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SUPERSONIC FLOW CALCULATIONS FOR A CONE WITH AN ELLIPTIC FLARE

by

Harry Lehrhaupt

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I

SUPERSONIC FLOW CALCULATIONS FOR A CONE WITH AN ELLIPTIC FLARE*

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A three-dimensional supersonic flow program, developed by the Grumman[1] Corporation, has been used to calculate the flow field about a cone at zero angle of attack with an elliptical flare. A schematic diagram of the body is shown in Fig. (1). Calculations are carried out to two cone lengths, with the cone length taken to be unity. Free stream conditions of $M_\infty = 8$ $\rho_\infty = .00308308$, and $p_\infty = 1$ atmosphere were utilized in the calculations.

Cross flow results in terms of the ratio W/v where v is the total velocity are shown in Figs. (2) to (5) for the meridian planes $\theta = 20, 40, 60$ and 80 degrees, respectively. The pressure coefficient distributions

$$C_p = (p/p_\infty - 1)/M_\infty^2 \gamma/2$$

on the body are shown in Figs. (6), (7) and (8) for the meridional planes $\theta = 30, 60$ and 90. As a comparison in Figs. (6) to (8) C_p results for an equivalent axisymmetric body utilizing Lomax's program[2] have also been included. An equivalent axisymmetric body is defined as that axisymmetric body

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1) Three-Dimensional Near Characteristics program written by Dick Scheuing an employee of Grumman for his doctoral thesis.

2) The program referred to here is the one described in the following report, Mamori Inouge, John V. Rakich and Howard Lomax, "A Description of Numerical Methods and Computer Programs for Axisymmetric Supersonic Flow Over Blunt-Nosed and Flared Bodies," NASA TN-2970, August 1965.

which is tangent to the given body along a meridinal plane. The C_p distributions for the equivalent bodies are seen to be in good agreement with the three-dimensional calculations. Such an agreement is to be expected at such high Mach numbers.

In Figs. (9) and (10) the shock shape as computed by the 3-D calculations is compared with the axisymmetric calculations of the Lomax program for equivalent bodies at $\theta = 60$ and $\theta = 90$. The agreement between the shock shapes is even better than the agreement in the C_p distribution.

A user's manual for the three-dimensional program is included as an appendix to this memorandum. It should be noted here that the program, in its present version, is irrotational. As such the results obtained remain strictly valid in the region ahead of the first reflected characteristics from the points on the shock where the shock is no longer axisymmetric. For slowly varying geometries calculations could be extended outside of the above region, in particular under expansion. Special care must be taken, however, in adverse pressure situations where embedded shocks could be formed.

USER'S MANUAL

Three Dimensional Near Characteristics

The program has been broken down into the following subdivisions:

A)	GRUM	-	main program.
B)	Subroutine FIRST	-	reads inputs and initializes data.
C)	Subroutines FIT1 FIT2 FIT3	-	Spline fitting routines FIT1 is the most general.
D)	Subroutine CHAR	-	Calculates speed of sound squared and slopes of characteristics.
E)	FUNCTIONS VAL4, VAL	-	written inorder to enable Scope to handle four dimensional arrays.
F)	Function HARDIF	-	3rd order, finite difference polynomial.
G)	Subroutine NOMDIM	-	nondimensionalizes free stream velocities, pressures and densities, $\bar{v} = v/\sqrt{P_\infty/\rho_\infty}$ $\bar{p} = P/p_\infty$, $\bar{\rho} = P/\rho_\infty$.
H)	Subroutines GRPH PLTS	-	plotting routines W/v and CP are plotted as functions of X for pts. on the body.

INPUTS

Inputs are broken down into three broad classifications RED, WHITE, BLUE.

A)	RED	-	body configuration geometry.
B)	WHITE	-	initial conditions.
C)	BLUE	-	control parameters, step size tolerances, printout and plotting options.

Coordinates used throughout are (X, r, θ).

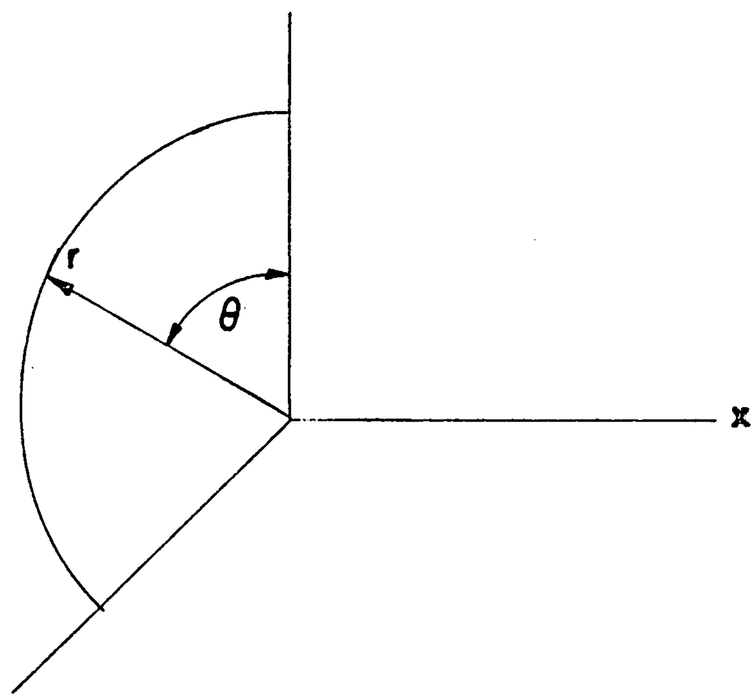


Fig. A

RED INPUTS

CARD 1 2I5, 17A4

MIB - number of (r, θ) planes required to define the body.

MKB - number of radii in defining body in each (r, θ) plane.

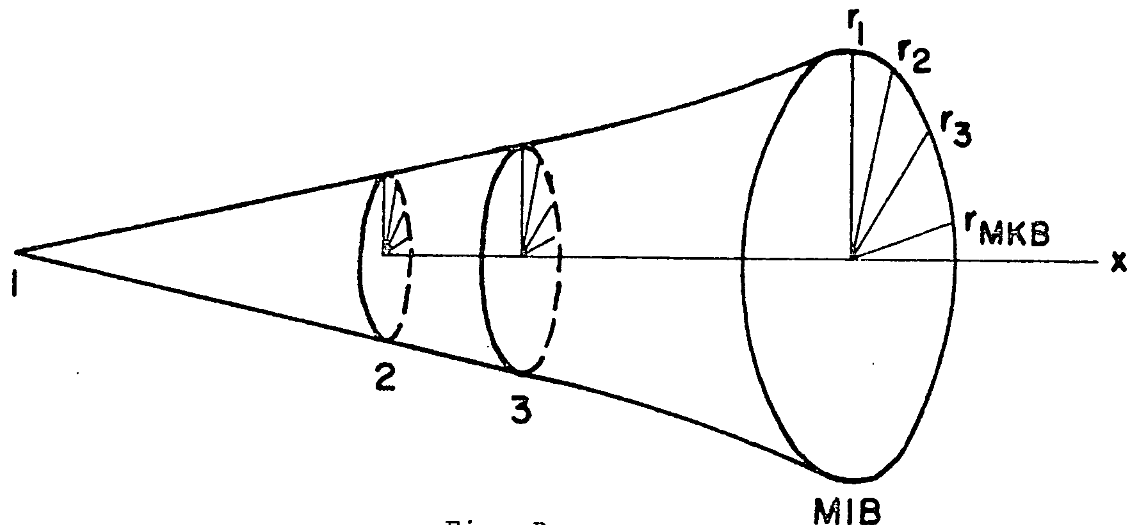


Fig. B

CONFIG - description of body being used (example: ELLIPTICAL CONE A/B 1.394)

CARD 2 (8F10.5) $[MIB/8] + 1$ cards

[ ] indicates greatest integer (example: $[7/3] = 2$, $[3/5] = 0$)

XB(IB) IB=1, MIB - stations where shape of body is defined.

CARD 3 (8F10.0) $\left[\frac{MKB}{8}\right] + 1$ cards

TB(KB) KB=1, MKB - angles for radii in (r, θ) plane $0° \leq \theta \leq 90°$ or $0° \leq \theta \leq 180°$.

CARD 4 (8F10.0) $MIB*\left(\left[\frac{MKB}{8}\right] + 1\right)$ cards

RB(IB, KB) KB=1, MKB; IB=1, MIB - radii at each r-θ plane

CARD 5 (8F10.0) $2*\left(\left[\frac{MKB}{8}\right] + 1\right)$ cards

RBP(IB, KB) KB=1, MKB; IB=1 and IB=MIB - slope $\frac{dr}{dx}$ at first and last r-θ plane

CARD 6 (3I5, 16A4)

MJD	-	number of points between body and shock (r) at initial profile.
MKD	-	number of meridional points (θ) data is specified at.
IVAXIS	-	velocities are cylindrical (1) or spherical (2).
START	-	alphanumeric label containing 64 characters.

CARD 7 (6F12.0) (free stream flow conditions)

EMINF	-	free stream Mach number.
PINF	-	free stream pressure.
RHOINF	-	free stream density.
GAMMA	-	γ = ratio of specific heats $\frac{C_p}{C_v}$.
ALPHA	-	angle of attack.
X1	-	station at which we define initial velocity distribution.

CARD 8 (6F10.0) $\left[\frac{MKD}{2}\right] + 1$ cards

TD(KD)	-	θ value of shock pt. (note at least two values are required; i.e., MKD $\geq$ 2).
RSI(KD)	-	r position of the shock point.
RSXI (KD)	-	slope of shock $\frac{d}{dx}$.

CARD 9 (4E15.0) MKD*MJD cards

UI(JD,KD) - x component of the velocity at pts. along initial profile.

VI(JD,KD) - r component of the velocity.

WI(JD,KD) - θ component of the velocity.

PHI(JD,KD) - helps locate where velocities are given between shock and the body $0 \leq PHI \leq 1$ where PHI = 0 on the body and PHI = 1 at shock

BLUE INPUTS

CARD 10 (10I5)

MI	-	number of steps we wish to march downstream from the initial profile (Note: program terminates either when MI is exceeded or when $x > XEND$).
MJ	-	number of pts. between body and shock (max is 21 , 11 is coarse grid) (Note: $MJD \leq MJ$).
MK	-	number of meridional (θ) planes ($MK \geq MKD$).
MAXM	-	=3 number of times we average slopes of characteristics.
MAXN	-	=15 maximum number of iterations that can be performed to find shock.
MODF	-	(1) one used (affects iteration of shock pt.) (2)
IPT	-	indicates r-θ plane at which we want total pressure calculated. (1) initial plane. (2) at each subsequent station.
KPT	-	meridional plane at which total pressure drop at shock is computed
IPUNCH	-	(0) no punch or plot. (1) punch cards at last station and plots C_p and W/v versus X.
NOPT	-	Print out occurs at every NOPT stations.

CARD 11 (6F10.0)

TOLEP	-	.00001 tolerence for shock.
CUNST	-	0.8 [Von Neuman stability constant.]
CTST	-	0.9 e stability factor
CNX	-	1.0
CNNX	-	0.9
XEND	-	position where calculations are stopped.

THREE DIMENSIONAL NEAR CHARACTERISTIC PROGRAM

Explanation of the Printed Output

Complete Body Radius Matrix

IB	-	Body cross-plane index number
XB	-	Axial location of a body cross-plane
K	-	Meridional plane index number ($0° \rightarrow 180°$ or $0° \rightarrow 90°$)
RB	-	Body radial coordinate (r_b)
RPB	-	First derivative of r_b with respect to x ($r_b' = \frac{\partial r_b}{\partial x}$)
RPPB	-	Second derivative ($r_b'' = \frac{\partial^2 r_b}{\partial x^2}$)
RPPPB	-	Third derivative ($r_b''' = \frac{\partial^3 r_b}{\partial x^3}$)

Upstream Flow Conditions

K	-	Meridional plane index number
Theta	-	Meridional plane coordinate (θ, in degrees)
UU	-	Axial component of the velocity upstream of the shock
VU	-	Radial component of the velocity upstream of the shock.
WU	-	Transverse component of the velocity upstream of the shock

New Data Surface Variables-Final Iteration

I	-	New data surface index number.
X2	-	Axial coordinate of the new data surface.
M	-	Number of iterations used in the calculation (M=1 first order, M=2, 3, 4 second order).
K	-	Meridional plane index number.
TH	-	Meridional plane coordinate (θ, in degrees).
R2	-	Body radial coordinate (r_b).
RX2	-	Body slope in the X direction $\left(\frac{\partial r}{\partial x}\right)_b$.
RT2	-	Body slope in the θ direction $\left(\frac{\partial r}{\partial \theta}\right)_b$.
DR2	-	Radial distance between successive grid points between the body and the shock (δ_r).
DRT2	-	Partial derivative of δ_r with respect to θ.
RS2	-	Shock radial coordinate (r_s)
RSX2	-	Shock slope in the X direction $\left(\frac{\partial r}{\partial x}\right)_s$.
RST2	-	Shock slope in the θ direction $\left(\frac{\partial r}{\partial \theta}\right)_s$.
J	-	Grid point index number in the radial direction (J=1 on body).
RP	-	Local radial coordinate.
U2	-	Local axial velocity component.
V2	-	Local radial velocity component.
W2	-	Local transverse velocity component.
LAMBDA1	-	Local slope of the first characteristic.
LAMBDA2	-	Local slope of the second characteristic

B

New Data Surface Variables-Final Iteration (continued)

MACH NO	-	Local Mach number
CP	-	Local pressure coefficient *

$$\frac{P/p_\infty - 1}{\frac{\gamma}{2} M_\infty^2}$$

* Based on a constant total pressure drop across the shock for all points.

