TECHNICAL NOTE R-128

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ANALYSIS OF FLOW FROM PLUG NOZZLES WITH SECONDARY EJECTOR SYSTEMS

by C. C. LEE and S. J. INMAN

January, 1965

RESEARCH LABORATORIES
BROWN ENGINEERING COMPANY, INC.
HUNTSVILLE, ALABAMA

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ANALYSIS OF FLOW FROM PLUG NOZZLES WITH SECONDARY EJECTOR SYSTEMS

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Prepared For

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P& VE LABORATORY
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ABSTRACT

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The method of characteristics is presented for the calculation of the supersonic flow field, with the Rankine-Hugoniot equations used to compute the flow properties across a shock. The secondary flow properties are calculated by the one-dimensional isentropic relationships. The gas is assumed to be an inviscid nonreacting perfect gas with constant specific heat. Sample calculations, as well as the listing of the FORTRAN program, are presented.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS

a	speed of sound, ft/sec
A	cross-sectional area of secondary flow, ft^2
A^*	cross-sectional area of secondary flow at which the Mach Number is unity, ft^2
h	enthalpy, ft^2/sec^2
M	Mach Number
m	mass flow rate, lbm/sec
p	pressure, lbf/ft^2
P_o	total pressure of the primary flow, lbf/ft^2
P_T	total pressure of the secondary flow, lbf/ft^2
s	entropy, $ft^2/sec^2\,°R$
T	temperature, °R
V	velocity, ft/sec
X, Y	Cartesian coordinates, ft
β	Mach angle, $\sin^{-1}\left(\frac{1}{M}\right)$
γ	ratio of specific heat
δ	shock angle with respect to stream direction behind a shock
ε	density ratio across shock
θ	flow angle with respect to x axis
μ	shock angle with respect to x axis
ρ	density, lbm/ft^3

INTRODUCTION

In recent years, considerable effort has been devoted to the problems associated with base pressures of plug nozzles. In the case of the plug nozzle with a secondary ejector system, the flow phenomenon is only partially understood. The purpose of this study is to demonstrate the essential features of the primary and secondary flow interaction. It is known that viscous effects play a major role in these flow cases, and also that the viscous effects can be superimposed on an inviscid flow field for the region of interest[1]. Therefore, the study has been divided into two stages. The first stage is to obtain an inviscid solution for the primary and secondary flow, and the second stage is to determine the viscous effects. This report presents the results of the first stage study.

The primary supersonic flow properties are determined by using the method of characteristics, and the flow is assumed to be rotational and axisymmetric. The gas is assumed to be perfect and inviscid. The flow properties across a shock are calculated by using the Rankine-Hugoniot equations. The Prandtl-Meyer equations are used to compute the flow properties at the lip of the shroud and at the corner of the plug. The secondary flow properties are determined by using the one-dimensional isentropic relationships.

In order to obtain the nozzle exit conditions as initial conditions for the jet computation, the calculations in Reference 2 have been adopted. A flow model for demonstrating the basic construction of a jet is shown in Figure 1. The theoretical analysis is presented in the order of computation. The equations of the analysis have been coded in IBM 7040 FORTRAN IV computer language. Some sample results are also presented in this report.

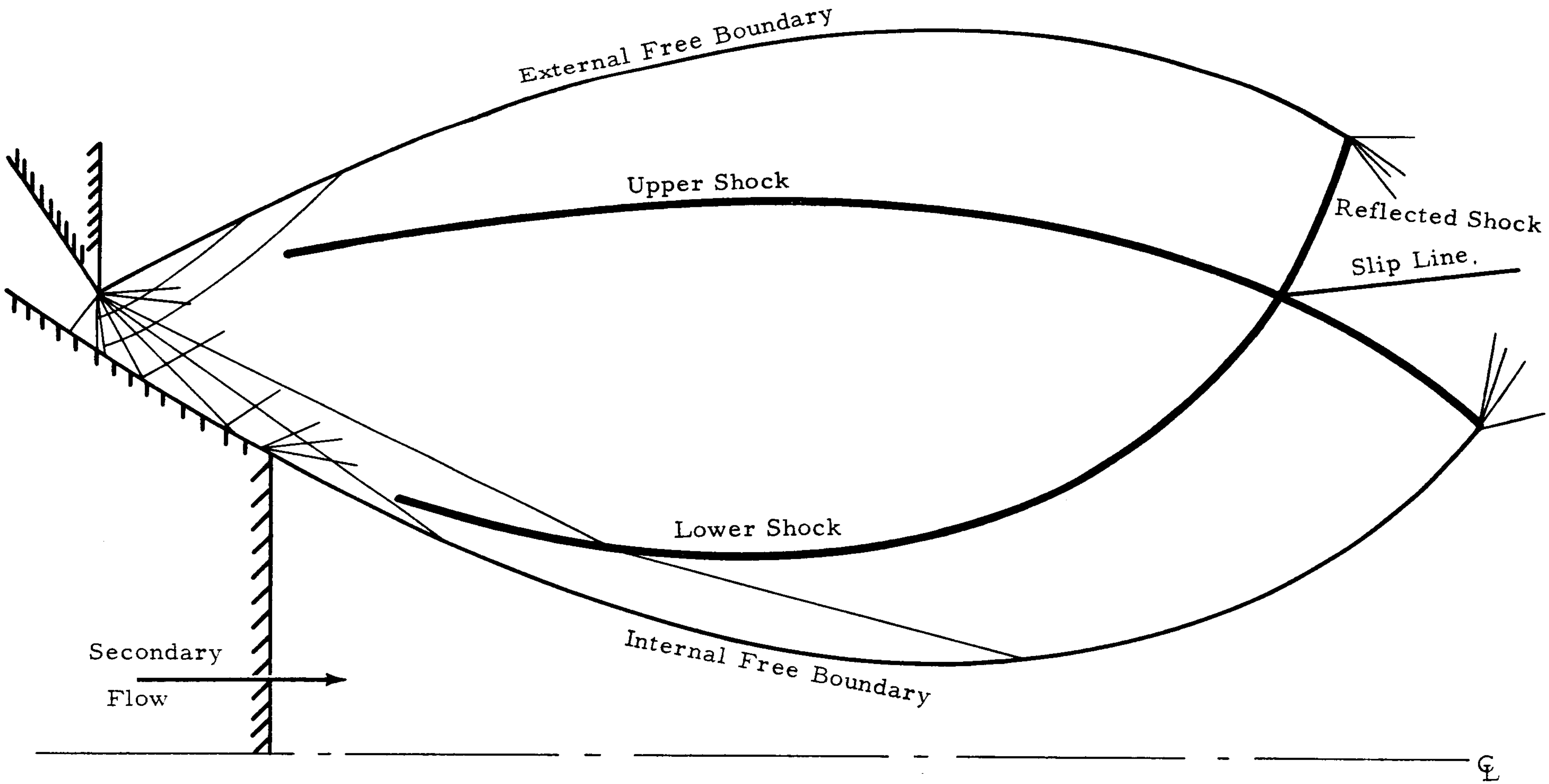

Figure 1. Aerodynamic Plug Nozzle Flow Schematic

METHOD OF ANALYSIS

The method of characteristics is used to calculate the downstream flow field of a plug nozzle. The Prandtl-Meyer equations are used to calculate the flow properties at the lip of the shroud and at the corner of the plug. The calculations of flow properties across shocks are based on the method presented in Reference 3. The secondary flow is determined by the one-dimensional isentropic relationships. The calculation procedures are summarized below.

In Reference 2 a computer program is presented which calculates the flow properties in the entire nozzle flow field. By knowing the conditions at the edge of the plug, the Prandtl-Meyer equations provide a means of computing the corner wave. Combining the Prandtl-Meyer equation

$$\frac{dV}{V} = - \frac{d\theta}{(M^2 - 1)^{\frac{1}{2}}} \tag{1}$$

and the energy equation

$$V\,dV = - \frac{dp}{\rho} \tag{2}$$

one obtains

$$dp = \frac{\rho V^2 d\theta}{(M^2 - 1)^{\frac{1}{2}}} \quad . \tag{3}$$

Once the corner waves are determined, the flow field calculations can be continued by using the method of characteristics. Since the nozzle flow field is computed along the right running characteristics, the same scheme can be applied to the downstream flow field.

At the internal boundary, an iteration is required to match the static pressure of the primary flow with that of the secondary flow. As shown in Figure 2, $\overline{bd}$ is a streamline, and

$$Y_d = Y_b + (X_d - X_b)(\tan\theta)_{bd} \quad . \tag{4}$$

$\overline{nd}$ is a right running characteristic

$$Y_d = Y_n + (X_d - X_n)[\tan(\theta - \beta)]_{nd} \quad . \tag{5}$$

Combining Equations 4 and 5, one obtains

$$X_d = \frac{Y_n - Y_b - X_n[\tan(\theta - \beta)]_{nd} + X_b(\tan\theta)_{bd}}{(\tan\theta)_{bd} - [\tan(\theta - \beta)]_{nd}} \quad . \tag{6}$$

Once the Y_d value is known, the cross sectional area is known. The Mach Number of the secondary flow can be computed by a method of successive approximations from the following equation

$$\frac{A}{A^*} = \frac{1}{M}\left[\left(\frac{2}{\gamma + 1}\right)\left(1 + \frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma + 1}{2(\gamma - 1)}} \quad .$$

By rearranging the above equation, the following function can be obtained to calculate the Mach Number

$$f(M) = M\left(\frac{A}{A^*}\right) - \left[\frac{2 + (\gamma - 1)M^2}{\gamma + 1}\right]^{\frac{\gamma + 1}{2(\gamma - 1)}} \quad .$$

Expanding this function in a Taylor's series

$$f(M + \Delta M) = f(M) + f'(M)\Delta M + f''(M)\frac{\Delta M^2}{2!} + \ldots + f^n(M)\frac{\Delta M^n}{n!} \tag{7}$$

where

$$f'(M) = \frac{A}{A^*} - M\left[\frac{2 + (\gamma - 1)M^2}{\gamma + 1}\right]^{\frac{3 - \gamma}{2(\gamma - 1)}} \quad .$$

By truncating Equation 7 at the first two terms and assuming a value for M, the following expression for ΔM may be obtained

$$\Delta M = - \frac{f(M)}{f'(M)} \quad .$$

A new approximation for M is

$$M = M + \Delta M \quad .$$

The Mach Number can be obtained by carrying on this process until the ΔM is within a desired limit.

The static pressure of the secondary flow can be determined by the following irrotational flow ralation

$$p = P_T\left(1 + \frac{\gamma - 1}{2} M^2\right)^{-\frac{\gamma}{\gamma - 1}} \quad . \tag{8}$$

The static pressure of the primary flow is equal to that of secondary flow and Equation 8 can also be used to compute the primary flow Mach Number. Of course, the total pressure would be different between the two flow fields. The flow angle at point d can be computed by the right running characteristic equation

$$\begin{aligned}(V_d - V_n)\left(\frac{\cot\beta}{V}\right)_{dn} + (\theta_d - \theta_n) - \left[\frac{\sin\beta\sin\theta}{Y\cos(\theta - \beta)}\right]_{dn}(X_d - X_n) \\ + \left(\frac{T}{a^2}\sin\beta\cos\beta\right)_{dn}(s_d - s_n) = 0 \quad .\end{aligned} \tag{9}$$

The θ_d value can be substituted into Equation 4, and the procedure repeated until the tolerance is met. This method has been proved to be convergent when iterated.

When characteristics of the same family intersect, it is an indication of shock. The flow properties across the shock can be computed by using the Rankine-Hugoniot equations. Moe and Troesch[3] have developed a method for the computations. A detailed form of this method presented by Eastman[4] has been adapted in the present calculations, and the symbols used in the equations are essentially those of the originals.

As shown in Figure 3, point 3 can be computed by using regular field point calculation. Point 4 can be solved by the following equations:

$$B = \frac{(Y_1 - Y_2) - (X_1 - X_2)(\tan\mu)_{14}}{(Y_3 - Y_2) - (X_3 - X_2)(\tan\mu)_{14}} \tag{10}$$

$$\begin{aligned} X_4 &= X_2 + B(X_3 - X_2) \\ Y_4 &= Y_2 + B(Y_3 - Y_2) \\ \theta_4 &= \theta_2 + B(\theta_3 - \theta_2) \\ V_4 &= V_2 + B(V_3 - V_2) \quad . \end{aligned} \tag{11}$$

Once point 4 is determined, the flow properties of point 11 can be computed by the Rankine-Hugoniot equations

$$\varepsilon = \frac{(\gamma - 1)M_4^2 \sin^2(\theta_4 - \mu_4) + 2}{(\gamma + 1)M_4^2 \sin^2(\theta_4 - \mu_4)} \tag{12}$$

$$p_{11} = p_4 + \rho_4 V_4^2 (1 - \varepsilon)\sin^2(\theta_4 - \mu_4) \tag{13}$$

$$h_{11} = h_4 + \frac{V_4^2}{2}(1 - \varepsilon^2)\sin^2(\theta_4 - \mu_4) \tag{14}$$

$$V_{n\,11} = V_4\, \varepsilon \sin(\theta_4 - \mu_4) \tag{15}$$

$$V_{T11} = V_4 \cos(\theta_4 - \mu_4) \tag{16}$$

$$V_{11} = \left(V_{n\,11}^{\;2} + V_{T11}^{\;2}\right)^{\frac{1}{2}} \tag{17}$$

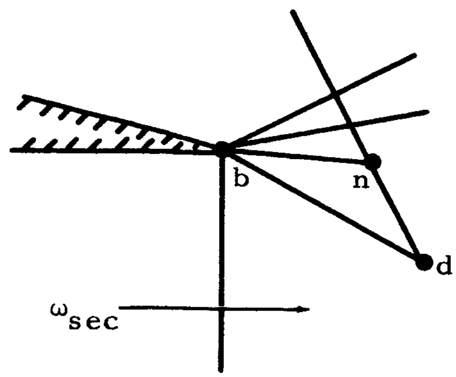

Figure 2. Nomenclature for Boundary Point Calculation

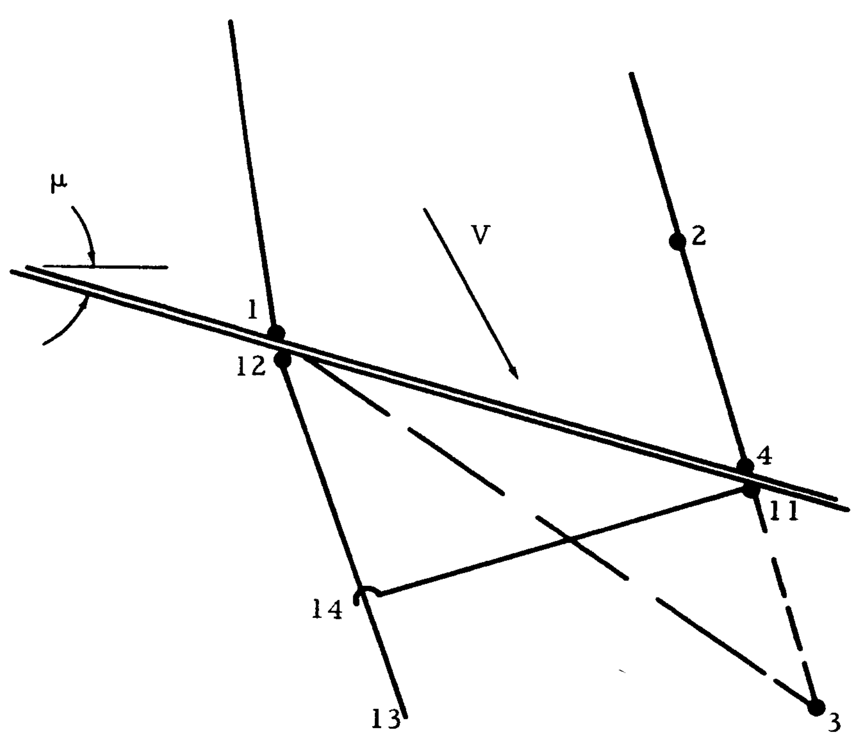

Figure 3. Characteristics Network for an Interior Shock

$$s_{11} = \tan^{-1}[\varepsilon \tan(\theta_4 - \mu_4)] \tag{18}$$

$$\theta_{11} = \mu_4 + \delta_{11} \quad . \tag{19}$$

Point 14 is an inserted left running characteristic point from point 11

$$G = \frac{(Y_{11} - Y_{12}) - (X_{11} - X_{12})[\tan(\theta + \beta)]_{11,14}}{(Y_{13} - Y_{12}) - (X_{13} - X_{12})[\tan(\theta + \beta)]_{11,14}} \tag{20}$$

$$\begin{aligned}
X_{14} &= X_{12} + G(X_{13} - X_{12}) \\
Y_{14} &= Y_{12} + G(Y_{13} - Y_{12}) \\
V_{14} &= V_{12} + G(V_{13} - V_{12}) \\
\theta_{14} &= \theta_{12} + G(\theta_{13} - \theta_{12}) \\
\beta_{14} &= \beta_{12} + G(\beta_{13} - \beta_{12}) \\
T_{14} &= T_{12} + G(T_{13} - T_{12}) \\
s_{14} &= s_{12} + G(s_{13} - s_{12}) \quad .
\end{aligned} \tag{21}$$

The flow angle at point 11 can be computed by using the left running characteristic equation

$$\begin{aligned}
\theta_{11} = \theta_{14} &+ (V_{11} - V_{14})\left(\frac{\cot\beta}{V}\right)_{11,14} - \left[\frac{\sin\beta\sin\theta}{Y\cos(\theta + \beta)}\right]_{11,14} (X_{11} - X_{14}) \\
&+ \left(\frac{T}{a^2}\sin\beta\cos\beta\right)_{11,14} (s_{11} - s_{14})
\end{aligned} \tag{22}$$

The iteration scheme is based on Reference 4. Assuming three values of μ_4, three sets of θ_{11} values will be obtained from Equations 19 and 22. The value of θ_{11} is assumed to vary parabolically with μ_{11}.

$$\theta_{11} = a_1 + b_1\mu_4 + c_1\mu_4^2 \tag{23}$$

$$\theta_{11} = a_2 + b_2\mu_4 + c_3\mu_4^2 \quad . \tag{24}$$

The μ_4 value can then be solved from Equations 23 and 24. The same numerical technique can be applied to the shock near the upper boundary. The lower shock is computed first since it is difficult to compute the upper shock and the lower shock simultaneously. The lower field and shock points are computed along the right running characteristics which originated from the lip of the shroud until the last one is reached or the shock deflection angle becomes excessive ($M < 1$). Then the upper field and shock points are calculated along the left running characteristics.

