7))
      AU1(1,3,3;NXM7)=QBVSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,3;NXM7))
      AU1(1,3,4;NXM7)=QBVSCATR(TE9(1;N51),INT(1;N51);AU1(1,3,4;NXM7))
      AU1(1,3,5;NXM7)=QBVSCATR(TE10(1;N51),INT(1;N51);AU1(1,3,5;NXM7))
      IF(L.GT.LTURB)GO TO 231
      CALL VEC3
      GO TO 232
 231  CALL VEC5
 232  CONTINUE
      CALL VEC4
      CALL BOUND
C     EDDY VISCOSITY CALCULATION.
      IF(L.LT.LTURB)GO TO 235
      LL=L/25
      LL=LL*25
      IF(LL.NE.L)GO TO 450
      CALL DERV
      CALL EDDY
 235  CONTINUE
      LL=L/500
      LL=LL*500
      IF(LL.NE.L)GO TO 450
C     SURFACE HEATING RATE AND SKIN FRICTION COEFFICIENT CALCULATIONS.
      WRITE(6,400) L
      WRITE(6,405)
      TE(1;N11)=CH(1;N11)
      DO 250 N=1,N11
      DSH1=(4.*SH(2,N)-3.*SH(1,N)-SH(3,N))/ZZ/S(N)
      CH(N)=VIS(1,N)*DSH1*XL
      DU1=(4.*U(2,N)-3.*U(1,N)-U(3,N))/ZZ/S(N)*XL1
      CF(N)=2.*VIS(1,N)*(DU1-U(1,N)*CUR(N)/EMDA(1,N))/RE
 250  WRITE(6,420) Y(N),S(N),US(N),CH(N),CF(N),PW(N)
C     THE CODE CALCULATES ONLY PRESSURE DRAG AT ANGLE OF ATTACK AS A FUNCTION OF
C     FUNCTION OF LOCAL BODY RADIUS NORMAL TO THE BODY AXIS.
      CP1(1)=PW(1)
      CP2(1)=0.
      CDP1(1)=0.
      CDP2(1)=0.
      DO 340 N=1,N14
      CP1(N+1)=(PW(N+1)+PW(N+N1))/2.
      CP2(N+1)=(PW(N+1)-PW(N+N1))/2.
      CDP1(N+1)=CDP1(N)+.5*DY*(CP1(N)*R(N)*SIN(THE(N))+CP1(N+1)*R(N+1)*
     1SIN(THE(N+1)))
 340  CDP2(N+1)=CDP2(N)+.5*DY*(CP2(N)*R(N)*COS(THE(N))+CP2(N+1)*R(N+1)*
     1COS(THE(N+1)))
      CDP(1)=2.*PW(1)
      DO 350 N=2,N1
 350  CDP(N)=(4.*COS(ALPHA)*CDP1(N)-8.*SIN(ALPHA)*CDP2(N)/PI)/R(N)**2
      WRITE(6,460)(R(N),CDP(N),N=1,N1)
 460  FORMAT(2X,'BODY RADIUS R=',F12.5,10X,'PRESSURE DRAG=',F12.5)
```

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C     CONVERGENCE CHECK, CONVERGENCE CRITERION IS THAT OVER 500 TIME STEPS,
C     THE HEATING RATES SHOULD NOT CHANGE BY MORE THAN  1 PERCENT.
      TE1(1;N11)=CH(1;N11)-TE(1;N11)
      TE1(1;N11)=VABS(TE1(1;N11);TE1(1;N11))
      TE2(1;N11)=CRIT*CH(1;N11)
      II=Q8SGE(TE1(1;N11),TE2(1;N11))
      IF(II.EQ.N11)GO TO 261
      LL=L/5000
      LL=LL*5000
      IF(LL.NE.L)GO TO 450
  261 CONTINUE
      DO 260 N=1,N11
      WRITE(6,421)N,Y(N)
      WRITE(6,431)
      WRITE(6,445)(ZN(M,N),U(M,N),V(M,N),WP(M,N),P(M,N),RO(M,N),T(M,N),
     1H(M,N),VIST(M,N),M=1,M1)
  260 CONTINUE
      IF(II.EQ.N11)GO TO 551
  400 FORMAT(//,10X,'NO.OF ITERATIONS=',I5)
  405 FORMAT(/,1X,'DIST.ALONG BODY',5X,'SHOCK STANDOFF DIST.',5X,'SHOCK
     1SPEED',5X,'STANTON NO.',5X,'SKIN FRICTION',5X,'WALL PR.')
  420 FORMAT(5X,F10.5,10X,F10.5,10X,F10.5,6X,F12.8,6X,F11.7,6X,F10.5)
  421 FORMAT(/,5X,'BODY STATION NO.=',I3,5X,'DIST. ALONG BODY=',F10.5,/)
  431 FORMAT(/,6X,'ZN',9X,'U',9X,'V',8X,'WP',9X,'P',8X,'RO',9X,'T',9X,
     1'H',8X,'VIST')
  445 FORMAT(1X,9F10.5)
  450 L=L+1
      IF(L.LE.LMAX)GO TO 1
  551 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EDDY
      DIMENSION PE(29),DPE(29),BLD(29),BLE(29),UE(29),CUT2(101)
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,SIGT
      COMMON/F5/S(29),SS(29),G(29),CUR(29),US(29),DS(29),VS(29),VN(29)
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),FMDA(101,29),ZN(101,29)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F11/DU(101,29),DSH(101,29),DWP(101,29),A6(101,29),
     1A7(101,29),A8(101,29)
      COMMON/F16/HINF,RE1,RE2
      DO 3075 N=1,N11
      DO 3070 M=15,M11
      IF(H(M,N).GE.HINF)GO TO 3072
 3070 CONTINUE
 3072 BLE(N)=ZN(M,N)
      UE(N)=U(M,N)
      PE(N)=P(M,N)
      BLD(N)=0.
      DO 3073 J=2,M
      J1=J-1
 3073 BLD(N)=BLD(N)+(2.-(U(J1,N)+U(J,N))/UE(N))*(ZN(J,N)-ZN(J1,N))/2.
 3075 CONTINUE
      DO 3085 N=2,N15
 3085 DPE(N)=(PE(N+1)-PE(N-1))/XX
      DO 3095 N=N1,N11,N14
 3095 DPE(N)=(PE(N)-PE(N-1))/XX*2.
      DPE(1)=(PE(2)-PE(N12))/XX
      DPE(N12)=(PE(N16)-PE(1))/XX
      DO 3110 N=1,N11
      CUT2(1;M1)=1./(1.+5.5*(ZN(1,N;M1)/BLE(N))**6)
      TV2(1,N;M1)=RE2*RO(1,N;M1)*UE(N)*BLD(N)*CUT2(1;M1)/VIS(1,N;M1)
      TV1(1,N)=0.
      CUTT=SQRT(VIS(1,N)*DU(1,N))
      CUT2(1;M1)=VABS(DU(1,N;M1);CUT2(1;M1))
      DO 3115 M=2,M1
      CUT=CUTT/SQRT(RO(M,N))
      UTAU=CUT/RE1
      PPLUS=-DPE(N)*VIS(M,N)/RE/RO(M,N)**2/UTAU**3
      CUT1=1.-11.8*PPLUS
      IF(CUT1.LE.0.)GO TO 3137
      APLUS=26./SQRT(CUT1)
      CNPLUS=ZN(M,N)*RO(M,N)*RE1/VIS(M,N)*CUT
      ANPLUS=CNPLUS/APLUS
      IF(ANPLUS.GT.12.)GO TO 3116
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      VISTL=.4*ZN(M,N)*(1.-1./EXP(ANPLUS))
      GO TO 3115
 3116 VISTL=.4*ZN(M,N)
 3115 TV1(M,N)=RE*RD(M,N)*VISTL**2/VIS(M,N)*CUT2(M)
 3137 MB=M-1
      DO 3130 M=1,MB
      DVIS=TV2(M,N)-TV1(M,N)
      IF(DVIS.LE.0.)GO TO 3135
 3130 VIST(M,N)=TV1(M,N)
      M=M+1
 3135 MB1=M1-M+1
 3110 VIST(M,N;MB1)=TV2(M,N;MB1)
      RETURN
      END
```

```
      SUBROUTINE SHOCK
      DIMENSION A2(29),VNF(29)
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,SIGT
      COMMON/F5/S(29),SS(29),G(29),CUR(29),US(29),DS(29),VS(29),VN(29)
      COMMON/F6/INT(29),TIMP(29),TEMP(29),TE(29),TE1(29),TE2(29),TE3(29)
     1,TE4(29),TE5(29),TE6(29),TE7(29)
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F12/TZ2(101,29),Z1(101,29),TZ3(101,29),TZ4(101,29)
      A2(1;N11)=SS(1;N11)/(1.+S(1;N11)*CUR(1;N11))
      G(1;N11)=1.+A2(1;N11)*A2(1;N11)
      G(1;N11)=VSQRT(G(1;N11);G(1;N11))
      TEMP(1;N11)=Q8VGATHR(P(M1,1;NXM1),INT(1;N11);TEMP(1;N11))
      TEMP(1;N11)=TEMP(1;N11)/GM1
      TE(1;N11)=(TEMP(1;N11)+GM7)/(1.+TEMP(1;N11)*GM7)
      VNF(1;N11)=GM8*(TEMP(1;N11)+GM7)
      VNF(1;N11)=VSQRT(VNF(1;N11);VNF(1;N11))
      US(1;N11)=VNF(1;N11)+(VN(1;N11)-VS(1;N11)*A2(1;N11))/G(1;N11)
      TE1(1;N11)=(1.-1./TE(1;N11))*VNF(1;N11)/G(1;N11)
      TE2(1;N11)=VS(1;N11)-TE1(1;N11)*A2(1;N11)
      TE3(1;N11)=VN(1;N11)+TE1(1;N11)
      TE4(1;N11)=TEMP(1;N11)/TE(1;N11)
      TEMP(1;N11)=VSQRT(TE4(1;N11);TEMP(1;N11))
      TE5(1;N11)=TE4(1;N11)*TEMP(1;N11)*GM6/(TE4(1;N11)+GM5)
      TE6(1;N11)=TE4(1;N11)*GM3
      TE7(1;N11)=TE6(1;N11)+(TE2(1;N11)*TE2(1;N11)+TE3(1;N11)*TE3(1;N11)
     1)/2.
      RO(M1,1;NXM1)=Q8VSCATR(TE(1;N11),INT(1;N11);RO(M1,1;NXM1))
      U(M1,1;NXM1)=Q8VSCATR(TE2(1;N11),INT(1;N11);U(M1,1;NXM1))
      V(M1,1;NXM1)=Q8VSCATR(TE3(1;N11),INT(1;N11);V(M1,1;NXM1))
      T(M1,1;NXM1)=Q8VSCATR(TE4(1;N11),INT(1;N11);T(M1,1;NXM1))
      VIS(M1,1;NXM1)=Q8VSCATR(TE5(1;N11),INT(1;N11);VIS(M1,1;NXM1))
      SH(M1,1;NXM1)=Q8VSCATR(TE6(1;N11),INT(1;N11);SH(M1,1;NXM1))
      H(M1,1;NXM1)=Q8VSCATR(TE7(1;N11),INT(1;N11);H(M1,1;NXM1))
      DO 60 N=2,N1
      DDEL=-(S(N)-S(N+N14))/2.
   60 WP(M1,N)=-GM4-TE1(N)*DDEL/BT(M1,N)
      DO 65 N=N12,N11
      DDEL=(S(N-N14)-S(N))/2.
   65 WP(M1,N)=GM4-TE1(N)*DDEL/BT(M1,N)
```

```
      WP(M1,1)=-U(M1,1)
      IF(MM.EQ.2)GO TO 70
      DS(1;N11)=US(1;N11)*G(1;N11)
      GO TO 71
 70   DS(1;N11)=(DS(1;N11)+US(1;N11)*G(1;N11))/2.
 71   S(1;N11)=S(1;N11)+DS(1;N11)*TIMP(1;N11)
      DO 75 N=1,N11
      S1(1,N;M1)=S(N)
      SS1(1,N;M1)=SS(N)
 75   DS1(1,N;M1)=DS(N)
      ZN(1,1;NXM)=S1(1,1;NXM)*(1.-Z1(1,1;NXM))
      EMDA(1,1;NXM)=1.+ZN(1,1;NXM)*CUR1(1,1;NXM)
      BT(1,1;NXM)=R1(1,1;NXM)+ZN(1,1;NXM)*THEC(1,1;NXM)
      RETURN
      END
```

```
      SUBROUTINE DERV
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,SIGT
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F11/DU(101,29),DSH(101,29),DWP(101,29),A6(101,29),
     1A7(101,29),A8(101,29)
      COMMON/F12/TZ2(101,29),Z1(101,29),TZ3(101,29),TZ4(101,29)
      TV1(1,1;NXM)=-ZZ*S1(1,1;NXM)*TZ2(1,1;NXM)/B2
      DU(2,1;NXM3)=(U(3,1;NXM3)-U(1,1;NXM3))/TV1(2,1;NXM3)
      DWP(2,1;NXM3)=(WP(3,1;NXM3)-WP(1,1;NXM3))/TV1(2,1;NXM3)
      DSH(2,1;NXM3)=(SH(3,1;NXM3)-SH(1,1;NXM3))/TV1(2,1;NXM3)
      DO 70 N=1,N11
      DU(1,N)=(4.*U(2,N)-3.*U(1,N)-U(3,N))/TV1(1,N)
      DWP(1,N)=(4.*WP(2,N)-3.*WP(1,N)-WP(3,N))/TV1(1,N)
      DSH(1,N)=(4.*SH(2,N)-3.*SH(1,N)-SH(3,N))/TV1(1,N)
      DU(M1,N)=-(4.*U(M11,N)-3.*U(M1,N)-U(M50,N))/TV1(M1,N)
      DSH(M1,N)=-(4.*SH(M11,N)-3.*SH(M1,N)-SH(M50,N))/TV1(M1,N)
70    DWP(M1,N)=-(4.*WP(M11,N)-3.*WP(M1,N)-WP(M50,N))/TV1(M1,N)
      A6(1,1;NXM)=VIS(1,1;NXM)/RE*(DU(1,1;NXM)-U(1,1;NXM)*CUR1(1,1;NXM)/
     1EMDA(1,1;NXM))
      A7(1,2;NXM4)=VIS(1,2;NXM4)/RE*(DWP(1,2;NXM4)-WP(1,2;NXM4)*THEC(1,2
     1;NXM4)/BT(1,2;NXM4))
      A8(1,1;NXM)=(1.-Z1(1,1;NXM))/S1(1,1;NXM)
      RETURN
      END
```

```
      SUBROUTINE BOUND
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,R2,RE,TW,GAMA,SIG,MM
      COMMON/F6/INT(29),TIMP(29),TEMP(29),TE(29),TE1(29),TE2(29),TE3(29)
     1,TE4(29),TE5(29),TE6(29),TE7(29)
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      TEMP(1;N11)=Q8VGATHR(P(2,1;NXM1),INT(1;N11);TEMP(1;N11))
      P(1,1;NXM1)=Q8VSCATR(TEMP(1;N11),INT(1;N11);P(1,1;NXM1))
      PW(1;N11)=TEMP(1;N11)
      TEMP(1;N11)=TEMP(1;N11)/TW/GM1
      RO(1,1;NXM1)=Q8VSCATR(TEMP(1;N11),INT(1;N11);RO(1,1;NXM1))
      RETURN
      END
```

```
 SUBROUTINE VEC1
 DIMENSION DP(101,29),A9(101,29),A10(101,29),A13(101,29),AA1(101,
129),AA2(101,29)
 COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
 COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
 COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
 COMMON/F4/XX,ZZ,FM,BETA,SIGT
 COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RU(101,29),
1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101 29)
 COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
 COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
129)
 COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
 COMMON/F11/DU(101,29),DSH(101,29),DWP(101,29),A6(101,29),
1A7(101,29),A8(101,29)
 COMMON/F12/TZ2(101,29),Z1(101,29),TZ3(101,29),TZ4(101,29)
 COMMON/F14/AU(101,29,5),AM(101,29,5),AN(101,29,5),AQ(101,29,5)
 AA1(1,1;NXM)=VIS(1,1;NXM)/RE*VIST(1,1;NXM)
 A6(1,1;NXM)=AA1(1,1;NXM)*DU(1,1;NXM)+A6(1,1;NXM)
 A7(1,2;NXM4) =AA1(1,2;NXM4)*OWP(1,2;NXM4)+A7(1,2;NXM4)
 TV1(1,1;NXM)=S1(1,1;NXM)*EMDA(1,1;NXM)*RO(1,1;NXM)
 AU(1,1,1;NXM)=TV1(1,1;NXM)
 AU(1,1,2;NXM)=TV1(1,1;NXM)*U(1,1;NXM)
 AU(1,1,3;NXM)=TV1(1,1;NXM)*V(1,1;NXM)
 AU(1,1,4;NXM)=TV1(1,1;NXM)*WP(1,1;NXM)
 AU(1,1,5;NXM)=TV1(1,1;NXM)*(H(1,1;NXM)-P(1,1;NXM)/RO(1,1;NXM))
 TV2(1,1;NXM)=S1(1,1;NXM)*RO(1,1;NXM)*U(1,1;NXM)
 AM(1,1,1;NXM)=TV2(1,1;NXM)
 AM(1,1,2;NXM)=TV2(1,1;NXM)*U(1,1;NXM)+S1(1,1;NXM)*P(1,1;NXM)
 AM(1,1,3;NXM)=TV2(1,1;NXM)*V(1,1;NXM)
 AM(1,1,4;NXM)=TV2(1,1;NXM)*WP(1,1;NXM)
 AM(1,1,5;NXM)=TV2(1,1;NXM)*H(1,1;NXM)
 DP(1,2;NXM5)=-(P(1,2;NXM5)-P(1,N12;NXM5))/2.