CONE WITH ELLIPSOIDAL FLARE

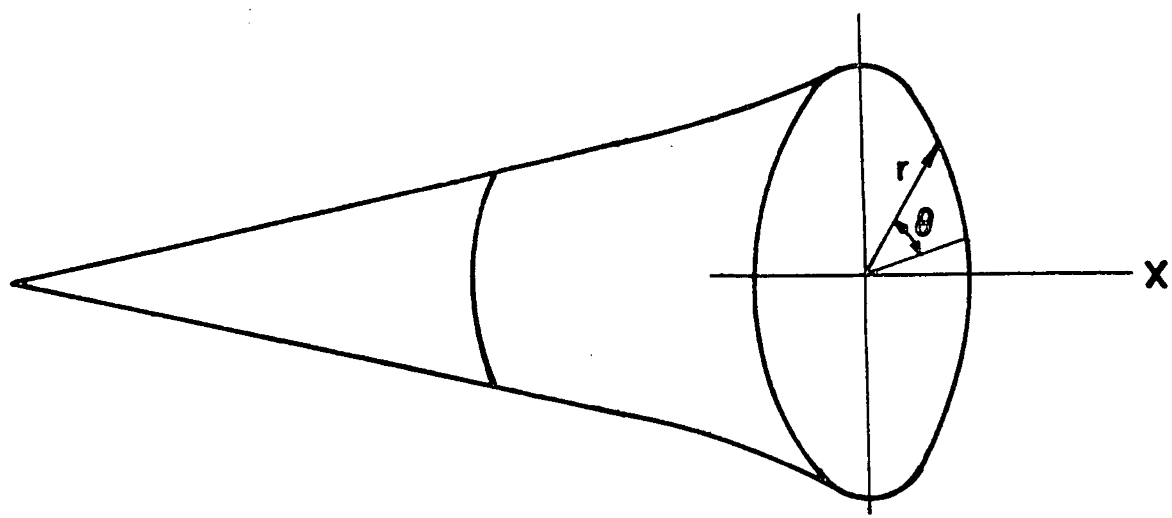


Fig. 1

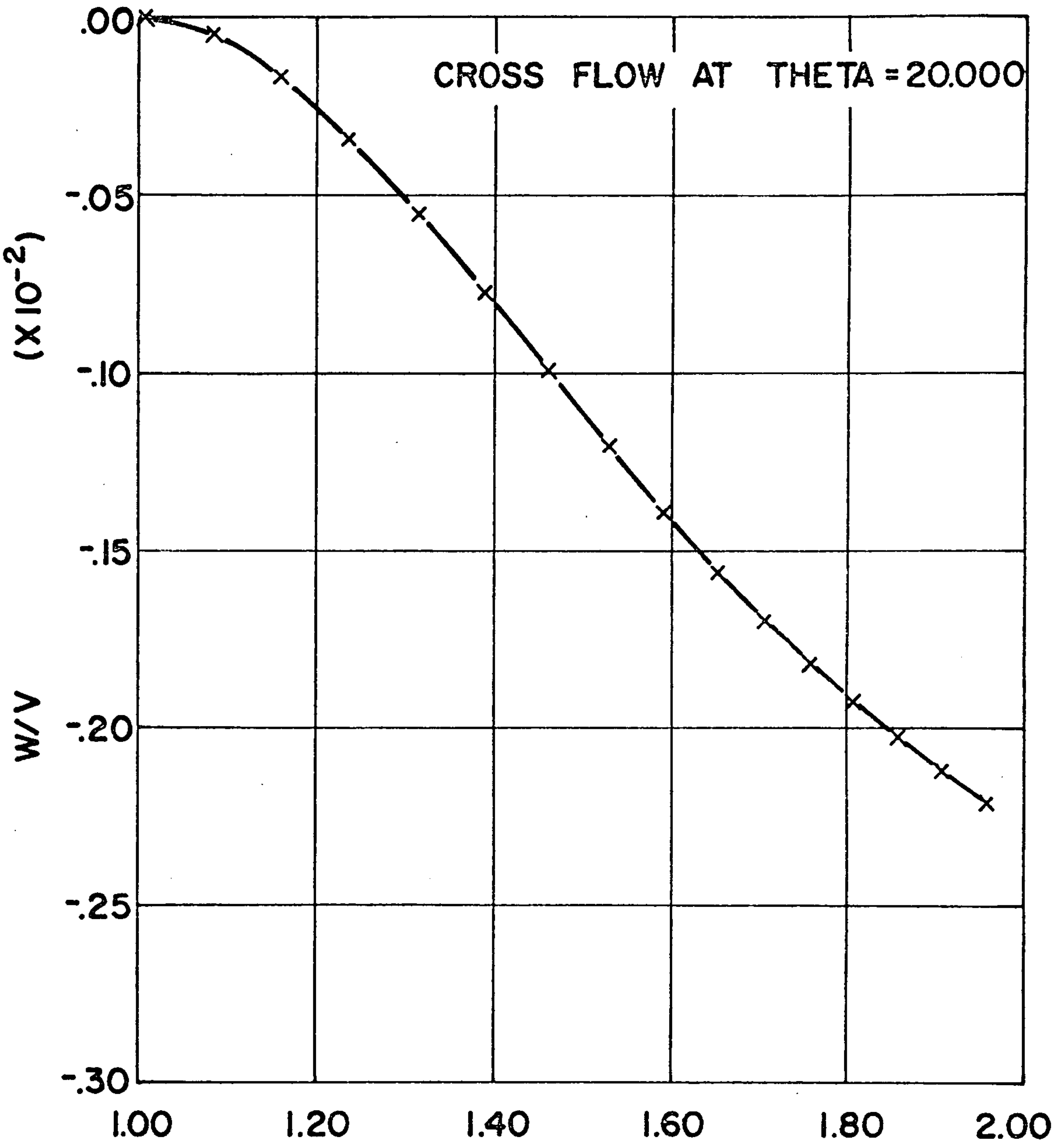
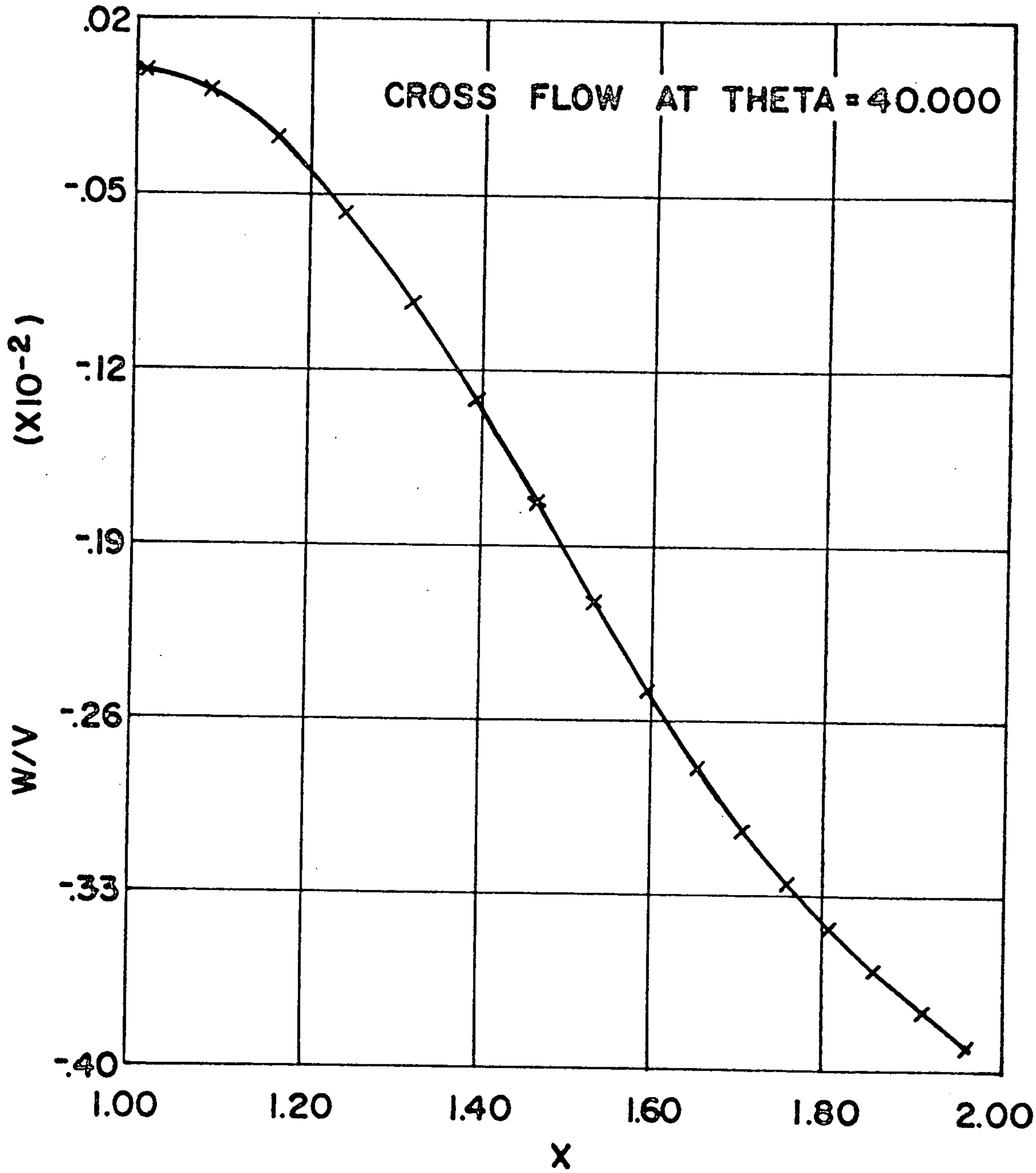