The methods of computing the upper shock are the same as those of the lower shock except that the calculations follow along the left running characteristics instead of the right running characteristics. The same set of equations, which are described in previous pages, can be used by replacing the term $(\theta + \beta)$ by $(\theta - \beta)$ in Equations 20 and 22 by a right running characteristic equation

$$\begin{aligned}\theta_{11} = \theta_{14} - (V_{11} - V_{14})\left(\frac{\cot\beta}{V}\right)_{11,14} + \left[\frac{\sin\beta\sin\theta}{Y\cos(\theta+\beta)}\right](X_{11} - X_{14}) \\ - \left[\frac{T}{a^2}\cos\beta\sin\beta\right](s_{11} - s_{14}) \quad .\end{aligned} \tag{25}$$

COMPUTING PROCEDURE

The computer program contains various phases of calculations: the determination of field points, solid boundary points, upper and lower shock points, upper and lower free boundary points, and the one-dimensional isentropic computations. The linkage of the system is shown in Figure 1.

The computation is initiated from a starting line which is assumed to be uniform and at a slightly supersonic condition. The nozzle field points and solid boundary points calculations are based on the program presented in Reference 2. The jet field points and shock points are computed along the right running characteristics until the last one originated from the lip is obtained or the flow behind the shock becomes subsonic. Then the upper field points and shock points are calculated along the left running characteristics. If the last point of the upper shock lies above the lower shock, the calculations of the lower shock have to be continued until it meets the upper shock. The flow properties at the intersection of the upper and lower shocks are interpolated between the nearest two shock points. Behind the shock intersection, two reflected shocks and a slip stream occur. A numerical scheme for solving this part of flow field can be found in Reference 5. This scheme is a combination of the shock routine, the field point calculations and the solid boundary point calculation, and the slip stream angle is iterated until the static pressure is equal on both sides.

When there is a secondary flow in the plug base, the solution for the boundary point between the primary and the secondary flow must be iterated to determine a common static pressure. The secondary flow is assumed to be governed by the one-dimensional isentropic relationships.

The calculation of the present type flow field can be carried very far downstream; however, due to the particular objectives of this study, the computer program has only been developed for the computation of flow field properties through the first shock intersection point.

SAMPLE RESULTS AND DISCUSSION

A sample case has been calculated by using the present computer program; the characteristic net has been plotted in Figure 4. When studying the mixing effect between the primary and the secondary flow, the lower boundary is the most important region. Since a fine net size is obtained at the lower boundary, no attempt has been made to refine the net size of the upper field points.

Three cases have been computed for studying the effects of the ambient pressure and the total pressure of the secondary flow on the plume shape. The effect of varying the ambient pressure in a fixed nozzle is shown in Figure 5. When the ambient pressue ratio (P_o/P_a) decreased from 594.1 to 101.3, the length (X/R_E) of the plume up to the shocks intersection decreased from 3.06 to 2.11. The effect of varying the secondary total pressure in a fixed nozzle is shown in Figure 6. When the secondary total pressure ratio (P_o/P_T) decreased from 64.12 to 27.79, the length (X/R_E) of the plume up to the shocks intersection decreased from 3.06 to 2.00.

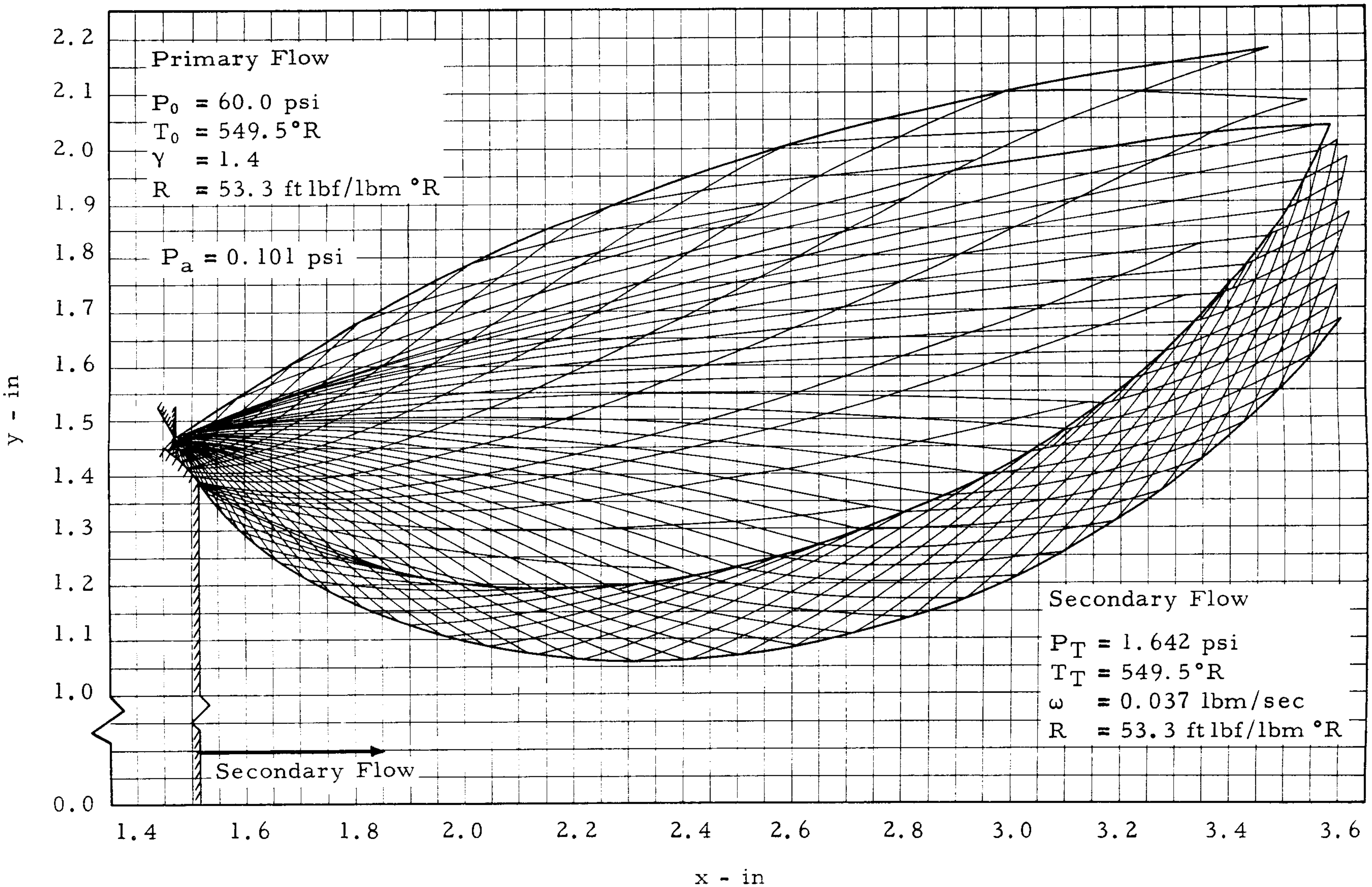

Figure 4. Characteristic Net for an Aerodynamic Plug Nozzle

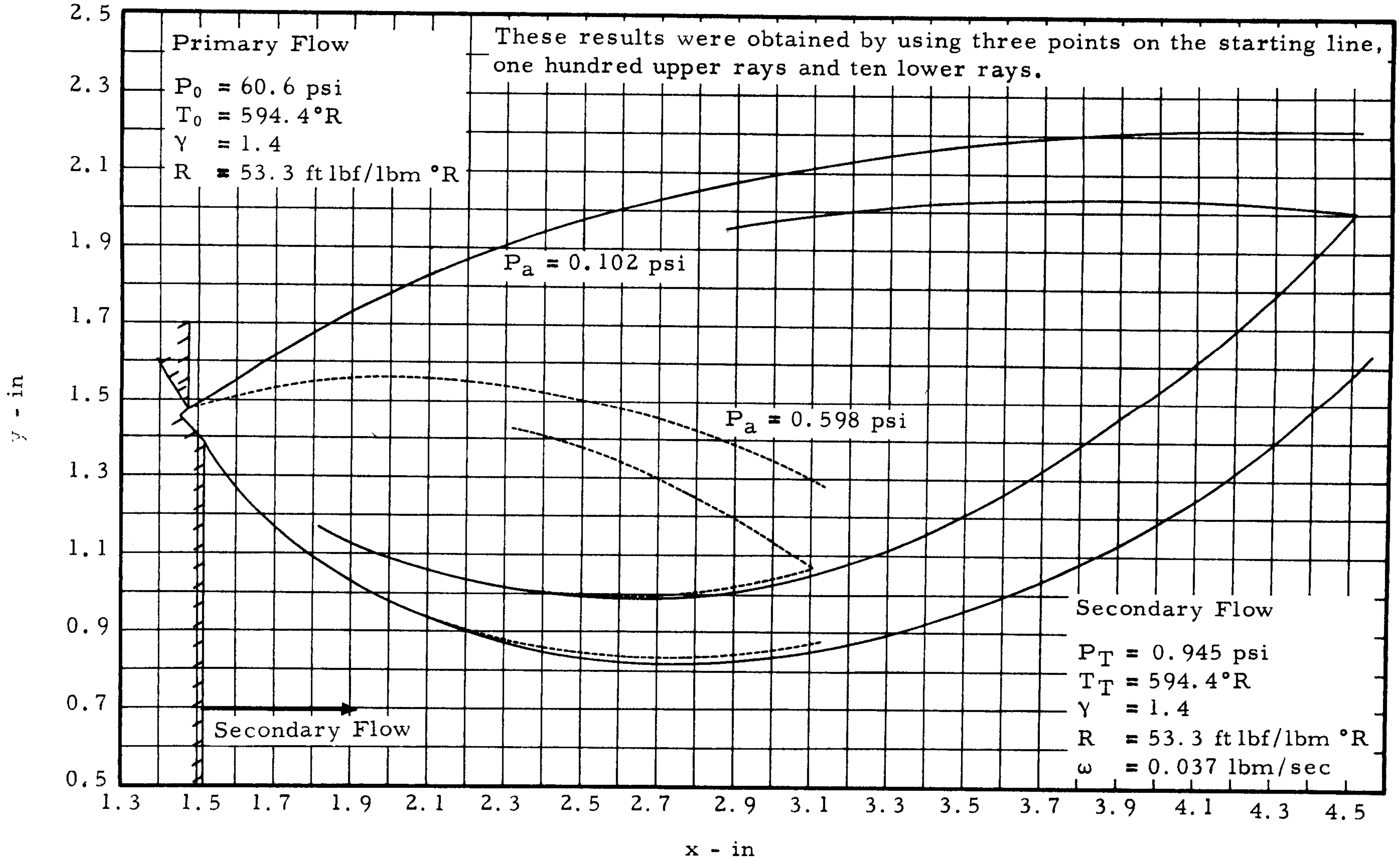

Figure 5. Variations of Plume Shapes for Various Ambient Pressures

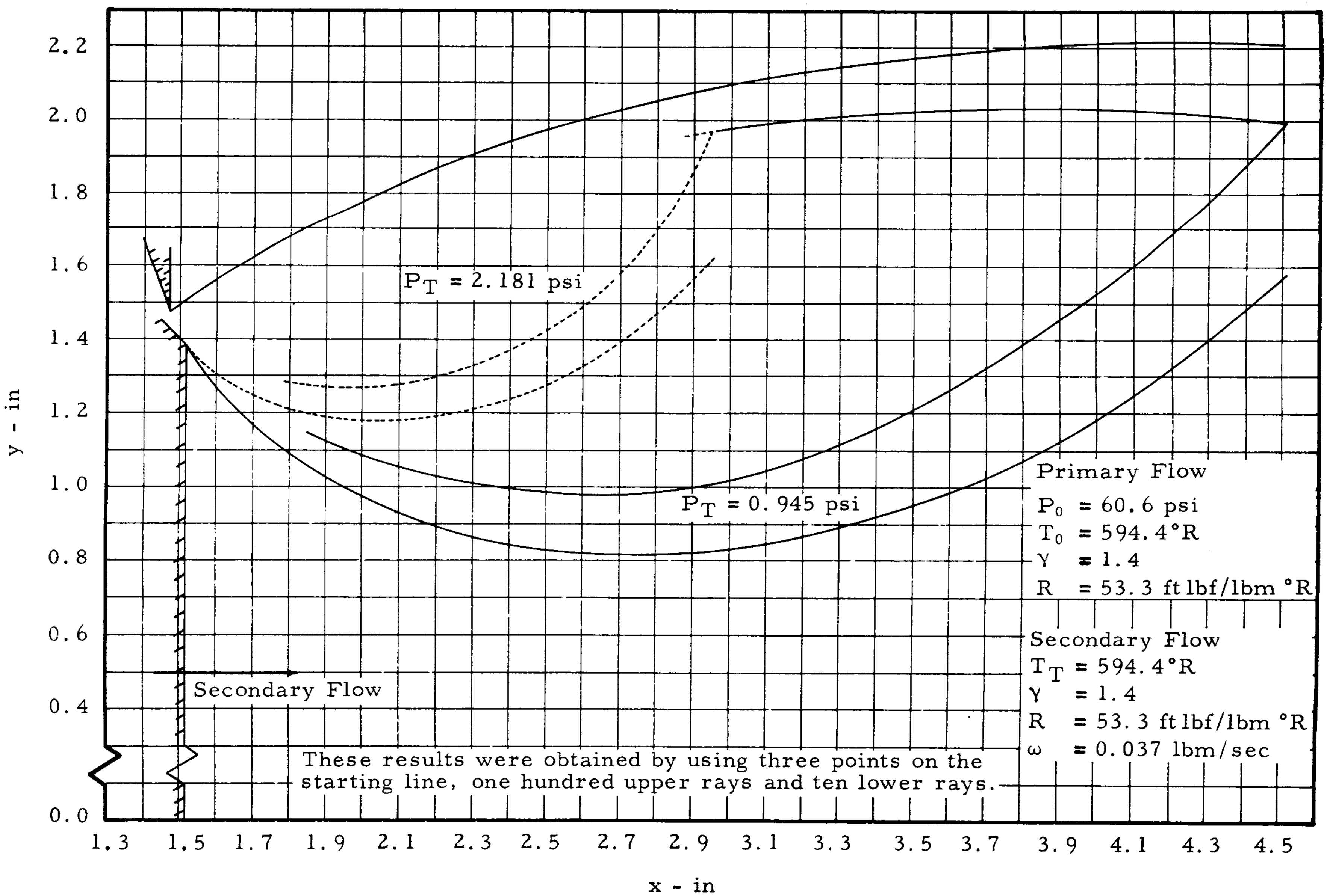

Figure 6. Variations of Plume Shapes for Various Secondary Total Pressure

REFERENCES

1. Chow, W. L., and A. L. Addy, "Interaction Between Primary and Secondary Streams of Supersonic Ejector Systems and Their Performance Characteristics", AIAA Journal, Volume 2, Number 4, pp. 686-695, April, 1964