 DP(1,N12;NXM5)=(P(1,2;NXM5)-P(1,N12;NXM5))/2.
 A9(1,2;NXM4)=EMDA(1,2;NXM4)*THES(1,2;NXM4)/BT(1,2;NXM4)
 A10(1,2;NXM4)=S1(1,2;NXM4)*THEC(1,2;NXM4)/BT(1,2;NXM4)
 AA1(1,2;NXM4)=EMDA(1,2;NXM4)*RO(1,2;NXM4)*V(1,2;NXM4)
 A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,1;NXM4)+SS1(1,2;
1NXM4)*AM(1,2,1;NXM4))-AA1(1,2;NXM4)
 AN(1,2,1;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
 AQ(1,2,1;NXM4)=A9(1,2;NXM4)*AM(1,2,1;NXM4)+A10(1,2;NXM4)*AA1(1,2;
1NXM4)+TV1(1,2;NXM4)*WP(1,2;NXM4)/BT(1,2;NXM4)-TZ3(1,2;NXM4)*A13(1,
22;NXM4)
 AA2(1,2;NXM4)=AA1(1,2;NXM4)*U(1,2;NXM4)-EMDA(1,2;NXM4)*A6(1,2;
1NXM4)
 A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,2;NXM4)+SS1(1,2;
1NXM4)*AM(1,2,2;NXM4))-AA2(1,2;NXM4)
```

```
 AN(1,2,2;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
 AQ(1,2,2;NXM4)=A9(1,2;NXM4)*AM(1,2,2;NXM4)+A10(1,2;NXM4)*AA2(1,2;
1NXM4)+TV1(1,2;NXM4)*U(1,2;NXM4)*WP(1,2;NXM4)/BT(1,2;NXM4)+TV2(1,2;
2NXM4)*CUR1(1,2;NXM4)*V(1,2;NXM4)-S1(1,2;NXM4)*CUR1(1,2;NXM4)*A6(1
3,2;NXM4)                  -P(1,2;NXM4)*S1(1,2;NXM4)*A9(1,2;NXM4)-TZ3
4(1,2;NXM4)*A13(1,2;NXM4)
 AA2(1,2;NXM4)=AA1(1,2;NXM4)*V(1,2;NXM4)+EMDA(1,2;NXM4)*P(1,2;NXM4)
 A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,3;NXM4)+SS1(1,2;
1NXM4)*AM(1,2,3;NXM4))-AA2(1,2;NXM4)
 AN(1,2,3;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
 AQ(1,2,3;NXM4)=A9(1,2;NXM4)*AM(1,2,3:NXM4)+A10(1,2;NXM4)*AA2(1,2;
1NXM4)+TV1(1,2;NXM4)*V(1,2;NXM4)*WP(1,2;NXM4)/BT(1,2;NXM4)-TV2(1,2;
2NXM4)*CUR1(1,2;NXM4)*U(1,2;NXM4)-P(1,2;NXM4)*(A10(1,2;NXM4)*EMDA(
31,2;NXM4)+S1(1,2;NXM4)*CUR1(1,2;NXM4))-TZ3(1,2;NXM4)*A13(1,2;NXM4)
 AA2(1,2;NXM4)=AA1(1,2;NXM4)*WP(1,2;NXM4)-EMDA(1,2;NXM4)*A7(1,2;
1NXM4)
 A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,4;NXM4)+SS1(1,2;
1NXM4)*AM(1,2,4;NXM4))-AA2(1,2;NXM4)
 AN(1,2,4;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
 AQ(1,2,4;NXM4)=A9(1,2;NXM4)*AM(1,2,4:NXM4)+A10(1,2;NXM4)*AA2(1,2;
1NXM4)+EMDA(1,2;NXM4)*S1(1,2;NXM4)/BT(1,2;NXM4)*(DP(1,2;NXM4)+RO(1,
22;NXM4)*WP(1,2;NXM4)*(2.*WP(1,2;NXM4)+U(1,2;NXM4)*THES(1,2;NXM4)+
3V(1,2;NXM4)*THEC(1,2;NXM4))-A7(1,2;NXM4)*THEC(1,2;
4NXM4))-TZ3(1,2;NXM4)*A13(1,2;NXM4)
 AA2(1,2;NYM4)=AA1(1,2;NXM4)*H(1,2;NXM4)-EMDA(1,2;NXM4)*(VIS(1,2;
1NXM4)/SIG/RF*(1.+VIST(1,2;NXM4)*SIG/SIGT)*DSH(1,2;NXM4)+U(1,2;NXM4
2)*A6(1,2;NXM4))
 A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,5;NXM4)+SS1(1,2;
1NXM4)*AM(1,2,5;NXM4))-AA2(1,2;NXM4)
 AN(1,2,5;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
 AQ(1,2,5;NXM4)=A9(1,2;NXM4)*AM(1,2,5;NXM4)+A10(1,2;NXM4)*AA2(1,2;
1NXM4)+TV1(1,2;NXM4)*H(1,2;NXM4)*WP(1,2;NXM4)/BT(1,2;NXM4)-TZ3(1,2;
2NXM4)*A13(1,2;NXM4)
 RETURN
 END
```

```
      SUBROUTINE VEC2
      DIMENSION A20(101)
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,SIGT
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F11/DU(101,29),DSH(101,29),DWP(101,29),A6(101,29),
     1A7(101,29),A8(101,29)
      COMMON/F12/TZ2(101,29),Z1(101,29),TZ3(101,29),TZ4(101,29)
      COMMON/F15/AUO(101,4),AMO(101,2,4),ANO(101,4),AQO(101,4)
      DO 100 I=1,2
      II=I
      IF(I.EQ.2.AND.MM.EQ.2)II=N12
      A20(1;M1)=S1(1,II;M1)*RO(1,II;M1)
      AMO(1,I,1;M1)=A20(1;M1)*(2.*U(1,II;M1)+WP(1,II;M1))
      AMO(1,I,2;M1)=A20(1;M1)*(P(1,II;M1)/RO(1,II;M1)+2.*U(1,II;M1)*
     1U(1,II;M1)+U(1,II;M1)*WP(1,II;M1))
      A20(1;M1)=A20(1;M1)*(2.*U(1,II;M1)+WP(1,II;M1))
      AMO(1,I,3;M1)=A20(1;M1)*V(1,II;M1)
  100 AMO(1,I,4;M1)=A20(1;M1)*H(1,II;M1)
      A20(1;M1)=S1(1,1;M1)*RO(1,1;M1)*EMDA(1,1;M1)
      AUO(1,1;M1)=A20(1;M1)
      AUO(1,2;M1)=A20(1;M1)*U(1,1;M1)
      AUO(1,3;M1)=A20(1;M1)*V(1,1;M1)
      AUO(1,4;M1)=A20(1;M1)*(H(1,1;M1)-P(1,1;M1)/RO(1,1;M1))
      A20(1;M1)=EMDA(1,1;M1)*RO(1,1;M1)
      ANO(1,1;M1)=A20(1;M1)*V(1,1;M1)-A8(1,1;M1)*(DS1(1,1;M1)*AUO(1,1;M1
     1)+SS1(1,1;M1)*AMO(1,1,1;M1))
      ANO(1,2;M1)=A20(1;M1)*(U(1,1;M1)*V(1,1;M1)-A6(1,1;M1)/RO(1,1;M1))-
     1A8(1,1;M1)*(DS1(1,1;M1)*AUO(1,2;M1)+SS1(1,1;M1)*AMO(1,1,2;M1))
      ANO(1,3;M1)=A20(1;M1)*(V(1,1;M1)**2+P(1,1;M1)/RO(1,1;M1))-A8(1,1;
     1M1)*(DS1(1,1;M1)*AUO(1,3;M1)+SS1(1,1;M1)*AMO(1,1,3;M1))
      ANO(1,4;M1)=A20(1;M1)*(V(1,1;M1)*H(1,1;M1)-VIS(1,1;M1)*DSH(1,1;M1)
     1/RE*(1./SIG+VIST(1,1;M1)/SIGT)/RO(1,1;M1)-U(1,1;M1)*A6(1,1;M1)
     2              /RO(1,1;M1))-A8(1,1;M1)*(DS1(1,1;M1)*AUO(1,4;M1)+SS1(1
     3,1;M1)*AMO(1,1,4;M1))
      A30=CUR1(1,1)*S1(1,1)
      AQO(1,1;M1)=A30*RO(1,1;M1)*V(1,1;M1)+ANO(1,1;M1)*TZ3(1,1;M1)
      AQO(1,2;M1)=2.*A30*(RO(1,1;M1)*U(1,1;M1)*V(1,1;M1)-A6(1,1;M1))
     1+ANO(1,2;M1)*TZ3(1,1;M1)
      AQO(1,3;M1)=A30*(-P(1,1;M1)+RO(1,1;M1)*(V(1,1;M1)**2-U(1,1;M1)**2)
     1)+ANO(1,3;M1)*TZ3(1,1;M1)
      AQO(1,4;M1)=A30*(RO(1,1;M1)*V(1,1;M1)*H(1,1;M1)-VIS(1,1;M1)*DSH(1,
```

```
     11;M1)/RE*(1./SIG+VIST(1,1;M1)/SIGT)-U(1,1;M1)*A6(1,1;M1))
     1+ANO(1,4;M1)*T73(1,1;M1)
      ANO(1,1;M1)=-TZ4(1,1;M1)*ANO(1,1;M1)
      ANO(1,2;M1)=-TZ4(1,1;M1)*ANO(1,2;M1)
      ANO(1,3;M1)=-TZ4(1,1;M1)*ANO(1,3;M1)
      ANO(1,4;M1)=-TZ4(1,1;M1)*ANO(1,4;M1)
      RETURN
      END
```

```
SUBROUTINE VEC3
COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
129)
COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
COMMON/F13/AU1(101,29,5),AU2(101,29,5)
RO(2,2;NXM8 )=AU1(2,2,1;NXM8 )/S1(2,2;NXM8 )/EMDA(2,2;NXM8 )
U(2,2;NXM8 )=AU1(2,2,2;NXM8 )/AU1(2,2,1;NXM8 )
V(2,2;NXM8 )=AU1(2,2,3;NXM8 )/AU1(2,2,1;NXM8 )
WP(2,2;NXM8 )=AU1(2,2,4;NXM8 )/AU1(2,2,1;NXM8 )
TV1(2,2;NXM8)=(U(2,2;NXM8)*U(2,2;NXM8)+V(2,2;NXM8)*V(2,2;NXM8))/2.
SH(2,2;NXM8)=(AU1(2,2,5;NXM8)/AU1(2,2,1;NXM8)-TV1(2,2;NXM8))*GAMA
H(2,2;NXM8)=SH(2,2;NXM8)+TV1(2,2;NXM8)
T(2,2;NXM8)=SH(2,2;NXM8)/GM3
P(2,2;NXM8)=GM9*RO(2,2;NXM8)*SH(2,2;NXM8)
TV2(2,2;NXM8)=VSQRT(T(2,2;NXM8);TV2(2,2;NXM8))
VIS(2,2;NXM8)=T(2,2;NXM8)*TV2(2,2;NXM8)*GM6/(T(2,2;NXM8)+GM5)
RETURN
END
```

```
      SUBROUTINE VEC4
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F13/AU1(101,29,5),AU2(101,29,5)
      RO(2,1;M11)=AU1(2,1,1;M11)/S1(2,1;M11)/EMDA(2,1;M11)
      U(2,1;M11)=AU1(2,1,2;M11)/AU1(2,1,1;M11)
      V(2,1;M11)=AU1(2,1,3;M11)/AU1(2,1,1;M11)
      WP(2,1;M11)=-U(2,1;M11)
      TV1(2,1;M11)=(U(2,1;M11)*U(2,1;M11)+V(2,1;M11)*V(2,1;M11))/2.
      SH(2,1;M11)=(AU1(2,1,4;M11)/AU1(2,1,1;M11)-TV1(2,1;M11))*GAMA
      H(2,1;M11)=SH(2,1;M11)+TV1(2,1;M11)
      T(2,1;M11)=SH(2,1;M11)/GM3
      P(2,1;M11)=GM9*RO(2,1;M11)*SH(2,1;M11)
      TV2(2,1;M11)=VSQRT(T(2,1;M11);TV2(2,1;M11))
      VIS(2,1;M11)=T(2,1;M11)*TV2(2,1;M11)*GM6/(T(2,1;M11)+GM5)
      RETURN
      END
```

```
      SUBROUTINE VECS
      COMMON/F1/N1,N11,N12,N16,N15,M1,M11,M50,N14
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM8,NXM5,NXM61
      COMMON/F3/GM1,GM2,GM3,GM4,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F7/U(101,29),V(101,29),T(101,29),P(101,29),RO(101,29),
     1WP(101,29),VIS(101,29),H(101,29),SH(101,29),PW(29),VIST(101,29)
      COMMON/F8/BT(101,29),EMDA(101,29),ZN(101,29)
      COMMON/F9/S1(101,29),SS1(101,29),DS1(101,29),CUR1(101,29),R1(101,
     129)
      COMMON/F10/THEC(101,29),THES(101,29),TV1(101,29),TV2(101,29)
      COMMON/F13/AU1(101,29,5),AU2(101,29,5)
      RO(2,2;NXM61)=AU1(2,2,1;NXM61)/S1(2,2;NXM61)/EMDA(2,2;NXM61)
      U(2,2;NXM61)=AU1(2,2,2;NXM61)/AU1(2,2,1;NXM61)
      V(2,2;NXM61)=AU1(2,2,3;NXM61)/AU1(2,2,1;NXM61)
      WP(2,2;NXM61)=AU1(2,2,4;NXM61)/AU1(2,2,1;NXM61)
      TV1(2,2;NXM61)=(U(2,2;NXM61)*U(2,2;NXM61)+V(2,2;NXM61)*V(2,2;NXM61
     1))/2.
      SH(2,2;NXM61)=(AU1(2,2,5;NXM61)/AU1(2,2,1;NXM61)-TV1(2,2;NXM61))*
     1GAMA
      H(2,2;NXM61)=SH(2,2;NXM61)+TV1(2,2;NXM61)
      T(2,2;NXM61)=SH(2,2;NXM61)/GM3
      P(2,2;NXM61)=GM9*RO(2,2;NXM61)*SH(2,2;NXM61)
      TV2(2,2;NXM61)=VSQRT(T(2,2;NXM61);TV2(2,2;NXM61))
      VIS(2,2;NXM61)=T(2,2;NXM61)*TV2(2,2;NXM61)*GM6/(T(2,2;NXM61)+GM5)
      DO 100 N=N1,N11,N14
      NN1=N-1
      NN2=N-2
      NN3=N-3
      U(2,N;M11)=2.5*U(2,NN1;M11)-2.*U(2,NN2;M11)+.5*U(2,NN3;M11)
      V(2,N;M11)=2.5*V(2,NN1;M11)-2.*V(2,NN2;M11)+.5*V(2,NN3;M11)
      P(2,N;M11)=2.5*P(2,NN1;M11)-2.*P(2,NN2;M11)+.5*P(2,NN3;M11)
      WP(2,N;M11)=2.5*WP(2,NN1;M11)-2.*WP(2,NN2;M11)+.5*WP(2,NN3;M11)
      SH(2,N;M11)=2.5*SH(2,NN1;M11)-2.*SH(2,NN2;M11)+.5*SH(2,NN3;M11)
      H(2,N;M11)=SH(2,N;M11)+(U(2,N;M11)**2+V(2,N;M11)**2)/2.
      T(2,N;M11)=SH(2,N;M11)/GM3
      RO(2,N;M11)=P(2,N;M11)/GM9/SH(2,N;M11)
  100 VIS(2,N;M11)=T(2,N;M11)**1.5*GM6/(T(2,N;M11)+GM5)
      RETURN
      END
```

APPENDIX B

LISTING FOR ZERO ANGLE-OF-ATTACK CODE

```
      PROGRAM BBODY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     TIME-DEPENDENT FINITE-DIFFERENCE METHOD FOR CALCULATING THE LAMINAR
C     AND TURBULENT HYPERSONIC FLOWS ABOUT BLUNT AXISYMMETRIC BODIES AT
C     ZERO  ANGLE OF ATTACK.  LOCAL TIME STEP IS USED TO MARCH THE
C     SOLUTION IN TIME.
C     REFERENCE AIAA PAPER NO. 77-172 (KUMAR AND GRAVES).
C     NBODY=1 FOR SPHERE-CONE.  CALL BCON.