CROSS FLOW AT THETA = 20.000
.00
-.05
-.10
-.15
-.20
-.25
-.30
W/V (X 10^-2)
1.00
1.20
1.40
1.60
1.80
2.00
X

Fig. 2



CROSS FLOW AT THETA = 40.000
.02
-.05
-.12
-.19
-.26
-.33
-.40
W/V (X10⁻²)
1.00
1.20
1.40
1.60
1.80
2.00
X

Fig. 3

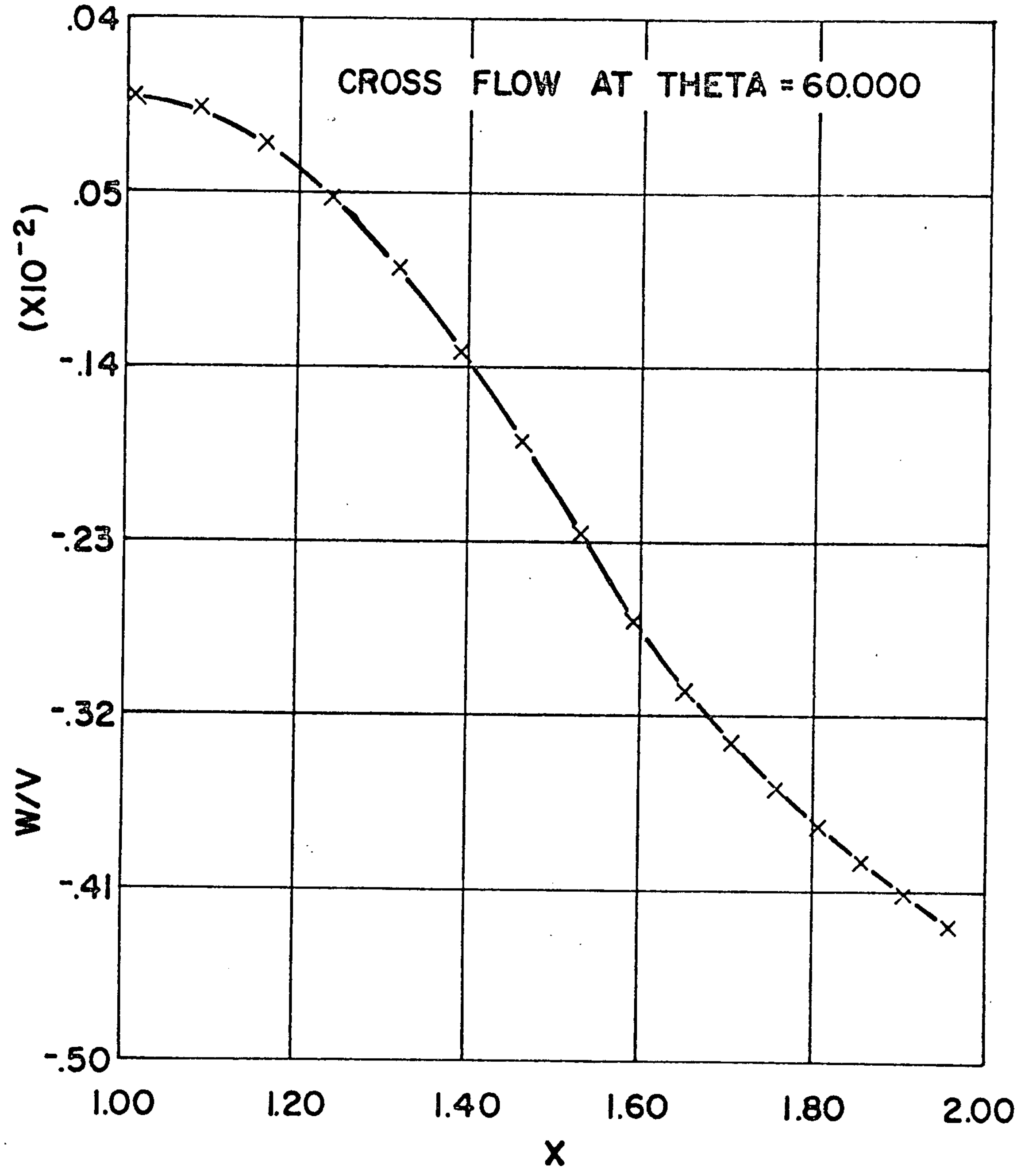
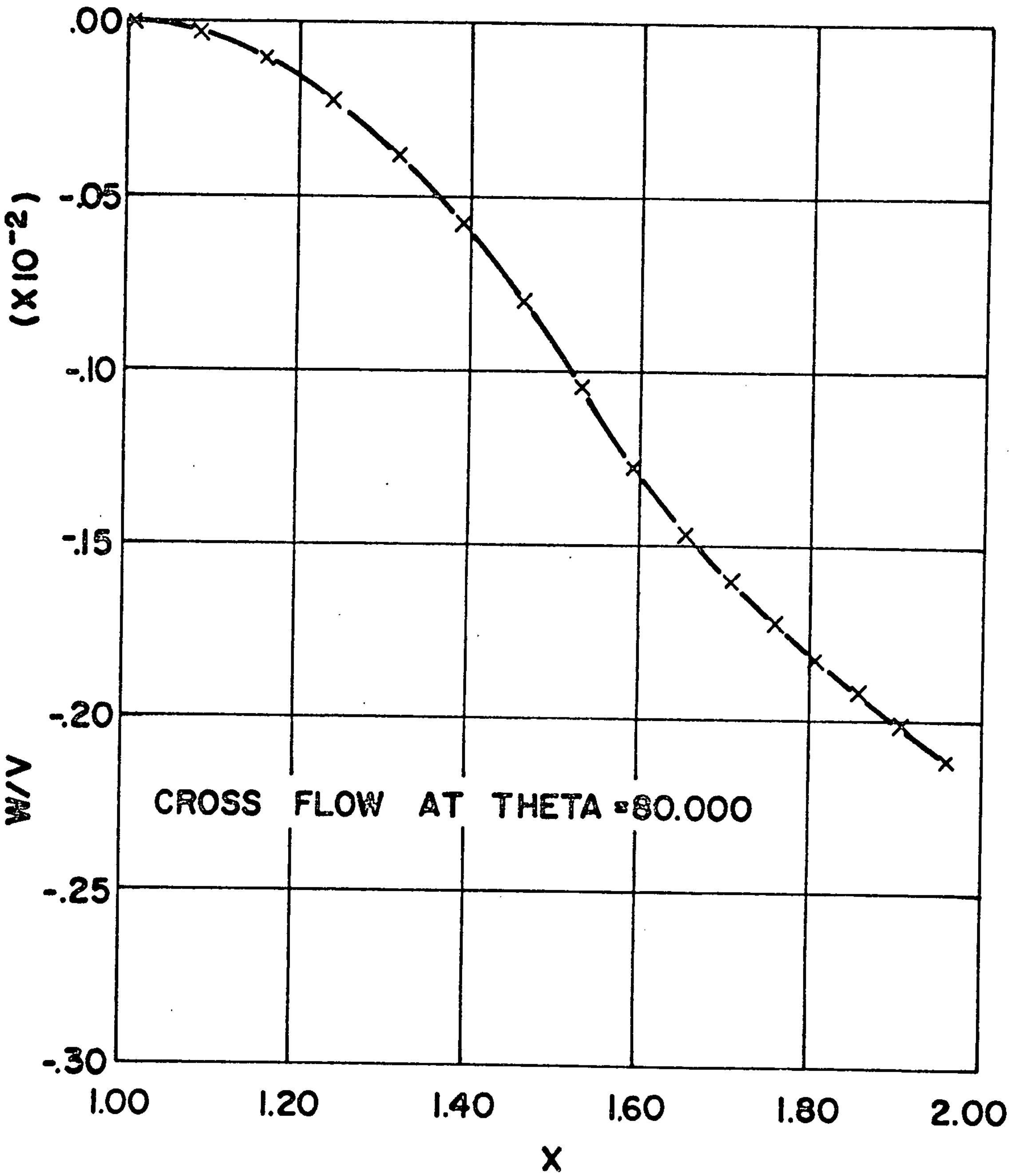

CROSS FLOW AT THETA = 60.000
.04
.05
-.14
-.23
-.32
-.41
-.50
W/V (X10^-2)
1.00
1.20
1.40
1.60
1.80
2.00
X

Fig. 4



.00
-.05
-.10
-.15
-.20
-.25
-.30
(X10⁻²)
W/V
CROSS FLOW AT THETA =80.000
1.00
1.20
1.40
1.60
1.80
2.00
X

Fig. 5

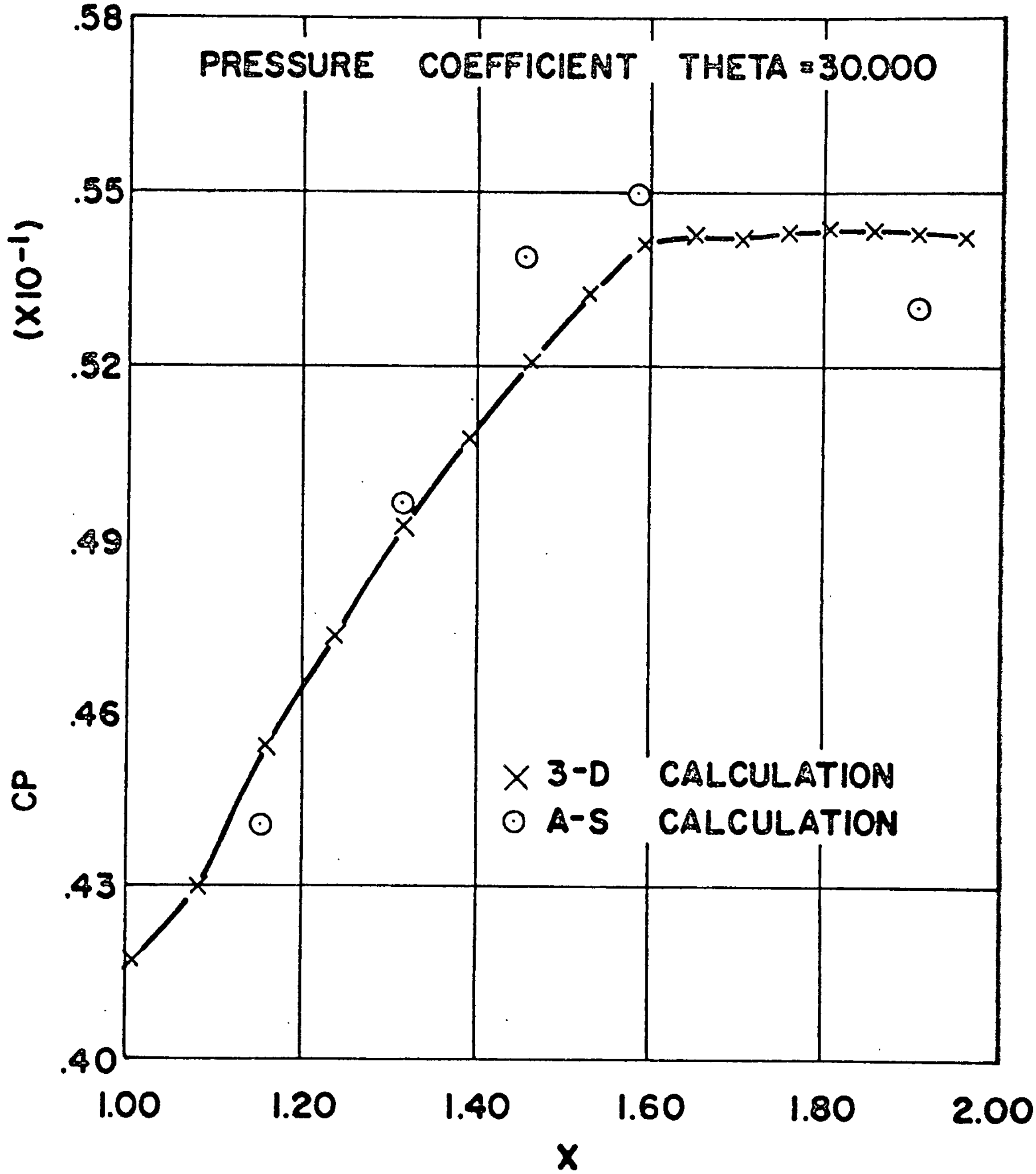

PRESSURE COEFFICIENT THETA =30.000
.58
.55
.52
.49
.46
.43
.40
CP
(X10⁻¹)
1.00
1.20
1.40
1.60
1.80
2.00
X
3-D CALCULATION
A-S CALCULATION