2. Lee, C. C., and S. J. Inman, "Numerical Analysis of Plug Nozzles by the Method of Characteristics", Technical Note R-101, Brown Engineering Company, Inc., May, 1964

3. Moe, M. M., and B. A. Troesch, "Jet Flows with Shock", ARS Journal, Volume 30, Number 5, pp. 487-489, May, 1960

4. Eastman, D. W., "Two Dimensional or Axially Symmetric Real Gas Flows by the Method of Characteristics, Part 1, Formulation of the Equations", Category Code No. 81205 Document No. D2-10597, Boeing Airplane Company, Seattle 24, Washington, December, 1961

5. Der. J., Jr., B. N. Mullings, G. H. Hoffman, B. N. Pridmore Brown, "Numerical Analysis of Supersonic Flow Through Curved Channels", ARL 63-117, Northrop Norair, Hawthorne, California, July, 1963

APPENDIX A

DESCRIPTION OF DATA INPUT AND OUTPUT

Input

This program requires the following input data:

1. Nozzle components (3 cards)

GAM(γ)	ratio of specific heats for primary flow
XM(Mest)	initial Mach Number
P(P_o)	total pressure for primary flow
T(T_o)	total temperature for primary flow
R	gas constant for primary flow
GW(γ_s)	ratio of specific heats for secondary flow
RW	gas constant for secondary flow
P_T	total pressure for secondary flow
TT	total temperature for secondary flow
PA(p_a)	ambient pressure
W(w)	secondary flow rate
N	number of points on starting line, must be < 100
N1	number of lower wall contour points, must be $\leqq 100$
NU(η)	the number of upper corner rays to be computed, must be $< (600 - N - NL - 1)$
NL	the number of lower corner rays to be computed, must be < 100

2. A title or job-description card

3. N1 lower wall contour points given as Cartesian coordinates

4. Upper corner point given as Cartesian coordinates

5. KK If input is in feet, KK = 0
   If input is in inches, KK = 1

Input cases can be stacked and processed several at a time. If a bad data case is found which cannot run to completion, the remaining data cases will not be processed. This is due to the computer system, not the program.

Output

1. Units of variables

2. Job title

3. Input conditions

4. Upper corner point

5. Lower wall contour points

6. Starting line points

Point	X	Y	M	THETA	T	P
↓	↓	↓	↓	↓	↓	↓

where X, Y are Cartesian coordinates; M is Mach Number, THETA is flow angle, T is temperature (°R), and P is pressure

7. Right running characteristics from the upper corner point

Point	X	Y	M	THETA	T	P
↓	↓	↓	↓	↓	↓	↓

8. External expansion

(a) Field routine points

Point	X	Y	M	THETA	T	P	ITR
↓	↓	↓	↓	↓	↓	↓	↓

where ITR is the number of iterations before convergence in calculations

(b) Body point routine

Point	X	Y	M	THETA	T	P	ITR
↓	↓	↓	↓	↓	↓	↓	↓

Field and body points alternate until the last point on the lower wall contour is reached or until the network is completed.

(c) Insert point

Point	X	Y	M	THETA	T	P

(d) Corner point

Point	X	Y	M	THETA	T	P

9. Thrust distribution along the plug

(a) SUMM (thrust at the throat)

(b) CFI (thrust coefficient at the throat)

(c) Mass flow rate

(d)	X	Y	T (thrust)	CF (thrust coefficient)
	↓	↓	↓	↓

for each point on the lower wall.

(e) AT - throat area

(f) Secondary mass flow rate

(g) Thrust from plug nozzle wall

(h) Thrust from base

(i) Total vacuum thrust

(j) Actual thrust (considering the ambient pressure)

10. Jet flow field computations

(a) Left running characteristics

(b) Flow properties computed along right running characteristics

(1) Field routine

Point	X	Y	M	THETA	T	P	ITR
↓	↓	↓	↓	↓	↓	↓	↓

(2) Free boundary point

Point	X	Y	M	THETA	T	P	ITR

(3) Secondary Mach Number

(4) Primary velocity

(5) Secondary flow temperature

(6) Secondary flow velocity

Repeat 10 until shock is encountered, then the insert point and shock points appear in the field points.

Point	X	Y	M	THETA	T	P	Shock Angle

Section 10 is repeated until the last right running characteristic is used or the deflection angle becomes too big.

11. Upper external flow field and boundary computed along left running characteristics.

(a) Upper free boundary point

Point	X	Y	M	THETA	T	P	ITR

(b) Field routine

Point	X	Y	M	THETA	T	P	ITR
↓	↓	↓	↓	↓	↓	↓	↓

Repeat from 11 until shock is encountered, then the insert point and shock points appear in the field points.

Point	X	Y	M	THETA	T	P	Shock Angle

Repeat from 11 until the upper shock crosses the lower shock or it becomes necessary to extend the lower shock to cross the upper shock.

12. Shock intersection

Characteristics of the shock intersection are printed in the following order:

B - upper shock

C - upper reflected shock

A - lower shock

D - lower reflected shock

Point	X	Y	M	THETA	T	P	Shock Angle

13. Punched card output

(a) First card - At first free boundary point: primary temperature, secondary temperature, primary velocity, secondary velocity (Format 4E12. 5)

(b) One card for each free boundary point. X, Y, Pressure (Format 3E16. 7)

End of Calculation

Point Number Identification

(a) Points numbered 1 are always free boundary points

(b) Points from one set of field points to the next set of field points connect with points one greater than their number (i. e., point 5 in a set of field points connects with point 4 of the preceding set of field points and connects with point 6 of the next set of field points. Also, each set of field points itself is a characteristic.

INPUT DATA AND FORMAT

Format	Data	Description	No. of Cards
(4E15.8)	GAM, XM, P, T	Symbols are defined in 1 of Input Description	1
(5E15.8)	R, GW, RW, PT, TT	Symbols are defined in 1 of Input Description	1
(2E15.8, 2I2, I3, I2)	PA, W, N, N1, NU, NL	Symbols are defined in 1 of Input Description	1
(13A6)	Title or Job Description Card	Maximum of 78 alphanumeric characters (Col. 1-78)	1
(2E15.8)	X, Y	Contour Cartesian coordinates lower wall points followed by one upper corner point	One for each point (N1 + 1)
(I2)	KK	Defined in 5 of Input Description	1

INPUT CARD FORMAT

1–15	16–30	31–45	46–60	61–75
GAM	XM	P	T	
R	GW	RW	PT	TT

1–15	16–30	31–32	33–34	35–37	38–39
PA	W	N	N1	NU	NL

TITLE CARD

1–15	16–30	
X	Y	(N1 + 1 contour point cards)

KK	
2	

SAMPLE DATA

```
              15             30             45             60             75
+0.14000000E+01+0.10500000E+01+0.60600000E+02+0.59440000E+03
+0.53300000E+02+0.14000000E+01+0.53300000E+02+0.94500000E+00+0.59440000E+03
                               3234 3739
+0.10200000E+00+0.03700000E+00030210010
45 Degree Cowl Plug Nozzle
+0.14520000E+01+0.14520000E+01   lower wall contour points
+0.15140000E+01+0.13900000E+01        ↓              ↓
+0.14730000E+01+0.14730000E+01   upper corner point
 2
01
```

APPENDIX B

FORTRAN LISTING

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
C      AERODYNAMIC  PLUG  NOZZLE  ANALYSIS
C      BY  USING  THE  METHOD  OF  CHARACTERISTICS
       DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
      1VLP(600)
       DIMENSION XB1(100),YB1(100)
       DIMENSION FRX(50),FRY(50),FRV(50),FRT(50),FRP(50),FRTH(50),
      1FLX(50 ),FLY(50 ),FLP(50 )
       COMMON YP,XP,TH,XMP,TP,PP,VLP,GAM,GM1,G,XM,N,P,T,R,L,M,J,NL,XXB2,
      1YYB2,NU,GP1,FE,PA
       COMMON FRX,FRY,FRV,FRT,FRP,FRTH,FLX,FLY,FLP,AT,NF
       COMMON YO,GW,RW,PT,TT ,W,XO
       DIMENSION SX(600),SY(600),SM(600),STH(600),ST(600),SP(600),SV(600)
       COMMON/BEN/SX,SY,SM,STH,ST,SP,SV
       COMMON/BUN/UX,UY,BX,BY,UI,UM,BM,UTH,BTH,UT,BT,UP,BP,UV,BV,UU,BU
       DIMENSION UX(2),UY(2),BX(2),BY(2),UM(2),BM(2),UTH(2),BTH(2),UT(2),
      1BT(2),UP(2),BP(2),UV(2),BV(2),UU(2),BU(2)
       DIMENSION EP(3),P7(3),P5(3)
       COMMON/MIKE/EPF,SH(2),CM,SI(2),CP,SL(2),CT,SZ(2),DM,SK(2),DP,
      1SJ(2),DT,SK1(2),I1,UB,UA,CU,DU
       COMMON/JUL/KXSH
    78 READ(5,1001)   GAM,XM,P,T,R,GW,RW,PT,TT,PA,W,N,N1,NU,NL
       KXSH=0
       UX(1)=0.
  1001 FORMAT(4E15.8/5E15.8/2E15.8,2I2,I3,I2)
  1003 FORMAT(2E15.8)
  1002 FORMAT(1H0,///,1H0,5HPOINT,10X,1HX,17X,1HY,17X,1HM,13X,5HTHETA,13X
      1,1HT,17X,1HP,10X,3HITR)
   300 FORMAT(1H1,48X,35HAERODYNAMIC  PLUG  NOZZLE  ANALYSIS/1H0,44X,43HB
      1Y  USING  THE  METHOD  OF  CHARACTERISTICS////1H0,5X,5HUNITS///1H0
      2,10X,16HCOORDINATES  X,Y,14X,3HIN./1H0,10X,25HINCLINED THROAT ANGL
      3E(FE),5X,7HDEGREES/1H0,10X,8HPRESSURE,22X,9HLBF/IN*IN/1H0,10X,11HT
      4EMPERATURE,19
      1X,15HDEGREES RANKINE/1H0,10X,16HGAS CONSTANT (R),14X,26HFT LBF/LBM
      1 DEGREES RANKINE/1H0,10X,4HAREA,26X,5HIN*IN/1H0,10X,6HTHRUST,24X,3
      1HLBF)
   301 FORMAT(13A6)
   302 FORMAT(1H0,13A6)
   303 FORMAT(1H0,5X,17HINPUT  CONDITIONS///                     1H0,10X,3H
      1PA=E15.8/1H0,7X,12HPRIMARY FLOW/1H0,10X,6HGAMMA=E15.8/1H0,10X,5HME
      2ST=E15.8/1H0,10X,2HR=E15.8/1H0,10X,3HPO=E15.8/1H0,10X,3HTO=E15.8/
      31H0,7X,15HSECONDARY  FLOW/1H0,10X,6HGAMMA=E15.8/1H0,10X,2HR=E15.8/
      41H0,10X,2HW=E15.8/1H0,10X,3HPT=E15.8/1H0,10X,3HTT=E15.8)
       READ(5,301)A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13
       WRITE(6,300)
       WRITE(6,302)A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13
```

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
      READ(5,1003)(XB1(I),YB1(I),I=1,N1),XXB2,YYB2
      WRITE(6,303)    PA,GAM,XM,R,P,T,GW,RW,W,PT,TT
      WRITE(6,1006)
      WRITE(6,1007)XXB2,YYB2
      WRITE(6,1008)
      WRITE(6,1007)(XB1(I),YB1(I),I=1,N1)
      READ(5,52)KK
      IF(KK.EQ.0)GO TO 401
      P=P*144.
      PT=PT*144.
      PA=PA*144.
      XXB2=XXB2/12.
      YYB2=YYB2/12.
      DO 402 K=1,N1
      XB1(K)=XB1(K)/12.
  402 YB1(K)=YB1(K)/12.
  401 YO=YB1(N1)
      XO=XB1(N1)
 1006 FORMAT(1HO,18HUPPER WALL CONTOUR/1HO,7X,1HX,16X,1HY)
 1007 FORMAT(1HO,2(E15.8,2X))
 1008 FORMAT(1HO,18HLOWER WALL CONTOUR/1HO,7X,1HX,16X,1HY)
      KIT=0
      NF=2
      GM1=GAM-1.
      GP1=GAM+1.
      G=32.2
      WRITE(6,1002)
   52 FORMAT(I2)
   84 F=ATAN((XXB2-XB1(1))/(YYB2-YB1(1)))
      FE=-(F+1.5707963)
      CALL STL2(XB1,YB1,N1)
      AT=3.1415927*(YYB2+YB1(1))*SQRT((XXB2-XB1(1))**2+(YYB2-YB1(1))**2)
      GO TO 2
 1005 FORMAT(6E13.6)
   79 FORMAT(1HO,6(3X,E15.8))
    2 CP=GAM*R/GM1
      K=N+NL
      DO 61 J=1,N
      H=CP*TP(K)*G
      A=SQRT(GM1*H)
   60 VLP(K)=XMP(K)*A
      FRX(J)=XP(K)
      FRY(J)=YP(K)
      FRV(J)=VLP(K)
      FRT(J)=TP(K)
```

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
      FRP(J)=PP(K)
      FRTH(J)=TH(K)
   61 K=K-1
      FLX(1)=XP(NL+1)
      FLY(1)=YP(NL+1)
      FLP(1)=PP(NL+1)
   74 CALL BPRTN(3,XXB2,YYB2,1)
      NR=N+1+NL
   86 M=NR-1
      L=2+NL
      J=NR-1
      CALL FLDRTN(3)
      M=1+NL
      L=2+NL
      CALL BPRTN(1,XB1,YB1,N1)
      FLX(NF)=XP(NL+1)
      FLY(NF)=YP(NL+1)
      FLP(NF)=PP(NL+1)
      NF=NF+1
      NR=NR+1
      IF(NR-(N+NL+NU))88,6 ,6
   88 IF(J .NE. 666) GO TO 86
      M=1+NL
      J=1+NL
      L=2
      CALL FLDRTN(3)
      M=1
      L=2
      CALL BPRTN(4,XXB2,YYB2,1)
  700 M=NR-1
      L=2
      J=NR-1
      CALL FLDRTN(3)
      IF(M.EQ.0)GO TO 6
      M=1
      L=2
      CALL BPRTN(4,XXB2,YYB2,1)
      I=1
      K=NR
  602 CALL SAVE (2,4,I,K,UI)
      NR=NR+1
      IF(NR-(N+NL+NU))700,6,6
    6 CONTINUE
      IF(N.EQ.0) GO TO 521
      WRITE(6,6978)
```

MAIN PROGRAM