C
      NBODY=1
C
      NBODY=2
      IF(NBODY.EQ.1)CALL BCON
      IF(NBODY.EQ.2)CALL BHYP
      STOP
      END
```

```
      SUBROUTINE BCON
      DIMENSION CDP(15),CDF(15),CD(15),QW(15)
      DIMENSION Y(15),THE(15),CH(15),TEMP1(15),TEMP2(101),Z(101),
     1T7(101),TZ1(101),THE1(101,15),GM(4)
      DIMENSION THE2(101,15),VAIR(101,15),DT(101,15),AU2(101,15,4)
      DIMENSION TAU(15,4),TAM(15,4),TAN1(15,4),TAN2(15,4),TAQ(15,4),
     1TAU1(15,4),CF(15),TE8(15),TE9(15),TE10(15)
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,DY,DZ
      COMMON/F5/S(15),SS(15),G(15),CUR(15),US(15),DS(15),VS(15),VN(15)
     1,R(15)
      COMMON/F6/INT(15),TIMP(15),TEMP(15),TE(15),TE1(15),TE2(15),TE3(15)
     1,TE4(15),TE5(15),TE6(15),TE7(15)
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F11/DU(101,15),DSH(101,15),A6(101,15),A8(101,15)
      COMMON/F12/TZ2(101,15),Z1(101,15),TZ3(101,15),TZ4(101,15)
      COMMON/F13/AU1(101,15,4)
      COMMON/F14/AU(101,15,4),AM(101,15,4),AN(101,15,4),AQ(101,15,4)
      COMMON/F15/AUO(101,4),AMO(101,2,4),ANO(101,4),AQO(101,4)
      COMMON/F16/HINF,RE1,RE2,SIGT
      CH(1;15)=0.
      VIST(1,1;1515)=0.
C     CONSTANTS AND FREESTREAM CONDITIONS
      PI=4.*ATAN(1.)
      GAMA=1.4
      RGAS=287.
      CP=GAMA*RGAS/(GAMA-1.)
      SIG=.72
      SIGT=.9
      ALPHA=0.
      CC=.001
      FM=10.3
      TF=46.26
      PF=100.77
      ROF=PF/RGAS/TF
      THC=45.*PI/180.
      TW=330.3
      TW=TW/TF
      RN=.03175
      DY=.185
      BETA=1.1
```

```
      FDT=1.
      THESH=2.*PI/180.
      VF=FM*(GAMA*RGAS*TF)**.5
      VISF=1.458/10.**6*TF**1.5/(TF+110.)
      RE=VF*ROF*RN/VISF
C     LMAX IS THE MAXIMUM NUMBER OF TIME STEPS AFTER WHICH THE PROGRAM
C     WILL STOP EVEN THOUGH THE SOLUTION MAY NOT BE CONVERGED.
      LMAX=20000
C     NT IS NUMBER OF MESH POINTS ALONG BODY SURFACE UPTO WHICH THE FLOW
C     IS LAMINAR.  THE FLOW BECOMES FULLY TURBULENT FOR NT+1.
      NT=2
      LTURB=25000
C     FOR LAMINAR FLOW, CALL VEC3 AND FOR TURBULENT FLOW, CALL VEC4.
C     LTURB IS THE NUMBER OF ITERATIONS UPTO WHICH THE FLOW REMAINS
C     LAMINAR.
C     CONVERGENCE CRITERION.
      CRIT=.01
      GM(1)=1.
      GM(2)=-1.
      GM(3)=1.
      GM(4)=1.
      GM1=1./GAMA/FM**2
      GM2=2.*GAMA/(1.+GAMA)
      GM3=CP*TF/VF**2
      GM5=110./TF
      GM6=1.+GM5
      GM7=(GAMA-1.)/(GAMA+1.)
      GM8=(1.+GAMA)/(2.*GAMA*FM**2)
      GM9=(GAMA-1.)/GAMA
      GM10=T**GM3/GAMA
      HINF=0.995*(.5+GM3)
      RE1=SQRT(RE)
      RE2=.0168*RE
C     MESH SIZES AND VECTOR LENGTHS
      N1=15
      N14=N1-1
      N50=N1-2
      N52=N1-3
      M1=101
      M11=M1-1
      M50=M1-2
      M51=M1-3
      M52=M1-4
      NXM=N1*M1
      NXM1=NXM-M11
      NXM2=NXM-1
      NXM3=NXM-[illegible]
      NXM4=NXM-M1
      NXM5=NXM-M1-1
      NXM6=NXM-2*M1-2
      NXM7=NXM-3*M1+1
```

```
      NXM8=NXM-2*M1-1
      NXM9=NXM-4*M1+1
      NXM10=4*NXM
      NXMM=NXM-2*M1+1
      NXMM2=NXM-2*M1-4
      NXMM3=NXM-4*M1-2
C     STEP SIZES
      DZ=-1./M11
      XX=2.*DY
      ZZ=2.*DZ
      Y(1;N1)=Q8VINTL(0.,DY;Y(1;N1))
      Z(1;M1)=Q8VINTL(1.,DZ;Z(1;M1))
      A1=PI/2.-THC
      YM=DY*N1A
      RO=((YM-A1)*SIN(THC)+COS(THC))*CN
C     NJ1 IS THE MESH POINT UPSTREAM OF JUNTURE POINT.
      NJ=A1/DY
      NJ1=NJ+1
      NJ2=NJ-1
      NJ3=NJ1+1
C     INITIAL SHOCK SHAPE AND SHOCK SLOPE.
      S(1;NJ1)=.17
      DO 17 N=NJ3,N1
 17    S(N)=S(N-1)+DY*SIN(THESH)
C      BODY GEOMETRY.
       DO 10 N=1,N1
      IF(Y(N).GT.A1)GO TO 11
      THE(N)=PI/2.-Y(N)
      CUR(N)=1.
      R(N)=COS(THE(N))
      GO TO 10
 11   THE(N)=THC
      CUR(N)=0.
      R(N)=COS(THC)+(Y(N)-A1)*SIN(THC)
 10   CONTINUE
      DO 20 N=1,N1
      VS(N)=COS(THE(N))
 20   VN(N)=-SIN(THE(N))
      DO 35 N=1,N1
      S1(1,N;M1)=S(N)
      CUR1(1,N;M1)=CUR(N)
      R1(1,N;M1)=R(N)
 35   THE1(1,N;M1)=THE(N)
      THEC(1,1;NXM)=VCOS(THE1(1,1;NXM);THEC(1,1;NXM))
      THES(1,1;NXM)=VSIN(THE1(1,1;NXM);THES(1,1;NXM))
      INT(1;N1)=Q8VINTL (1,M1;INT(1;N1))
C     CALCULATION OF THE STARTING SOLUTION.
      DO 40 N=1,N1
 40   TEMP(N)=SIN(THE(N))**2*(.9+.1*(N-1)/N1)
      P(1,1;NXM)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );P(1,1;NXM))
      TEMP(1;N1)=0.
```

```
      V(1,1;NXM)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );V(1,1;NXM))
      U(1,1;NXM)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );U(1,1;NXM))
      TEMP(1;N1)=TW
      T(1,1;NXM)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );T(1,1;NXM))
      SS(1)=0.
      DO 15 N=2,NJ
15    SS(N)=(S(N+1)-S(N-1))/XX
      DO 16 N=NJ1,N1
16    SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      TE5(1;N1)=SS(1;N1)/(1.+S(1;N1)*CUR(1;N1))
      TE6(1;N1)=1.+TE5(1;N1)*TE5(1;N1)
      TE6(1;N1)=VSQRT(TE6(1;N1);TE6(1;N1))
      TE7(1;N1)=-(VN(1;N1)-VS(1;N1)*TE5(1;N1))/TE6(1;N1)
      TEMP(1;N1)=(TE7(1;N1)*TE7(1;N1)/GM8-GM7)*GM1
      P(M1,1;NXM1)=Q8VSCATR(TEMP(1;N1),INT(1;N1);P(M1,1;NXM1))
      TEMP(1;N1)=TEMP(1;N1)/GM1
      TE(1;N1)=(TEMP(1;N1)+GM7)/(1.+TEMP(1;N1)*GM7)
      TE1(1;N1)=(1.-1./TE(1;N1))*TE7(1;N1)/TE6(1;N1)
      TE2(1;N1)=VS(1;N1)-TE1(1;N1)*TE5(1;N1)
      TE3(1;N1)=VN(1;N1)+TE1(1;N1)
      TE4(1;N1)=TEMP(1;N1)/TE(1;N1)
      U(M1,1;NXM1)=Q8VSCATR(TE2(1;N1),INT(1;N1);U(M1,1;NXM1))
      V(M1,1;NXM1)=Q8VSCATR(TE3(1;N1),INT(1;N1);V(M1,1;NXM1))
      T(M1,1;NXM1)=Q8VSCATR(TE4(1;N1),INT(1;N1);T(M1,1;NXM1))
      DO 50 N=1,N1
      DXU=(U(M1,N)-U(1,N))/M11
      DXV=(V(M1,N)-V(1,N))/M11
      DXP=(P(M1,N)-P(1,N))/M11
      DXT=(T(M1,N)-T(1,N))/M11
      U(1,N;M11)=Q8VINTL(U(1,N),DXU;U(1,N;M11))
      V(1,N;M11)=Q8VINTL(V(1,N),DXV;V(1,N;M11))
      P(1,N;M11)=Q8VINTL(P(1,N),DXP;P(1,N;M11))
50    T(1,N;M11)=Q8VINTL(T(1,N),DXT;T(1,N;M11))
      RO(1,1;NXM)=P(1,1;NXM)/T(1,1;NXM)/GM1
      SH(1,1;NXM)=T(1,1;NXM)*GM3
      H(1,1;NXM)=SH(1,1;NXM)+(U(1,1;NXM)**2+V(1,1;NXM)**2)/2.
      TV2(1,1;NXM)=VSQRT(T(1,1;NXM);TV2(1,1;NXM))
      VIS(1,1;NXM)=T(1,1;NXM)*TV2(1,1;NXM)*GM6/(T(1,1;NXM)+GM5)
      B1=(BETA+1.)/(BETA-1.)
      B2=2.*BETA/ALOG(B1)
      TZ(1;M1)=B1**(Z(1;M1))
      TZ1(1;M1)=BETA*(TZ(1;M1)-1.)/(TZ(1;M1)+1.)
      DO 30 N=1,N1
30    Z1(1,N;M1)=TZ1(1;M1)
      ZN(1,1;NXM)=S1(1,1;NXM)*(1.-Z1(1,1;NXM))
      EMDA(1,1;NXM)=1.+ZN(1,1;NXM)*CUR1(1,1;NXM)
      BT(1,1;NXM)=S1(1,1;NXM)+ZN(1,1;NXM)*THEC(1,1;NXM)
      TZ2(1,1;NXM)=BETA**2-Z1(1,1;NXM)**2
      TZ3(1,1;NXM)=2.*Z1(1,1;NXM)/TZ2(1,1;NXM)
      TZ4(1,1;NXM)=B2/TZ2(1,1;NXM)
      WRITE (6,399) ALPHA,RE,FM
```

```
399   FORMAT(/,1X,'ALPHA',F8.5,5X,'REYN NO.',F15.3,5X,'MACH NO.',F8.3,/)
      WRITE(6,435)(Y(N),THE(N),R(N),CUR(N),N=1,N1)
      DO 60 N=1,N1
      WRITE(6,421)N,Y(N)
      WRITE(6,430)
      WRITE(6,440)(Z1(M,N),U(M,N),V(M,N),P(M,N),RO(M,N),T(M,N),H(M,N),
     1VIST(M,N),M=1,M1)
60    CONTINUE
430   FORMAT(/,6X,'Z1',9X,'U',9X,'V',8X,'P',8X,'RO',9X,'T',9X,'H',9X,
     1'VIST')
435   FORMAT(2X,'Y=',F10.5,5X,'THE=',F10.5,5X,'R=',F10.5,5X,'CUR=',F10.5
     1)
      DM=-1./4./M11
      TEMP2(1;M11)=Q8VINTL(1.+DM,DM;TEMP2(1;M11))
      DO 2 I=1,4
2     AU1(1,1,I;NXM)=1.
      TE8(1;N1)=1.
      TE9(1;N1)=0.
      TE10(1;N1)=GM10
      L=1
C     MARCHING IN TIME STARTS HERE.
1     CONTINUE
      MM=1
C     LOCAL TIME STEP CALCULATION.
      VAIR(1,1;NXM2)=GAMA*P(1,1;NXM2)/RO(1,1;NXM2)
      VAIR(1,1;NXM2)=VSQRT(VAIR(1,1;NXM2);VAIR(1,1;NXM2))
      DT(1,1;NXM2)=FDT*(ZN(2,1;NXM2)-ZN(1,1;NXM2))/(VABS(V(1,1;NXM2);
     1THE2(1,1;NXM2))+VAIR(1,1;NXM2))
      DO 70 N=1,N1
70    DT(1,N;M11)=DT(1,N;M11)*TEMP2(1;M11)
      TIMP(1;N1 )=Q8VGATHR(DT(M11,1;NXM1),INT(1;N1 );TIMP(1;N1 ))
      DT(M1,1;NXM1)=Q8VSCATR(TIMP(1;N1 ),INT(1;N1 );DT(M1,1;NXM1))
C     PREDICTOR STEP.
      SS(1)=0.
      DO  74 N=2,NJ
74    SS(N)=(S(N+1)-S(N-1))/XX
      DO 75 N=NJ1,N1
75    SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 110 I=1,4
      AU1(2,2,I;NXM6)=AU(2,2,I;NXM6)-DT(2,2;NXM6)*((AM(2,3,I;NXM6)-AM(2,
     12,I;NXM6))/DY+(AN(3,2,I;NXM6)-AN(2,2,I;NXM6))/DZ+AQ(2,2,I;NXM6))
      AU1(2,N1,I;M50)=AU(2,N1,I;M50)-DT(2,N1;M50)*((AM(2,N1,I;M50)-AM(2,
     1N14,I;M50))/DY+(AN(3,N1,I;M50)-AN(2,N1,I;M50))/DZ+AQ(2,N1,I;M50))
      AU1(2,NJ1,I;M50)=AU(2,NJ1,I;M50)+DT(2,NJ1;M50)*((4.*AM(2,NJ,I;M50)
     1-3.*AM(2,NJ1,I;M50)-AM(2,NJ2,I;M50))/XX-(AN(3,NJ1,I;M50)-AN(2,NJ1,
     2I;M50))/DZ-AQ(2,NJ1,I;M50))
      TAU(1,I;N1 )=Q8VGATHR(AU(M1,1,I;NXM1),INT(1;N1 );TAU(1,I;N1 ))
      TAM(1,I;N1 )=Q8VGATHR(AM(M1,1,I;NXM1),INT(1;N1 );TAM(1,I;N1 ))
```

```
      TAN1(1,I;N1 )=Q8VGATHR(AN(M1,1,I;NXM1),INT(1;N1 );TAN1(1,I;N1 ))
      TAN2(1,I;N1 )=Q8VGATHR(AN(M11,1,I;NXM1),INT(1;N1 );TAN2(1,I;N1 ))
      TAQ(1,I;N1 )=Q8VGATHR(AQ(M1,1,I;NXM1),INT(1;N1 );TAQ(1,I;N1 ))
      TAU1(2,I;N50)=TAU(2,I;N50)-TIMP(2;N50)*((TAM(3,I;N50)-TAM(2,I;N50)
     1)/DY+(TAN1(2,I;N50)-TAN2(2,I;N50))/DZ+TAQ(2,I;N50))
      TAU1(N1,I)=TAU(N1,I)-TIMP(N1)*((TAM(N1,I)-TAM(N14,I))/DY+(TAN1(N1,
     1I)-TAN2(N1,I))/DZ+TAQ(N1,I))
      TAU1(NJ1,I)=TAU(NJ1,I)+TIMP(NJ1)*((4.*TAM(NJ,I)-3.*TAM(NJ1,I)-TAM(
     1NJ2,I))/XX-(TAN1(NJ1,I)-TAN2(NJ1,I))/DZ-TAQ(NJ1,I))
110   AU1(M1,2,I;NXMM)=Q8VSCATR(TAU1(2,I;N14),INT(1;N14);AU1(M1,2,I)
     1NXMM))
      CALL VEC2
      DO 150 I=1,4
      AU1(2,1,I;M50)=AU0(2,I;M50)-DT(2,1;M50)*((AMO(2,2,I;M50)-AMO(2,1,I
     1;M50))/DY+(ANO(3,I;M50)-ANO(2,I;M50))/DZ+AQO(2,I;M50))
150   AU1(M1,1,I)=AU0(M1,I)-DT(M1,1)*((AMO(M1,2,I)-AMO(M1,1,I))/DY+(ANO(
     1M1,I)-ANO(M11,I))/DZ+AQO(M1,I))
      AU1(1,2,1;NXMM)=Q8VSCATR(TE8(1;N14),INT(1;N14);AU1(1,2,1;NXMM))
      AU1(1,2,2;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,2;NXMM))
      AU1(1,2,3;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,3;NXMM))
      AU1(1,2,4;NXMM)=Q8VSCATR(TE10(1;N14),INT(1;N14);AU1(1,2,4;NXMM))
      IF(L.GT.LTURB)GO TO 154
      CALL VEC3
      GO TO 155
154   CALL VEC5
155   CONTINUE
      CALL BOUND
C     CORRECTOR STEP.
      DO 160 I=1,4
      AU2(2,2,I;NXM5)=AU(2,2,I;NXM5)+AU1(2,2,I;NXM5)
160   AU2(2,1,I;M11)=AU0(2,I;M11)+AU1(2,1,I;M11)
      MM=2
      SS(1)=0.