Fig. 6

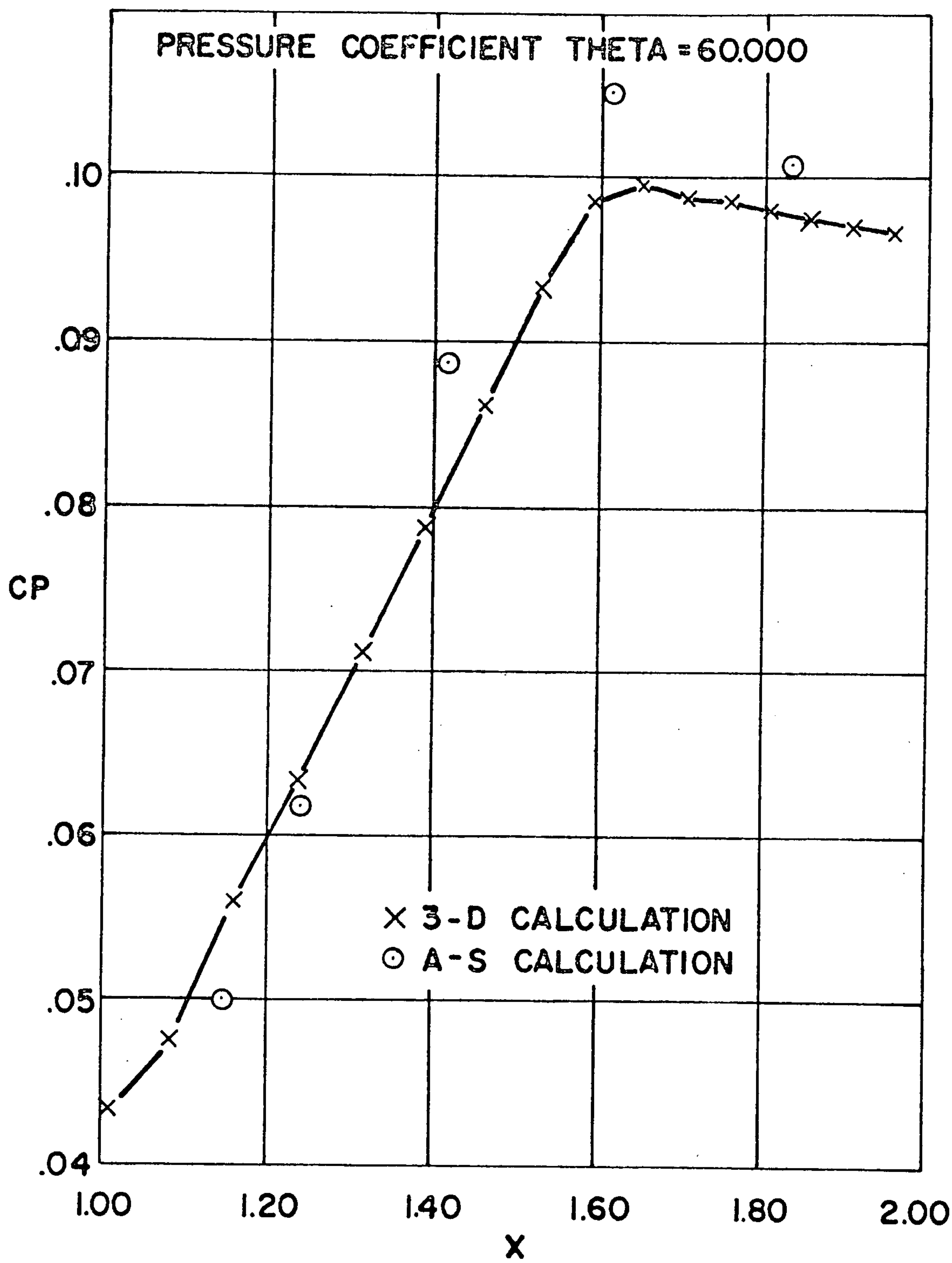

PRESSURE COEFFICIENT THETA = 60.000
CP
.04
.05
.06
.07
.08
.09
.10
1.00
1.20
1.40
1.60
1.80
2.00
X
× 3-D CALCULATION
⊙ A-S CALCULATION

Fig. 7

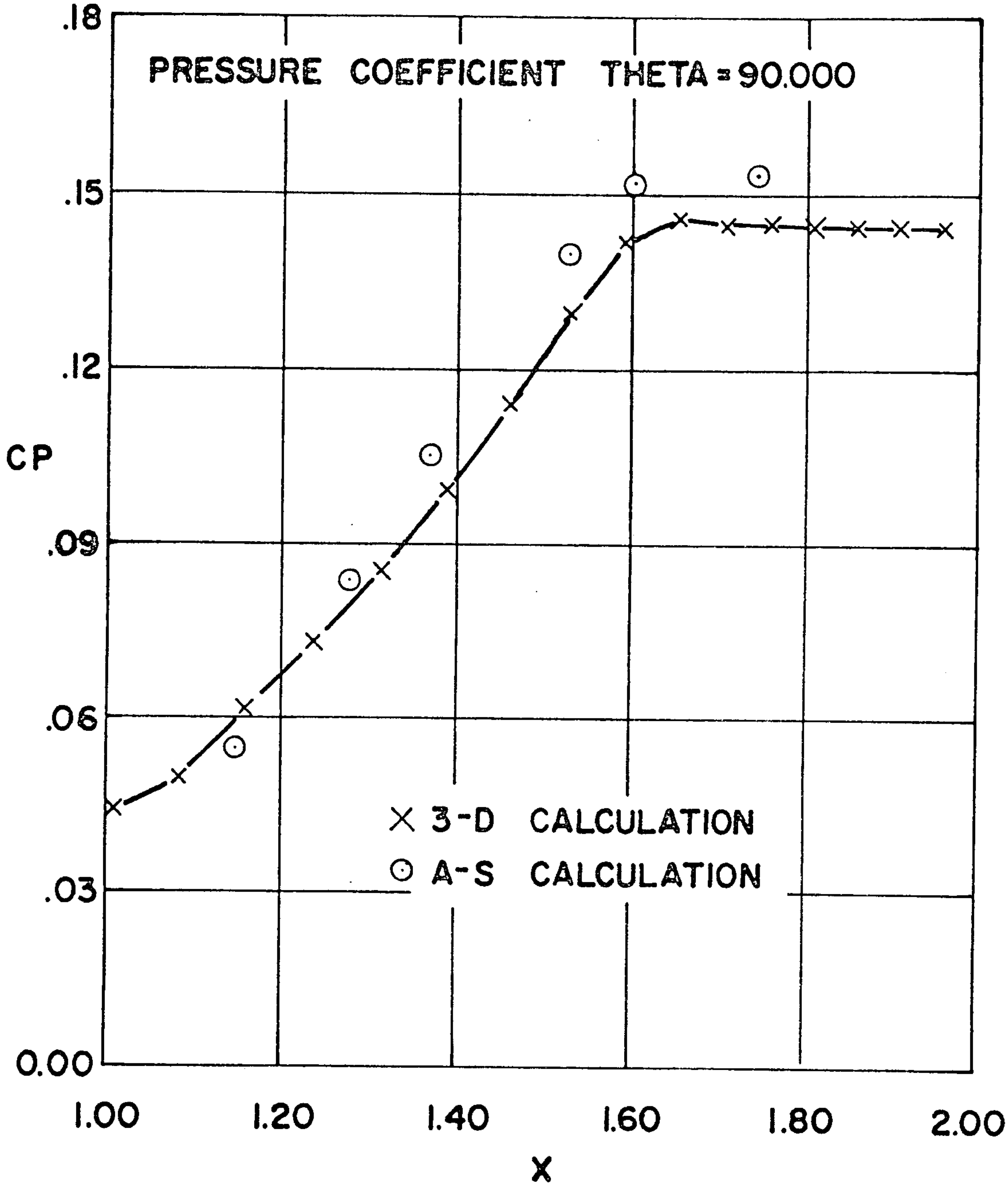

PRESSURE COEFFICIENT THETA = 90.000
.18
.15
.12
CP
.09
.06
.03
0.00
1.00
1.20
1.40
1.60
1.80
2.00
X
3-D CALCULATION
A-S CALCULATION

Fig. 8

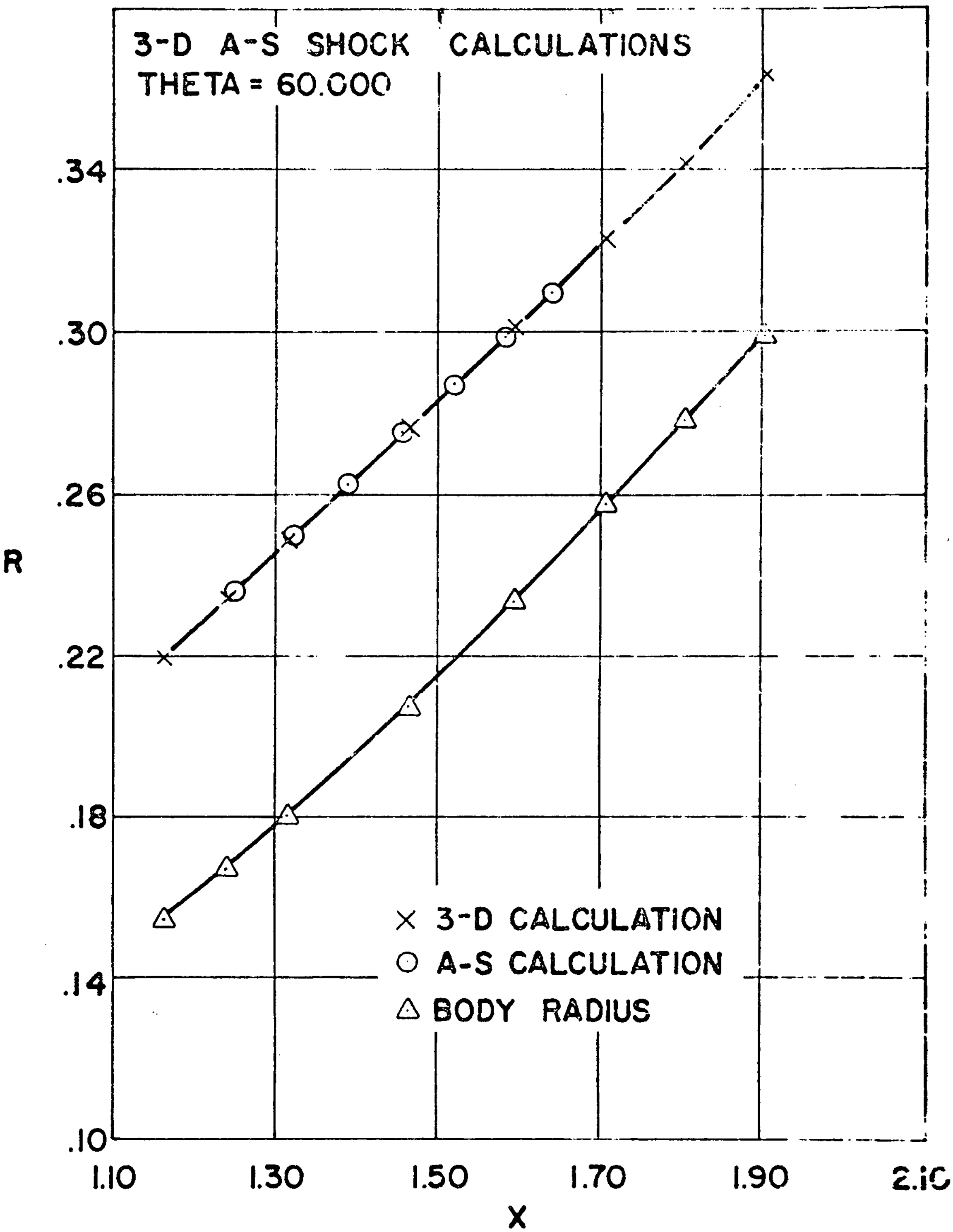

3-D A-S SHOCK CALCULATIONS
THETA = 60.000
.34
.30
.26
.22
.18
.14
.10
R
1.10
1.30
1.50
1.70
1.90
2.10
X
× 3-D CALCULATION
⊙ A-S CALCULATION
△ BODY RADIUS