```
6978 FORMAT(//////32X,59HFLOW PROPERTIES COMPUTED ALONG LEFT RUNNING CH
    1ARACTERISTICS)
     LSK=I
     CALL FLDRTN(4)
     BACKSPACE 2
     BACKSPACE 2
     KN=K
     KNR=KN
     IF(M.EQ.0) GO TO 620
     DO 6543 I=1,KNR
     CALL TRANS (I,I,1)
6543 CONTINUE
 623 CONTINUE
     JM=1
     L=1
     N=LSK
     JN=LSK
     IF(M.NE.0) GO TO 797
     JN=JN+NB-NR+1
     N=JN
     JM=NB-NR+2
     L=2
     J=JM
     M=JM
     CALL FLDRTN(5)
 797 CALL BPRTN(5,XXB2,YYB2,1)
     I=1
     M1=JM+1
 605 CALL SAVE (3,1,I,M1,UI)
     L=2
     JM=JM+1
     IF(JM.GE. N)GO TO 788
     IF(N.EQ.JN) GO TO  962
 788 Q1=BX(2)-BX(1)
     Q2=BY(2)-BY(1)
     Q3=UX(2)-BX(1)
     Q4=UY(2)-BY(1)
     ZY=0.
     IF(Q4.LT.0.)ZY=3.1415927
     KZ=1
     GO TO 6144
6143 CONTINUE
     IF(JM.GE.N) GO TO 606
 962 CONTINUE
     J=JM
```

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
      M=JM
      CALL FLDRTN(5)
      GO TO 797
 6144 ZX=ATAN(Q1/Q2)
      ZY=ATAN(Q3/Q4)+ZY
      Q1=BX(1)-UX(2)
      Q2=BX(2)-UX(1)
      IF(UY(1).LT.UY(2)) GO TO 6245
      Q3=BY(1)-UY(1)
      Q4=BY(2)-UY(2)
 6246 IF(ZY.GT.ZX.AND.Q1*Q2.LT.O..AND.Q3*Q4.LT.O.) GO TO 614
      GO TO (6143,6145),KZ
 6245 Q3=BY(1)-UY(2)
      Q4=BY(2)-UY(1)
      GO TO 6246
  614 CONTINUE
      PAUSE 6666
 2000 BACKSPACE 4
      BACKSPACE 4
      READ(4)I
      READ(4)(XP(K),YP(K),XMP(K),TH(K),TP(K),PP(K),VLP(K),K=1,I),BU(2)
      BACKSPACE 4
      BACKSPACE 4
      IF(BX(2).NE.XP(1))GO TO 2000
      BM(2)=XMP(1)
      BTH(2)=TH(1)
      BT(2)=TP(1)
      BP(2)=PP(1)
      BACKSPACE 4
      BACKSPACE 4
      READ(4)I
      IU=I+2
      READ(4)(XP(K),YP(K),XMP(K),TH(K),TP(K),PP(K),VLP(K),K=3,IU),BU(1)
      BACKSPACE4
      BACKSPACE 4
      BM(1)=XMP(3)
      BTH(1)=TH(3)
      BT(1)=TP(3)
      BP(1)=PP(3)
      I1=IU+1
 2001 BACKSPACE 1
      BACKSPACE 1
      READ(1)I
      READ(1)(SX(K),SY(K),SM(K),STH(K),ST(K),SP(K),SV(K),K=1,I),UU(2)
      BACKSPACE 1
```

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
      BACKSPACE 1
      IF(UX(2).NE.SX(1))GO  TO 2001
      UM(2)=SM(1)
      UTH(2)=STH(1)
      UT(2)=ST(1)
      UP(2)=SP(1)
      BACKSPACE 1
      BACKSPACE 1
      I2=IU+3
      READ(1)I
      IL=IU+2+I
      READ(1)(XP(K),YP(K),XMP(K),TH(K),TP(K),PP(K),VLP(K),K=I2,IL),UU(1)
      BACKSPACE 1
      BACKSPACE 1
      UM(1)=XMP(I2)
      UTH(1)=TH(I2)
      UT(1)=TP(I2)
      UP(1)=PP(I2)
      C=(UY(2)-UY(1))/(UX(2)-UX(1))
      D=(BY(2)-BY(1))/(BX(2)-BX(1))
      XP(1)=(BY(1)-UY(1)+C*UX(1)-D*BX(1))/(C-D)
      XP(I1)=XP(1)
      YP(1)=UY(1)+C*(XP(1)-UX(1))
      YP(I1)=YP(1)
      E=(XP(1)-UX(1))/(UX(2)-UX(1))
      XMP(1)=UM(1)+E*(UM(2)-UM(1))
      TH(1)=UTH(1)+E*(UTH(2)-UTH(1))
      TP(1)=UT(1)+E*(UT(2)-UT(1))
      PP(1)=UP(1)+E*(UP(2)-UP(1))
      UB=UU(1)+E*(UU(2)-UU(1))
      E=(XP(1)-BX(1))/(BX(2)-BX(1))
      XMP(I1)=BM(1)+E*(BM(2)-BM(1))
      TH(I1)=BTH(1)+E*(BTH(2)-BTH(1))
      TP(I1)=BT(1)+E*(BT(2)-BT(1))
      PP(I1)=BP(1)+E*(BP(2)-BP(1))
      UA=BU(1)+E*(BU(2)-BU(1))
      CALL RESK
      QX=XP(1)*12.
      QY=YP(1)*12.
      I=1
      QT=TH(1)*57.29578
      QP=PP(1)/144.
      WRITE(6,8990)
      U=UB*57.29578
      WRITE(6,99)I1,QX,QY,XMP(1),QT,TP(1),QP,U
```

MAIN PROGRAM

```
      QT=EPF*57.29578
      QP=CP/144.
      U=CU*57.29578
      WRITE(6,99)I1,QX,QY,CM,QT,CT,QP,U
      QT=TH(I1)*57.29578
      QP=PP(I1)/144.
      U=UA*57.29578
      WRITE(6,99) I,QX,QY,XMP(I1),QT,TP(I1),QP,U
      QP=DP/144.
      QT=EPF*57.29578
      U=DU*57.29578
      WRITE(6,99) I,QX,QY,DM,QT,DT,QP,U
   99 FORMAT(1H0,I3,7(3X,E15.8))
 8990 FORMAT(1H0,18HSHOCK INTERSECTION)
      GO TO 521
      CALL TRANS(1,1,2)
      CALL TRANS(1,I1,3)
      CALL TRANS(I1,1,1)
      UI=CU
      M=IU+3
      J=I1+1
      CALL TRANS(J,I1,3)
      L=IL
      CALL FLDRTN(7)
      CU=UI
      IL=M
      JPL=L
      UI=DU
      M=3
      J=2
      CALL TRANS(2,1,3)
      L=IU
      CALL FLDRTN(8)
      DU=UI
      JPU=L
      IU=M
      PP(I1)=CP
      TP(I1)=CT
      XMP(I1)=CM
      PP(1)=DP
      TP(1)=DT
      XMP(1)=DM
  511 KNT=0
      KEY=0
      MK=0
```

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
      THX=.01745329
      EP(1)=EPF
      EP(2)=EPF+THX
      EP(3)=EP(2)+THX
      MQ=3
      YD=YP(1)
      YC=YP(I1)
      TD=TP(1)
      TC=TP(I1)
      XMD=XMP(1)
      XMC=XMP(I1)
      XD=XP(1)
      XC=XP(I1)
      PC=PP(I1)
      PD=PP(1)
  506 DO 500 I=1,MQ
      YP(1)=YD
      YP(I1)=YC
      TP(1)=TD
      TP(I1)=TC
      XMP(1)=XMD
      XMP(I1)=XMC
      XP(1)=XD
      XP(I1)=XC
      PP(I1)=PC
      PP(1)=PD
      M=I1
      L=M+1
      MB=-1
      CALL BPRTN(1,EP(I),XX,MB)
      M=1
      L=2
      CALL BPRTN(2,EP(I),XX,MB)
      IF(XP(I1).GT.XP(1)) GO TO 501
      P7(I)=PD+(XP(I1)-XD)/(XP(1)-XD)*(PP(1)-PD)
      P5(I)=PP(I1)
      GO TO 500
  501 P7(I)=PC+(XP(1)-XC)/(XP(I1)-XC)*(PP(I1)-PC)
      P5(I)=PP(1)
  500 CONTINUE
      IF(KEY.EQ.0)GO TO 502
      IF(MQ.NE.3)GO TO 503
  504 CALL SOLUT(EP,P5,P7,THX,MQ,EPP,EPM)
      KNT=KNT+1
      IF(KNT.GT.20.AND.MQ.NE.1)STOP
```

MAIN PROGRAM

```
      GO TO 506
  502 XDPP=P5(1)-P7(1)
      XDP=P5(2)-P7(2)
      DPP=ABS(XDPP)
      DP=ABS(XDP)
      KEY=1
      IF(XDPP*XDP.LT.0.) GO TO 504
      IF(DPP.GT.DP)GO TO 504
      THX=-THX
      EP(2)=EP(1)+THX
      EP(3)=EP(2)+THX
      GO TO 506
  503 EPF=EP(1)
      XD=XP(1)
      XC=XP(I1)
  514 QX=XP(I1)*12.
      QY=YP(I1)*12.
      QT=TH(I1)*57.29578
      QP=PP(I1)/144.
      WRITE(6,510)
      WRITE(6, 99)I1,QX,QY,XMP(I1),QT,TP(I1),QP
  517 QX=XP(1)*12.
      QY=YP(1)*12.
      QT=TH(1)*57.29578
      QP=PP(1)/144.
      WRITE(6,510)
      L=1
      WRITE(6, 99)L,QX,QY,XMP(1),QT,TP(1),QP
  510 FORMAT(1H0,9 HSLIP LINE)
  521 CALL FLDRTN(4)
      GO TO 78
  606 BACKSPACE 3
      BACKSPACE 3
      CALL FLDRTN(9)
      J2=KNR
      J1=1
      Q1=SX(2)
      Q2=SY(2)
      Q3=SM(2)
      Q4=STH(2)
      Q5=ST(2)
      Q6=SP(2)
      Q7=SV(2)
      DO 609 JK=LSK,KNR
      CALL TRANS (J1,J2,2)
```

LIST OF FORTRAN PROGRAM

MAIN PROGRAM

```
      J1=J1+1
  609 J2=J2-1
      J1=J1-1
      LSK=J1
      DO 615 JK=1,J1
      CALL TRANS (JK,JK,1)
  615 CONTINUE
      BACKSPACE 3
      BACKSPACE 3
      READ(3) I
      K=I+J1
      J1=J1+1
      READ(3)(XP(K1),YP(K1),XMP(K1),TH(K1),TP(K1),PP(K1),VLP(K1),K1=J1,K
     1)
      BACKSPACE 3
      BACKSPACE 3
      XP(J1)=Q1
      YP(J1)=Q2
      XMP(J1)=Q3
      TH(J1)=Q4
      TP(J1)=Q5
      PP(J1)=Q6
      VLP(J2)=Q7
      UX(1)=XP(K)
      UY(1)=YP(K)
      BX(2)=XP(LSK)
      BY(2)=YP(LSK)
      L=2
      M=LSK+1
      MM=M
      J=M
      CALL FLDRTN(6)
  616 L=2
      M=1
      CALL BPRTN(4,XXB2,YYB2,1)
      K=MM
      DO 950 I=1,MM
      IF(XP(K).NE.XP(K-1)) GO TO 951
  950 K=K-1
  951 KK=K
      DO 952 I=1,KK
      CALL TRANS(I,K,2)
  952 K=K-1
      WRITE(4)KK
      WRITE(4)(SX(I),SY(I),SM(I),STH(I),ST(I),SP(I),SV(I),I=1,KK),U1
```

MAIN PROGRAM

```
      MM=MM+1
      M=MM
      K=LSK+N-1
      Q1=UY(2)-UY(1)
      Q2=UX(2)-UX(1)
      Q3=BY(2)-UY(1)
      Q4=BX(2)-UX(1)
      ZY=0.
      KZ=2
      GO TO 6144
 6145 CONTINUE
      J=M
      CALL FLDRTN(3)
      GO TO 616
  620 NB=N+NL+NU-1
      I=NB
      J8=1
      DO 621JI=NR,NB
      CALL TRANS (J8,I,3)
      I=I-1
  621 J8=J8+1
      DO 622 I=1,KNR
      CALL TRANS(J8,I,1)
  622 J8=J8+1
      KNR=J8-1
      GO TO 623
      END
```

SUBROUTINE STL2

```
      SUBROUTINE STL2(XB,YB,N1)
C     STARTING  LINE  COMPUTATION
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600)
      COMMON YP,XP,TH,XMP,TP,PP,VLP,GAM,GM1,G,XM,N,P,T,R,L,M,J,NL,XXB2,
     1YYB2,NU,GP1,FE,PA
      DIMENSION XB(100),YB(100)
      PI=3.1415927
   12 THST=FE+PI/2.
      FE=FE+(PI/2.-ARSIN(1./XM)+SQRT(GP1/GM1)*ATAN(SQRT(GM1/GP1*(XM*XM-1
     1.)))-ATAN(SQRT(XM*XM-1.)))
   16 JJ=1
      TSC=SIN(PI+FE)/COS(PI+FE)
    1 YD=YB(JJ+1)-YB(JJ)
      XD=XB(JJ+1)-XB(JJ)
      XA=1./(YD/XD-    TSC)*(YYB2-YB(JJ)+YD/XD*XB(JJ)-XXB2*TSC)
      IF(XA-XB(JJ))3,2,2
    2 IF(XA-XB(JJ+1))4,4,5
    5 JJ=JJ+1
      GO TO 1
    3 WRITE(6,6)XA,XB(JJ),XB(JJ+1)
    6 FORMAT(1H0,3E15.8)
      STOP
    4 YP(NL+1)=YB(JJ)+(XA-XB(JJ))/XD*YD
      XP(NL+1)=XA
   14 TH(NL+1)=ATAN((YB(JJ+1)-YB(JJ))/(XB(JJ+1)-XB(JJ)))
   15 XMP(NL+1)=XM
      PP(NL+1)=P/((1.+GM1/2.*XM**2)**(GAM/GM1))
      TP(NL+1)=T/(1.+GM1/2.*XM**2)
      THP=TH(NL+1)*57.29578
      QX=XP(NL+1)*12.
      QY=YP(NL+1)*12.
      QP=PP(NL+1)/144.
      KN=NL+1
      WRITE(6,10)KN,QX,QY,XM,THP,TP(KN),QP
      XN=N
      XN=XN-1.
      DX=(XXB2-XA)/XN
      MQ=2+NL
      MR=N+NL
      DO 9 MM=MQ,MR
      XP(MM)=XP(MM-1)+DX
      YP(MM)=YP(MM-1)+(YYB2-YP(NL+1))/(XXB2-XP(NL+1))*DX
      XMP(MM)=XM
      TH(MM)=TH(NL+1)
```

LIST OF FORTRAN PROGRAM

SUBROUTINE STL2

```
      TP(MM)=TP(NL+1)
      PP(MM)=PP(NL+1)
      QX=XP(MM)*12.
      QY=YP(MM)*12.
      KN=1+NL
    9 WRITE(6,10)MM,QX,QY,XM,THP,TP(MM),QP
   10 FORMAT(1H0,I3,2X,6(3X,E15.8),I5)
      RETURN
      END
```

SUBROUTINE BPRTN

```
      SUBROUTINE BPRTN(KODE,X,Y,NX)
C     BODY  POINT  CALCULATIONS
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600)
      DIMENSION X(100),Y(100)
      DIMENSION FRX(50),FRY(50),FRV(50),FRT(50),FRP(50),FRTH(50),
     1FLX(50 ),FLY(50 ),FLP(50 )
      COMMON YP,XP,TH,XMP,TP,PP,VLP,GAM,GM1,G,XM,N,P,T,R,L,M,J,NL,XXB2,
     1YYB2,NU,GP1,FE,PA
      COMMON FRX,FRY,FRV,FRT,FRP,FRTH,FLX,FLY,FLP,AT,NF
      COMMON YO,GW,RW,PT,TT ,W,XO
      COMMON/LEE/WX
      CALL SSWTCH(2,JSW)
      IJK=0
      IF(KODE .EQ. 3) GO TO 65
      ITR=1
 1004 FORMAT(1H0,40X,18HBODY POINT ROUTINE)
      CP=GAM*R/GM1
      H1=CP*TP(L)*G
      A1=SQRT(GM1*H1)
      V1=XMP(L)*A1
      B1=ARSIN(A1/V1)
      H=WX
      PS=P*(2./GP1)**(GAM/GM1)
      TS=T*(2./GP1)
      S1=CP*ALOG((TP(L)/TS)/((PP(L)/PS )**(GM1/GAM)))+500.
      SB=CP*ALOG((TP(M)/TS)/((PP(M)/PS )**(GM1/GAM)))+500.
      IF(NX.LT.0) GO TO 3000
      IF(KODE.EQ.5)GO TO 5999
      IF(KODE.EQ.4)GO TO 3336
      IF(JSW.EQ.2)
     1WRITE(6,1004)
      DO 1 I=1,NX
      K=I
      IF(X(I)-XP(M))1,1,2
    1 CONTINUE
   20 GO TO (60,61,52),KODE
   60 KEY=1
      GO TO 23
   61 CONTINUE
   23 K=NX
      TH3=ATAN((Y(K)-Y(K-1))/(X(K)-X(K-1)))
      B3=ARSIN(1./XMP(M))
      B4=B3
      A3=SQRT(GM1*CP*TP(M)*G)
```