      DO 174 N=2,NJ
174   SS(N)=(S(N+1)-S(N-1))/XX
      DO 175 N=NJ1,N1
175   SS(N)=-(4.*S(N-1)-3.*S(N)-S(N-2))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 180 I=1,4
      AU1(2,2,I;NXM5)=0.5*(AU2(2,2,I;NXM5)-DT(2,2;NXM5)*((AM(2,2,I;NXM5)
     1-AM(2,1,I;NXM5))/DY+(AN(2,2,I;NXM5)-AN(1,2,I;NXM5))/DZ+AQ(2,2,I;
     2NXM5)))
180   AU1(2,NJ1,I;M11)=.5*(AU2(2,NJ1,I;M11)+DT(2,NJ1;M11)*((4.*AM(2,NJ,
     1I;M11)-3.*AM(2,NJ1,I;M11)-AM(2,NJ2,I;M11))/XX-(AN(2,NJ1,I;M11)-AN(
     21,NJ1,I;M11))/DZ-AQ(2,NJ1,I;M11)))
      U(1,2;M1)=-U(1,2;M1)
      CALL VEC2
      DO 190 I=1,4
190   AU1(2,1,I;M11)=.5*(AU2(2,1,I;M11)-DT(2,1;M11)*((AMO(2,1,I;M11)-AMO
```

```
     1(2,2,I;M11))/DY+(ANO(2,I;M11)-ANO(1,I;M11))/DZ+AQO(2,I;M11)))
C     FOURTH ODER DAMPING.  CC IS THE DAMPING COEFFICIENT.
      DO 200 I=1,4
      AU2(3,2,I;NXMM2)=AU(5,2,I;NXMM2)+AU(1,2,I;NXMM2)-4.*(AU(4,2,I;NXMM
     12)+AU(2,2,I;NXMM2))+6.*AU(3,2,I;NXMM2)
      TE1(1;N50)=Q8VGATHR(AU(1,2,I;NXM7),INT(1;N50);TE1(1;N50))
      TE2(1;N50)=Q8VGATHR(AU(2,2,I;NXM7),INT(1;N50);TE2(1;N50))
      TE3(1;N50)=Q8VGATHR(AU(3,2,I;NXM7),INT(1;N50);TE3(1;N50))
      TE4(1;N50)=Q8VGATHR(AU(4,2,I;NXM7),INT(1;N50);TE4(1;N50))
      TE5(1;N50)=TE4(1;N50)-TE1(1;N50)-3.*(TE3(1;N50)-TE2(1;N50))
      AU2(2,2,I;NXM7)=Q8VSCATR(TE5(1;N50),INT(1;N50);AU2(2,2,I;NXM7))
      TE1(1;N50)=Q8VGATHR(AU(M51,2,I;NXM7),INT(1;N50);TE1(1;N50))
      TE2(1;N50)=Q8VGATHR(AU(M50,2,I;NXM7),INT(1;N50);TE2(1;N50))
      TE3(1;N50)=Q8VGATHR(AU(M11,2,I;NXM7),INT(1;N50);TE3(1;N50))
      TE4(1;N50)=Q8VGATHR(AU(M1,2,I;NXM7),INT(1;N50);TE4(1;N50))
      TE5(1;N50)=TE1(1;N50)-TE4(1;N50)-3.*(TE2(1;N50)-TE3(1;N50))
      AU2(M11,2,I;NXM7)=Q8VSCATR(TE5(1;N50),INT(1;N50);AU2(M11,2,I;NXM7)
     1)
      AU2(3,1,I;M52)=AUO(5,I;M52)+AUO(1,I;M52)-4.*(AUO(4,I;M52)+AUO(2,I;
     2M52))+6.*AUO(3,I;M52)
      AU2(2,1,I)=AUO(4,I)-AUO(1,I)-3.*(AUO(3,I)-AUO(2,I))
      AU2(M11,1,I)=AUO(M51,I)-AUO(M1,I)-3.*(AUO(M50,I)-AUO(M11,I))
       AN(2,3,I;NXMM3)=AU1(2,3,I;NXMM3)-CC*(AU(2,5,I;NXMM3)+AU(2,1,I;NXM
     1M3)-4.*(AU(2,4,I;NXMM3)+AU(2,2,I;NXMM3))+6.*AU(2,3,I;NXMM3)+AU2(2,
     23,I;NXMM3))
      TE1(1;N52)=Q8VGATHR(AU1(M1,2,I;NXM9),INT(1;N52);TE1(1;N52))
      AN(M1,2,I;NXM9)=Q8VSCATR(TE1(1;N52),INT(1;N52);AN(M1,2,I;NXM9))
       AN(2,N14,I;M50)=AU1(2,N14,I;M50)-CC*(AU(2,N52,I;M50)-AU(2,N1,I;M
     150)-3.*(AU(2,N50,I;M50)-AU(2,N14,I;M50))+AU2(2,N14,I;M50))
       AN(2,2,I;M50)=AU1(2,2,I;M50)-CC*(AU(2,4,I;M50)+GM(I)*AU(2,2,
     1I;M50)-4.*(AU(2,3,I;M50)+AU(2,1,I;M50))+6.*AU(2,2,I;M50)+AU2(2,2,I
     2;M50))
      AU1(2,2,I;NXM6)=AN(2,2,I;NXM6)
      IF(I.EQ.2)GO TO 200
      AU1(2,1,I;M50)=AU1(2,1,I;M50)-CC*(2.*AU(2,3,I;M50)-8.*AU(2,2,I;M50
     1)+6.*AUO(2,I;M50)+AU2(2,1,I;M50))
  200 CONTINUE
      AU1(1,2,1;NXMM)=Q8VSCATR(TE8(1;N14),INT(1;N14);AU1(1,2,1;NXMM))
      AU1(1,2,2;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,2;NXMM))
      AU1(1,2,3;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,3;NXMM))
      AU1(1,2,4;NXMM)=Q8VSCATR(TE10(1;N14),INT(1;N14);AU1(1,2,4;NXMM))
      IF(L.GT.LTURB)GO TO 231
      CALL VEC3
      GO TO 232
  231 CALL VEC5
  232 CONTINUE
      CALL BOUND
C     EDDY VISCOSITY CALCULATION.
      IF(L.LT.LTURB)GO TO 235
      LL=L/25
      LL=LL*25
```

```
      IF(LL.NE.L)GO TO 450
      CALL DERV
      CALL EDDY(NT)
  235  CONTINUE
      LL=L/500
      LL=LL*500
      IF(LL.NE.L)GO TO 450
C     SURFACE HEATING RATE AND SKIN FRICTION COEFFICIENT CALCULATIONS.
      WRITE(6,400) L
      WRITE(6,405)
      XL1=    -B2/(BETA**2-1.)
      XL=-2.*B2/(BETA**2-1.)/SIG/RE
      TE(1;N1)=CH(1;N1)
      DO 250 N=1,N1
      DSH1=(4.*SH(2,N)-3.*SH(1,N)-SH(3,N))/ZZ/S(N)
      CH(N)=VIS(1,N)*DSH1*XL
      DU1=(4.*U(2,N)-3.*U(1,N)-U(3,N))/ZZ/S(N)*XL1
      CF(N)=2.*VIS(1,N)*(DU1-U(1,N)*CUR(N)/EMDA(1,N))/RE
      QW(N)=CH(N)*.5*ROF*VF**3
  250 WRITE(6,420) Y(N),S(N),US(N),CH(N),CF(N),PW(N),QW(N)
      CDP(1)=0.
      DO 340 N=1,N14
  340 CDP(N+1)=CDP(N)+.5*DY*(PW(N)*R(N)*SIN(THE(N))+PW(N+1)*R(N+1)*SIN(
     1THE(N+1)))
      CDF(1)=0.
      EC=-B2/(BETA**2-1.)/ZZ
      DO 350 N=1,N14
  350 CDF(N+1)=CDF(N)+EC*.5*DY*(VIS(1,N)*R(N)*COS(THE(N))*(4.*U(2,N)-3.*
     1U(1,N)-U(3,N))/S(N)+VIS(1,N+1)*R(N+1)*COS(THE(N+1))*(4.*U(2,N+1)-
     13.*U(1,N+1)-U(3,N+1))/S(N+1))
      DO 355 N=2,N1
      CDP(N)=4.*CDP(N)/R(N)**2
      CDF(N)=4.*CDF(N)/R(N)**2/RE
  355 CD(N)=CDP(N)+CDF(N)
      WRITE(6,465)
      WRITE(6,460)(R(N),CDP(N),CDF(N),CD(N),N=1,N1)
  460 FORMAT(1X,4F11.6)
  465 FORMAT(/,8X,'R',8X,'CDP',8X,'CDF',8X,'CD')
C     CONVERGENCE CHECK. CONVERGENCE CRITERION IS THAT OVER 500 TIME STEPS,
C     THE HEATING RATES SHOULD NOT CHANGE BY MORE THAN  1 PERCENT.
      TE1(1;N1)=CH(1;N1)-TE(1;N1)
      TE1(1;N1)=VABS(TE1(1;N1);TE1(1;N1))
      TE2(1;N1)= CRIT*CH(1;N1)
      II=Q8SGE(TE1(1;N1),TE2(1;N1))
      IF(II.EQ.N1)GO TO 261
      LL=L/5000
      LL=LL*5000
      IF(LL.NE.L)GO TO 450
  261 CONTINUE
      DO 260 N=1,N1
      WRITE(6,421)N,Y(N)
```

```
      WRITE(6,431)
      WRITE(6,440)(ZN(M,N),U(M,N),V(M,N),P(M,N),RO(M,N),T(M,N),H(M,N),
     1VIST(M,N),M=1,M1)
 260  CONTINUE
      IF(II.EQ.N1)GO TO 551
 400  FORMAT(10X,'NO. OF ITERATIONS',I5)
 405  FORMAT(/,1X,'DIST.ALONG BODY',5X,'SHOCK STANDOFF DIST.',5X,'SHOCK
     1SPEED',5X,'STANTON NO.',5X,'SKIN FRICTION',5X,'WALL PR.',
     25X,'WALL HEATING,W/M2')
 420  FORMAT(5X,F10.5,10X,F10.5,10X,F10.5,6X,F12.8,4X,F11.7,4X,F10.5,
     15X,F15.7)
 421  FORMAT(/,5X,'BODY STATION NO.=',I3,5X,'DIST. ALONG BODY=',F10.5,/)
 440  FORMAT(1X,8F10.5)
 431  FORMAT(/,6X,'ZN',9X,'U',9X,'V',8X,'P',8X,'RO',9X,'T',9X,'H',9X,
     1'VIST')
 450  L=L+1
      IF(L.LE.LMAX)GO TO 1
 551  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BHYP
      DIMENSION CDP(15),CDF(15),CD(15),QW(15)
      DIMENSION Y(15),THF(15),CH(15),TEMP1(15),TEMP2(101),Z(101),
     1TZ(101),TZ1(101),THE1(101,15),GM(4)
      DIMENSION THF2(101,15),VAIR(101,15),DT(101,15),AU2(101,15,4)
      DIMENSION TAU(15,4),TAM(15,4),TAN1(15,4),TAN2(15,4),TAQ(15,4),
     1TAU1(15,4),CF(15),TE8(15),TE9(15),TE10(15)
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,DY,DZ
      COMMON/F5/S(15),SS(15),G(15),CUR(15),US(15),DS(15),VS(15),VN(15)
     1,R(15)
      COMMON/F6/INT(15),TIMP(15),TEMP(15),TE(15),TE1(15),TE2(15),TE3(15)
     1,TE4(15),TE5(15),TE6(15),TE7(15)
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F11/DU(101,15),DSH(101,15),A6(101,15),A8(101,15)
      COMMON/F12/TZ2(101,15),Z1(101,15),TZ3(101,15),TZ4(101,15)
      COMMON/F13/AU1(101,15,4)
      COMMON/F14/AU(101,15,4),AM(101,15,4),AN(101,15,4),AQ(101,15,4)
      COMMON/F15/AU0(101,4),AM0(101,2,4),AN0(101,4),AQ0(101,4)
      COMMON/F16/HINF,RE1,RE2,SIGT
      CH(1;15)=0.
      VIST(1,1;1515)=0.
C     CONSTANTS AND FREESTREAM CONDITIONS
      PI=4.*ATAN(1.)
      GAMA=1.4
      RGAS=287.
      CP=GAMA*RGAS/(GAMA-1.)
      SIG=.72
      SIGT=.9
      ALPHA=0.
      CC=.001
      FM=10.3
      TF=46.26
      PF=100.77
      ROF=PF/RGAS/TF
      THC=45.*PI/180.
      TW=330.3
      TW=TW/TF
      RN=.03175
      DY=.185
      BETA=1.1
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```
      FDT=1.
      THESH=2.*PI/180.
      VF=FM*(GAMA*RGAS*TF)**.5
      VISF=1.458/10.**6*TF**1.5/(TF+110.)
      RE=VF*ROF*RN/VISF
C     LMAX IS THE MAXIMUM NUMBER OF TIME STEPS AFTER WHICH THE PROGRAM
C     WILL STOP EVEN THOUGH THE SOLUTION MAY NOT BE CONVERGED.
      LMAX=20000
C     NT IS NUMBER OF MESH POINTS ALONG BODY SURFACE UPTO WHICH THE FLOW
C     IS LAMINAR.  THE FLOW BECOMES FULLY TURBULENT FOR NT+1.
      NT=2
      LTURB=25000
C     FOR LAMINAR FLOW, CALL VEC3 AND FOR TURBULENT FLOW, CALL VEC4.
C     LTURB IS THE NUMBER OF ITERATIONS UPTO WHICH THE FLOW REMAINS
C     LAMINAR.
C     CONVERGENCE CRITERION.
      CRIT=.01
      GM(1)=1.
      GM(2)=-1.
      GM(3)=1.
      GM(4)=1.
      GM1=1./GAMA/FM**2
      GM2=2.*GAMA/(1.+GAMA)
      GM3=CP*TF/VF**2
      GM5=110./TF
      GM6=1.+GM5
      GM7=(GAMA-1.)/(GAMA+1.)
      GM8=(1.+GAMA)/(2.*GAMA*FM**2)
      GM9=(GAMA-1.)/GAMA
      GM10=TW*GM3/GAMA
      HINF=0.995*(.5+GM3)
      RE1=SQRT(RE)
      RE2=.0168*RE
C     MESH SIZES AND VECTOR LENGTHS
      N1=15
      N14=N1-1
      N50=N1-2
      N52=N1-3
      M1=101
      M11=M1-1
      M50=M1-2
      M51=M1-3
      M52=M1-4
      NXM=N1*M1
      NXM1=NXM-M11
      NXM2=NXM-1
      NXM3=NXM-2
      NXM4=NXM-M1
      NXM5=NXM-M1-1
      NXM6=NXM-2*M1-2
      NXM7=NXM-3*M1+1
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      NXM8=NXM-2*M1-1
      NXM9=NXM-4*M1+1
      NXM10=4*NXM
      NXMM=NXM-2*M1+1
      NXMM2=NXM-2*M1-4
      NXMM3=NXM-4*M1-2
C     STEP SIZES
      DZ=-1./M11
      XX=2.*DY
      ZZ=2.*DZ
      Y(1;N1)=QBVINTL(0.,DY;Y(1;N1))
      Z(1;M1)=QBVINTL(1.,DZ;Z(1;M1))
C     INITIAL SHOCK SHAPE AND SHOCK SLOPE.
      S(1)=.17
      DO 17 N=2,N1
 17    S(N)=S(N-1)+DY*SIN(THESH)
C      BODY GEOMETRY.
      CUR(1)=1.
      THE(1)=PI/2.
      R(1)=0.
      A=1./TAN(THC)**2
      B=SQRT(A)
      DO 10 N=2,N1
      Q1=DY*SQRT((B**2+R(N-1)**2)/(B**2+(1.+(A/B)**2)*R(N-1)**2))
      Q2=DY*SQRT((B**2+(R(N-1)+Q1/2.)**2)/(B**2+(1.+(A/B)**2)*
     1(R(N-1)+Q1/2.)**2))
      Q3=DY*SQRT((B**2+(R(N-1)+Q2/2.)**2)/(B**2+(1.+(A/B)**2)
     1*(R(N-1)+Q2/2.)**2))
      Q4=DY*SQRT((B**2+(R(N-1)+Q3)**2)/(B**2+(1.+(A/B)**2)*(R(N-1)+Q3)
     1**2))
      R(N)=R(N-1)+(Q1+2.*Q2+2.*Q3+Q4)/6.
      X=A*SQRT(B**2+R(N)**2)/B
      CUR(N)=A**4*B**4/(A**4*R(N)**2+B**4*X**2)**1.5
      X=B*X/(A*SQRT(X**2-A**2))
 10   THE(N)=ATAN(X)
      DO 20 N=1,N1
      VS(N)=COS(THE(N))
 20   VN(N)=-SIN(THE(N))
      DO 35 N=1,N1
      S1(1,N;M1)=S(N)
      CUR1(1,N;M1)=CUR(N)
      R1(1,N;M1)=R(N)
 35   THE1(1,N;M1)=THE(N)
      THEC(1,1;NXM)=VCOS(THE1(1,1;NXM);THEC(1,1;NXM))
      THES(1,1;NXM)=VSIN(THE1(1,1;NXM);THES(1,1;NXM))
      INT(1;N1)=QBVINTL (1,M1;INT(1;N1))
C     CALCULATION OF THE STARTING SOLUTION.
      DO 40 N=1,N1
 40   TEMP(N)=SIN(THE(N))**2*(.9+.1*(N-1)/N1)
      P(1,1;NXM)=QBVSCATR(TEMP(1;N1 ),INT(1;N1 );P(1,1;NXM))
      TEMP(1;N1)=0.
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```
      V(1,1;NXM)=QAVSCATR(TEMP(1;N1 ),INT(1;N1 );V(1,1;NXM))
      U(1,1;NXM)=QAVSCATR(TEMP(1;N1 ),INT(1;N1 );U(1,1;NXM))
      TEMP(1;N1)=TW
      T(1,1;NXM)=QAVSCATR(TEMP(1;N1 ),INT(1;N1 );T(1,1;NXM))
      SS(1)=0.