Fig. 9

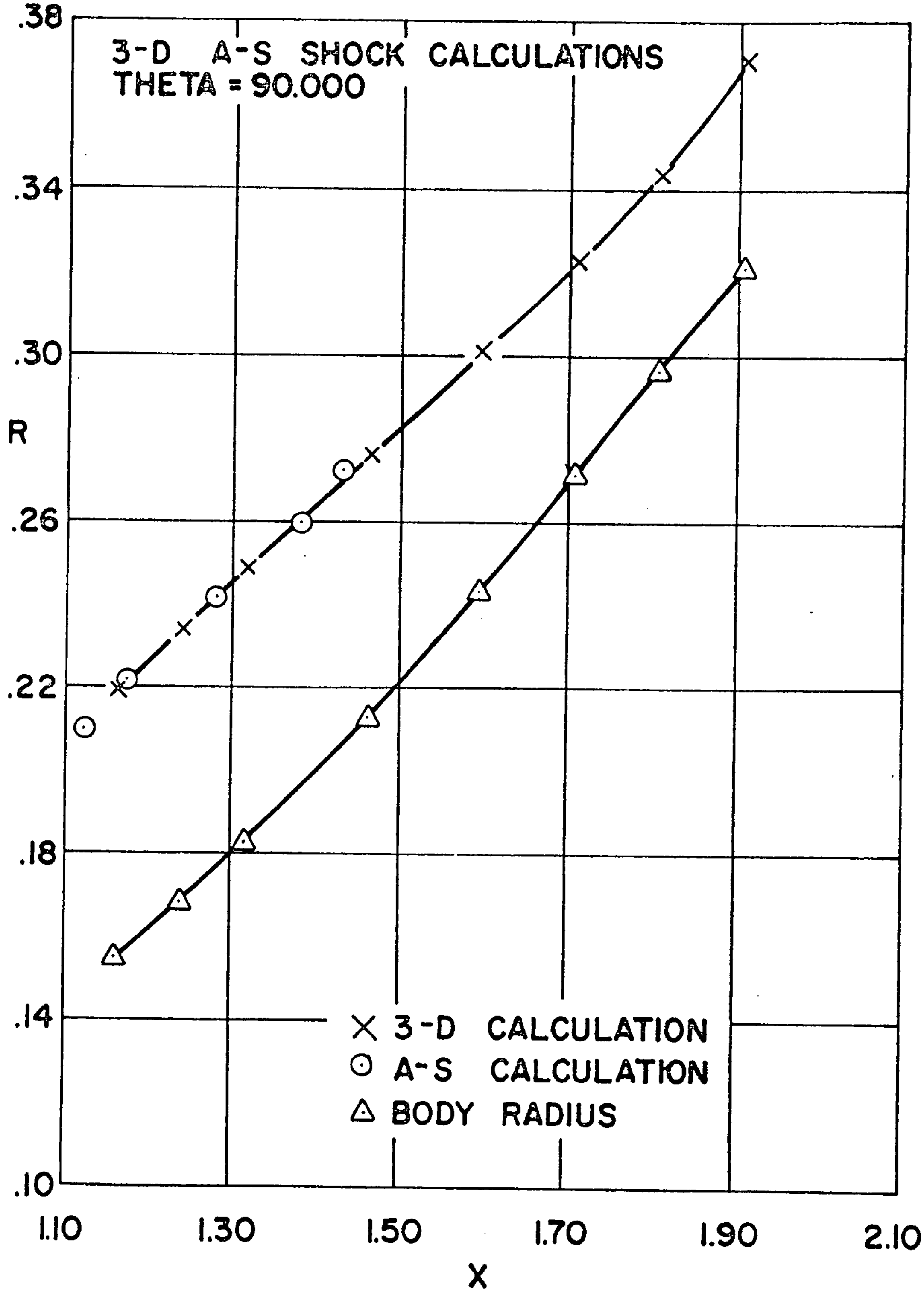

3-D A-S SHOCK CALCULATIONS
THETA = 90.000
.38
.34
.30
R
.26
.22
.18
.14
.10
1.10
1.30
1.50
1.70
1.90
2.10
X
3-D CALCULATION
A-S CALCULATION
BODY RADIUS

Fig. 10

APPENDIX A

Listing of input data used to generate output for this report

```
789
   13     10    CIRCULAR CONE FLARE A/B=1
0.0        1.0        1.1        1.2        1.3        1.4        1.5        1.6
1.65       1.7        1.8        1.9        2.0
0.0        10.0       20.0       30.0       40.0       50.0       60.0       70.0
80.0       90.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0        0.0
0.13165    0.13165     0.13165    0.13165   0.13165    0.13165    0.13165    0.13165
0.13165    0.13165
0.14482    0.14485    0.14493    0.14506    0.14522    0.14539    0.14555    0.14568
0.14577    0.14580
0.15798    0.15810    0.15843    0.15894    0.15957    0.16025    0.16090    0.16143
0.16178    0.16191
0.17115    0.17140    0.17211    0.17323    0.17463    0.17617    0.17764    0.17887
0.17969    0.17998
0.18431    0.18473    0.18596    0.18789    0.19034    0.19305    0.19571    0.19796
0.19947    0.2
0.19748    0.19810    0.19993    0.20284    0.20659    0.21081    0.21502    0.21865
0.22112    0.2220
0.21064    0.21150    0.21401    0.21803    0.22329    0.22934    0.23549    0.24088
0.24461    0.24595
0.21723    0.21820    0.22107    0.22568    0.23175    0.23878    0.24600    0.25238
0.25682    0.25842
0.22381    0.22490    0.22812    0.23332    0.24020    0.24822    0.25650    0.26387
0.26902    0.27088
0.23697    0.23831    0.24224    0.24861    0.25711    0.26711    0.27752    0.28685
0.29343    0.29582
0.25014    0.25171    0.25635    0.26391    0.27402    0.28599    0.29853    0.30984
0.31784    0.32075
0.26330    0.26511    0.27046    0.27920    0.29093    0.30487    0.31954    0.33282
0.34225    0.34568
0.13165    0.13165     0.13165    0.13165   0.13165    0.13165    0.13165    0.13165
0.13165    0.13165
0.13165    0.13403    0.14113    0.15292    0.16911    0.18883    0.21013    0.22986
0.24410    0.24933
   21      2      1 7.5 DEGREE CONE FLARE-MACH 8-ALPHA 0
8.0          2116.22       0.00308308   1.4          0.0          1.0
0.0          0.189336      0.189336     90.0         0.189336     0.189336
   7662.5452484    1003.0345164       0.0000000        0.0000000
   7665.2918489     982.2874374       0.0000000         .0495957
   7667.9937256     962.3296744       0.0000000         .0992289
7669.6591866    943.0656566     0.0              0.1489004
   7673.2959001     924.4107210       0.0000000         .1986111
   7675.9110928     906.2887550       0.0000000         .2483619
   7678.5117211     888.6302815       0.0000000         .2981535
   7681.1046278     871.3708484       0.0000000         .3479867
   7683.6966936     854.4496187       0.0000000         .3978626
   7686.2949918     837.8080570       0.0000000         .4477818
   7688.9069613     821.3886714       0.0000000         .4977452
   7691.5406049     805.1336870       0.0000000         .5477537
   7694.2047323     788.9835793       0.0000000         .5978081
   7696.9092701     772.8753366       0.0000000         .6479093
   7699.6656742     756.7402754       0.0000000         .6980581
   7702.4874993     740.5011376       0.0000000         .7482554
   7705.3912149     724.0680319       0.0000000         .7985021
   7708.3974240     707.3324669       0.0000000         .8487991
   7711.5327652     690.1581140       0.0000000         .8991471
```

7714.8330479	672.3656533	0.0000000	.9495471
7718.3487679	653.7061513	0.0000000	1.0000000
7662.5452484	1003.0345164	0.0000000	0.0000000
7665.2918489	982.2874374	0.0000000	.0495957
7667.9937256	962.3296744	0.0000000	.0992289
7669.6591866	943.0656566	0.0	0.1489004
7673.2959001	924.4107210	0.0000000	.1986111
7675.9110928	906.2887550	0.0000000	.2483619
7678.5117211	888.6302815	0.0000000	.2981535
7681.1046278	871.3708484	0.0000000	.3479867
7683.6966936	854.4496187	0.0000000	.3978626
7686.2949918	837.8080570	0.0000000	.4477818
7688.9069613	821.3886714	0.0000000	.4977452
7691.5406049	805.1336870	0.0000000	.5477537
7694.2047323	788.9835793	0.0000000	.5978081
7696.9092701	772.8753366	0.0000000	.6479093
7699.6656742	756.7402754	0.0000000	.6980581
7702.4874993	740.5011376	0.0000000	.7482554
7705.3912149	724.0680319	0.0000000	.7985021
7708.3974240	707.3324669	0.0000000	.8487991
7711.5327652	690.1581140	0.0000000	.8991471
7714.8330479	672.3656533	0.0000000	.9495471
7718.3487679	653.7061513	0.0000000	1.0000000