SUBROUTINE BPRTN

```
      V3=XMP(M)*A3
      T3=TP(M)
      TH4=TH(M)
   58 CONTINUE
   34 C1=(TH3-B3+TH4-B4)/2.
   43 C1=SIN(C1)/COS(C1)
      B=((Y(K)-YP(L))-(X(K)-XP(L))*C1)/((YP(M)-YP(L))-(XP(M)-XP(L))*C1)
      X4=XP(L)+B*(XP(M)-XP(L))
      Y4=YP(L)+B*(YP(M)-YP(L))
      XM4=XMP(L)+B*(XMP(M)-XMP(L))
      TH4=TH(L)+B*(TH(M)-TH(L))
      T4=TP(L)+B*(TP(M)-TP(L))
      P4=PP(L)+B*(PP(M)-PP(L))
      S4=S1+B*(SB-S1)
      TH44=TH4*57.29578
      A4=SQRT(GM1*CP*T4*G)
      V4=XM4*A4
      B4=ARSIN(1./XM4)
   45 C3=COS((TH3-B3+TH4-B4)/2.)
   47 C1=(B3+B4)/2.
      C2=COS(C1)
      C1=SIN(C1)
   48 V3=V4+((V3+V4)/2.*C1/C2)*((TH4-TH3+C1*SIN((TH3+TH4)/2.)/((Y(K)
     1+Y4)/2.*C3)*(X(K)-X4)-((T3+T4)/2.)/(((A3+A4)/2.)**2)*C1*C2 *
     1(SB-S4)*G))
   50 H3=H-.5*V3*V3
      A3=SQRT(GM1*H3)
      B3=ARSIN(A3/V3)
      XMP3=V3/A3
      T3=H3/(CP*G)
      P3=PP(M)*(T3/TP(M))**(GAM/GM1)
      THP=TH3*57.29578
      IF(ABS(B-BP)-.000001)56,56,57
   57 BP=B
      GO TO 58
   56 IF(JSW.EQ.2)
     1WRITE(6,205)
  205 FORMAT(1H0,12HINSERT POINT)
      QX=X4*12.
      QY=Y4*12.
      QP=P4/144.
      IF(JSW.EQ.2)
     1WRITE(6,1006)M,QX,QY,XM4,TH44,T4,QP
      IF(JSW.EQ.2)
     1WRITE(6,206)
```

SUBROUTINE BPRTN

```
  206 FORMAT(1H0,12HCORNER POINT)
      QX=X(K)*12.
      QY=Y(K)*12.
      QP=P3/144.
      IF(JSW.EQ.2)
     1WRITE(6,1006)M,QX,QY,XMP3,THP,T3,QP
      VLP(M)=V3
      XP(M)=X(K)
      YP(M)=Y(K)
      XMP(M)=XMP3
      TH(M)=TH3
      TP(M)=T3
      PP(M)=P3
   51 CONTINUE
      MP=1
      FLX(NF)=XP(NL+1)
      FLY(NF)=YP(NL+1)
      FLP(NF)=PP(NL+1)
  500 FORMAT(6E13.6)
      GW2=GW-1.
      GW1=GW+1.
      HB=CP*G*TP(M)
      AB=SQRT(GM1*HB)
      VB=XMP(M)*AB
      EB=PP(M)/(R*TP(M))
      PBO=PP(M)*(1.+GM1/2.*XMP(M)**2)**(GAM/GM1)
      TBO=TP(M)*(1.+GM1/2.*XMP(M)**2)
      IF(W.EQ.0.)GO TO 4441
      AS=W/(PT*SQRT(GW*G/TT/RW*(2./GW1)**(GW1/GW2)))
      IF(JSW.EQ.2)
     1WRITE(6,6666)AS
 6666 FORMAT(1H0,6HASTAR=E15.8)
      CALL PRR(YO,PS,AS,PT,GW,XMS,MP,XO,XM1,XM2,PM1,PM2)
      IF(MP.EQ.3)GO TO 7777
      XM1=XO
      PM1=PS
      IF(JSW.EQ.2)
     1WRITE(6,305)
  305 FORMAT(1H0/1H0,34HTHRUST DISTRIBUTION ALONG THE PLUG)
      SUMM=0.
      SUMV=0.
      NZ=N-1
      DO 91 I=1,NZ
      P12=(FRP(I)+FRP(I+1))/2.
      T12=(FRT(I)+FRT(I+1))/2.
```

SUBROUTINE BPRTN

```
      RO12=P12/(R*T12)
      A12=3.1415927*(FRY(I)+FRY(I+1))*SQRT((FRX(I)-FRX(I+1))**2+(FRY(I)
     1-FRY(I+1))**2)
      TH12=(FRTH(I)+FRTH(I+1))/2.
      FE12=ATAN((FRX(I)-FRX(I+1))/(FRY(I+1)-FRY(I)))
      V12=(FRV(I)+FRV(I+1))/2.
      SQ=FE12-TH12
      VM=RO12*V12*A12*COS(SQ)
      VMOM=VM/G*V12*COS(TH12)
      VMOMP=P12*A12*COS(FE12)
      VMO=VMOM+VMOMP
      SUMM=SUMM+VMO
      SUMV=SUMV+VM
   91 CONTINUE
      CFI=SUMM/(P*AT)
      IF(JSW.EQ.2)
     1WRITE(6,96)SUMM,CFI
      IF(JSW.EQ.2)
     1WRITE(6,400)SUMV
  400 FORMAT(1H0,23HPRIMARY MASS FLOW RATE=E15.8)
   96 FORMAT(1H0,5HSUMM=E15.8,3X,4HCFI=E15.8)
      SUMP=0.
      NB=NF-1
      DO 92 I=1,NB
      IF(SUMP)602,602,601
  602 CONTINUE
      IF(FLX(1)-FLX(I+1))600,92,92
  600 IF(I.EQ.1)GO TO 601
      P12=(FLP(1)+FLP(I+1))/2.
      A12=3.1415927*(FLY(1)+FLY(I+1))*SQRT((FLX(1)-FLX(I+1))**2
     1+(FLY(1)-FLY(I+1))**2)
      FE12=ATAN((FLX(1)-FLX(I+1))/(FLY(I+1)-FLY(1)))
      PI=P12*A12*COS(FE12)
      IF(FLY(1)-FLY(I+1))72,73,73
  601 P12=(FLP(I)+FLP(I+1))/2.
      A12=3.1415927*(FLY(I)+FLY(I+1))*SQRT((FLX(I)-FLX(I+1))**2
     1+(FLY(I)-FLY(I+1))**2)
      FE12=ATAN((FLX(I)-FLX(I+1))/(FLY(I+1)-FLY(I)))
      PI=P12*A12*COS(FE12)
      IF(FLY(I)-FLY(I+1))72,73,73
   72 PI=-PI
   73 SUMP=SUMP+PI
      TOT=SUMM+SUMP
      CF=TOT/(P*AT)
      QX=FLX(I+1)*12.
```

SUBROUTINE BPRTN

```
      QY=FLY(I+1)*12.
      IF(JSW.EQ.2)
     1WRITE(6,94)QX,QY,TOT,CF
   92 CONTINUE
   94 FORMAT(1H0,2HX=E15.8,3X,2HY=E15.8,3X,2HT=E15.8,3X,3HCF=E15.8)
      AX=AT*144.
      IF(JSW.EQ.2)
     1WRITE(6,93)AX
   93 FORMAT(1H0,3HAT=E15.8)
      TS=TT/(1.+GW2/2.*XMS**2)
      HS=GW*RW/GW2*TS*G
      SS=SQRT(GW2*HS)
      VS=XMS*SS
      RS=PS/RW/TS
      AB=3.1415927*Y0**2
      XXM=RS*VS*AB
      XMB=XXM/G*VS+PS*AB
      TVAC=TOT+XMB
      IF(JSW.EQ.2)
     1WRITE(6,5000)XXM
 5000 FORMAT(1H0,25HSECONDARY MASS FLOW RATE=E15.8)
      CFVAC=TVAC/(P*AT)
      AE=3.1415927*YYB2    **2
      THRUST=TVAC-PA*AE
      CFREAL=THRUST/(P*AT)
      PB=PS/144.
      IF(JSW.EQ.2)
     1WRITE(6,6111)TOT,XMB,TVAC,THRUST
 6111 FORMAT(1H0,29HTHRUST FROM PLUG NOZZLE WALL=E15.8/1H0,17HTHRUST FRO
     1M BASE=E15.8/1H0,20HTOTAL VACUUM THRUST=E15.8/1H0,49HACTUAL THRUST
     1 (CONSIDERING THE AMBIENT PRESSURE)=E15.8)
 4442 PB=PP(M)
      IF(PP(M)-PS)503,503,504
  503 IF(JSW.EQ.2)
     1WRITE(6,507)PB,PS
  507 FORMAT(1H0,2(3X,E15.8))
      STOP
  504 DTT=G*(PB-PS)*SQRT(XMP(M)**2-1.)/EB/VB/VB
      FL=NL
      DT=DTT/(FL-1.)
      IK=NL
      NLL=NL-1
      DO 505 I=1,NLL
      IK=IK-1
      PP(IK)=PB-EB*VB**2/(G*SQRT(XMP(M)**2-1.))*(FLOAT(I)*DT)
```

SUBROUTINE BPRTN

```
      XP(IK)=XP(M)
      TH(IK)=TH(M)-(FLOAT(I)*DT)
      YP(IK)=YP(M)
      XMP(IK)=SQRT(2./GM1*((PBO/PP(IK))**(GM1/GAM)-1.))
  505 TP(IK)=TBO/(1.+GM1/2.*XMP(IK)**2)
      CALL TRANS(NL,M,3)
      IF(JSW.EQ.2) WRITE(6,6222)
 6222 FORMAT(//////1HO,50X,27HJET FLOW FIELD COMPUTATIONS/1HO,30X,70H(RE
     1SULTS VALID EXCLUDING THOSE BEYOND THE POINT OF SHOCK INTERSECTION
     1))
      IF(JSW.EQ.2)
     1WRITE(6,501)
  501 FORMAT(1HO,28HLEFT RUNNING CHARACTERISTICS)
      I=NL
      DO 506II=1,NL
      THP=TH(I)*57.29578
      QP=PP(I)/144.
      IF(JSW.EQ.2)
     1WRITE(6,1006)I,QX,QY,XMP(I),THP,TP(I),QP
  506 I=I-1
      AA=SQRT(GM1*CP*TP(1)*G)
      VPD=XMP(1)*AA
      IF(JSW.EQ.2)
     1WRITE(6,7002)VPD
      TSEC=TT*(PS/PT)**((GW-1.)/GW)
      CPP=GW*RW/(GW-1.)
      HSEC=CPP*TSEC*G
      ASEC=SQRT((GW-1.)*HSEC)
      VSEC=ASEC*XMS
      IF(JSW.EQ.2)
     1WRITE(6,7003)TSEC
      IF(JSW.EQ.2)
     1WRITE(6,7004)VSEC
      IF(JSW.EQ.2)
     1WRITE(7,7799)TP(1),TSEC,VPD,VSEC
 7799 FORMAT(4E12.5)
      J=666
      IF(JSW.EQ.2) WRITE(6,6223)
 6223 FORMAT(1HO,30X,60HFLOW PROPERTIES COMPUTED ALONG RIGHT RUNNING CHA
     1RACTERISTICS)
      RETURN
   65 NZ=N+NL
      TH3=TH(NZ)
      XMP3=XMP(NZ)
      P3=PP(NZ)
```

SUBROUTINE BPRTN

```
      T3=TP(NZ)
      K=1
   52 CONTINUE
  401 IF(JSW.EQ.2)
     1WRITE(6,207)
  207 FORMAT(1H0,29HRIGHT RUNNING CHARACTERISTICS)
 1007 FORMAT(I2,E15.8,I2)
      C3=(GAM+1.)/GM1
      C4=1./C3
      TERM=TH3-SQRT(C3)*ATAN(SQRT(C4*(XMP3**2-1.)))+ATAN(SQRT(XMP3**2-1.
     1))
      XME=SQRT(2./GM1*((1.+GM1/2.*XMP3**2)/((PA/P3)**(GM1/GAM))-1.)
     1)
      XNU=NU
      DM=(XME-XMP3)/(XNU-1.)
      XM=XMP3
   53 DO 54 II=1,NU
      XMP(NZ)=XM
      TH(NZ)=TERM+SQRT(C3)*ATAN(SQRT(C4*(XM*XM-1.)))-ATAN(SQRT(XM*XM-1.
     1))
      RTHP=TH(NZ)* 57.29578
      TP(NZ)=          T3/(1.+GM1/2.*XM*XM)*(1.+GM1/2.*XMP3**2)
      PP(NZ)=P3*((1.+GM1/2.*XMP3**2)/(1.+GM1/2.*XM*XM))
     1**(GAM/GM1)
      XM=XM+DM
  995 XP(NZ)=X(K)
      YP(NZ)=Y(K)
  544 QX=X(K)*12.
      QY=Y(K)*12.
      QP=PP(NZ)/144.
      IF(JSW.EQ.2)
     1WRITE(6,1006)NZ,QX,QY,XMP(NZ),RTHP   ,TP(NZ),QP
   54 NZ=NZ+1
      RETURN
    2 J=K-1
      XB1=X(J)
      XB2=X(K)
      YB1=Y(J)
      YB2=Y(K)
  300 CONTINUE
      XTH3=TH(M)
      XY3=YP(M)
      XXMX3=XMP(M)
      XB=XB1
      BB=B1
```

LIST OF FORTRAN PROGRAM

SUBROUTINE BPRTN

```
      VB=V1
      TB=TP(L)
      AB=A1
      KCNT=0
      IF(NX.LT.0) GO TO 22
      KKNT=0
   11 KKNT=KKNT+1
      IF(KKNT-50)111,111,133
  133 IF(JSW.EQ.2)
     1WRITE(6,134)XBP,XB,XB1,XB2
  134 FORMAT(1H0,4E15.8)
      GO TO 13
  111 TH(M)=ATAN((YB2-YB1)/(XB2-XB1))
   22 GO TO (33,44),KODE
   33 Z1=(TH(L)-B1+TH(M)-BB)/2.
      Z9=TH(L)-TH(M)
      GO TO 55
   44 Z1=(TH(L)+B1+TH(M)+BB)/2.
      Z9=TH(M)-TH(L)
   55 Z2=COS(Z1)
      KCNT=KCNT+1
      Z10=SIN((B1+BB)/2.)
      Z3=SIN(Z1)/Z2
      Z4=SIN(TH(M))/COS(TH(M))
      Z5=SIN((TH(L)+TH(M))/2.)
      Z7=(B1+BB)/2.
      Z8=COS(Z7)
      Z6=SIN(Z7)
      XBP=(YP(L)-YB1-XP(L)*Z3+XB1*Z4)/(Z4-Z3)
      YP(M)=YB1+(XBP-XB1)*Z4
      VBP=V1+((V1+VB)/2.*Z6/Z8)*(Z9+(Z5*Z10/((YP(L)+YP(M))/2.*Z2)) *(
     1XBP-XP(L))-((TP(L)+TB)/2./(((A1+AB)/2.)**2)*Z6*Z8)*(SB-S1)*G)
   12 HBP=H-VBP*VBP/2.
      AB =SQRT(GM1*HBP)
      XMP(M)=VBP/AB
      TB =GM1*HBP/(GAM*R*G)
      IF(XMP(M)-1.)997,998,998
  997 IF(JSW.EQ.2)
     1WRITE(6,134)XMP(M)
      N=0
      NU=0
      NL=0
      RETURN
  998 CONTINUE
      IF(ABS((XBP-XB)/XB)-.000001)3,3,4
```

SUBROUTINE BPRTN

```
    4 BB=ARSIN(1./XMP(M))
      XB=XBP
      ITR=ITR+1
      VB=VBP
      IF(KCNT-50)22,22,333
  333 IF(JSW.EQ.2)
     1WRITE(6,134)XBP,XB,XB1,XB2
    3 IF(NX.LT.0)GO TO 13
      IF(XB1-XBP)6,13,5
    6 IF(XBP-XB2)13,13,9
    9 XB1=XB2
      YB1=YB2
      J=J+1
      K=K+1
      IF(K-NX)21,21,200
  200 TH(M)=XTH3
      YP(M)=XY3
      XMP(M)=XXMX3
      GO TO 20
   21 XB2=X(K)
      YB2=Y(K)
      GO TO 11
    5 XB2=XB1
      YB2=YB1
      J=J-1
      K=K-1
      XB1=X(J)
      YB1=Y(J)
      IF(J)20,20,11
   13 THB2=TH(M)*57.29578
      PP(M)=PP(M)*(TB/TP(M))**(GAM/GM1)
      TP(M)=TB
      QX=XBP*12.
      QY=YP(M)*12.
      QP=PP(M)/144.
      VLP(M)=VBP
      XP(M)=XBP
      IF(NX.GT.0.AND.JSW.EQ.2)
     1WRITE(6,1006)M,QX,QY,XMP(M),THB2,TP(M),QP,ITR
      RETURN
 1006 FORMAT (1H0,I3,2X,6(3X,E15.8),I5)
 3336 THD=TH(1)
      IF(JSW.EQ.2)
     1WRITE(6,7000)
 7000 FORMAT(1H0,40X,19HFREE BOUNDARY POINT)
```