      DO 15 N=2,N14
15    SS(N)=(S(N+1)-S(N-1))/XX
      SS(N1)=-(4.*S(N14)-3.*S(N1)-S(N50))/XX
      TE5(1;N1)=SS(1;N1)/(1.+S(1;N1)*CUR(1;N1))
      TE6(1;N1)=1.+TE5(1;N1)*TE5(1;N1)
      TE6(1;N1)=VSQRT(TE6(1;N1);TE6(1;N1))
      TE7(1;N1)=-(VN(1;N1)-VS(1;N1)*TE5(1;N1))/TE6(1;N1)
      TEMP(1;N1)=(TE7(1;N1)*TE7(1;N1)/GM8-GM7)*GM1
      P(M1,1;NXM1)=QAVSCATR(TEMP(1;N1),INT(1;N1);P(M1,1;NXM1))
      TEMP(1;N1)=TEMP(1;N1)/GM1
      TE(1;N1)=(TEMP(1;N1)+GM7)/(1.+TEMP(1;N1)*GM7)
      TE1(1;N1)=(1.-1./TE(1;N1))*TE7(1;N1)/TE6(1;N1)
      TE2(1;N1)=VS(1;N1)-TE1(1;N1)*TE5(1;N1)
      TE3(1;N1)=VN(1;N1)+TE1(1;N1)
      TE4(1;N1)=TEMP(1;N1)/TE(1;N1)
      U(M1,1;NXM1)=QAVSCATR(TE2(1;N1),INT(1;N1);U(M1,1;NXM1))
      V(M1,1;NXM1)=QAVSCATR(TE3(1;N1),INT(1;N1);V(M1,1;NXM1))
      T(M1,1;NXM1)=QAVSCATR(TE4(1;N1),INT(1;N1);T(M1,1;NXM1))
      DO 50 N=1,N1
      DXU=(U(M1,N)-U(1,N))/M11
      DXV=(V(M1,N)-V(1,N))/M11
      DXP=(P(M1,N)-P(1,N))/M11
      DXT=(T(M1,N)-T(1,N))/M11
      U(1,N;M11)=QAVINTL(U(1,N),DXU;U(1,N;M11))
      V(1,N;M11)=QAVINTL(V(1,N),DXV;V(1,N;M11))
      P(1,N;M11)=QAVINTL(P(1,N),DXP;P(1,N;M11))
50    T(1,N;M11)=QAVINTL(T(1,N),DXT;T(1,N;M11))
      RO(1,1;NXM)=P(1,1;NXM)/T(1,1;NXM)/GM1
      SH(1,1;NXM)=T(1,1;NXM)*GM3
      H(1,1;NXM)=SH(1,1;NXM)+(U(1,1;NXM)**2+V(1,1;NXM)**2)/2.
      TV2(1,1;NXM)=VSQRT(T(1,1;NXM);TV2(1,1;NXM))
      VIS(1,1;NXM)=T(1,1;NXM)*TV2(1,1;NXM)*GM6/(T(1,1;NXM)+GM5)
      B1=(BETA+1.)/(BETA-1.)
      B2=2.*BETA/ALOG(B1)
      TZ(1;M1)=B1**(Z(1;M1))
      TZ1(1;M1)=BETA*(TZ(1;M1)-1.)/(TZ(1;M1)+1.)
      DO 30 N=1,N1
30    Z1(1,N;M1)=TZ1(1;M1)
      ZN(1,1;NXM)=S1(1,1;NXM)*(1.-Z1(1,1;NXM))
      EMDA(1,1;NXM)=1.+ZN(1,1;NXM)*CUR1(1,1;NXM)
      BT(1,1;NXM)=R1(1,1;NXM)+ZN(1,1;NXM)*THEC(1,1;NXM)
      TZ2(1,1;NXM)=BETA**2-Z1(1,1;NXM)**2
      TZ3(1,1;NXM)=2.*Z1(1,1;NXM)/TZ2(1,1;NXM)
      TZ4(1,1;NXM)=B2/TZ2(1,1;NXM)
      WRITE (6,399) ALPHA,RE,FM
399   FORMAT(/,1X,'ALPHA',F8.5,5X,'REYN NO.',F15.3,5X,'MACH NO.',F8.3,/)
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      WRITE(6,435)(Y(N),THE(N),R(N),CUR(N),N=1,N1)
      DO 60 N=1,N1
      WRITE(6,421)N,Y(N)
      WRITE(6,430)
      WRITE(6,440)(Z1(M,N),U(M,N),V(M,N),P(M,N),RO(M,N),T(M,N),H(M,N),
     1VIST(M,N),M=1,M1)
60    CONTINUE
430   FORMAT(/,6X,'Z1',9X,'U',9X,'V',8X,'P',8X,'RO',9X,'T',9X,'H',9X,
     1'VIST')
435   FORMAT(2X,'Y=',F10.5,5X,'THE=',F10.5,5X,'R=',F10.5,5X,'CUR=',F10.5
     1)
      DM=-1./4./M11
      TEMP2(1;M11)=Q8VINTL(1.+DM,DM;TEMP2(1;M11))
      DO 2 I=1,4
2     AU1(1,1,I;NXM)=1.
      TE8(1;N1)=1.
      TE9(1;N1)=0.
      TE10(1;N1)=GM10
      L=1
C     MARCHING IN TIME STARTS HERE.
1     CONTINUE
      MM=1
C     LOCAL TIME STEP CALCULATION.
      VAIR(1,1;NXM2)=GAMA*P(1,1;NXM2)/RO(1,1;NXM2)
      VAIR(1,1;NXM2)=VSQRT(VAIR(1,1;NXM2);VAIR(1,1;NXM2))
      DT(1,1;NXM2)=FDT*(ZN(2,1;NXM2)-ZN(1,1;NXM2))/(VABS(V(1,1;NXM2);
     1THE2(1,1;NXM2))+VAIR(1,1;NXM2))
      DO 70 N=1,N1
70    DT(1,N;M11)=DT(1,N;M11)*TEMP2(1;M11)
      TIMP(1;N1 )=Q8VGATHR(DT(M11,1;NXM1),INT(1;N1 );TIMP(1;N1 ))
      DT(M1,1;NXM1)=Q8VSCATR(TIMP(1;N1 ),INT(1;N1 );DT(M1,1;NXM1))
C     PREDICTOR STEP.
      SS(1)=0.
      DO 74 N=2,N14
74    SS(N)=(S(N+1)-S(N-1))/XX
      SS(N1)=-(4.*S(N14)-3.*S(N1)-S(N50))/XX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 110 I=1,4
      AU1(2,2,I;NXM6)=AU(2,2,I;NXM6)-DT(2,2;NXM6)*((AM(2,3,I;NXM6)-AM(2,
     12,I;NXM6))/DY+(AN(3,2,I;NXM6)-AN(2,2,I;NXM6))/DZ+AQ(2,2,I;NXM6))
      AU1(2,N1,I;M50)=AU(2,N1,I;M50)-DT(2,N1;M50)*((AM(2,N1,I;M50)-AM(2,
     1N14,I;M50))/DY+(AN(3,N1,I;M50)-AN(2,N1,I;M50))/DZ+AQ(2,N1,I;M50))
      TAU(1,I;N1 )=Q8VGATHR(AU(M1,1,I;NXM1),INT(1;N1 );TAU(1,I;N1 ))
      TAM(1,I;N1 )=Q8VGATHR(AM(M1,1,I;NXM1),INT(1;N1 );TAM(1,I;N1 ))
      TAN1(1,I;N1 )=Q8VGATHR(AN(M1,1,I;NXM1),INT(1;N1 );TAN1(1,I;N1 ))
      TAN2(1,I;N1 )=Q8VGATHR(AN(M11,1,I;NXM1),INT(1;N1 );TAN2(1,I;N1 ))
      TAQ(1,I;N1 )=Q8VGATHR(AQ(M1,1,I;NXM1),INT(1;N1 );TAQ(1,I;N1 ))
      TAU1(2,I;N50)=TAU(2,I;N50)-TIMP(2;N50)*((TAM(3,I;N50)-TAM(2,I;N50)
     1)/DY+(TAN1(2,I;N50)-TAN2(2,I;N50))/DZ+TAQ(2,I;N50))
```

```
      TAU1(N1,I)=TAU(N1,I)-TIMP(N1)*((TAM(N1,I)-TAM(N14,I))/DY+(TAN1(N1,
     1I)-TAN2(N1,I))/DZ+TAQ(N1,I))
  110 AU1(M1,2,I;NXMM)=Q8VSCATR(TAU1(2,I;N14),INT(1;N14);AU1(M1,2,I;
     1NXMM))
      CALL VEC2
      DO 150 I=1,4
      AU1(2,1,I;M50)=AU0(2,I;M50)-DT(2,1;M50)*((AM0(2,2,I;M50)-AM0(2,1,I
     1;M50))/DY+(AN0(3,I;M50)-AN0(2,I;M50))/DZ+AQ0(2,I;M50))
  150 AU1(M1,1,I)=AU0(M1,I)-DT(M1,1)*((AM0(M1,2,I)-AM0(M1,1,I))/DY+(AN0(
     1M1,I)-AN0(M11,I))/DZ+AQ0(M1,I))
      AU1(1,2,1;NXMM)=Q8VSCATR(TE8(1;N14),INT(1;N14);AU1(1,2,1;NXMM))
      AU1(1,2,2;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,2;NXMM))
      AU1(1,2,3;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,3;NXMM))
      AU1(1,2,4;NXMM)=Q8VSCATR(TE10(1;N14),INT(1;N14);AU1(1,2,4;NXMM))
      IF(L.GT.LTURB)GO TO 154
      CALL VEC3
      GO TO 155
  154 CALL [illegible]5
  155 CONTINUE
      CALL BOUND
C     CORRECTOR STEP.
      DO 160 I=1,4
      AU2(2,2,I;NXM5)=AU(2,2,I;NXM5)+AU1(2,2,I;NXM5)
  160 AU2(2,1,I;M11)=AU0(2,I;M11)+AU1(2,1,I;M11)
      MM=2
      SS(1)=0.
      DO 174 N=2,N14
  174 SS(N)=(S(N+1)-S(N-1))/DY
      SS(N1)=-(4.*S(N14)-3.*S(N1)-S(N50))/YX
      CALL SHOCK
      CALL DERV
      CALL VEC1
      DO 180 I=1,4
  180 AU1(2,2,I;NXM5)=0.5*(AU2(2,2,I;NXM5)-DT(2,2;N[illegible]) * ((M([illegible],2,I[illegible]
     1-AM(2,1,I;NXM5))/DY+(AN(2,2,I;NXM5[illegible],2,[illegible];NXM5))/DZ+[illegible],2,I;
     2NXM5)))
      U(1,2;M1)=-U(1,2;M1)
      CALL VEC2
      DO 190 I=1,4
  190 AU1(2,1,I;M11)=.5*(AU2(2,1,I;M11)-DT(2,1;M11)*((AMO(2,[illegible],I;M11)-AMO
     1(2,2,I;M11))/DY+(ANO(2,I;M11)-ANO(1,[illegible];M11))[illegible]+AQ[illegible](2,I[illegible])))
C     FOURTH ODER DAMPING.  CC IS THE DAMPING COEFFICIENT.
      DO 200 I=1,4
      AU2(3,2,I;NXMM2)=AU(5,2,I;NXMM2)+AU(1,2,I;NXMM2)-4.*(AU(4,2,I;NXMM
     12)+AU(2,2,I;NXMM2))+6.*AU(3,2,I;NXMM2)
      TE1(1;N50)=Q8VGATHR(AU(1,2,I;NXM7),INT(1;N50);TE1(1;N50))
      TE2(1;N50)=Q8VGATHR(AU(2,2,I;NXM7),INT(1;N50);TE2(1;N50))
      TE3(1;N50)=Q8VGATHR(AU(3,2,I;NXM7),INT(1;N50);TE3(1;N50))
      TE4(1;N50)=Q8VGATHR(AU(4,2,I;NXM7),INT(1;N50);TE4(1;N50))
      TE5(1;N50)=TE4(1;N50)-TE1(1;N50)-3.*(TE3(1;N50)-TE2(1;N50))
      AU2(2,2,I;NXM7)=Q8VSCATR(TE5(1;N50),INT(1;N50);AU2(2,2,I;NXM7))
```

```
      TE1(1;N50)=Q8VGATHR(AU(M51,2,I;NXM7),INT(1;N50);TE1(1;N50))
      TE2(1;N50)=Q8VGATHR(AU(M50,2,I;NXM7),INT(1;N50);TE2(1;N50))
      TE3(1;N50)=Q8VGATHR(AU(M11,2,I;NXM7),INT(1;N50);TE3(1;N50))
      TE4(1;N50)=Q8VGATHR(AU(M1,2,I;NXM7),INT(1;N50);TE4(1;N50))
      TE5(1;N50)=TE1(1;N50)-TE4(1;N50)-3.*(TE2(1;N50)-TE3(1;N50))
      AU2(M11,2,I;NXM7)=Q8VSCATR(TE5(1;N50),INT(1;N50);AU2(M11,2,I;NXM7)
     1)
      AU2(3,1,I;M52)=AU0(5,I;M52)+AU0(1,I;M52)-4.*(AU0(4,I;M52)+AU0(2,I;
     2M52))+6.*AU0(3,I;M52)
      AU2(2,1,I)=AU0(4,I)-AU0(1,I)-3.*(AU0(3,I)-AU0(2,I))
      AU2(M11,1,I)=AU0(M51,I)-AU0(M1,I)-3.*(AU0(M50,I)-AU0(M11,I))
       AN(2,3,I;NXMM3)=AU1(2,3,I;NXMM3)-CC*(AU(2,5,I;NXMM3)+AU(2,1,I;NXM
     1M3)-4.*(AU(2,4,I;NXMM3)+AU(2,2,I;NXMM3))+6.*AU(2,3,I;NXMM3)+AU2(2,
     23,I;NXMM3))
      TE1(1;N52)=Q8VGATHR(AU1(M1,2,I;NXM9),INT(1;N52);TE1(1;N52))
      AN(M1,2,I;NXM9)=Q8VSCATR(TE1(1;N52),INT(1;N52);AN(M1,2,I;NXM9))
       AN(2,N14,I;M50)=AU1(2,N14,I;M50)-CC*(AU(2,N52,I;M50)-AU(2,N1,I;M
     150)-3.*(AU(2,N50,I;M50)-AU(2,N14,I;M50))+AU2(2,N14,I;M50))
       AN(2,2,I;M50)=AU1(2,2,I;M50)-CC*(AU(2,4,I;M50)+GM(I)*AU(2,2,
     1I;M50)-4.*(AU(2,3,I;M50)+AU(2,1,I;M50))+6.*AU(2,2,I;M50)+AU2(2,2,I
     2;M50))
      AU1(2,2,I;NXM6)=AN(2,2,I;NXM6)
      IF(I.EQ.2)GO TO 200
      AU1(2,1,I;M50)=AU1(2,1,I;M50)-CC*(2.*AU(2,3,I;M50)-8.*AU(2,2,I;M50
     1)+6.*AU0(2,I;M50)+AU2(2,1,I;M50))
  200 CONTINUE
      AU1(1,2,1;NXMM)=Q8VSCATR(TE8(1;N14),INT(1;N14);AU1(1,2,1;NXMM))
      AU1(1,2,2;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,2;NXMM))
      AU1(1,2,3;NXMM)=Q8VSCATR(TE9(1;N14),INT(1;N14);AU1(1,2,3;NXMM))
      AU1(1,2,4;NXMM)=Q8VSCATR(TE10(1;N14),INT(1;N14);AU1(1,2,4;NXMM))
      IF(L.GT.LTURB)GO TO 231
      CALL VEC3
      GO TO 232
  231 CALL VEC5
  232 CONTINUE
      CALL BOUND
C     EDDY VISCOSITY CALCULATION.
      IF(L.LT.LTURB)GO TO 235
      LL=L/25
      LL=LL*25
      IF(LL.NE.L)GO TO 450
      CALL DERV
      CALL EDDY(NT)
  235  CONTINUE
      LL=L/500
      LL=LL*500
      IF(LL.NE.L)GO TO 450
C     SURFACE HEATING RATE AND SKIN FRICTION COEFFICIENT CALCULATIONS.
      WRITE(6,400) L
      WRITE(6,405)
      XL1=    -B2/(BETA**2-1.)
```

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      XL=-2.*B2/(BETA**2-1.)/SIG/RE
      TE(1;N1)=CH(1;N1)
      DO 250 N=1,N1
      DSH1=(4.*SH(2,N)-3.*SH(1,N)-SH(3,N))/ZZ/S(N)
      CH(N)=VIS(1,N)*DSH1*XL
      DU1=(4.*U(2,N)-3.*U(1,N)-U(3,N))/ZZ/S(N)*XL1
      CF(N)=2.*VIS(1,N)*(DU1-U(1,N)*CUR(N)/EMDA(1,N))/RE
      QW(N)=CH(N)*.5*ROF*VF**3
  250 WRITE(6,420) Y(N),S(N),US(N),CH(N),CF(N),PW(N),QW(N)
      CDP(1)=0.
      DO 340 N=1,N14
  340 CDP(N+1)=CDP(N)+.5*DY*(PW(N)*R(N)*SIN(THE(N))+PW(N+1)*R(N+1)*SIN(
     1THE(N+1)))
      CDF(1)=0.