150 21 10 3 15 1 2 1 1 10

0.00001 0.8 0.9 1.0 0.9 1.36

c

APPENDIX B

Program listing

```
Y825007,P1,T1300,CM137000.LEHRHAUPT(GRUM-PLOT)
RUN(S)
LGO(LC=77000)
789
      BLOCK DATA
      COMMON/TITLE/TITL1(3),TITL2(3),LABLE(4)/PLTS/XORI,YORI,SX,SY,J
     1L,ITPN,VALUE,H
      DATA TITL1,TITL2,XORI,YORI,SX,SY,J,L,ITPN/30H                X
     1            ,30H                                    ,0.5,0.5,15.0,9
     2,3,8/,LABLE,VALUE/30H CROSS FLOW              THETA =    ,0,12.56/
     3 0.2/
      END
```

```
      DS=DT
      CALL FIT3 (MK,1)
      DO 2314 K=1,MK
 2314 RT2(K)=FP(K)
C
C     FIRST  ORDER  SOLUTION  (M=1)
      M=1
      DO 3214 K=1,MK
      DRST=CVNST*DR1(K)
C
C     SHOCK  POINT  (M=1)  (3000)
      N=1
      IN1=1
      IN2=1
      RSTR=RST1(K)/RS1(K)
      RSX(2)=RSX1(K)
      RC=RS1(K)-DR1(K)
      EKAY1=RC+DX*EL1(MJM1,K,1)
      EKAY2=1./(DR1(K)+DX*(EL1(MJ,K,1)-EL1(MJM1,K,1)))
 3001 RP=RS1(K)+.5*(RSX1(K)+RSX(2))*DX
      EKAY=(RP-EKAY1)*EKAY2
      RA(1)=RC+EKAY*DR1(K)
      DO 3002 NN=1,6
 3002 FA(1,NN)=VAL(F1,1,MJM1,K,1,NN)+EKAY*(VAL(F1,1,MJ,K,1,NN)-VAL(F1,1,
     1MJM1,K,1,NN))
      CALL CHAR(FA(1,1),FA(1,2),FA(1,3),0.,A,ELA(1,1),ELA(1,2))
      GA(1)=(2.*FA(1,3)*(FA(1,1)*FA(1,4)+FA(1,2)*FA(1,5))-(A-FA(1,3)**2)
     1*FA(1,6)-FA(1,2)*(A+FA(1,3)**2))/(RA(1)*(A-FA(1,1)**2))
      GGA(1)=FA(1,1)+ELA(1,2)*FA(1,2)+GA(1)*DX
      W1A=(FA(1,4)+ELA(1,1)*(FA(1,5)-FA(1,3)))/RA(1)
      WWA=FA(1,3)+W1A*DX
      W2(MJ,K)=WWA
 3003 ENRS=1./SQRT(1.+RSX(2)**2+RSTR**2)
      GO TO (3004,3005,3004),IN1
 3004 VNU=ENRS*(RSX(2)*UU(K)-VU(K)+RSTR*WU(K))
      VNU2=VNU**2
      EPS=G2+G3/VNU2
 3005 V2(MJ,K)=VU(K)+(1.-EPS)*ENRS*VNU
      U2(MJ,K)=GGA(1)-ELA(1,2)*V2(MJ,K)
      VD2=U2(MJ,K)**2+V2(MJ,K)**2+W2(MJ,K)**2
      VND=SQRT(VD2+VNU2-VINF2)
      EPC=VND/VNU
      DEPEP(2)=(EPC-EPS)/EPS
      IF (TOLEP-ABS(DEPEP(2))) 3006,3011,3011
 3006 GO TO (3007,3008),IN2
 3007 IN1=2
      IN2=2
      EPS=.5*(EPS+EPC)
      VNU2=G3/(EPS-G2)
      VNU=SQRT(VNU2)
      RSX(1)=RSX(2)
      RSX(2)=(UU(K)*(VU(K)-WU(K)*RSTR)+VNU*SQRT((VINF2-VNU2)*(1.+RSTR**2
     1)-(VU(K)*RSTR+WU(K))**2))/(UU(K)**2-VNU2)
      GO TO 3009
 3008 IN1=3
      TEMPOR=RSX(2)
      RSX(2)=RSX(2)-(RSX(1)-RSX(2))*DEPEP(2)/(DEPEP(1)-DEPEP(2))
      RSX(1)=TEMPOR
```

```
 3009 DEPEP(1)=DEPEP(2)
      N=N+1
      IF (N-MAXN) 3010,9001,9001
 3010 GO TO (3001,3003),MODE
 3011 RS2(K)=RS1(K)+.5*(RSX1(K)+RSX(2))*DX
      RSX2(K)=RSX(2)
      CALL CHAR(U2(MJ,K),V2(MJ,K),W2(MJ,K),0.,A,EL2(MJ,K,1),EL2(MJ,K,2))
      EL1B(MJ,K)=.5*(ELA(1,1)+EL2(MJ,K,1))
      EL2B(MJ,K)=EL2(MJ,K,2)
      DR2(K)=(RS2(K)-R2(K))/MJM1
C
C     BODY  POINT  (M=1)  (3100)
      RP=R2(K)
      RC=R1(K)
      EKAY=(RP-RC-DX*EL1(1,K,2))/(DR1(K)+DX*(EL1(2,K,2)-EL1(1,K,2)))
      RA(2)=RC+EKAY*DR1(K)
      DO 3101 NN=1,6
 3101 FA(2,NN)=VAL(F1,1,1,K,1,NN)+EKAY*(VAL(F1,1,2,K,1,NN)-VAL(F1,1,1,K,
     11,NN))
      CALL CHAR(FA(2,1),FA(2,2),FA(2,3),0.,A,ELA(2,1),ELA(2,2))
      GA(2)=(2.*FA(2,3)*(FA(2,1)*FA(2,4)+FA(2,2)*FA(2,5))-(A-FA(2,3)**2)
     1*FA(2,6)-FA(2,2)*(A+FA(2,3)**2))/(RA(2)*(A-FA(2,1)**2))
      GGA(2)=FA(2,1)+ELA(2,1)*FA(2,2)+GA(2)*DX
      W2B=(FA(2,4)+ELA(2,2)*(FA(2,5)-FA(2,3)))/RA(2)
      WWB=FA(2,3)+W2B*DX
      V2(1,K)=(GGA(2)*RX2(K)+WWB*RT2(K)/R2(K))/(1.+RX2(K)*ELA(2,1))
      U2(1,K)=GGA(2)-ELA(2,1)*V2(1,K)
      W2(1,K)=WWB
      CALL CHAR(U2(1,K),V2(1,K),W2(1,K),0.,A,EL2(1,K,1),EL2(1,K,2))
      EL1B(1,K)=EL2(1,K,1)
      EL2B(1,K)=.5*(ELA(2,2)+EL2(1,K,2))
C
C     FIELD  POINTS  (M=1)  (3200)
      DO 3213 J=2,MJM1
      RP=RP+DR2(K)
      L=0
      JJ=J-1
 3201 L=L+1
 3202 RC=R1(K)+(JJ-1)*DR1(K)
      IF (RP-RC-DX*EL1(JJ,K,L))3203,3204,3205
 3203 JJ=JJ-1
      GO TO 3202
 3204 EKAY=0.0
      GO TO 3208
 3205 IF (RC+DR1(K)+DX*EL1(JJ+1,K,L)-RP) 3206,3206,3207
 3206 JJ=JJ+1
      GO TO 3202
 3207 EKAY=(RP-RC-DX*EL1(JJ,K,L))/(DR1(K)+DX*(EL1(JJ+1,K,L)-EL1(JJ,K,L))
     1)
 3208 RA(L)=RC+EKAY*DR1(K)
      DO 3209 NN=1,6
 3209 FA(L,NN)=VAL(F1,1,JJ,K,1,NN)+EKAY*(VAL(F1,1,JJ+1,K,1,NN)-VAL(F1,1,
     1JJ,K,1,NN))
      CALL CHAR(FA(L,1),FA(L,2),FA(L,3),0.,A,ELA(L,1),ELA(L,2))
      GA(L)=(2.*FA(L,3)*(FA(L,1)*FA(L,4)+FA(L,2)*FA(L,5))-(A-FA(L,3)**2)
     1*FA(L,6)-FA(L,2)*(A+FA(L,3)**2))/(RA(L)*(A-FA(L,1)**2))
      GGA(L)=FA(L,1)+ELA(L,3-L)*FA(L,2)+GA(L)*DX
      GO TO (3201,3210),L
```

```
3210 IF (DRST-RA(2)+RA(1)) 3211,3212,3212
3211 CNX=CNX*CNNX
     GO TO 2305
3212 W1A=(FA(1,4)+ELA(1,1)*(FA(1,5)-FA(1,3)))/RA(1)
     WWA=FA(1,3)+W1A*DX
     V2(J,K)=(GGA(2)-GGA(1))/(ELA(2,1)-ELA(1,2))
     U2(J,K)=GGA(1)-ELA(1,2)*V2(J,K)
     W2(J,K)=WWA
     CALL CHAR(U2(J,K),V2(J,K),W2(J,K),0.,A,EL2(J,K,1),EL2(J,K,2))
     EL1B(J,K)=.5*(ELA(1,1)+EL2(J,K,1))
3213 EL2B(J,K)=.5*(ELA(2,2)+EL2(J,K,2))
3214 CONTINUE
     DO 5209 M=2,MAXM
C
C    COMPLETE  NEW  DATA  SURFACE  MATRIX  (4000)
     DS=DT
     DO 4001 K=1,MK
4001 F(K)=DR2(K)
     CALL FIT3(MK,1)
     DO 4002 K=1,MK
     DRT2(K)=FP(K)
4002 RST2(K)=RT2(K)+MJM1*DRT2(K)
     DO 4104 K=1,MK
     DS=DR2(K)
     DO 4103 NN=1,5
     DO 4101 J=1,MJ
4101 F(J)=VAL(F2,2,J,K,1,NN)
     CALL FIT1(MJ,3,3,0.,0.)
     DO 4102 J=1,MJ
4102 CALL VAL4(F2,2,J,K,3,NN,FP(J))
4103 CONTINUE
4104 CONTINUE
     DO 4206 J=1,MJ
     DS=DT
     DO 4205 NN=1,5
     KEND=1
     IF (3-NN) 4202,4201,4202
4201 KEND=2
4202 DO 4203 K=1,MK
4203 F(K)=VAL(F2,2,J,K,1,NN)
     CALL FIT3(MK,KEND)
     DO 4204 K=1,MK
4204 CALL VAL4(F2,2,J,K,2,NN,FP(K)-VAL(F2,2,J,K,3,NN)*(RT2(K)+(J-1)*
    1DRT2(K)))
4205 CONTINUE
4206 CONTINUE
     MO=M-1
C
C    SECOND  ORDER  SOLUTION  (M=2,3,...)
     DO 5208 K=1,MK
     DRST=CVNST*DR1(K)
C
C    SHOCK  POINT  (M=2,3,...)  (5000)
     N=1
     IN1=1
     IN2=1
     RPO=RS2(K)
     RSTR=RST2(K)/RS2(K)
```

```
      RSX(2)=RSX2(K)
      A=A0-G1*(U2(MJ,K)**2+V2(MJ,K)**2+W2(MJ,K)**2)
      GP=(2.*W2(MJ,K)*(U2(MJ,K)*UT2(MJ,K)+V2(MJ,K)*VT2(MJ,K))
     1-(A-W2(MJ,K)**2)*WT2(MJ,K)-V2(MJ,K)*(A+W2(MJ,K)**2))/(RPO*
     2(A-U2(MJ,K)**2))
      W1P=(UT2(MJ,K)+EL2(MJ,K,1)*(VT2(MJ,K)-W2(MJ,K)))/RPO
 5001 RP=RS1(K)+.5*(RSX1(K)+RSX(2))*DX
      RA(1)=RP-VAL(F2,2,MJ,K,1,4)*DX
      CAPA(1)=-VAL(F2,2,MJ,K,2,4)*DX/RA(1)
      DR=RA(1)-RS1(K)+DR1(K)
      DO 5002 NN=1,6
 5002 FA(1,NN)=VAL(F1,1,MJM1,K,1,NN)+DR*(VAL(F1,1,MJM1,K,2,NN)+.5*DR*
     1(VAL(F1,1,MJM1,K,3,NN)+DR* VAL(F1,1,MJM1,K,4,NN)/3.0))
      CALL CHAR(FA(1,1),FA(1,2),FA(1,3),CAPA(1),A,ELA(1,1),ELA(1,2))
      DO 5003 NN=4,6
      FAR=VAL(F1,1,MJM1,K,2,NN-3)+DR*(VAL(F1,1,MJM1,K,3,NN-3)+
     10.5*DR*VAL(F1,1,MJM1,K,4,NN-3))
 5003 FA(1,NN)=FA(1,NN)-VAL(F2,2,MJ,K,2,4)*DX*FAR
      GA(1)=(2.*FA(1,3)*FA(1,1)*FA(1,4)+(2.*FA(1,2)*FA(1,3)+(A-FA(1,3)
     1**2)*CAPA(1))*FA(1,5)-(A-FA(1,3)**2)*FA(1,6)-(FA(1,2)*FA(1,3)+
     2(A-FA(1,3)**2)*CAPA(1))*FA(1,3)-A*FA(1,2))/(RA(1)*(A-FA(1,1)**2))
      GBAR(1)=.5*(GA(1)+GP)
      ELBAR(1)=.5*(ELA(1,2)+EL2(MJ,K,2))
      GGA(1)=FA(1,1)+ELBAR(1)*FA(1,2)+GBAR(1)*DX
      W1A=(FA(1,4)+ELA(1,1)*(FA(1,5)-FA(1,3)))/RA(1)
      W1BAR=.5*(W1A+W1P)
      WWA=FA(1,3)+.5*CAPA(1)*FA(1,2)+W1BAR*DX
 5004 ENRS=1./SQRT(1.+RSX(2)**2+RSTR**2)
      GO TO (5005,5006,5005),IN1
 5005 VNU=ENRS*(RSX(2)*UU(K)-VU(K)+RSTR*WU(K))
      VNU2=VNU**2
      EPS=G2+G3/VNU2
 5006 V2(MJ,K)=VU(K)+(1.-EPS)*ENRS*VNU
      U2(MJ,K)=GGA(1)-ELBAR(1)*V2(MJ,K)
      W2(MJ,K)=WWA-.5*CAPA(1)*V2(MJ,K)
      VD2=U2(MJ,K)**2+V2(MJ,K)**2+W2(MJ,K)**2
      VND=SQRT(VD2+VNU2-VINF2)
      EPC=VND/VNU
      DEPEP(2)=(EPC-EPS)/EPS
      IF (TOLEP-ABS(DEPEP(2))) 5007,5012,5012
 5007 GO TO (5008,5009),IN2
 5008 IN1=2
      IN2=2
      EPS=.5*(EPS+EPC)
      VNU2=G3/(EPS-G2)
      VNU=SQRT(VNU2)
      RSX(1)=RSX(2)
      RSX(2)=(UU(K)*(VU(K)-WU(K)*RSTR)+VNU*SQRT((VINF2-VNU2)*(1.+RSTR**2