LIST OF FORTRAN PROGRAM

SUBROUTINE BPRTN

```
      TD=TP(1)
      SD=SB
      AB=SQRT(GM1*CP*TP(1)*G)
      AD=AB
      VB=XMP(1)*AB
      VD=VB
      BB=ARSIN(AB/VB)
      BD=BB
      PBO=PP(1)*(1.+GM1/2.*XMP(1)**2)**(GAM/GM1)
 3333 Z1=(TH(2)-B1+THD-BD)/2.
      Z2=SIN(Z1)
      Z3=COS(Z1)
      Z4=Z2/Z3
      Z5=(TH(1)+THD)/2.
      Z6=SIN(Z5)/COS(Z5)
      XPD=(YP(2)-YP(1)-XP(2)*Z4+XP(1)*Z6)/(Z6-Z4)
      YPD=YP(1)+(XPD-XP(1))*Z6
      IF(W.EQ.0.)GO TO 4443
      CALL PRR(YPD,PS,AS,PT,GW,XMS,MP,XPD,XM1,XM2,PM1,PM2)
      IF(MP.EQ.3)GO TO 7777
      XMD=SQRT(2./GM1*((PBO/PS)**(GM1/GAM)-1.))
      PD=PS
      TD=TP(1)*(PD/PP(1))**(GM1/GAM)
      HD=CP*TD*G
      AD=SQRT(GM1*HD)
      VPD=XMD*AD
      BD=ARSIN(AD/VPD)
 4446 Z3=COS((TH(2)-B1+THD-BD)/2.)
      Z7=(B1+BD)/2.
      Z8=SIN(Z7)
      Z11=COS(Z7)
      Z9=Z8/Z11
      Z10=SIN((TH(2)+THD)/2.)
      Z12=(TP(2)+TD)/2.
      TPD=TH(2)-(VPD-V1)*COS(B1+BD)/SIN(B1+BD)/((VPD+V1)/2.)+Z8*Z10/((
     1YP(2)+YPD)/2.*Z3)*(XPD-XP(2))-(((TD+TP(2))/2.)/(((AD+A1)/2.)**2)
     1*Z8*Z11)*(SD-S1)*G
      IF(ABS((TPD-THD)/THD)-.00001)3335,5552,5552
 5552 THD=TPD
      IJK=IJK+1
      IF(IJK-50)3333,3335,3335
 3335 XP(1)=XPD
      XM2=XM1
      XM1=XPD
      PM2=PM1
```

SUBROUTINE BPRTN

```
      MP=2
      PM1=PS
      YP(1)=YPD
      VLP(1)=VPD
      TH(1)=TPD
      TPD=TPD*57.29578
      TP(1)=TD
      PP(1)=PD
      XPD=XPD*12.
      YPD=YPD*12.
      PD=PD/144.
      KA=1
      IF(JSW.EQ.2)
     1WRITE(6,1006)KA,XPD,YPD,XMD,TPD,TD,PD,IJK
      IF(JSW.EQ.2)
     1WRITE(6,7001)XMS
      IF(JSW.EQ.2)
     1WRITE(6,7002)VPD
      TSEC=TT*(PS/PT)**((GW-1.)/GW)
      CPP=GW*RW/(GW-1.)
      HSEC=CPP*TSEC*G
      ASEC=SQRT((GW-1.)*HSEC)
      VSEC=ASEC*XMS
      IF(JSW.EQ.2)
     1WRITE(6,7003)TSEC
      IF(JSW.EQ.2)
     1WRITE(6,7004)VSEC
 7003 FORMAT(1H0,27HSECONDARY FLOW TEMPERATURE=E15.8)
 7004 FORMAT(1H0,24HSECONDARY FLOW VELOCITY=E15.8)
 7002 FORMAT(1H0,17HPRIMARY VELOCITY=E15.8)
 7001 FORMAT(1H0,22HSECONDARY MACH NUMBER=E15.8)
      IF(JSW.EQ.2)
     1WRITE(7,1666)XP(1),YP(1),PP(1)
 1666 FORMAT(3E16.7)
      RETURN
 7777 IF(JSW.EQ.2)
     1WRITE(6,7778)
      N=0
      NL=0
      NU=0
 7778 FORMAT(1H0,10X,20HSECONDARY FLOW CHOKE)
      RETURN
 4441 PS=PT
      GO TO 4442
 4443 VPD=VD
```

LIST OF FORTRAN PROGRAM

SUBROUTINE BPRTN

```
      XMD=XMP(1)
      PD=PP(1)
      GO TO 4446
 5999 IF(JSW.EQ.2)
     1WRITE(6,5001)
 5001 FORMAT(1H0,40X,25HUPPER FREE BOUNDARY POINT)
      II=1
      JP=II
      J=2
      ITR=1
      B3=ARSIN(1./XMP(II))
      B2=ARSIN(1./XMP(J))
      H3=CP*G*TP(II)
      H2=CP*G*TP(J)
      A3=SQRT(GM1*H3)
      A2=SQRT(GM1*H2)
      V3=A3*XMP(II)
      S3=CP*ALOG((TP(II)/TS)/((PP(II)/PS)**(GM1/GAM)))+500.
      S2=CP*ALOG((TP(J)/TS)/((PP(J)/PS)**(GM1/GAM)))+500.
      T3=TH (II)
      C2=(B3+B2)/2.
      C11=SIN(C2)
      C12=COS(C2)
 5003 C1=(T3+TH (J))/2.
      C3=(T3+TH (JP))/2.
      C4=C1+C2
      C5=SIN(C4)
      C6=COS(C4)
      C7=C5/C6
      C8=SIN(C3)
      C9=COS(C3)
      C10=C8/C9
      X3=(YP(J)-YP(JP)+XP(JP)*C10-XP(J)*C7)/(C10-C7)
      Y3=YP(J)+C7*(X3-XP(J))
      T3P=TH(J)+(V3-VLP(J))*C12/C11/((V3+VLP(J))/2.)-C11*C5/(YP(J)+Y3)/2
     1.*C6 *(X3-XP(J))+(TP(2)+T3)/2./(((A2+A3)/2.)**2)*C11*C12*(S3-S2)*G
      IF(ABS((T3P-T3)/T3)-.00001)5010,5010,5002
 5002 T3=T3P
      IF(ITR.EQ.50)GO TO 5010
      ITR=ITR+1
      GO TO 5003
 5010 XP(II)=X3
      YP(II)=Y3
      TH (II)=T3
      TX=T3*57.29578
```

SUBROUTINE BPRTN

```
      QX=X3*12.
      QY=Y3*12.
      QP=PP(II)/144.
      IF(JSW.EQ.2)
     1WRITE(6,1006)II,QX,QY,XMP(II),TX,TP(II),QP,ITR
      RETURN
 3000 TH(M)=X(1)
      XB1=XP(M)
      YB1=YP(M)
      GO TO 300
      END
```

LIST OF FORTRAN PROGRAM

SUBROUTINE FLDRTN

```
      SUBROUTINE FLDRTN (IZ)
C     FIELD  POINT  CALCULATIONS  INCLUDING  SHOCK  POINT  CALCULATIONS
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600)
      DIMENSION FRX(50),FRY(50),FRV(50),FRT(50),FRP(50),FRTH(50),
     1FLX(50),FLY(50),FLP(50)
      DIMENSION U4(3),TH11(3),TH1(3)
      DIMENSION H(3),A(3),V(3),B(3),S(3)
      COMMON YP,XP,TH,XMP,TP,PP,VLP,GAM,GM1,G,XM,N,P,T,R,L,M,J,NL,XXB2,
     1YYB2,NU,GP1,FE,PA
      COMMON FRX,FRY,FRV,FRT,FRP,FRTH,FLX,FLY,FLP,AT,NF
      COMMON YO,GW,RW,PQ,TQ,WH,XO
      DIMENSION SX(600),SY(600),SM(600),STH(600),ST(600),SP(600),SV(600)
      COMMON/BEN/SX,SY,SM,STH,ST,SP,SV
      COMMON/LEE/W
      COMMON/BUN/UX,UY,BX,BY,UI,UM,BM,UTH,BTH,UT,BT,UP,BP,UV,BV,UU,BU
      DIMENSION UX(2),UY(2),BX(2),BY(2),UM(2),BM(2),UTH(2),BTH(2),UT(2),
     1BT(2),UP(2),BP(2),UV(2),BV(2),UU(2),BU(2)
      COMMON/TERRY/CP,PT,TT,X14,Y14,XM14,TH14,T14,P14,S14,V14,B14,A14,
     1H,A,V,B,S
      COMMON/JUL/KX
      CALL SSWTCH(2,JSW)
      IF(M.EQ.(N+NU+NL-2)) M9=1
      IF(IZ.EQ.9) GO TO 6661
      MS=1
      CP=GAM*R/GM1
      KY=0
      XTH=.0174532925
      IF(IZ.EQ.10.OR.IZ.EQ.11)GO TO 831
      IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 4
      IF(IZ.EQ.5)XTH=-XTH
      IF(IZ.EQ.4)GO TO 400
      IF(JSW.EQ.2)
     1WRITE(6,2)
    2 FORMAT(1H0,40X,13HFIELD ROUTINE)
      IF(IZ.EQ.6) GO TO 1555
   24 II=M
   25 DO 10 IJ=L,M
      ITR=1
   18 J=J-1
   11 JP=II+1
      IF(IZ.NE.5.AND.IZ.NE.8) GO TO 20
      J1=JP
      JP=J
      J=J1
```

SUBROUTINE FLDRTN

```
 20 DO 8 I=1,2
    J1=J
    IF(I.EQ.2)J1=JP
    H(I)=CP*TP(J1)*G
    A(I)=SQRT(GM1*H(I))
    V(I)=XMP(J1)*A(I)
    B(I)=ARSIN(A(I)/V(I))
    PT=P*(2./GP1)**(GAM/GM1)
    TT=T*(2./GP1)
    S(I)=CP*ALOG((TP(J1)/TT)/((PP(J1)/PT)**(GM1/GAM)))+500.
  8 CONTINUE
    IF(KX.NE.5) W=H(1)+V(1)*V(1)/2.
    KX=5
    TP(II)=TP(J)
    B(3)=B(1)
    TH(II)=TH(J)
    S(3)=S(1)
    A(3)=A(1)
    V(3)=V(1)
227 CONTINUE
    Z1=(TH(J)+B(1)+TH(II)+B(3))/2.
    Z2=(TH(JP)-B(2)+TH(II)-B(3))/2.
    Z4=(B(1)+B(3))/2.
    Z5=(B(2)+B(3))/2.
    Z6=(V(1)+V(3))/2.
    Z7=(V(2)+V(3))/2.
    Z12=COS(Z1)
    Z13=COS(Z2)
    Z16=COS(Z4)
    Z17=COS(Z5)
  5 FORMAT(1H0,I3,2X,6(3X,E15.8),I3,E13.6)
    Z8=SIN(Z1)/Z12
    Z9=SIN(Z2)/Z13
    Z10=SIN(Z4)
    Z11=SIN(Z5)
    Z14=Z16/Z10
    Z15=Z17/Z11
    Z18=(TP(J)+TP(II))/2.
    Z19=(TH(J)+TH(II))/2.
    Z20=(TH(JP)+TH(II))/2.
    Z21=2.*Z18
    Z32=((A(2)+A(3))/2.)**2
    Z38=(TP(JP)+TP(II))/2.
    Z22=((A(1)+A(3))/2.)**2
    Y8=ABS(Z8)
```

LIST OF FORTRAN PROGRAM

SUBROUTINE FLDRTN

```
      IF(Y8.LE..000001)XP(II)=XP(JP)+(YP(J)-YP(JP))/Z9
      IF(Y8.GT..000001)
     1XP(II)=(XP(J)+1./Z8*(YP(JP)-YP(J)-XP(JP)*Z9))/(1.-Z9/Z8)
      Z25=XP(II)-XP(JP)
      Z26=XP(II)-XP(J)
      YP(II)=YP(JP)+Z9*Z25
      Z23=(YP(J)+YP(II))/2.
      Z24=(YP(JP)+YP(II))/2.
      S(3)=S(1)+((S(2)-S(1))*Z26*(Z10/Z12))/(Z26*Z10/Z12+Z25*Z11/Z13)
      V(3)=1./(Z14/Z6+Z15/Z7)*(TH(JP)-TH(J)+Z14/Z6*V(1)+Z15/Z7*V(2)+
     1Z10*SIN(Z19)/(Z23*Z12)*Z26+Z11*SIN(Z20)/(Z24*Z13)*Z25-Z18/(Z22)*Z
     210*Z16*(S(3)-S(1))*G-(Z38/Z32)*Z11*Z17*(S(3)-S(2))*G)
      TH3P=TH(J)+(V(3)-V(1))*(Z14/Z6)-(Z10*SIN(Z19))/(Z23*Z12)*Z26+Z18/
     1Z22*Z10*Z16*(S(3)-S(1))*G
      H(3)=W-V(3)*V(3)/2.
      A(3)=SQRT(GM1*H(3))
      TP(II)=GM1*H(3)/(GAM*R*G)
      IF(ITR-50)67,67,68
   68 IF(JSW.EQ.2)
     1WRITE(6,5)II,TH3P,TH(II)
      ITR=1
      GO TO 6
   67 IF(ITR-1)7,7,66
   66 IF(ABS(TH3P-TH(II))-.000001)6,6,7
    7 B(3)=ARSIN(A(3)/V(3))
      TH(II)=TH3P
      ITR=ITR+1
      GO TO 227
    6 TH(II)=TH3P
      VLP(II)=V(3)
      THPP=TH(II)*57.29578
      PP(II)=PP(J)*((H(3)/H(1))**(GAM/GM1))/(EXP((S(3)-S(1))/R))
      XMP(II)=V(3)/A(3)
      QX=XP(II)*12.
      QY=YP(II)*12.
      QP=PP(II)/144.
  500 FORMAT(1H0,6I5)
      IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 555
      IF(KEY.EQ.9.OR.KEY.EQ.8)GO TO 555
      IF(KEY.EQ.4)GO TO 9
      IF(IZ.EQ.5)GO TO 3122
      IF(L.NE.2)GO TO 3111
      N9=N9+1
      IF(KEY.EQ.3)GO TO 99
 9999 TT2=YP(II)-YP(II+1)
```

LIST OF FORTRAN PROGRAM

SUBROUTINE FLDRTN

```
      TT1=TT2/(XP(II)-XP(II+1))
      THETA=ATAN(TT1)
      IF(((THETA.GE.0.).AND.(TT2.GE.0.)).OR.((THETA.LT.0.).AND.(TT2.LT.0
     1.)))GO TO 3111
      GO TO 3
   99 IF(YP(II)-YP(LMN))3111,98,98
   98 IF((II-1).LE.LMN)JX=JX+1
      IF(JSW.EQ.2)
     1WRITE(6,6789)QX,QY,XMP(II),THPP,TP(II),QP
      IP=II+1
      CALL TRANS(II,IP,3)
      I9=I9-1
      YP(II)=YP(II+1)
      IF((II-1).NE.LMN)GO TO 31
      JX=JX-1+(II-LMN)
      J=LMN
      LMN=II
      JP=JP+1
      II=II+1
      GO TO 15
  555 IF(KITE.NE.500)U4(1)=UI
      IF(IZ.NE.5.AND.IZ.NE.8)GO TO 988
      J1=J
      J=JP
      JP=J1
  988 IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 155
      U4(2)=U4(1)+XTH
      U4(3)=U4(2)+XTH
      LN=3
      IF(JSW.EQ.2)
     1WRITE(6,6789)QX,QY,XMP(II),THPP,TP(II),QP
      GO TO 155
  501 CONTINUE
      IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 5033
      IF(JSW.EQ.2)
     1WRITE(6,5)II,QX,QY,XMP(II),THPP,TP(II),QP,ITR
      IF(KEY.NE.9)IXI=II
      IF(KEY.EQ.9)I99=I99-1
      J=I99
      II=II-1
      KEY=9
      GO TO 11
    3 IF((II.GT.(N9+NL)).AND.(IZ.NE.5))GO TO 3111
      IF(JSW.EQ.2)
     1WRITE(6,6789)QX,QY,XMP(II),THPP,TP(II),QP
```