      FC=-B2/(BETA**2-1.)/ZZ
      DO 350 N=1,N14
  350 CDF(N+1)=CDF(N)+FC*.5*DY*(VIS(1,N)*R(N)*COS(THE(N))*(4.*U(2,N)-3.*
     1U(1,N)-U(3,N))/S(N)+VIS(1,N+1)*R(N+1)*COS(THE(N+1))*(4.*U(2,N+1)-
     13.*U(1,N+1)-U(3,N+1))/S(N+1))
      DO 355 N=2,N1
      CDP(N)=4.*CDP(N)/R(N)**2
      CDF(N)=4.*CDF(N)/R(N)* Z/RE
  355 CD(N)=CDP(N)+CDF(N)
      WRITE(6,465)
      WRITE(6,460)(R(N),CDP(N),CDF(N),CD(N),N=1,N1)
  460 FORMAT(1X,4F11.6)
  465 FORMAT(/,8X,'R',8X,'CDP',8X,'CDF',8X,'CD')
C     CONVERGENCE CHECK, CONVERGENCE CRITERION IS THAT OVER 500 TIME STEPS,
C     THE HEATING RATES SHOULD NOT CHANGE BY MORE THAN  1 PERCENT.
      TE1(1;N1)=CH(1;N1)-TE(1;N1)
      TE1(1;N1)=VABS(TE1(1;N1);TE1(1;N1))
      TE2(1;N1)= CRIT*CH(1;N1)
      II=Q8SGE(TE1(1;N1),TE2(1;N1))
      IF(II.EQ.N1)GO TO 261
      LL=L/5000
      LL=LL*5000
      IF(LL.NE.L)GO TO 450
  261 CONTINUE
      DO 260 N=1,N1
      WRITE(6,421)N,Y(N)
      WRITE(6,431)
      WRITE(6,440)(ZN(M,N),U(M,N),V(M,N),P(M,N),RO(M,N),T(M,N),H(M,N),
     1VIST(M,N),M=1,M1)
  260 CONTINUE
      IF(II.EQ.N1)GO TO 551
  400 FORMAT(10X,'NO. OF ITERATIONS',I5)
  405 FORMAT(/,1X,'DIST.ALONG BODY',5X,'SHOCK STANDOFF DIST.',5X,'SHOCK
     1SPEED',5X,'STANTON NO.',5X,'SKIN FRICTION',5X,'WALL PR.',
     25X,'WALL HEATING,W/M2')
  420 FORMAT(5X,F10.5,10X,F10.5,10X,F10.5,6X,F12.8,4X,F11.7,4X,F10.5,
     15X,F15.3)
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421   FORMAT(/,5X,'BODY STATION NO.=',I3,5X,'DIST. ALONG BODY=',F10.5,/)
440   FORMAT(1X,8F10.5)
431   FORMAT(/,6X,'ZN',9X,'U',9X,'V',8X,'P',8X,'RO',9X,'T'.9X,'H',9X,
     1'VIST')
450   L=L+1
      IF(L.LE.LMAX)GO TO 1
551   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EDDY(NT)
      DIMENSION PE(15),DPE(15),BLD(15),BLE(15),UE(15),CUT2(101)
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,DY,DZ
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F11/DU(101,15),DSH(101,15),A6(101,15),A8(101,15)
      COMMON/F16/HINF,RE1,RE2,SIGT
      NT1=NT-1
      NT2=NT+1
      DO 3075 N=NT,N1
      DO 3070 M=15,M11
      IF(H(M,N).GE.HINF)GO TO 3072
 3070 CONTINUE
 3072 BLE(N)=ZN(M,N)
      UE(N)=U(M,N)
      PE(N)=P(M,N)
      BLD(N)=0.
      IF(N.EQ.1)GO TO 3075
      DO 3073 J=2,M
      J1=J-1
 3073 BLD(N)=BLD(N)+(2.-(U(J1,N)+U(J,N))/UE(N))*(ZN(J,N)-ZN(J1,N))/2.
 3075 CONTINUE
      DO 3035 N=NT2,N14
 3035 DPE(N)=(PE(N+1)-PE(N-1))/XX
      DPE(N1)=(PE(N1)-PE(N14))/XX*2.
      DO 3110 N=NT2,N1
      CUT2(1;M1)=1./(1.+5.5*(ZN(1,N;M1)/BLE(N))**6)
      TV2(1,N;M1)=RE2*RO(1,N;M1)*UE(N)*BLD(N)*CUT2(1;M1)/VIS(1,N;M1)
      TV1(1,N)=0.
      CUTT=SQRT(VIS(1,N)*DU(1,N))
      CUT2(1;M1)=VABS(DU(1,N;M1);CUT2(1;M1))
      DO 3115 M=2,M1
      CUT=CUTT/SQRT(RO(M,N))
      UTAU=CUT/RE1
      VPLUS=V(1,N)/UTAU
      VPLUS=-VPLUS*5.9
      APLUS=26.*EXP(VPLUS)
      CNPLUS=ZN(M,N)*RO(M,N)*RE1/VIS(M,N)*CUT
      ANPLUS=CNPLUS/APLUS
      IF(ANPLUS.GT.12.)GO TO 3116
      VISTL=.4*ZN(M,N)*(1.-1./EXP(ANPLUS))
      GO TO 3115
 3116 VISTL=.4*ZN(M,N)
```

```
3115 TV1(M,N)=RE*RO(M,N)*VISTL*VISTL/VIS(M,N)*CUT2(M)
3137 MB=M-1
     DO 3130 M=1,MB
     DVIS=TV2(M,N)-TV1(M,N)
     IF(DVIS.LE.0.)GO TO 3135
3130 VIST(M,N)=TV1(M,N)
     M=M+1
3135 MB1=M1-M+1
3110 VIST(M,N;MB1)=TV2(M,N;MB1)
     RETURN
     END
```

```
      SUBROUTINE SHOCK
      DIMENSION A2(15),VNF(15)
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,DY,DZ
      COMMON/F5/S(15),SS(15),G(15),CUR(15),US(15),DS(15),VS(15),VN(15)
     1,R(15)
      COMMON/F6/INT(15),TIMP(15),TEMP(15),TE(15),TE1(15),TE2(15),TE3(15)
     1,TE4(15),TE5(15),TE6(15),TE7(15)
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZM(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F12/TZ2(101,15),Z1(101,15),TZ3(101,15),TZ4(101,15)
      A2(1;N1 )=SS(1;N1 )/(1.+S(1;N1 )*CUR(1;N1 ))
      G(1;N1)=1.+A2(1;N1)*A2(1;N1)
      G(1;N1 )=VSQRT(G(1;N1 );G(1;N1 ))
      TEMP(1;N1 )=Q8VGATHR(P(M1,1;NXM1),INT(1;N1 );TEMP(1;N1 ))
      TEMP(1;N1 )=TEMP(1;N1 )/GM1
      TE(1;N1 )=(TEMP(1;N1 )+GM7)/(1.+TEMP(1;N1 )*GM7)
      VNF(1;N1 )=GM8*(TEMP(1;N1 )+GM7)
      VNF(1;N1 )=VSQRT(VNF(1;N1 );VNF(1;N1 ))
      US(1;N1 )=VNF(1;N1 )+(VN(1;N1 )-VS(1;N1 )*A2(1;N1 ))/G(1;N1 )
      TE1(1;N1 )=(1.-1./TE(1;N1 ))*VNF(1;N1 )/G(1;N1 )
      TE2(1;N1 )=VS(1;N1 )-TE1(1;N1 )*A2(1;N1 )
      TE3(1;N1 )=VN(1;N1 )+TE1(1;N1 )
      TE4(1;N1 )=TEMP(1;N1 )/TE(1;N1 )
      TEMP(1;N1 )=VSQRT(TE4(1;N1 );TEMP(1;N1 ))
      TE5(1;N1 )=TE4(1;N1 )*TEMP(1;N1 )*GM6/(TE4(1;N1 )+GM5)
      TE6(1;N1 )=TE4(1;N1 )+GM3
      TE7(1;N1)=TE6(1;N1)+(TE2(1;N1)*TE2(1;N1)+TE3(1;N1)*TE3(1;N1))/2.
      RO(M1,1;NXM1)=Q8VSCATR(TE(1;N1 ),INT(1;N1 );RO(M1,1;NXM1))
      U(M1,1;NXM1)=Q8VSCATR(TE2(1;N1 ),INT(1;N1 );U(M1,1;NXM1))
      V(M1,1;NXM1)=Q8VSCATR(TE3(1;N1 ),INT(1;N1 );V(M1,1;NXM1))
      T(M1,1;NXM1)=Q8VSCATR(TE4(1;N1 ),INT(1;N1 );T(M1,1;NXM1))
      VIS(M1,1;NXM1)=Q8VSCATR(TE5(1;N1 ),INT(1;N1 );VIS(M1,1;NXM1))
      SH(M1,1;NXM1)=Q8VSCATR(TE6(1;N1 ),INT(1;N1 );SH(M1,1;NXM1))
      H(M1,1;NXM1)=Q8VSCATR(TE7(1;N1 ),INT(1;N1 );H(M1,1;NXM1))
      IF(MM.EQ.2)GO TO 70
      DS(1;N1 )=US(1;N1 )*G(1;N1 )
      GO TO 71
 70   DS(1;N1 )=(DS(1;N1 )+US(1;N1 )*G(1;N1 ))/2.
 71   S(1;N1 )=S(1;N1 )+DS(1;N1 )*TIMP(1;N1 )
      DO 75 N=1,N1
      S1(1,N;M1)=S(N)
```

```
      SS1(1,N;M1)=SS(N)
75    DS1(1,N;M1)=DS(N)
      ZN(1,1;NXM)=S1(1,1;NXM)*(1.-Z1(1,1;NXM))
      EMDA(1,1;NXM)=1.+ZN(1,1;NXM)*CUR1(1,1;NXM)
      BT(1,1;NXM)=R1(1,1;NXM)+ZN(1,1;NXM)*THEC(1,1;NXM)
      RETURN
      END
```

```
      SUBROUTINE DERV
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,DY,DZ
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F11/DU(101,15),DSH(101,15),A6(101,15),A8(101,15)
      COMMON/F12/TZ2(101,15),Z1(101,15),TZ3(101,15),TZ4(101,15)
      TV1(1,1;NXM)=-ZZ*S1(1,1;NXM)*TZ2(1,1;NXM)/B2
      DU(2,1;NXM3)=(U(3,1;NXM3)-U(1,1;NXM3))/TV1(2,1;NXM3)
      DSH(2,1;NXM3)=(SH(3,1;NXM3)-SH(1,1;NXM3))/TV1(2,1;NXM3)
      DO 70 N=1,N1
      DU(1,N)=(4.*U(2,N)-3.*U(1,N)-U(3,N))/TV1(1,N)
      DSH(1,N)=(4.*SH(2,N)-3.*SH(1,N)-SH(3,N))/TV1(1,N)
      DU(M1,N)=-(4.*U(M11,N)-3.*U(M1,N)-U(M50,N))/TV1(M1,N)
      DSH(M1,N)=-(4.*SH(M11,N)-3.*SH(M1,N)-SH(M50,N))/TV1(M1,N)
   70 CONTINUE
      A6(1,1;NXM)=VIS(1,1;NXM)/RE*(DU(1,1;NXM)-U(1,1;NXM)*CUR1(1,1;NXM)/
     1EMDA(1,1;NXM))
      A8(1,1;NXM)=(1.-Z1(1,1;NXM))/S1(1,1;NXM)
      RETURN
      END
```

```
      SUBROUTINE BOUND
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,BZ,RE,TW,GAMA,SIG,MM
      COMMON/F4/XX,ZZ,FM,BETA,DY,DZ
      COMMON/F6/INT(15),TTMP(15),TEMP(15),TE(15),TE1(15),TE2(15),TE3(15)
     1,TE4(15),TE5(15),TE6(15),TE7(15)
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VTS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      TEMP(1;N1 )=Q8VGATHR(P(2,1;NXM1),INT(1;N1 );TEMP(1;N1 ))
      P(1,1;NXM1)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );P(1,1;NXM1))
      PW(1;N1 )=TEMP(1;N1 )
      TEMP(1;N1 )=TEMP(1;N1 )/TW/GM1
      RO(1,1;NXM1)=Q8VSCATR(TEMP(1;N1 ),INT(1;N1 );RO(1,1;NXM1))
      RETURN
      END
```

```
      SUBROUTINE VEC1
      DIMENSION A9(101,15),A10(101,15),A13(101,15),AA1(101,15),
     1AA2(101,15)
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F11/DU(101,15),DSH(101,15),A6(101,15),A8(101,15)
      COMMON/F12/TZ2(101,15),Z1(101,15),TZ3(101,15),TZ4(101,15)
      COMMON/F14/AU(101,15,4),AM(101,15,4),AN(101,15,4),AQ(101,15,4)
      COMMON/F16/HINF,RF1,RF2,SIGT
      AA1(1,1;NXM)=VIS(1,1;NXM)/RE*VIST(1,1;NXM)
      A6(1,1;NXM)=AA1(1,1;NXM)*DU(1,1;NXM)+A6(1,1;NXM)
      TV1(1,1;NXM)=S1(1,1;NXM)*EMDA(1,1;NXM)*RO(1,1;NXM)
      AU(1,1,1;NXM)=TV1(1,1;NXM)
      AU(1,1,2;NXM)=TV1(1,1;NXM)*U(1,1;NXM)
      AU(1,1,3;NXM)=TV1(1,1;NXM)*V(1,1;NXM)
      AU(1,1,4;NXM)=TV1(1,1;NXM)*(H(1,1;NXM)-P(1,1;NXM)/RO(1,1;NXM))
      TV2(1,1;NXM)=S1(1,1;NXM)*RO(1,1;NXM)*U(1,1;NXM)
      AM(1,1,1;NXM)=TV2(1,1;NXM)
      AM(1,1,2;NXM)=TV2(1,1;NXM)*U(1,1;NXM)+S1(1,1;NXM)*P(1,1;NXM)
      AM(1,1,3;NXM)=TV2(1,1;NXM)*V(1,1;NXM)
      AM(1,1,4;NXM)=TV2(1,1;NXM)*H(1,1;NXM)
      A9(1,2;NXM4)=EMDA(1,2;NXM4)*THES(1,2;NXM4)/BT(1,2;NXM4)
      A10(1,2;NXM4)=S1(1,2;NXM4)*THEC(1,2;NXM4)/BT(1,2;NXM4)
      AA1(1,2;NXM4)=EMDA(1,2;NXM4)*RO(1,2;NXM4)*V(1,2;NXM4)
      A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,1;NXM4)+SS1(1,2;
     1NXM4)*AM(1,2,1;NXM4))-AA1(1,2;NXM4)
      AN(1,2,1;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
      AQ(1,2,1;NXM4)=A9(1,2;NXM4)*AM(1,2,1;NXM4)+A10(1,2;NXM4)*AA1(1,2;
     1NXM4)-TZ3(1,2;NXM4)*A13(1,2;NXM4)
      AA2(1,2;NXM4)=AA1(1,2;NXM4)*U(1,2;NXM4)-EMDA(1,2;NXM4)*A6(1,2;NXM4
     1)
      A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,2;NXM4)+SS1(1,2;
     1NXM4)*AM(1,2,2;NXM4))-AA2(1,2;NXM4)
      AN(1,2,2;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
      AQ(1,2,2;NXM4)=A9(1,2;NXM4)*AM(1,2,2;NXM4)+A10(1,2;NXM4)*AA2(1,2;
     1NXM4)+TV2(1,2;NXM4)*CUR1(1,2;NXM4)*V(1,2;NXM4)-S1(1,2;NXM4)*CUR1(
     21,2;NXM4)*A6(1,2;NXM4)-P(1,2;NXM4)*S1(1,2;NXM4)*A9(1,2;NXM4)-
     3TZ3(1,2;NXM4)*A13(1,2;NXM4)
      AA2(1,2;NXM4)=AA1(1,2;NXM4)*V(1,2;NXM4)+EMDA(1,2;NXM4)*P(1,2;NXM4)
      A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,3;NXM4)+SS1(1,2;
     1NXM4)*AM(1,2,3;NXM4))-AA2(1,2;NXM4)
```

```