     1)-(VU(K)*RSTR+WU(K))**2))/(UU(K)**2-VNU2)
      GO TO 5010
 5009 IN1=3
      TEMPOR=RSX(2)
      RSX(2)=RSX(2)-(RSX(1)-RSX(2))*DEPEP(2)/(DEPEP(1)-DEPEP(2))
      RSX(1)=TEMPOR
 5010 DEPEP(1)=DEPEP(2)
      N=N+1
      IF (N-MAXN) 5011,9001,9001
 5011 GO TO (5001,5004),MODE
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```
 5012 RS2(K)=RS1(K)+.5*(RSX1(K)+RSX(2))*DX
      RSX2(K)=RSX(2)
      CALL CHAR(U2(MJ,K),V2(MJ,K),W2(MJ,K),0.,A,EL2(MJ,K,1),EL2(MJ,K,2))
      EL1B(MJ,K)=.5*(ELA(1,1)+EL2(MJ,K,1))
      EL2B(MJ,K)=EL2(MJ,K,2)
      DRO=DR2(K)
      DR2(K)=(RS2(K)-R2(K))/MJM1
C
C     BODY  POINT  (M=2,3,...)  (5100)
      RPO=R2(K)
      A=A0-G1*(U2(1,K)**2+V2(1,K)**2+W2(1,K)**2)
      GP=(2.*W2(1,K)*(U2(1,K)*UT2(1,K)+V2(1,K)*VT2(1,K))-(A-W2(1,K)**2)*
     1WT2(1,K)-V2(1,K)*(A+W2(1,K)**2))/(RPO*(A-U2(1,K)**2))
      W2P=(UT2(1,K)+EL2(1,K,2)*(VT2(1,K)-W2(1,K)))/RPO
      RP=R2(K)
      RA(2)=RP-VAL(F2,2,1,K,1,5)*DX
      CAPA(2)=-VAL(F2,2,1,K,2,5)*DX/RA(2)
      DR=RA(2)-R1(K)
      DO 5101 NN=1,6
 5101 FA(2,NN)=HARDIF(VAL(F1,1,1,K,1,NN),VAL(F1,1,1,K,2,NN),
     1VAL(F1,1,1,K,3,NN),VAL(F1,1,1,K,4,NN),DR)
      CALL CHAR (FA(2,1),FA(2,2),FA(2,3),CAPA(2),A,ELA(2,1),ELA(2,2))
      DO 5102 NN=4,6
      FAR=VAL(F1,1,1,K,2,NN-3)-DR*(VAL(F1,1,1,K,3,NN-3)+0.5*DR*
     1VAL(F1,1,1,K,4,NN-3))
 5102 FA(2,NN)=FA(2,NN)-VAL(F2,2,1,K,2,5)*DX*FAR
      GA(2)=(2.*FA(2,3)*FA(2,1)*FA(2,4)+(2.*FA(2,2)*FA(2,3)+(A-FA(2,3)
     1**2)*CAPA(2))*FA(2,5)-(A-FA(2,3)**2)*FA(2,6)-(FA(2,2)*FA(2,3)+
     2(A-FA(2,3)**2)*CAPA(2))*FA(2,3)-A*FA(2,2))/(RA(2)*(A-FA(2,1)**2))
      GBAR(2)=.5*(GA(2)+GP)
      ELBAR(2)=.5*(ELA(2,1)+EL2(1,K,1))
      GGA(2)=FA(2,1)+ELBAR(2)*FA(2,2)+GBAR(2)*DX
      W2B=(FA(2,4)+ELA(2,2)*(FA(2,5)-FA(2,3)))/RA(2)
      W2BAR=.5*(W2B+W2P)
      WWB=FA(2,3)+.5*CAPA(2)*FA(2,2)+W2BAR*DX
      V2(1,K)=(GGA(2)*RX2(K)+WWB*RT2(K)/R2(K))/(1.+ELBAR(2)*RX2(K)+.5*
     1CAPA(2)*RT2(K)/R2(K))
      U2(1,K)=GGA(2)-ELBAR(2)*V2(1,K)
      W2(1,K)=WWB-.5*CAPA(2)*V2(1,K)
      CALL CHAR(U2(1,K),V2(1,K),W2(1,K),0.,A,EL2(1,K,1),EL2(1,K,2))
      EL1B(1,K)=EL2(1,K,1)
      EL2B(1,K)=.5*(ELA(2,2)+EL2(1,K,2))
C
C     FIELD  POINTS  (M=2,3,...)  (5200)
      DO 5207 J=2,MJM1
      IF (DRST-(EL2B(J,K)-EL1B(J,K))*DX) 5201,5202,5202
 5201 CNX=CNX*CNNX
      GO TO 2305
 5202 RPO=RPO+DRO
      A=A0-G1*(U2(J,K)**2+V2(J,K)**2+W2(J,K)**2)
      GP=(2.*W2(J,K)*(U2(J,K)*UT2(J,K)+V2(J,K)*VT2(J,K))-(A-W2(J,K)**2)*
     1WT2(J,K)-V2(J,K)*(A+W2(J,K)**2))/(RPO*(A-U2(J,K)**2))
      W1P=(UT2(J,K)+EL2(J,K,1)*(VT2(J,K)-W2(J,K)))/RPO
      RP=RP+DR2(K)
      L=0
 5203 L=L+1
      RA(L)=RP-VAL(F2,2,J,K,1,L+3)*DX
      CAPA(L)=-VAL(F2,2,J,K,2,L+3)*DX/RA(L)
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      JJ=1+INT((RA(L)-R1(K))/DR1(K))
      DR=RA(L)-R1(K)-(JJ-1)*DR1(K)
      DO 5204 NN=1,6
 5204 FA(L,NN)=HARDIF(VAL(F1,1,JJ,K,1,NN),VAL(F1,1,JJ,K,2,NN),
     1VAL(F1,1,JJ,K,3,NN),VAL(F1,1,JJ,K,4,NN),DR)
      CALL CHAR(FA(L,1),FA(L,2),FA(L,3),CAPA(L),A,ELA(L,1),ELA(L,2))
      DO 5205 NN=4,6
      FAR=HARDIF(VAL(F1,1,K,2,NN-3),VAL(F1,1,JJ,K,3,NN-3),
     1VAL(F1,1,JJ,K,4,NN-3),0.0,DR)
 5205 FA(L,NN)=FA(L,NN)-VAL(F2,2,J,K,2,L+3)*DX*FAR
      GA(L)=(2.*FA(L,3)*FA(L,1)*FA(L,4)+(2.*FA(L,2)*FA(L,3)+(A-FA(L,3)
     1**2)*CAPA(L))*FA(L,5)-(A-FA(L,3)**2)*FA(L,6)-(FA(L,2)*FA(L,3)+
     2(A-FA(L,3)**2)*CAPA(L))*FA(L,3)-A*FA(L,2))/(RA(L)*(A-FA(L,1)**2))
      GBAR(L)=.5*(GA(L)+GP)
      ELBAR(L)=.5*(ELA(L,3-L)+EL2(J,K,3-L))
      GGA(L)=FA(L,1)+ELBAR(L)*FA(L,2)+GBAR(L)*DX
      GO TO (5203,5206),L
 5206 W1A=(FA(1,4)+ELA(1,1)*(FA(1,5)-FA(1,3)))/RA(1)
      W1BAR=.5*(W1A+W1P)
      WWA=FA(1,3)+.5*CAPA(1)*FA(1,2)+W1BAR*DX
      V2(J,K)=(GGA(2)-GGA(1))/(ELBAR(2)-ELBAR(1))
      U2(J,K)=GGA(1)-ELBAR(1)*V2(J,K)
      W2(J,K)=WWA-.5*CAPA(1)*V2(J,K)
      CALL CHAR(U2(J,K),V2(J,K),W2(J,K),0.,A,EL2(J,K,1),EL2(J,K,2))
      EL1B(J,K)=.5*(ELA(1,1)+EL2(J,K,1))
 5207 EL2B(J,K)=.5*(ELA(2,2)+EL2(J,K,2))
 5208 CONTINUE
 5209 CONTINUE
C
C     DELTA  THETA  STABILITY  AND  PRESSURE  COEFFICIENT  (6000)
      MO=M-1
      GO TO (6001,6002,6004),IPT
 6001 IPT=3
      VNU2=(RSX1(KPT)*UU(KPT)-VU(KPT)+RST1(KPT)*WU(KPT)/RS1(KPT))**2/
     1(1.+RSX1(KPT)**2+(RST1(KPT)/RS1(KPT))**2)
      GO TO 6003
 6002 VNU2=(RSX2(KPT)*UU(KPT)-VU(KPT)+RST2(KPT)*WU(KPT)/RS2(KPT))**2/
     1(1.+RSX2(KPT)**2+(RST2(KPT)/RS2(KPT))**2)
 6003 PTRAT=(G5*VNU2-G2)/((G2+G3/VNU2)*(G5*VNU2-G2))**G4
 6004 NPRT=1
      IF(IJL.NE.IJL/NOPT*NOPT)NPRT=2
      IJL=IJL+1
      GO TO(604,607),NPRT
  604 WRITE (IW,20019) I,X2,MO
20019 FORMAT (1H1,30X,53HNEW  DATA  SURFACE  VARIABLES - FINAL  ITERATIO
     1N  (I=I5,6H , X2=F9.5,5H , M=I5,1H)/)
  607 DO 6007 K=1,MK
      GO TO (608,609),NPRT
  608 WRITE (IW,20020) K,T(K),R2(K),RX2(K),RT2(K),DR2(K),DRT2(K),RS2(K),
     1RSX2(K),RST2(K)
20020 FORMAT (///3H K=I4,4H TH=F9.4,4H R2=F10.6,5H RX2=F8.6,5H RT2=F9.6,
     15H DR2=F8.6,6H DRT2=F9.6,5H RS2=F10.6,6H RSX2=F8.6,6H RST2=F9.6//
     214X,1HJ,6X,2HRP,12X,2HU2,12X,2HV2,12X,2HW2,10X,7HLAMBDA1,7X,
     37HLAMBDA2,7X,7HMACH NO,9X,2HCP/)
  609 RP=R2(K)-DR2(K)
      DO 6006 J=1,MJ
      RP=RP+DR2(K)
      VP2=U2(J,K)**2+V2(J,K)**2+W2(J,K)**2
```

```
      A=A0-G1*VP2
      EM2=VP2/A
      EM(J,K)=SQRT(EM2)
      BETA=SQRT(EM2-1.)
      TANALF=ABS(W2(J,K))/SQRT(U2(J,K)**2+V2(J,K)**2)
      ELAMB=(BETA*TANALF+1.)/(BETA-TANALF)
      TEST=DX/DT-CTST*(RP*U2(J,K)-DX*V2(J,K))/(ELAMB*SQRT(U2(J,K)**2+
     1V2(J,K)**2))
      IF (TEST) 6005,6005,9002
 6005 CP(J,K)=(PTRAT*A**G4-CCP1)*CCP2
      GO TO(6006,6007),NPRT
 6006 WRITE (IW,20021) J,RP,U2(J,K),V2(J,K),W2(J,K),EL2(J,K,1),
     1EL2(J,K,2),EM(J,K),CP(J,K)
20021 FORMAT (10X,I5,8F14.7)
 6007 CONTINUE
      GO TO(610,611),NPRT
  610 ICD=ICD+1
      CALL PLTS(X2,ICD,U2,V2,W2,CP,RS2,MK)
      IF(ICD.GT.100)ICD=0
  611 CONTINUE
      GO TO (2101,9003),IEND
 9001 WRITE (IW,20022)
20022 FORMAT (10X,42HSHOCK  POINT  CALCULATION  NOT  CONVERGING)
      GO TO 9999
 9002 WRITE (IW,20023) K,J,DX,RP,VP2,A,EM(J,K),BETA,TANALF,ELAMB,TEST
20023 FORMAT (/////10X,38HSECOND  ORDER  SOLUTION  UNSTABLE   K=I5,5X,
     12HJ=I5////9F13.8)
      GO TO 9999
C     PUNCH  OUT  RESULTS
 9003 GO TO (9004,9999),IPUNCH
 9004 WRITE (7,30001) (T(K),RS2(K),RSX2(K),K=1,MK)
30001 FORMAT (6F12.7)
      DO 9005 K=1,MK
 9005 WRITE (7,30002) (U2(J,K),V2(J,K),W2(J,K),P(J),J=1,MJ)
30002 FORMAT (4F15.7)
      WRITE(6,650)X2
  650 FORMAT(*0  PUNCHED OUTPUT IS FOR X2  =*,E15.6)
      CALL PLTS(X2,101,U2,V2,W2,CP,RS2,MK)
      CALL GRPH(4,R2,R2,22)
 9999 CALL EXIT
      END
```

```
      SUBROUTINE FIRST
      DIMENSION CONFIG(17),START(16),TB(20),KSP(20),DTH(20),TD(20),
     1PHI(21,20),TPHI(21,20),FT(21,20),U1(21,20),V1(21,20),W1(21,20)
      COMMON /FIR/XB(20),RB(20,20),RBP(20,20),RBPP(20,20),RBPPP(20,20),
     1UU(20),VU(20),WU(20),R1(20),RX1(20),RT1(20),DR1(20),DRT1(20),
     2RS1(20),RSX1(20),RST1(20),F1(10080)     ,EL1(21,20,2),T(20),P(21),
     3TOLEP,CVNST,CTST,CNX,CNNX,XEND,DT,DTD,X1,VINF2,G2,G3,G4,G5,CCP1,
     4CCP2,MI,MJ,MK,MAXM,MAXN,MODE,IPT,KPT,MIBM1,MJM1
      COMMON /F2/S(50)/F12/FPPP(50)/F13/DS/F123/F(50),FP(50),FPP(50)
     1/C1/G1,A0/HESH/NOPT    ,IPUNCH
      EQUIVALENCE(F1(1),U1(1)),(F1(1681),V1(1)),(F1(3361),W1(1)),
     1(PHI(1),TPHI(1))
      IR=5
      IW=6
      READ (IR,10001) MIB,MKB,CONFIG,(XB(IB),IB=1,MIB)                  RED
      WRITE(IW,10001) MIB,MKB,CONFIG,(XB(IB),IB=1,MIB)
10001 FORMAT (2I5,17A4/(8F10.5))
      READ (IR,10002) (TB(KB),KB=1,MKB)                                 RED
      WRITE(IW,10002) (TB(KB),KB=1,MKB)
10002 FORMAT (8F10.5)
      DO 11 IB=1,MIB
   11 READ (IR,10003) (RB(IB,KB),KB=1,MKB)                              RED
10003 FORMAT (8F10.0)