LIST OF FORTRAN PROGRAM

SUBROUTINE FLDRTN

```
      KEY=3
      IP=II+1
      CALL TRANS(II,IP,3)
      IF(JSW.EQ.2)
     1WRITE(6,42)
   42 FORMAT(1H0,40X,17HSHOCK ENCOUNTERED)
      UI=TH(II+1)+B(2)
      IF(IZ.EQ.5)UI=TH(II+1)-B(2)
      U44=UI
      JX=1
      LN=3
      LMN=II+1
      X12=XP(LMN)
      Y12=YP(LMN)
      XM12=XMP(LMN)
      TH12=TH(LMN)
      T12=TP(LMN)
      P12=PP(LMN)
      V12=VLP(LMN)
      B12=B(2)
      I9=LMN-2
      S12=S(2)
      GO TO 31
    9 GO TO 311
  311 IF((II-1).EQ.LMN)GO TO 15
 3111 IF(JSW.EQ.2)
     1WRITE(6,5)II,QX,QY,XMP(II),THPP,TP(II),QP,ITR
      GO TO 31
   21 IF(KEY.EQ.8)I99=I99-1
      IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 2121
      J=I99
 1111 KEY=8
      GO TO 11
   15 X22=X12
      IF(IZ.NE.5)GO TO 989
      J1=J
      J=JP
      JP=J1
  989 CONTINUE
      Y22=Y12
      XM22=XM12
      T22=T12
      TH22=TH12
      P22=P12
      B22=B12
```

SUBROUTINE FLDRTN

```
      S22=S12
      V22=V12
      XJP=XP(J)
      LN=3
      U4(1)=UI
      U4(2)=U4(1)+XTH
      U4(3)=U4(2)+XTH
      YJP=YP(J)
      KKK=0
  155 DO 22 I=1,LN
      IF(XP(II).LT.XP(JP))GO TO 21
 2121 CONTINUE
      C=(UI+U4(I))/2.
      C1=SIN(C)
      C2=COS(C)
      C=C1/C2
      BB=((YJP  -YP(JP))-(XJP  -XP(JP))*C)/((YP(II)-YP(JP))-(XP(II)-XP(
     1JP))*C)
      X4=XP(JP)+BB*(XP(II)-XP(JP))
      Y4=YP(JP)+BB*(YP(II)-YP(JP))
      TH4=TH(JP)+BB*(TH(II)-TH(JP))
      T4=TP(JP)+BB*(TP(II)-TP(JP))
      V4=VLP(JP)+BB*(VLP(II)-VLP(JP))
      P4=PP(JP)+BB*(PP(II)-PP(JP))
      R2=PP(JP)/R/TP(JP)
      A4=SQRT(GM1*CP*T4*G)
      XM4=V4/A4
      R3=PP(II)/R/TP(II)
      R4=R2+BB*(R3-R2)
      H4=W-V4**2/2.
      IF(LN.EQ.3.AND.KITE.NE.500) GO TO 503
      IF(X4.GT.XP(II))GO TO 501
 5033 CONTINUE
      IF(X4.LT.XP(JP))GO TO 601
  503 CONTINUE
      X11=X4
      C1=SIN(TH4-U4(I))
      EP=(GM1*XM4**2*C1**2+2.)/(GP1*XM4**2*C1**2)
      Y11=Y4
   35 P11=P4+R4*V4*V4/G*(1.-EP)*C1**2
      H11=H4+V4*V4/2.*(1.-EP*EP)*C1**2
      T11=GM1*H11/GAM/R/G
      S11=500.+GAM*R/GM1*ALOG((T11/TT)/((P11/PT)**(GM1/GAM)))
      VN11=V4*EP*C1
      VT11=V4*COS(TH4-U4(I))
```

LIST OF FORTRAN PROGRAM

SUBROUTINE FLDRTN

```
      V11=SQRT(VN11**2+VT11**2)
      A11=SQRT(GM1*H11)
      B11=ARSIN(A11/V11)
      R11=R4/EP
      D11=ATAN( EP*C1/COS(TH4-U4(I)))
      TH11(I)=U4(I)+D11
      XM11=V11/A11
      IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 41
   91 FORMAT(1H0,10I5)
      I9=I99
      H13=W-VLP(I9)**2/2.
      A13=SQRT(GM1*H13)
      B13=ARSIN(A13/VLP(I9))
      TH14=(TH22+TH(I9))/2.
      B14=(B22+B13)/2.
      TH1(I)=TH11(I)
      IJX=0
      X12=X22
      Y12=Y22
      XM12=XM22
      TH12=TH22
      T12=T22
      P12=P22
      V12=V22
      B12=B22
      S12=S22
   36 C=(TH1(I)+TH14+B11+B14)/2.
      IF(IZ.EQ.5)C=(TH1(I)-B11+TH14-B14)/2.
      C1=SIN(C)
      C2=COS(C)
      C=C1/C2
   84 GP=((Y11-Y12)-(X11-X12)*C)/((YP(I9   )-Y12)-(XP(I9   )-X12)*C)
      X14=X12+GP*(XP(I9   )-X12)
      Y14=Y12+GP*(YP(I9   )-Y12)
      IF(X14.GT.XP(I9))GO TO 83
      IF(X14.LT.X12)GO TO 383
      V14=V12+GP*(VLP(I9   )-V12)
      TH14=TH12+GP*(TH(I9   )-TH12)
      H13=W-VLP(I9   )**2/2.
      A13=SQRT(GM1*H13)
      B13=ARSIN(A13/VLP(I9   ))
      S13=CP*ALOG((TP(I9   )/TT)/((PP(I9   )/PT)**(GM1/GAM)))+500.
      B14=B12+GP*(B13-B12)
      T14=T12+GP*(TP(I9   )-T12)
      A14=SQRT(GM1*CP*T14*G)
```

SUBROUTINE FLORTN

```
      S14=S12+GP*(S13-S12)
      P14=P12+GP*(PP(I9   )-P12)
      XM14=V14/A14
      IF(ABS(GP-GP0)-.000001)82,82,38
   38 GP0=GP
      IJX=IJX+1
      IF(IJX.EQ.100)GO TO 82
      GO TO 36
   83 CONTINUE
      X12=XP(I9)
      Y12=YP(I9)
      XM12=XMP(I9)
      TH12=TH(I9)
      T12=TP(I9)
      P12=PP(I9)
      V12=VLP(I9)
      H12=W-V12**2/2.
      A12=SQRT(GM1*H12)
      B12=ARSIN(A12/V12)
      S12=CP*ALOG((T12/TT)/((P12/PT)**(GM1/GAM)))+500.
      I9=I9-1
      IF(I9.LE.0.OR.(KITE.EQ.500.AND.I9.LE.L-2)) GO TO 401
      H13=W-VLP(I9)**2/2.
      A13=SQRT(GM1*H13)
      B13=ARSIN(A13/VLP(I9))
      TH14=(TH12+TH(I9))/2.
      B14=(B12+B13)/2.
      GO TO 36
  401 IF(JSW.EQ.2)
     1WRITE(6,402)
      QX14=X14*12.
      IF(JSW.EQ.2)
     1WRITE(6,6789)QX14
  402 FORMAT(1H0,10X,47HSHOCK ROUTINE RAN OUT OF POINTS BELOW THE SHOCK)
      KKK=KKK+1
      IF(KKK.EQ.20)GO TO 987
      U4(1)=U4(1)+XTH
      U4(2)=U4(2)+XTH
      U4(3)=U4(3)+XTH
      LN=3
      GO TO 155
  987 CONTINUE
      N=0
      NL=0
      NU=0
```

SUBROUTINE FLDRTN

```
      STOP
      RETURN
   82 CONTINUE
      C1=(B14+B11)/2.
      C2=SIN(C1)
      C3=COS(C1)
      TH1(I)=TH14+(V11-V14)*C3/C2/((V11+V14)/2.)-C2*SIN((TH1(I)+TH14)/2.
     1)/((Y11+Y14)/2.*COS((TH1(I)+B11+TH14+B14)/2.))*(X11-X14)+(T11+T14)
     2/2./(((A11+A14)/2.)**2)*C2*C3*(S11-S14)*G
       IF(IZ.EQ.5)TH1(I)=
     1        TH14-(V11-V14)*C3/C2/((V11+V14)/2.)+C2*SIN((TH1(I)+TH14)/2.
     2)/((Y11+Y14)/2.*COS((TH1(I)-B11+TH14-B14)/2.))*(X11-X14)-(T11+T14)
     3/2./(((A11+A14)/2.)**2)*C2*C3*(S11-S14)*G
       IF(LN.NE.1)GO TO 22
       QX=X14*12.
       QY=Y14*12.
       QP=P14/144.
       THP=TH14*57.29578
       IF(JSW.EQ.2)
     1WRITE(6,5678)
 5678 FORMAT(1H0,5X,12HINSERT POINT)
       IF(JSW.EQ.2)
     1WRITE(6,6789)QX,QY,XM14,THP,T14,QP
 6789 FORMAT(1H0,5X,6(3X,E15.8))
   22 CONTINUE
      IF(LN.EQ.1)GO TO 41
      CALL SOLUT (U4,TH1,TH11,XTH,LN,U441,U442)
      IF(LN.EQ.1) U44=U4(1)
      IF(LN.EQ.1) GO TO 155
      IF(KY.EQ.3)GO TO 838
      GO TO 155
 4004 CONTINUE
      M9=N+NL+NU-M
      M=0
       IF(JSW.EQ.2)
     1WRITE(6,4010)
 4010 FORMAT(1H0,24HDEFLECTION ANGLE TOO BIG)
      LMN=0
      KEY=1
      J=II
      RETURN
  835 B123=B11
      S123=S11
      IU9=199
      GO TO 912
```

SUBROUTINE FLDRTN

```
 834 B125=B11
     S125=S11
     IL9=I99
     GO TO 912
 911 JK=J
     GO TO 9122
  41 IF(KEY.EQ.9)II=IXI
     KEY=4
     XP(II)=X4
     YP(II)=Y4
     XMP(II)=V4/A4
     VLP(II)=V4
     TH(II)=TH4
     PP(II)=P4
     TP(II)=T4
     QX=X4*12.
     QY=Y4*12.
     QP=P4/144.
     THPP=TH(II)*57.29578
     NQ=4
     U444=U4(1)*57.29578
     IF(JSW.EQ.2)
    1WRITE(6,5)II,QX,QY,XMP(II),THPP,T4,QP,NQ,U444
     IF(IZ.EQ.5)GO TO 4005
     IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 911
     XM2=XMP(II)**2
     XM4=XM2**2
     FUN=1./(4.*GAM*XM2)*(GP1*XM2-(3.-GAM)+SQRT(GP1*(GP1*XM4-2.*(3.-
    1GAM)*XM2+(GAM+9.))))
     ANG=ARSIN(SQRT(FUN))
     AGL=ABS(TH(II)-U4(1))
     IF(AGL.GE.ANG)GO TO 4004
4005 CONTINUE
     X12=X11
     Y12=Y11
     V12=V11
     TH12=TH11(1)
     B12=B11
     T12=T11
     S12=S11
     IF(KITE.NE.500) L=2
     J=I9+1
     M=I9+1
     JK=I9+2
     I99=I9+1
```

SUBROUTINE FLDRTN

```
9122 IF((IZ.EQ.3.AND.KITE.EQ.500).OR.IZ.EQ.7) GO TO 835
     IF((IZ.EQ.5.AND.KITE.EQ.500).OR.IZ.EQ.8) GO TO 834
 912 JX=II-1
     DO 97 IX=JK,JX
     XP(IX)=X11
     YP(IX)=Y11
     XMP(IX)=V11/A11
     TP(IX)=T11
     PP(IX)=P11
     TH(IX)=TH11(1)
  97 VLP(IX)=V11
     QP=P11/144.
     THPP=TH11(1)*57.29578
     NQ=11
     NQQ=I1-1
     IF(JSW.EQ.2)
    1WRITE(6,5)NQQ,QX,QY,XMP(NQQ),THPP,T11,QP,NQ
     IF(IZ.EQ.7.OR.IZ.EQ.8) GO TO 913
     LMN=LMN+1
     IF(J-1)17,24,24
  31 II=II-1
     IF(IZ.EQ.5)J=JP
  10 CONTINUE
  17 IF(KITE.EQ.500) GO TO9914
     IF(KEY.NE.3) GO TO 95
     I99=I9
     KEY=4
  95 UI=U44
     IF(IZ.EQ.3)UXI=UI
     IF (NK.EQ.3) GO TO 914
     IF (NK.NE.2) RETURN
     UX(1)=UX(2)
     UY(1)=UY(2)
     UY(2)=YP(LMN)
     UX(2)=XP(LMN)
     RETURN
 914 BX(1)=BX(2)
     BY(1)=BY(2)
     BX(2)=XP(LMN)
     BY(2)=YP(LMN)
     RETURN
 913 M=LL
     L=JP
     RETURN
 601 JP=JP+1
```

SUBROUTINE FLDRTN

```
      IF(IZ.EQ.6) GO TO 602
      IF(JP.GT.M+1) GO TO 602
      II=II+1
      JX=JX+1
      LMN=LMN+1
      IF(JSW.EQ.2)
     1WRITE(6,403)
  604 CONTINUE
  403 FORMAT(1H0,10X,18HIGNORE ABOVE POINT)
      KKK=0
      U4(1)=UI
      U4(2)=U4(1)+XTH
      U4(3)=U4(2)+XTH
      LN=3
      IF(IZ.EQ.7.OR.IZ.EQ.8) LN=1
      GO TO 155
  602 JP=JP-1
      NK=3
      IF(IZ.EQ.5)NK=2
      IF(IZ.EQ.7.OR.(IZ.EQ.3.AND.KITE.EQ.500))NK=1
      IF(IZ.EQ.8.OR.(IZ.EQ.5.AND.KITE.EQ.500))NK=4
      IP=II+1
      CALL TRANS(II,IP,3)
      BACKSPACE NK
      BACKSPACE NK
      READ(NK)I
      I=M9+I-1
      LL=LL-1
      KQ=0
      IF(KITE.EQ.500)KQ=I-LL
      M8=M9-KQ
      I=I-KQ
      READ(NK)(SX(K),SY(K),SM(K),STH(K),ST(K),SP(K),SV(K),K=M8,I)
      BACKSPACE NK
      BACKSPACE NK
      IF(JP.GT.LL.AND.KITE.EQ.500) GO TO 917
      IF(NK.EQ.3) GO TO 915
      IF(NK.NE.2) GO TO 916
      IF(UX(1).NE.0.) GO TO 9166
      UX(2)=XP(J)
      UY(2)=YP(J)
      BX(1)=XP(N)
      BY(1)=YP(N)
 9166 BX(2)=BX(1)
      BY(2)=BY(1)
```

LIST OF FORTRAN PROGRAM

SUBROUTINE FLDRTN

```
      BX(1)=SX(I)
      BY(1)=SY(I)
      GO TO 916
  915 UX(2)=UX(1)
      UY(2)=UY(1)
      UX(1)=SX(I)
      UY(1)=SY(I)
  916 CONTINUE
      N=I
 1212 DO 603 KI=JP,I
      CALL TRANS(KI,KI,1)
  603 CONTINUE
      KX=I-II
      IF(JP.EQ.N) GO TO 1111
      GO TO 604
  400 KEY=1
      N9=0
      JX=0
      LMN=0
      RETURN
  383 KY=3
      U4(1)=U4(1)+XTH
      U4(2)=U4(2)+XTH
      U4(3)=U4(3)+XTH
      GO TO 155
 3122 IF(KEY.EQ.3)GO TO 3999
      TT2=YP(II)-YP(II+1)
      TT1=TT2/(XP(II)-XP(II+1))
      THETA=ATAN(TT1)
      IF(((THETA.LE.O.).AND.(TT2.LE.O.)).OR.((THETA.GT.O.).AND.(TT2.GT.
     1O.)))GO TO 3111
      GO TO 3
 3999 IF(YP(II)-YP(LMN))98,98,3111
 1555 LMN=M-1
      M9=M
      NK=3
      JP=M+1
      J=LMN
      II=M
      I99=LMN-2
      I9=LMN-2
      LN=3
      UI=UXI
      KEY=4
      LM=LMN-1
```