      AN(1,2,3;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
      TV1(1,2;NXM4)=A9(1,2;NXM4)*AM(1,2,3;NXM4)+A10(1,2;NXM4)*AA2(1,2;
     1NXM4)-TV2(1,2;NXM4)*CUR1(1,2;NXM4)*U(1,2;NXM4)
        AO(1,2,3;NXM4)=TV1(1,2;NXM4)  -P(1,2;NXM4)*(A10(1,2;NXM4)*EMDA(
     31,2;NXM4)+S1(1,2;NXM4)*CUR1(1,2;NXM4))-TZ3(1,2;NXM4)*A13(1,2;NXM4)
      AA2(1,2;NXM4)=AA1(1,2;NXM4)*H(1,2;NXM4)-EMDA(1,2;NXM4)*(VIS(1,2;
     1NXM4)/SIG/RE*(1.+VIST(1,2;NXM4)*SIG/SIGT)*DSH(1,2;NXM4)+
     2U(1,2;NXM4)*A6(1,2;NXM4))
      A13(1,2;NXM4)=A8(1,2;NXM4)*(DS1(1,2;NXM4)*AU(1,2,4;NXM4)+SS1(1,2;
     1NXM4)*AM(1,2,4;NXM4))-AA2(1,2;NXM4)
      AN(1,2,4;NXM4)=TZ4(1,2;NXM4)*A13(1,2;NXM4)
      AO(1,2,4;NXM4)=A9(1,2;NXM4)*AM(1,2,4;NXM4)+A10(1,2;NXM4)*AA2(1,2;
     1NXM4)-TZ3(1,2;NXM4)*A13(1,2;NXM4)
      RETURN
      END
```

```
      SUBROUTINE VFC2
      DIMENSION A20(101)
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F11/DU(101,15),DSH(101,15),A6(101,15),A8(101,15)
      COMMON/F12/TZ2(101,15),Z1(101,15),TZ3(101,15),TZ4(101,15)
      COMMON/F15/AUO(101,4),AMO(101,2,4),ANO(101,4),AQO(101,4)
      COMMON/F16/HINF,RE1,RE2,SIGT
      DO 100 I=1,2
      A20(1;M1)=S1(1,I;M1)*RO(1,I;M1)
      AMO(1,I,1;M1)=2.*A20(1;M1)*U(1,I;M1)
      AMO(1,I,2;M1)=A20(1;M1)*(P(1,I;M1)/RO(1,I;M1)+2.*U(1,I;M1)**2)
      AMO(1,I,3;M1)=AMO(1,I,1;M1)*V(1,I;M1)
100   AMO(1,I,4;M1)=AMO(1,I,1;M1)*H(1,I;M1)
      A20(1;M1)=S1(1,1;M1)*RO(1,1;M1)*EMDA(1,1;M1)
      AUO(1,1;M1)=A20(1;M1)
      AUO(1,2;M1)=A20(1;M1)*U(1,1;M1)
      AUO(1,3;M1)=A20(1;M1)*V(1,1;M1)
      AUO(1,4;M1)=A20(1;M1)*(H(1,1;M1)-P(1,1;M1)/RO(1,1;M1))
      A20(1;M1)=EMDA(1,1;M1)*RO(1,1;M1)
      ANO(1,1;M1)=A20(1;M1)*V(1,1;M1)-A8(1,1;M1)*(DS1(1,1;M1)*AUO(1,1;M1
     1)+SS1(1,1;M1)*AMO(1,1,1;M1))
      ANO(1,2;M1)=A20(1;M1)*(U(1,1;M1)*V(1,1;M1)-A6(1,1;M1)/RO(1,1;M1))-
     1A8(1,1;M1)*(DS1(1,1;M1)*AUO(1,2;M1)+SS1(1,1;M1)*AMO(1,1,2;M1))
      ANO(1,3;M1)=A20(1;M1)*(V(1,1;M1)*V(1,1;M1)+P(1,1;M1)/RO(1,1;M1))-
     1A8(1,1;M1)*(DS1(1,1;M1)*AUO(1,3;M1)+SS1(1,1;M1)*AMO(1,1,3;M1))
      ANO(1,4;M1)=A20(1;M1)*(V(1,1;M1)*H(1,1;M1)-VIS(1,1;M1)*DSH(1,1;M1)
     1/SIG/RE/RO(1,1;M1)-U(1,1;M1)*A6(1,1;M1)/RO(1,1;M1))-A8(1,1;M1)*(DS
     21(1,1;M1)*AUO(1,4;M1)+SS1(1,1;M1)*AMO(1,1,4;M1))
      A30=CUR1(1,1)*S1(1,1)
      AQO(1,1;M1)=A30*RO(1,1;M1)*V(1,1;M1)+ANO(1,1;M1)*TZ3(1,1;M1)
      AQO(1,2;M1)=2.*A30*(RO(1,1;M1)*U(1,1;M1)*V(1,1;M1)-A6(1,1;M1))+
     1ANO(1,2;M1)*TZ3(1,1;M1)
      AQO(1,3;M1)=A30*(-P(1,1;M1)+RO(1,1;M1)*(V(1,1;M1)*V(1,1;M1)-
     1U(1,1;M1)*U(1,1;M1)))+ANO(1,3;M1)*TZ3(1,1;M1)
      AQO(1,4;M1)=A30*(RO(1,1;M1)*V(1,1;M1)*H(1,1;M1)-VIS(1,1;M1)*DSH(1,
     11;M1)/RE/SIG-U(1,1;M1)*A6(1,1;M1))+ANO(1,4;M1)*TZ3(1,1;M1)
      ANO(1,1;M1)=-TZ4(1,1;M1)*ANO(1,1;M1)
      ANO(1,2;M1)=-TZ4(1,1;M1)*ANO(1,2;M1)
      ANO(1,3;M1)=-TZ4(1,1;M1)*ANO(1,3;M1)
      ANO(1,4;M1)=-TZ4(1,1;M1)*ANO(1,4;M1)
      RETURN
      END
```

```
      SUBROUTINE VFC3
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F6/INT(15),TIMP(15),TEMP(15),TE(15),TE1(15),TE2(15),TE3(15)
     1,TE4(15),TE5(15),TE6(15),TE7(15)
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),RI(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),OS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F13/AU1(101,15,4)
      RO(2,1;NXM2)=AU1(2,1,1;NXM2)/S1(2,1;NXM2)/EMDA(2,1;NXM2)
      U(2,2;NXM5)=AU1(2,2,2;NXM5)/AU1(2,2,1;NXM5)
      V(2,1;NXM2)=AU1(2,1,3;NXM2)/AU1(2,1,1;NXM2)
       TE(1;N1)=Q8VGATHR(V(1,1;NXM1),INT(1;N1);TE(1;N1))
      TE1(1;N1)=Q8VGATHR(V(3,1;NXM1),INT(1;N1);TE1(1;N1))
      TE2(1;N1)=(3.*TE(1;N1)+TE1(1;N1))/4.
      V(2,1;NXM1)=Q8VSCATR(TE2(1;N1),INT(1;N1);V(2,1;NXM1))
      TV1(2,1;NXM2)=(U(2,1;NXM2)*U(2,1;NXM2)+V(2,1;NXM2)*V(2,1;NXM2))/2.
      SH(2,1;NXM2)=(AU1(2,1,4;NXM2)/AU1(2,1,1;NXM2)-TV1(2,1;NXM2))*GAMA
      H(2,1;NXM2)=SH(2,1;NXM2)+TV1(2,1;NXM2)
      T(2,1;NXM2)=SH(2,1;NXM2)/GM3
      P(2,1;NXM2)=GM9*RO(2,1;NXM2)*SH(2,1;NXM2)
      TV2(2,1;NXM2)=VSQRT(T(2,1;NXM2);TV2(2,1;NXM2))
      VIS(2,1;NXM2)=T(2,1;NXM2)*TV2(2,1;NXM2)*GM6/(T(2,1;NXM2)+GM5)
      RETURN
      END
```

```
      SUBROUTINE VFCS
      COMMON/F1/N1,N14,N50,N52,M1,M11,M50
      COMMON/F2/NXM,NXM1,NXM3,NXM4,NXM5,NXM8,NXM2
      COMMON/F3/GM1,GM2,GM3,GM5,GM6,GM7,GM8,GM9,B2,RE,TW,GAMA,SIG,MM
      COMMON/F6/INT(15),TIMP(15),TEMP(15),TE(15),TE1(15),TE2(15),TE3(15)
     1,TE4(15),TE5(15),TE6(15),TE7(15)
      COMMON/F7/U(101,15),V(101,15),T(101,15),P(101,15),RO(101,15),
     1VIS(101,15),H(101,15),SH(101,15),PW(15),VIST(101,15)
      COMMON/F8/BT(101,15),EMDA(101,15),ZN(101,15),R1(101,15)
      COMMON/F9/S1(101,15),SS1(101,15),DS1(101,15),CUR1(101,15)
      COMMON/F10/THEC(101,15),THES(101,15),TV1(101,15),TV2(101,15)
      COMMON/F13/AU1(101,15,4)
      RO(2,1;NXM5)=AU1(2,1,1;NXM5)/S1(2,1;NXM5)/EMDA(2,1;NXM5)
      U(2,2;NXM8)=AU1(2,2,2;NXM8)/AU1(2,2,1;NXM8)
      V(2,1;NXM5)=AU1(2,1,3;NXM5)/AU1(2,1,1;NXM5)
       TE(1;N1)=Q8VGATHR(V(1,1;NXM1),INT(1;N1);TE(1;N1))
      TE1(1;N1)=Q8VGATHR(V(3,1;NXM1),INT(1;N1);TE1(1;N1))
      TE2(1;N1)=(3.*TE(1;N1)+TE1(1;N1))/4.
      V(2,1;NXM1)=Q8VSCATR(TE2(1;N1),INT(1;N1);V(2,1;NXM1))
      TV1(2,1;NXM5)=(U(2,1;NXM5)*U(2,1;NXM5)+V(2,1;NXM5)*V(2,1;NXM5))/2.
      SH(2,1;NXM5)=(AU1(2,1,4;NXM5)/AU1(2,1,1;NXM5)-TV1(2,1;NXM5))*GAMA
      H(2,1;NXM5)=SH(2,1;NXM5)+TV1(2,1;NXM5)
      T(2,1;NXM5)=SH(2,1;NXM5)/GM3
      P(2,1;NXM5)=GM9*RO(2,1;NXM5)*SH(2,1;NXM5)
      U(2,N1;M11)=2.5*U(2,N14;M11)-2.*U(2,N50;M11)+.5*U(2,N52;M11)
      V(2,N1;M11)=2.5*V(2,N14;M11)-2.*V(2,N50;M11)+.5*V(2,N52;M11)
      P(2,N1;M11)=2.5*P(2,N14;M11)-2.*P(2,N50;M11)+.5*P(2,N52;M11)
      SH(2,N1;M11)=SH(2,N14;M11)*2.5-2.*SH(2,N50;M11)+.5*SH(2,N52;M11)
      H(2,N1;M11)=SH(2,N1;M11)+(U(2,N1;M11)*U(2,N1;M11)+V(2,N1;M11)*V(2,
     1N1;M11))/2.
      T(2,N1;M11)=SH(2,N1;M11)/GM3
      RO(2,N1;M11)=P(2,N1;M11)/GM9/SH(2,N1;M11)
      TV2(2,1;NXM2)=VSQRT(T(2,1;NXM2);TV2(2,1;NXM2))
      VIS(2,1;NXM2)=T(2,1;NXM2)*TV2(2,1;NXM2)*GM6/(T(2,1;NXM2)+GM5)
      RETURN
      END
```

APPENDIX C

SAMPLE INPUT

In this appendix, various input parameters are prescribed for the laminar flow past a sphere cone. The first sample problem investigates the flow at 5° angle of attack by using the code given in appendix A. The second problem investigates the flow past a hyperboloid at zero angle of attack by using the code given in appendix B.

Input parameter NBODY is prescribed in the main program BBODY. The rest of the parameters are prescribed either in BCON or BHYP depending on whether NBODY = 1 or 2.

Input for Sample Problem 1

NBODY = 1

CC = .001

FM = 10.3

TF = 46.26

PF = 100.77

ALPHA = .087266 (5°)

THC = .7854 (45°)

TW = 330.6

RN = .03175

DY = .185

BETA = 1.1

FDT = 1.0

THESH = .0349 (2°)

LMAX = 20000

LTURB = 25000

CRIT = .01

APPENDIX C (continued)

Input for Sample Problem 2

NBODY	=	2
CC	=	.001
FM	=	10.3
TF	=	46.26
PF	=	100.77
ALPHA	=	0
THC	=	.7854 (45°)
TW	=	330.6
RN	=	.03175
DY	=	.185
BETA	=	1.1
FDT	=	1.0
THECH	=	.0349 (2°)
LAMX	=	20000
LTURB	=	25000
CRIT	=	.01

APPENDIX D

SAMPLE OUTPUT

The sample outputs are given here for the two cases discussed in appendix C. The code initially prints the body geometry parameters and complete starting solution. The shock shape, heating rates, surface pressures, skin friction, etc., are printed after every 500 time steps. The detailed flow quantities are printed after every 5000 time steps and after the solution is converged. Only a portion of the complete output is presented here which includes the body geometry parameters, a sample of gross flow quantities and a sample of detailed flow quantities. Detailed flow quantities are given here only at one body station although these quantities are printed at each body station in the complete output.

Output for Sample Problem 1

Y=	.00000	THE=	1.57080	R=	.00000	CUR=	1.00000
Y=	.18500	THE=	[illegible]	R=	.18391	CUR=	1.00000
Y=	.37000	THE=	1.20080	R=	.36162	CUR=	1.00000
Y=	.55500	THE=	[illegible]	R=	.52694	CUR=	1.00000
Y=	.74000	THE=	[illegible]	R=	.67429	CUR=	1.00000
Y=	.92500	THE=	.78540	R=	.80552	CUR=	1.00000
Y=	1.11000	THE=	.78540	R=	.93663	CUR=	.00000
Y=	1.29500	THE=	.78540	R=	1.06745	CUR=	.00000
Y=	1.48000	THE=	.78540	R=	1.19626	CUR=	.00000
Y=	1.66500	THE=	.78540	R=	1.32906	CUR=	.00000
Y=	1.85000	THE=	.78540	R=	1.45989	CUR=	.00000
Y=	2.03500	THE=	.78540	R=	1.59071	CUR=	.00000
Y=	2.22000	THE=	.78540	R=	1.72152	CUR=	.00000
Y=	2.40500	THE=	.78540	R=	1.85234	CUR=	.00000
Y=	2.59000	THE=	.78540	R=	1.98315	CUR=	.00000
Y=	.18500	THE=	[illegible]	R=	.18391	CUR=	1.00000
Y=	.37000	THE=	[illegible]	R=	.36162	CUR=	1.00000
Y=	.55500	THE=	[illegible]	R=	.52694	CUR=	1.00000
Y=	.74000	THE=	[illegible]	R=	.67429	CUR=	1.00000
Y=	.92500	THE=	.78540	R=	.80552	CUR=	1.00000
Y=	1.11000	THE=	.78540	R=	.93663	CUR=	.00000
Y=	1.29500	THE=	.78540	R=	1.06745	CUR=	.00000
Y=	1.48000	THE=	.78540	R=	1.19426	CUR=	.00000
Y=	1.66500	THE=	.78540	R=	1.32906	CUR=	.00000
Y=	1.85000	THE=	.78540	R=	1.45989	CUR=	.00000
Y=	2.03500	THE=	.78540	R=	1.59071	CUR=	.00000
Y=	2.22000	THE=	.78540	R=	1.72152	CUR=	.00000
Y=	2.40500	THE=	.78540	R=	1.85234	CUR=	.00000
Y=	2.59000	THE=	.78540	R=	1.98315	CUR=	.00000

DIST.ALONG BODY	SHOCK STANDOFF DIST.	SHOCK SPEED	STANTON NO.	SKIN FRICTION	WALL PR.