      READ (IR,10004) (RBP(1,KB),KB=1,MKB)                              RED
10004 FORMAT (8F10.0)
      READ (IR,10005) (RBP(MIB,KB),KB=1,MKB)                            RED
10005 FORMAT (8F10.0)
      READ (IR,10006) MJD,MKD,IVAXIS,START,EMINF,PINF,RHOINF,           WHITE
     1GAMMA,ALPHA,X1,(TD(KD),RS1(KD),RSX1(KD),KD=1,MKD)                 WHITE
      WRITE(IW,10006) MJD,MKD,IVAXIS,START,EMINF,PINF,RHOINF,           WHITE
     1GAMMA,ALPHA,X1,(TD(KD),RS1(KD),RSX1(KD),KD=1,MKD)                 WHITE
10006 FORMAT (3I5,16A4/6F12.6/(6F12.6))
      DO 21 KD=1,MKD
      READ (IR,10007) (U1(JD,KD),V1(JD,KD),W1(JD,KD),                   WHITE
     1PHI(JD,KD),JD=1,MJD)                                              WHITE
   21 WRITE(IW,10007) (U1(JD,KD),V1(JD,KD),W1(JD,KD),                   WHITE
     1PHI(JD,KD),JD=1,MJD)
10007 FORMAT (4F15.7)
      CALL NOMDIM(U1,V1,W1,GAMMA,EMINF,PINF,RHOINF,MJD,MKD)
      READ (IR,10008) MI,MJ,MK,MAXM,MAXN,MODE,IPT,KPT,IPUNCH,NOPT,      BLUE
     1TOLEP,CVNST,CTST,CNX,CNNX,XEND                                    BLUE
      WRITE(IW,10008) MI,MJ,MK,MAXM,MAXN,MODE,IPT,KPT,IPUNCH,NOPT,      BLUE
     1TOLEP,CVNST,CTST,CNX,CNNX,XEND                                    BLUE
10008 FORMAT(10I5/6F10.5)
      WRITE (IW,20001) CONFIG,START
20001 FORMAT (1H1,39X,50HTHREE  DIMENSIONAL  NEAR  CHARACTERISTICS  PROG
     1RAM///32X,13HCONFIGURATION,11X,17A4//32X,24HSTARTING  VELOCITY  DA
     2TA,16A4///)
C
C     CONSTANT  FACTORS  (900)
      MIBM1=MIB-1
      MKBM1=MKB-1
      MJDM1=MJD-1
      MKDM1=MKD-1
      MIM1=MI-1
      MJM1=MJ-1
      MKM1=MK-1
      DP=1./MJM1
```

```
      P(1)=0.0
      DO 901 J=2,MJ
  901 P(J)=P(J-1)+DP
      DTOR=3.141593/180
      DTD=TD(MKD)/MKM1
      DT=DTD*DTOR
      T(1)=0.0
      DO 902 K=2,MK
  902 T(K)=T(K-1)+DTD
      EMINF2=EMINF**2
      AINF=GAMMA*PINF/RHOINF
      AAINF=SQRT(AINF)
      VINF2=EMINF2*AINF
      VINF=SQRT(VINF2)
      G1=.5*(GAMMA-1.)
      G2=(GAMMA-1.)/(GAMMA+1.)
      G3=2.*AINF/(GAMMA+1.)
      G4=GAMMA/(GAMMA-1.)
      G5=2.*GAMMA/(AINF*(GAMMA+1.))
      VLIM2=VINF2+AINF/G1
      VLIM=SQRT(VLIM2)
      A0=G1*VLIM2
      CCP1=AINF**G4
      CCP2=2./(GAMMA*EMINF2*CCP1)
      IPUNCH=2-IPUNCH
C
C     COMPLETE  BODY  RADIUS  MATRIX  (1000)
      IF (MKB-MK) 1001,1051,1001
 1001 DO 1002 KB=1,MKB
 1002 S(KB)=TB(KB)
      DO 1005 K=1,MKM1
      DO 1003 KB=1,MKBM1
      KSP(K)=KB
      IF (S(KB+1)-T(K)) 1003,1003,1004
 1003 CONTINUE
 1004 KS=KSP(K)
 1005 DTH(K)=T(K)-S(KS)
      KSP(MK)=MKB
      DTH(MK)=0.0
      DO 1008 IB=1,MIB
      DO 1006 KB=1,MKB
 1006 F(KB)=RB(IB,KB)
      CALL FIT2 (MKB,1,1,0.,0.)
      DO 1007 K=1,MK
      KS=KSP(K)
 1007 RB(IB,K)=F(KS)+DTH(K)*(FP(KS)+.5*DTH(K)*(FPP(KS)+DTH(K)*FPPP(KS)/
     13.))
 1008 CONTINUE
      DO 1009 KB=1,MKB
 1009 F(KB)=RBP(1,KB)
      CALL FIT2 (MKB,1,1,0.,0.)
      DO 1010 K=1,MK
      KS=KSP(K)
 1010 RBP(1,K)=F(KS)+DTH(K)*(FP(KS)+.5*DTH(K)*(FPP(KS)+DTH(K)*FPPP(KS)/
     13.))
      DO 1011 KB=1,MKB
 1011 F(KB)=RBP(MIB,KB)
      CALL FIT2 (MKB,1,1,0.,0.)
```

```
      DO 1012 K=1,MK
      KS=KSP(K)
 1012 RBP(MIB,K)=F(KS)+DTH(K)*(FP(KS)+.5*DTH(K)*(FPP(KS)+DTH(K)*FPPP(KS)
     1/3.))
 1051 DO 1052 IB=1,MIB
 1052 S(IB)=XB(IB)
      DO 1055 K=1,MK
      DO 1053 IB=1,MIB
 1053 F(IB)=RB(IB,K)
      CALL FIT2 (MIB,1,1,RBP(1,K),RBP(MIB,K))
      DO 1054 IB=1,MIB
      RBP(IB,K)=FP(IB)
      RBPP(IB,K)=FPP(IB)
 1054 RBPPP(IB,K)=FPPP(IB)
 1055 CONTINUE
      WRITE (IW,20002)
20002 FORMAT (////40X,30HCOMPLETE  BODY  RADIUS  MATRIX/)
      DO 1056 IB=1,MIB
 1056 WRITE (IW,20003) IB,XB(IB),(K,RB(IB,K),RBP(IB,K),RBPP(IB,K),
     1RBPPP(IB,K),K=1,MK)
20003 FORMAT (///10X,3HIB=I5,10X,3HXB=F10.5///14X,1HK,15X,2HRB,19X,
     13HRBP,19X,4HRBPP,17X,5HRBPPP//(10X,I5,4F22.6))
C
C     UPSTREAM  FLOW  CONDITIONS  (1200)
      VFACT1=VINF*COS(ALPHA*DTOR)
      VFACT2=VINF*SIN(ALPHA*DTOR)
      DO 1201 K=1,MK
      UU(K)=VFACT1
      VU(K)=-VFACT2*COS(T(K)*DTOR)
 1201 WU(K)=VFACT2*SIN(T(K)*DTOR)
      WRITE (IW,20004) EMINF,PINF,RHOINF,GAMMA,AAINF,VLIM,ALPHA,
     1(K,T(K),UU(K),VU(K),WU(K),K=1,MK)
20004 FORMAT (1H1,40X,26HUPSTREAM  FLOW  CONDITIONS////12X,28HFREE  STRE
     1AM  MACH  NUMBER =F10.5//16X,24HFREE  STREAM  PRESSURE =F10.5//17X
     2,23HFREE  STREAM  DENSITY =F10.8//19X,21HFREE  STREAM  GAMMA =
     3F10.5//8X,32HFREE  STREAM  SPEED  OF  SOUND =F10.4//20X,20HLIMITIN
     4G  VELOCITY =F10.4//21X,19HANGLE  OF  ATTACK =F10.5//////
     519X,1HK,12X,5HTHETA,20X,2HUU,20X,2HVU,20X,2HWU//(15X,I5,4F22.6))
C
C     FIRST  INITIAL  DATA  SURFACE  (2000)
      DO 2002 IB=1,MIBM1
      IS=IB
      IF (XB(IB+1)-X1) 2002,2002,2003
 2002 CONTINUE
 2003 DEX=X1-XB(IS)
      DO 2004 K=1,MK
      R1(K)=RB(IS,K)+DEX*(RBP(IS,K)+.5*DEX*(RBPP(IS,K)+DEX*RBPPP(IS,K)/
     13.))
      RX1(K)=RBP(IS,K)+DEX*(RBPP(IS,K)+.5*DEX*RBPPP(IS,K))
 2004 F(K)=R1(K)
      DS=DT
      CALL FIT3 (MK,1)
      DO 2005 K=1,MK
 2005 RT1(K)=FP(K)
      IF (1-IVAXIS) 2011,2020,2011
 2011 DO 2013 KD=1,MKD
      DO 2012 JD=1,MJD
      SPHI=SIN(PHI(JD,KD)*DTOR)
```

```
      CPHI=COS(PHI(JD,KD)*DTOR)
      TPHI(JD,KD)=SPHI/CPHI
      TEMPOR=U1(JD,KD)*SPHI+V1(JD,KD)*CPH
      U1(JD,KD)=U1(JD,KD)*CPHI-V1(JD,KD)*
 2012 V1(JD,KD)=TEMPOR
      WRITE(IW,10007) (U1(JD,KD),V1(JD,KD
     1PHI(JD,KD),JD=1,MJD)
 2013 CONTINUE
 2020 IF (MJD-MJ) 2021,2040,2021
 2021 DO 2032 KD=1,MKD
      DO 2022 JD=1,MJD
 2022 S(JD)=TPHI(JD,KD)
      DO 2025 NN=1,3
      DO 2023 JD=1,MJD
 2023 F(JD)=VAL(F1,1,JD,KD,1,NN)
      CALL FIT2 (MJD,3,3,0.,0.)
      DO 2024 JD=1,MJD
      CALL VAL4(F1,1,JD,KD,2,NN,FP(JD))
      CALL VAL4(F1,1,JD,KD,3,NN,FPP(JD))
 2024 CALL VAL4(F1,1,JD,KD,4,NN,FPPP(JD))
 2025 CONTINUE
      DTPHI=(S(MJD)-S(1))/MJM1
      TP=S(1)-DTPHI
      DO 2029 JJ=1,MJ
      TP=TP+DTPHI
      DO 2026 JD=1,MJDM1
      JS=JD
      IF (S(JD+1)-TP) 2026,2026,2027
 2026 CONTINUE
      JS=MJD
 2027 DTP=TP-S(JS)
      DO 2028 NN=1,3
 2028 FT(JJ,NN)=HARDIF(VAL(F1,1,JS,KD,1,NN
     1VAL(F1,1,JS,KD,3,NN),VAL(F1,1,JS,KD,
 2029 CONTINUE
      DO 2031 JJ=1,MJ
      DO 2030 NN=1,3
 2030 CALL VAL4(F1,1,JJ,KD,1,NN,FT(JJ,NN))
 2031 CONTINUE
 2032 CONTINUE
 2040 IF (MKD-MK) 2041,2061,2041
 2041 DO 2042 KD=1,MKD
 2042 S(KD)=TD(KD)
      DO 2045 K=1,MKM1
      DO 2043 KD=1,MKDM1
      KSP(K)=KD
      IF (S(KD+1)-T(K)) 2043,2043,2044
 2043 CONTINUE
 2044 KS=KSP(K)
 2045 DTH(K)=T(K)-S(KS)
      KSP(MK)=MKD
      DTH(MK)=0.0
      DO 2051 JJ=1,MJ
      DO 2050 NN=1,3
      DO 2046 KD=1,MKD
 2046 F(KD)=VAL(F1,1,JJ,KD,1,NN)
      KEND=1
      IF (3-NN) 2047,2047,2048
 2047 KEND=2
 2048 CALL FIT2 (MK
      DO 2049 K=1,M
      KS=KSP(K)
 2049 CALL VAL4(F1,
     1DTH(K)))
 2050 CONTINUE
 2051 CONTINUE
      DO 2052 KD=1,
 2052 F(KD)=RS1(KD
      CALL FIT2 (MK
      DO 2053 K=1,M
      KS=KSP(K)
 2053 RS1(K)=F(KS)
     1))
      DO 2054 KD=1,
 2054 F(KD)=RSX1(KD
      CALL FIT2 (MK
      DO 2055 K=1,M
      KS=KSP(K)
 2055 RSX1(K)=F(KS)
     1))
 2061 DO 2062 K=1,M
      DR1(K)=(RS1(K
 2062 F(K)=DR1(K)
      CALL FIT3 (MK
      DO 2064 K=1,M
      DRT1(K)=FP(K)
      RST1(K)=RT1(K
      DO 2063 JJ=1,
      CALL CHAR(U1(
 2063 CONTINUE
 2064 CONTINUE
      RETURN
      END
```

```
FUNCTION HARDIF(A,B,C,D,DR)
HARDIF=A+DR*(B+0.5*DR*(C+DR*D/3.0))
RETURN
END
```

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```
      FUNCTION VAL(VAR,IS,I,J,K,L)
      DIMENSION VAR(1),NN(3,2)
      DATA NN/21,420,1680,21,420,1260/
      LOC=I+(J-1)*NN(1,IS)+(K-1)*NN(2,IS)+(L-1)*NN(3,IS)
      IF(LOC.GT.10080-(IS-1)*3780)WRITE(6,1001)
 1001 FORMAT(* +++++++++++++++++++++++^+++FLAG++++++++++ +++++++++++++
      VAL=VAR(LOC)
      RETURN
      END
```

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