SUBROUTINE FLORTN

```
      H(1)=CP*TP(LM)*G
      A(1)=SQRT(GM1*H(1))
      V12=VLP(LM)
      B12=ARSIN(A(1)/V12)
      X12=XP(LM)
      Y12=YP(LM)
      XM12=XMP(LM)
      TH12=TH(LM)
      T12=TP(LM)
      P12=PP(LM)
      S12=CP*ALOG((TP(LM)/TT)/((PP(LM)/PT)**(GM1/GAM)))+500.
      GO TO 15
    4 GPO=0.
      U4(1)=UI
      I99=J-1
      M9=M
      KITE=500
      ITR=1
      JP=M+1
      LL=L
      JX=J-1
      IF(JP.GT.LL) GO TO 917
      KE=2
      IF(IZ.EQ.7)KE=1
   62 CALL INSPT(J,JP,M,KE)
      IF(X14.GT.XP(M).AND.X14.LT.XP(JP)) GO TO 138
      GPO=0.
      M=M+1
      JP=JP+1
      JX=JX+1
      GO TO 62
  138 LMN=J
      YJP=YP(J)
      XJP=XP(J)
      LN=1
      M=JP-1
      L=M
      J=J+1
      GO TO 24
  917 CALL EXIT
  838 U44=U441
      IF(U44.GE.UI.AND.U44.LE.U4(1).AND.IZ.NE.5)GO TO 417
      IF(U44.LE.UI.AND.U44.GE.U4(1).AND.IZ.EQ.5)GO TO 417
      U44=U442
      IF(U44.GE.UI.AND.U44.LE.U4(1).AND.IZ.NE.5)GO TO 417
```

SUBROUTINE FLDRTN

```
      IF(U44.LE.UI.AND.U44.GE.U4(1).AND.IZ.EQ.5)GO TO 417
      GO TO 155
 417  U4(1)=U44
      LN=1
      GO TO 155
6661  UX(2)=XP(LMN)
      UY(2)=YP(LMN)
      RETURN
 831  LMN=M-1
      II=M
      JP=II+1
      M9=L+1
      KEY=4
      LMX=LMN-1
      X22=XP(LMX)
      Y22=YP(LMX)
      T22=TP(LMX)
      TH22=TH(LMX)
      P22=PP(LMX)
      XM22=XMP(LMX)
      LL=J
      V22=VLP(LMX)
      J=M-1
      XJP=XP(J)
      YJP=YP(J)
      IF(IZ.EQ.10) GO TO 833
      I99=IU9
      IZ=3
      B22=B123
      S22=S123
      XTH=-XTH
      GO TO 601
 833  I99=IL9
      IZ=5
      B22=B125
      S22=S125
      GO TO 601
9914  UI=U44
      M=LL
      L=LMN+1
      RETURN
      END
```

SUBROUTINE SAVE

```
      SUBROUTINE SAVE(N1,N2,I,K,UI)
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600)
      DIMENSION SX(600),SY(600),SM(600),STH(600),ST(600),SP(600),SV(600)
      COMMON YP,XP,TH,XMP,TP,PP,VLP
      COMMON/BEN/SX,SY,SM,STH,ST,SP,SV
  602 CALL TRANS(I,K,2)
      IF(XP(K).EQ.XP(K-1))GO TO 601
      IF(K.EQ.1)GO TO 601
      I=I+1
      K=K-1
      GO TO 602
  601 WRITE(N1)I
      WRITE(N1)(SX(L),SY(L),SM(L),STH(L),ST(L),SP(L),SV(L),L=1,I),UI
      IF(K.EQ.1)RETURN
      K1=K-1
      I1=I+1
      CALL TRANS(I1,K1,2)
      I1=I+2
      K1=K1-1
      KN=K1
      DO 964 J=1,KN
      IF(XP(K1).NE.XP(K1-1))GO TO 965
  964 K1=K1-1
  965 K1=K1-1
      IL=2
  966 CALL TRANS(I1,K1,2)
      K1=K1-1
      IL=IL+1
      I1=I1+1
      IF(K1.GE.1)GO TO 966
      IL=IL-1
      I1=I1-1
      IP=I+1
      K=I1
      WRITE(N2)IL
      WRITE(N2)(SX(L),SY(L),SM(L),STH(L),ST(L),SP(L),SV(L),L=IP,I1),UI
      RETURN
      END
```

LIST OF FORTRAN PROGRAM

SUBROUTINE TRANS

```
      SUBROUTINE TRANS(I,J,KODE)
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600),SX(600),SY(600),SM(600),STH(600),ST(600),SP(600),SV(600)
      COMMON YP,XP,TH,XMP,TP,PP,VLP
      COMMON/BEN/SX,SY,SM,STH,ST,SP,SV
      GO TO(1,2,3),KODE
    1 XP(I)=SX(J)
      YP(I)=SY(J)
      VLP(I)=SV(J)
      XMP(I)=SM(J)
      TH(I)=STH(J)
      TP(I)=ST(J)
      PP(I)=SP(J)
      RETURN
    2 SX(I)=XP(J)
        SY(I)=YP(J)
      SV(I)=VLP(J)
      SM(I)=XMP(J)
      STH(I)=TH(J)
      SP(I)=PP(J)
      ST(I)=TP(J)
      RETURN
    3 XP(I)=XP(J)
      YP(I)=YP(J)
      TH(I)=TH(J)
      XMP(I)=XMP(J)
      PP(I)=PP(J)
      TP(I)=TP(J)
      VLP(I)=VLP(J)
      RETURN
      END
```

SUBROUTINE MIR

```
      SUBROUTINE MIR (N1,N2,A)
C     SOLVES  A  SET  OF  SIMULTANEOUS  EQUATIONS
      DIMENSION A(4,6)
      N3 = N1 +1
      N = N2 + 1
      DO 100 II = 1,N1
      N4 = N3 - II
      IF(N4.EQ.1) GO TO 8
      JJ1 = 0.
      TEST = ABS(A(1,1))
      DO 6 JJ = 2,N4
      IF(TEST.GE.ABS(A(JJ,1)))  GO TO 6
      JJ1 = JJ
      TEST = ABS(A(JJ,1))
    6 CONTINUE
      IF(JJ1.EQ.0)  GO TO 8
      DO 7 JJ = 1,N2
      A(N3,JJ) = A(1,JJ)
      A(1,JJ) = A(JJ1,JJ)
    7 A(JJ1,JJ) = A(N3,JJ)
    8 A(N3,N2) = 1./A(1,1)
      DO 15 J1 = 1,N2
   15 A(J1,N) = A(1,J1)
      DO 20 J = 2,N2
      J1 = J-1
   20 A(N3,J1) = A(1,J)*A(N3,N2)
      DO 30 K = 2,N1
      K1 = K-1
      DO 25 J = 2,N2
      J1 = J-1
   25 A(K1,J1) = -A(K,1)*A(J,N)*A(N3,N2) + A(K,J)
   30 A(K1,N2)= -A(K,1)*A(N3,N2)
      DO 100 J = 1,N2
  100 A(N1,J) = A(N3,J)
      RETURN
      END
```

LIST OF FORTRAN PROGRAM

SUBROUTINE PRR

```
      SUBROUTINE PRR(Y,PS,AS,PT,GW,XM,MP,X,XM1,XM2,PM1,PM2)
C     BASE  PRESSURE  ROUTINE
      K=0
      GW1=GW+1.
      GW2=GW-1.
      GW3=1.-GW
      GO TO (4,5),MP
    5 PTS=PT*(GW1/2.)**(GW/GW3)
      PX=PM1+((PM1-PM2)/(XM1-XM2))*(X-XM1)
      IF(PX.GE.PTS) GO TO 4
      XM=4.
      GO TO 1
    4 XM=.1
    1 A=3.1415927*Y*Y
      IF(A-AS)6,7,8
    7 XM=1.
      GO TO 2
    6 WRITE(6,9)A
      MP=3
      RETURN
    9 FORMAT(1H0,2HA=E15.8)
    8 CONTINUE
      FM=XM*A/AS-((2.+GW2*XM**2)/GW1)**(GW1/(2.*GW2))
      FPM=A/AS-XM*((2.+GW2*XM**2)/GW1)**((3.-GW)/(2.*GW2))
      DM=-FM/FPM
      IF(ABS(DM)-.00001)2,2,3
    3 XM=XM+DM
      K=K+1
      IF(K.EQ.50) GO TO 2
      GO TO 1
    2 PS=PT*(1.+GW2/2.*XM**2)**(-GW/GW2)
      RETURN
      END
```

SUBROUTINE RESK

```
      SUBROUTINE RESK
C     REFLECTED  SHOCK  ROUTINE
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600)
      COMMON YP,XP,TH,XMP,TP,PP,VLP,GAM
      COMMON/MIKE/EP(3),XMC(3),PC(3),TC(3),XMD(3),PD(3),TD(3),I1,UB,UA,
     1UC,UD
      KT=1
      KNT=1
      THX=.01745329
      Q1=0.
      Q2=1.
      DQ=.1
   99 EP(1)=Q1*TH(1)+Q2*TH(I1)
      EP(2)=EP(1)+THX
      EP(3)=EP(2)+THX
      KEY=0
      M=3
    9 DO 3 I=1,M
      D=EP(I)-TH( 1)
      PC(I)=PP( 1)
      TC(I)=TP( 1)
      XMC(I)=XMP( 1)
      CALL SHCK (XMC(I),D,GAM,PC(I),TC(I))
      IF(PC(I).EQ.PP( 1)) GO TO 20
      UC=D+TH( 1)
      D=TH(I1)-EP(I)
      PD(I)=PP(I1)
      TD(I)=TP(I1)
      XMD(I)=XMP(I1)
      CALL SHCK(XMD(I),D,GAM,PD(I),TD(I))
      IF(PD(I).EQ.PP(I1))GO TO 20
    3 UD=TH(I1)-D
      IF(KEY.EQ.0) GO TO 4
      IF(M.NE.3) RETURN
    6 CALL SOLUT(EP,PC,PD,THX,M,EPP,EPM)
      KNT=KNT+1
      IF(KNT.GT.20.AND.M.NE.1) STOP
      GO TO 9
    4 XDPP=PC(1)-PD(1)
      XDP=PC(2)-PD(2)
      DPP=ABS(XDPP)
      DP=ABS(XDP)
      KEY=1
      IF(XDPP*XDP.LT.0.)GO TO 6
```

SUBROUTINE RESK

```
      IF(DPP.GT.DP)GO TO 6
      THX=-THX
      EP(2)=EP(1)+THX
      EP(3)=EP(2)+THX
      GO TO 9
   20 Q1=Q1+DQ
      Q2=Q2-DQ
      IF(Q1.LE.1..AND.Q2.GE.0.) GO TO 99
      WRITE(6,7)
    7 FORMAT(1H0,18HDELTA.GT.DELTA-MAX)
      CALL EXIT
      END
```

SUBROUTINE INSPT

```
      SUBROUTINE INSPT(I,J,K,KODE)
C     INSERT  POINT  ROUTINE
      DIMENSION YP(600),XP(600),TH(600),XMP(600),TP(600),PP(600),
     1VLP(600)
      DIMENSION H(3),A(3),V(3),B(3),S(3)
      COMMON YP,XP,TH,XMP,TP,PP,VLP,GAM,GM1,G
      COMMON/TERRY/CP,PT,TT,X14,Y14,XM14,TH14,T14,P14,S14,V14,B14,A14,
     1H,A,V,B,S
      KNT=0
      GPO=0.
      DO 3 LI=1,3
      IX=K
      IF(LI.EQ.1)IX=I
      IF(LI.EQ.2)IX=J
      H(LI)=CP*TP(IX)*G
      A(LI)=SQRT(GM1*H(LI))
      V(LI)=XMP(IX)*A(LI)
      B(LI)=ARSIN(A(LI)/V(LI))
    3 S(LI)=CP*ALOG((TP(IX)/TT)/((PP(IX)/PT)**(GM1/GAM)))+500.
      TH14=(TH(J)+TH(K))/2.
      B14=(B(2)+B(3))/2.
   36 IF(KODE.EQ.1) C=(TH(I)-B(1)+TH14-B14)/2.
      IF(KODE.EQ.2) C=(TH(I)+TH14+B(1)+B14)/2.
      C1=SIN(C)
      C2=COS(C)
      C=C1/C2
      GP=((YP(I)-YP(J))-(XP(I)-XP(J))*C)/((YP(K)-YP(J))-(XP(K)-XP(J))*C)
      B14=B(2)+GP*(B(3)-B(2))
      TH14=TH(J)+GP*(TH(K)-TH(J))
      IF(ABS(GP-GPO)-.000001)82,82,38
   38 GPO=GP
      KNT=KNT+1
      IF(KNT.EQ.100)GO TO 82
      GO TO 36
   82 X14=XP(J)+GP*(XP(K)-XP(J))
      Y14=YP(J)+GP*(YP(K)-YP(J))
      V14=VLP(J)+GP*(VLP(K)-VLP(J))
      A14=A(2)+GP*(A(3)-A(2))
      S14=S(2)+GP*(S(3)-S(2))
      T14=TP(J)+GP*(TP(K)-TP(J))
      P14=PP(J)+GP*(PP(K)-PP(J))
      XM14=XMP(J)+GP*(XMP(K)-XMP(J))
      RETURN
      END
```

LIST OF FORTRAN PROGRAM

SUBROUTINE SHCK

```
      SUBROUTINE SHCK(XM1,DLT,GAM,P1,T1)
C     OBLIQUE  SHOCK  ROUTINE
   10 FORMAT(5E15.8)
      IJK=0
      DLO=DLT
      GM1=GAM-1.
      GP1=GAM+1.
      W=ARSIN(1./XM1)
      DW=-.001
      XM2=XM1**2
      XM4=XM2**2
      F=1./(4.*GAM*XM2)*(GP1*XM2-3.+GAM+SQRT(GP1*(GP1*XM4-2.*(3.-GAM)*
     1XM2+(GAM+9.))))
      WMAX=ARSIN(SQRT(F))
      DMAX=ATAN((XM2*SIN(2.*WMAX)-2.*COS(WMAX)/SIN(WMAX))/(XM2*(GAM+
     1COS(2.*WMAX))+2.))
      IF(DLT.GT.DMAX) GO TO 2
    1 CONTINUE
      W=W+DW
      WW=W/.01745329
      X1=SIN(W)
      X2=COS(W)
      X3=XM2*SIN(2.*W)
      X4=XM2*COS(2.*W)
      X6=X2/X1
      X5=XM2*GAM+X4+2.
      DI=ATAN((X3-2.*X6)/X5)
      IF(ABS(DLT-DI).LE..00001)GO TO 3
      DDW=2.*COS(DI)**2/X5*(X4+1./(X1**2)+(X3-2.*X6)*X3/X5)
      D1=DI/.01745329
      DW=(DLO-DI)/DDW
      IJK=IJK+1
      IF(IJK.LT.50) GO TO 1
    3 X7=XM2*X1**2
      X8=2.*GAM*X7-GM1
      X9=GM1* X7+2.
      X10=GP1**2*X7
      P2=P1*X8/GP1
      XMM=SQRT((X10*XM2-4.*(X7-1.)*(GAM*X7+1.))/(X8*X9))
      T2=T1*X8*X9/X10
      P1=P2
      T1=T2
      XM1=XMM
      GO TO 5
    5 DLT=W
```

SUBROUTINE SHCK

```
2 RETURN
  END
```

LIST OF FORTRAN PROGRAM

SUBROUTINE SOLUT

```
      SUBROUTINE SOLUT(EP,PC,PD,THX,KS,EPP,EPM)
C     ITERATION  SCHEME  TO  SOLVE  FOR  SHOCK  ANGLE
      DIMENSION EP(3),PC(3),PD(3),Q(4,6)
      DO 39 I=1,3
      Q(I,1)=1.
      Q(I,2)=EP(I)
      Q(I,3)=EP(I)**2
      Q(I,4)=PC(I)
   39 Q(I,5)=PD(I)
      CALL MIR(3,5,Q)
      X1=Q(2,1)-Q(2,2)
      X2=Q(3,1)-Q(3,2)
      X3=SQRT(X1**2-4.*X2*(Q(1,1)-Q(1,2)))
      X4=2.*X2
      EPP=(X3-X1)/X4
      EPM=(-X1-X3)/X4
      IF((EPP.GT.EP(1).AND.EPP.LT.EP(3)).OR.(EPP.LT.EP(1).AND.EPP.GT.
     1EP(3)))GO TO 7
      IF((EPM.GT.EP(1).AND.EPM.LT.EP(3)).OR.(EPM.LT.EP(1).AND.EPM.GT.EP(
     13)))GO TO 8
      EP(1)=EP(1)+THX
      EP(2)=EP(2)+THX
      EP(3)=EP(3)+THX
      KS=3
      RETURN
    7 EP(1)=EPP
    9 KS=1
      RETURN
    8 EP(1)=EPM
      GO TO 9
      END
```