.00000	.13557	.00004	.01505293	.0025617	.91426
.18500	.14045	.00013	.01415144	.0074099	.84524
.37000	.14996	.00003	.01264774	.0115721	.72239
.55500	.17266	.00012	.00969472	.0130620	.55316
.74000	.20772	.00004	.00702096	.0115430	.41929
.92500	.23449	.00019	.00641287	.0091428	.40057
1.11000	.25139	.00012	.00550861	.0073637	.38865
1.29500	.26154	.00002	.00455064	.0058511	.38980
1.48000	.26862	-.00001	.00413224	.0050109	.40107
1.66500	.27551	-.00003	.00422406	.0044300	.41004
1.85000	.28350	-.00004	.00419389	.0041276	.42719
2.03500	.29290	-.00003	.00393946	.0039861	.43579
2.22000	.30447	-.00003	.00361695	.0039390	.44175
2.40500	.31749	-.00002	.00367270	.0039254	.44420
2.59000	.33275	.00001	.00365924	.0039303	.44639
.18500	.13556	.00009	.01505263	.0021227	.91467
.37000	.14953	.00001	.01414954	.0079566	.84513
.55500	.15624	-.00002	.01173446	.0108345	.71288
.74000	.18179	.00024	.00881607	.0102766	.58927
.92500	.20205	.00023	.00775231	.0076511	.57691
1.11000	.21692	.00014	.00672767	.0060163	.57364
1.29500	.23086	.00001	.00619179	.0049912	.59321
1.48000	.24623	-.00005	.00507114	.0045866	.60752
1.66500	.26458	-.00003	.00562347	.0044666	.61590
1.85000	.27464	-.00002	.00541233	.0044102	.62021
2.03500	.30016	-.00001	.00522457	.0043533	.62269
2.22000	.32848	-.00009	.00594667	.0042968	.62365
2.40500	.35149	-.00001	.00430786	.0042478	.62358
2.59000	.37479	.00001	.00430714	.0042658	.62289

BODY RADIUS R=	.00000	PRESSURE DRAG=	1.82652
BODY RADIUS R=	.18391	PRESSURE DRAG=	4.73372
BODY RADIUS R=	.36162	PRESSURE DRAG=	1.54367
BODY RADIUS R=	.52694	PRESSURE DRAG=	1.50372
BODY RADIUS R=	.67429	PRESSURE DRAG=	1.31448
BODY RADIUS R=	.80552	PRESSURE DRAG=	1.25162
BODY RADIUS R=	.93663	PRESSURE DRAG=	1.19083
BODY RADIUS R=	1.06745	PRESSURE DRAG=	1.13526
BODY RADIUS R=	1.19626	PRESSURE DRAG=	1.10622
BODY RADIUS R=	1.32906	PRESSURE DRAG=	1.09322
BODY RADIUS R=	1.45969	PRESSURE DRAG=	1.08124
BODY RADIUS R=	1.59071	PRESSURE DRAG=	1.08122
BODY RADIUS R=	1.72152	PRESSURE DRAG=	1.07934
BODY RADIUS R=	1.85234	PRESSURE DRAG=	1.07643
BODY RADIUS R=	1.98315	PRESSURE DRAG=	1.07765

ZN	U	V	WP	P	PC	T	H	[illegible]
.00000	.00000	.00000	.00000	.91826	1[illegible]	7.14[illegible]	.16841	.00000
.00040	.00799	.00[illegible]7	-.00799	.91826	15.[illegible]	8.[illegible]	.20305	.00000
.00081	.01479	-.00036	-.01479	.91827	13.72226	9.93[illegible]	.23432	.00000
.00123	.020[illegible]	-.00025	-.020[illegible]	.91826	12.19602	11.16345	.26376	.00000
.00167	.02611	-.00052	-.0261[illegible]	.91829	11.[illegible]251	12.34706	.29113	.00000
.00211	.03[illegible]2	-.00067	-.030[illegible]2	.91830	10.[illegible]	13.43622	.31716	.00000
.00257	.03501	-.00126	-.03501	.91[illegible]	9.42930	14.46474	.34147	.00000
.00304	.03872	-.00177	-.03872	.91831	[illegible]	15.43063	.36437	.00000
.00352	.04199	-.00221	-.04199	.91831	8.35256	16.32468	.38569	.00000
.00402	.04485	-.00291	-.04485	.91831	7.94722	17.16243	.40544	.00000
.00453	.04732	-.00356	-.04732	.91831	7.[illegible]73	17.9[illegible]	.42355	.00000
.00506	.04945	-.00425	-.04945	.91830	7.32514	18.[illegible]971	.44000	.00000
.00559	.05125	-.00498	-.05125	.91828	7.06757	19.24276	.45478	.00000
.00615	.05277	-.00575	-.05277	.91827	6.87974	19.79512	.46790	.00000
.00672	.05402	-.00654	-.05402	.91826	6.72518	20.27976	.47937	.00000
.00730	.05505	-.00735	-.05505	.91823	6.56939	20.69715	.48927	.00000
.00790	.05588	-.00817	-.05588	.91820	6.47639	21.05108	.49766	.00000
.00851	.05654	-.00901	-.05654	.91817	6.38566	21.34599	.50466	.00000
.00914	.05706	-.00986	-.05706	.91813	6.31712	21.58654	.51037	.00000
.00979	.05747	-.01071	-.05747	.91809	6.26[illegible]	21.77937	.51494	.00000
.01045	.05779	-.01158	-.05779	.91804	6.21776	21.92964	.51851	.00000
.01113	.05804	-.01245	-.05804	.91799	6.17519	22.04367	.52122	.00000
.01183	.05824	-.01332	-.05824	.91793	6.17124	22.12[illegible]7	.52323	.00000
.01255	.05840	-.01420	-.05840	.91787	6.14412	22.18832	.52467	.00000
.01328	.05853	-.01511	-.05853	.91780	6.13227	22.22454	.52566	.00000
.01403	.05864	-.01602	-.05864	.91773	6.12437	22.25642	.52632	.00000
.01481	.05874	-.01694	-.05874	.91765	6.11933	22.27272	.52672	.00000
.01560	.05883	-.01788	-.05883	.91756	6.11630	22.28[illegible]	.52696	.00000
.01641	.05892	-.01884	-.05892	.91746	6.11451	22.28553	.52707	.00000
.01724	.05901	-.01982	-.05901	.91736	6.11375	22.28604	.52711	.00000
.01809	.05909	-.02082	-.05909	.91725	6.11347	22.28445	.52709	.00000
.01896	.05918	-.02183	-.05918	.91713	6.11345	22.28160	.52705	.00000
.01985	.05926	-.02289	-.05926	.91700	6.11356	22.27[illegible]1	.52700	.00000
.02077	.05935	-.02398	-.05935	.91686	6.11372	22.27399	.52693	.00000
.02170	.05944	-.02506	-.05944	.91670	6.11397	22.26974	.52686	.00000
.02265	.05953	-.02618	-.05953	.91654	6.11[illegible]	22.26535	.52680	.00000
.02364	.05963	-.02733	-.05963	.91636	6.11[illegible]	22.2[illegible]	.52673	.00000
.02464	.05972	-.02851	-.05972	.91617	6.114[illegible]	22.25[illegible]	.52666	.00000
.02567	.05982	-.02971	-.05982	.91597	6.11397	22.2[illegible]	.52659	.00000
.02672	.05993	-.03094	-.05993	.91576	6.113[illegible]	22.24[illegible]	.52652	.00000
.02779	.06003	-.03220	-.06003	.91552	6.113[illegible]	22.24[illegible]	.52645	.00000
.02887	.06014	-.03349	-.06014	.91527	6.11[illegible]	22.237[illegible]	.52639	[illegible]
.03001	.06026	-.03481	-.06026	.91501	6.11[illegible]	22.23[illegible]	.52632	[illegible]
.03115	.06038	-.03616	-.06038	.91473	6.11245	22.22[illegible]	.526[illegible]	.00000
.03232	.06050	-.03754	-.06050	.91443	6.11[illegible]	22.22[illegible]72	.526[illegible]	[illegible]
.03352	.06063	-.03895	-.06063	.91411	6.11125	22.21[illegible]	.52612	[illegible]
.03474	.06076	-.04039	-.06076	.91377	6.11[illegible]	22.21[illegible]	.526[illegible]	[illegible]
.03598	.06090	-.04187	-.06090	.91341	6.10[illegible]	22.20[illegible]	.52599	[illegible]
.03725	.06104	-.04338	-.06104	.91303	6.10[illegible]1	22.19[illegible]1	.52593	[illegible]
.03855	.06119	-.04492	-.06119	.91262	6.10765	22.1[illegible]	.525[illegible]	[illegible]
.03987	.06135	-.04649	-.06135	.91219	6.10547	22.1[illegible]	.525[illegible]	[illegible]
.04122	.06151	-.04810	-.06151	.91173	6.10517	22.18[illegible]	.52573	[illegible]
.04259	.06167	-.04975	-.06167	.91125	6.10374	22.17463	.52567	[illegible]
.04399	.06185	-.05142	-.06185	.91074	6.10217	22.16[illegible]	.52560	[illegible]
.04542	.06203	-.05314	-.06203	.910[illegible]	6.10047	22.1[illegible]	.52554	[illegible]
.04687	.06221	-.05489	-.06221	.90963	[illegible]	22.1[illegible]	.525[illegible]	[illegible]
.04835	.06241	-.05668	-.06241	.909[illegible]2	[illegible]	[illegible]	.52541	[illegible]
.04986	.06260	-.05850	-.06260	.90[illegible]	6.[illegible]	[illegible]	.52535	[illegible]
.05140	.06281	-.06036	-.06281	.90772	6.09[illegible]	22.13[illegible]	.525[illegible]	[illegible]
.05296	.06303	-.06226	-.06303	.90[illegible]	6.0[illegible]	22.12[illegible]	.52523	[illegible]
.05454	.06325	-.06419	-.06325	.90617	6.08673	22.11[illegible]	.52517	[illegible]
.05616	.06348	-.06617	-.06348	.90548	6.08405	22.10[illegible]	.525[illegible]	[illegible]
.05779	.06371	-.06818	-.06371	.90466	6.0[illegible]	22.09[illegible]	.525[illegible]	[illegible]
.05946	.06396	-.07023	-.06396	.90379	6.07769	22.08[illegible]	.524[illegible]	[illegible]
.06115	.06421	-.07232	-.06421	.90289	6.07420	22.07733	.52493	[illegible]
.06287	.06446	-.07445	-.06446	.90193	6.07047	22.0[illegible]	.524[illegible]7	[illegible]
.06461	.06473	-.07661	-.06473	.90093	6.06652	22.05740	.524[illegible]	[illegible]
.06638	.06500	-.07882	-.06500	.89988	6.06233	22.04[illegible]	.52475	[illegible]
.06818	.06528	-.08106	-.06528	.89878	6.05786	22.03519	.52470	[illegible]
.07000	.06557	-.08335	-.06557	.89763	6.05318	22.02508	.52464	[illegible]
.07184	.06587	-.08567	-.06587	.89643	6.04821	22.01362	.52459	[illegible]
.07371	.06617	-.08804	-.06617	.89517	6.04276	22.00160	.52453	[illegible]
.07560	.06648	-.09044	-.06648	.89386	6.03743	21.98961	.52448	[illegible]
.07751	.06679	-.09288	-.06679	.89248	6.03160	21.97704	.52443	[illegible]
.07945	.06712	-.09537	-.06712	.89105	6.02547	21.96406	.52438	.00000
.08141	.06745	-.09789	-.06745	.88955	6.01903	21.95072	.524[illegible]	.00000
.08339	.06778	-.10045	-.06778	.88800	6.01226	21.93694	[illegible]	.00000
.08539	.06813	-.10305	-.06813	.88637	6.00516	21.92274	.52424	.00000
.08742	.06848	-.10569	-.06848	.88468	5.99771	21.90811	.52419	.00000
.08946	.06883	-.10837	-.06883	.88293	5.98992	21.89304	.52415	.00000
.09152	.06920	-.11108	-.06920	.88110	5.98176	21.87751	.52411	.00000
.09360	.06957	-.11384	-.06957	.87920	5.97324	21.86152	.52406	.00000
.09570	.06994	-.11663	-.06994	.87723	5.96433	21.84505	.52402	.00000
.09782	.07032	-.11946	-.07032	.87518	5.95504	21.82809	.52398	.00000
.09995	.07071	-.12233	-.07071	.87306	5.94535	21.81064	.52395	.00000
.10210	.07110	-.12524	-.07110	.87086	5.93526	21.79268	.52391	.00000
.10426	.07149	-.12818	-.07149	.86858	5.92475	21.77420	.52388	.00000
.10644	.07190	-.13116	-.07190	.86622	5.91382	21.75519	.52384	.00000
.10863	.07230	-.13418	-.07230	.86378	5.90246	21.73564	.52381	.00000
.11083	.07271	-.13723	-.07271	.86126	5.89066	21.71554	.52378	.00000
.11305	.07313	-.14032	-.07313	.85865	5.87841	21.69488	.52376	.00000
.11527	.07355	-.14344	-.07355	.85595	5.86570	21.67364	.52373	.00000
.11750	.07397	-.14660	-.07397	.85317	5.85253	21.65183	.52371	.00000
.11974	.07440	-.14980	-.07440	.85030	5.83890	21.62942	.52368	.00000
.12199	.07483	-.15302	-.07483	.84734	5.82477	21.60640	.52366	.00000
.12424	.07526	-.15629	-.07526	.84430	5.81016	21.58280	.52364	.00000
.12650	.07570	-.15958	-.07570	.84115	5.79504	21.55848	.52362	.00000
.12877	.07614	-.16291	-.07614	.83794	5.77956	21.53377	.52361	.00000
.13103	.07659	-.16629	-.07659	.83455	5.76316	21.50761	.52359	.00000
.13330	.07704	-.16963	-.07704	.83126	5.74725	21.48264	.52359	.00000
.13557	.07753	-.17307	-.07753	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX D (continued)

Output for Sample Problem 2

Y=	.00000	TH=	1.57080	R=	.00000	CUR=	1.00000
Y=	.18500	TH=	1.39178	R=	.18399	CUR=	.90841
Y=	.37000	TH=	1.24216	R=	.36275	CUR=	.76[illegible]
Y=	.55500	TH=	1.13961	R=	.53594	CUR=	.5[illegible]
Y=	.74000	TH=	1.05103	R=	.69760	CUR=	.34[illegible]
Y=	.92500	TH=	.994[illegible]	R=	.85553	CUR=	.2[illegible]
Y=	1.11000	TH=	.95[illegible]	R=	1.00841	CUR=	.1[illegible]
Y=	1.29500	TH=	.92[illegible]	R=	1.15753	CUR=	.14[illegible]
Y=	1.48000	TH=	.9[illegible]	R=	1.30370	CUR=	.10[illegible]
Y=	1.66500	TH=	.8[illegible]	R=	1.44755	CUR=	.0[illegible]
Y=	1.85000	TH=	.8[illegible]	R=	1.58956	CUR=	.00[illegible]
Y=	2.03500	TH=	.85721	R=	1.73007	CUR=	.0[illegible]
Y=	2.22000	TH=	.84815	R=	1.86936	CUR=	.0[illegible]
Y=	2.40500	TH=	.84069	R=	2.00765	CUR=	.0[illegible]
Y=	2.59000	TH=	.83448	R=	2.14510	CUR=	.0[illegible]

DIST. ALONG BODY	SHOCK STANDOFF DIST.	SHOCK [illegible]	S[illegible]	[illegible]	[illegible]
.00000	.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.18500	.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.37000	.19332	[illegible]	[illegible]	[illegible]	[illegible]
.55500	.2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.74000	.22[illegible]	[illegible]	[illegible]	.0[illegible]	[illegible]
.92500	.23369	[illegible]	[illegible]	[illegible]	[illegible]
1.11000	.2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.29500	[illegible]	[illegible]	[illegible]	.00[illegible]	[illegible]
1.48000	.32[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.66500	[illegible]	[illegible]	.0095[illegible]	[illegible]	[illegible]
1.85000	.37[illegible]	[illegible]	[illegible]	.008[illegible]	[illegible]
2.03500	.3945[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.22000	.41612	[illegible]	[illegible]	[illegible]	[illegible]
2.40500	.43743	[illegible]	[illegible]	[illegible]	[illegible]
2.59000	.45843	[illegible]	[illegible]	[illegible]	[illegible]

R	CUP	CDF	CD
.000000	.000000	.000000	.000000
.183388	1.775029	.000671	1.77[illegible]
.362746	1.722245	.001359	1.723[illegible]
.533944	1.653768	.002156	1.655924
.697802	1.5[illegible]46	.002652	1.5874[illegible]
.855530	1.521590	.003364	1.524[illegible]74
1.008414	1.466548	.003763	1.470310
1.157527	1.419367	.004022	1.423388
1.303698	1.379181	.004192	1.383373
1.447551	1.344956	.004298	1.349254
1.589555	1.315735	.004358	1.320093
1.730068	1.290680	.004386	1.295066
1.869363	1.269111	.004390	1.273502
2.007651	1.250433	.004380	1.254813
2.145100	1.234084	.004366	1.238450

ZN	U	V	P	RO	T	H	VIST
.00000	.00000	.00000	.92642	19.27104	7.14008	.16526	.00000
.00049	.00000	-.00003	.92642	[illegible]	8.72832	.20568	.00000
.00097	.00000	-.00013	[illegible]	[illegible]	10.14936	.23917	.00000
.00147	.00000	-.00033	.92635	[illegible]	11.46990	.27029	.00000
.00199	.00000	-.00062	.92634	[illegible]	[illegible]	.29720	.00000
.00252	.00000	-.00099	.92635	[illegible]	13.54679	.32630	.00000
.00307	.00000	-.00143	.92635	9.22510	14.91778	.35154	.00000
.00363	.00000	-.00194	[illegible]	[illegible]	15.91333	.37500	.00000
.00421	.00000	-.00250	.92636	8.17519	16.82996	.39660	.00000
.00480	.00000	-.00313	.92635	7.76752	17.50766	.41634	.00000
.00541	.00000	-.00380	.92634	7.46767	18.42419	.43417	.00000
.00604	.00000	-.00452	.92633	7.20544	19.09970	.45009	.00000
.00668	.00000	-.00527	.92631	6.96563	19.69427	.46411	.00000
.00734	.00000	-.00605	.92628	6.80740	20.20995	.47626	.00000
.00802	.00000	-.00685	.92625	6.66225	20.64958	.48663	.00000
.00872	.00000	-.00766	.92622	6.54154	21.01766	.49531	[illegible]
.00943	.00000	-.00851	.92618	6.45237	21.31959	.50243	.00000
.01016	.00000	-.00936	.92614	6.37954	21.56192	[illegible]	.00000
.01092	.00000	-.01022	.92609	[illegible]	21.75175	[illegible]	[illegible]
.01169	.00000	-.01109	.92603	[illegible]	[illegible]	.51606	[illegible]
[illegible]	.00000	[illegible]	[illegible]	[illegible]	22.00423	[illegible]	.00000
[illegible]	.00000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.00000
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[illegible]	.00000	[illegible]	[illegible]	[illegible]	22.22054	[illegible]	.00000
[illegible]	.00000	-.01950	[illegible]	[illegible]	22.22214	[illegible]	.00000
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.02160	.00000	[illegible]	.92498	[illegible]	22.22161	[illegible]	.00000
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.16190	.00000	-.17444	.83220	5.72963	21.57194	.52356	.00000

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*Research Associate Professor, Department of Mechanical Engineering and Mechanics, Old Dominion University, Norfolk, Virginia 23508

16. Abstract

This report is a user's guide for a computer code which calculates the laminar and turbulent hypersonic flows about blunt axisymmetric bodies, such as spherically blunted cones, hyperboloids, etc., at zero and small angles of attack. The code is written in STAR FORTRAN language for the CDC-STAR-100 computer. Time-dependent, viscous-shock-layer-type equations are used to describe the flow field. These equations are solved by an explicit, two-step, time asymptotic, finite-difference method. For the turbulent flow, a two-layer, eddy-viscosity model is used. The code provides complete flow-field properties including shock location, surface pressure distribution, surface heat-transfer rates, and skin-friction coefficients. This report contains descriptions of the input and output, the listing of the program, and a sample flow-field solution.

17. Key Words (Suggested by Author(s))

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