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FORTRAN IV (IBM 7090) PROGRAM FOR THE DESIGN OF CONTOURED AXISYMMETRIC NOZZLES FOR HIGH TEMPERATURE AIR

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NOLTR 64-219

Aerodynamics Research Report No. 235

FORTRAN IV (IBM 7090) PROGRAM FOR THE DESIGN OF CONTOURED AXISYMMETRIC NOZZLES FOR HIGH TEMPERATURE AIR

by
Walter J. Glowacki

ABSTRACT: A computer program is presented for designing contoured axisymmetric nozzles when the supply air temperature is high enough to produce real gas effects. The real gas properties of high temperature air in thermodynamic equilibrium are computed using empirical equations and assuming that the air undergoes an isentropic expansion. These properties are used to determine the potential core contour by solving the inviscid flow equations by the method of characteristics. The turbulent boundary layer growth is computed from a numerical integration of the momentum integral equation and is added to the potential core to obtain the nozzle contour. The heat transfer rate is calculated from a form of Reynolds analogy. The computer program covering these phases of nozzle design is presented with the instructions necessary for using it.

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FORTRAN IV (IBM 7090) Program for the Design of Contoured Axisymmetric Nozzles for High Temperature Air

The departure of high temperature air from an ideal gas must be considered in the design of aerodynamic facilities concerned with the simulation of high speed flight. In the present report, a computer program is presented which uses the thermodynamic and transport properties of high temperature air in designing contoured axisymmetric nozzles for such facilities.

The author would like to acknowledge the contributions of Dr. K. R. Enkenhus, Dr. J. Conlan, E. F. Maher, and L. E. Brown in the formulation and coding of this computer program.

R. E. ODENING
Captain, USN
Commander

K R Enkenhus

K. R. ENKENHUS
By direction

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INTRODUCTION

A computer program for the design of contoured axisymmetric nozzles for wind tunnels operating with air at elevated supply temperatures has been developed at the U. S. Naval Ordnance Laboratory. The program uses the properties of equilibrium high temperature air to compute the potential core flow by the method of characteristics and a turbulent boundary layer correction which is added to the core to obtain the nozzle contour. The procedure used and examples of the results obtained have been presented and discussed previously (ref. (1)), but the computer program itself has not yet been published. In this report, the FORTRAN (IBM 7090) program is presented with the instructions necessary for using it. Since the analysis upon which the computer program is based has been described in adequate detail in reference (1), the details of the analysis will not be repeated in the present work. The FORTRAN program can be obtained on cards from the author.

PRELIMINARY REMARKS

The design of a contoured nozzle for use with high temperature air has been divided into three main phases. First, certain thermodynamic and aerodynamic properties of the air are determined; then, the potential core flow is computed using the air properties; and finally, a boundary layer correction is computed using the air properties and is added to the core to obtain the nozzle contour. The nozzle design program as written consists of three separate computer programs, one covering each of the three phases.

The three computer programs have been written in FORTRAN IV for the IBSYS operating system currently in use at the U. S. Naval Ordnance Laboratory. For use with other monitoring systems, some changes in input/output statements and in library subroutines and functions may be required. Each program writes on the system tape (unit 6) and/or on a separate tape, as desired. The separate tape from each program is required for input to the next program. Therefore, to avoid difficulties with tape positioning or switching, each program is written so as to terminate after computing a single case. The three programs, stacked in the proper order and with the necessary tape units available, will proceed smoothly from one to the next. The output tape of each program is rewound automatically by the succeeding program before input.

ISENTROPIC EXPANSION PROGRAM

The isentropic expansion program uses equations for the enthalpy, entropy, compressibility, and sound speed of air to compute the required air properties assuming an isentropic expansion from the desired supply temperature and pressure to the desired test section Mach number. The air properties are tabulated on the output tape. The equations for the enthalpy, entropy, and compressibility of air had been formulated by Grabau (ref. (2)). The sound speed equation was obtained by differentiating the entropy equation (ref. (3)).

After the accuracy of the four equations was tested by comparing computed points to the original data (ref. (4)), the enthalpy and entropy equations were judged to be somewhat too inaccurate for the iterative procedure which must be used. Therefore, the errors in the enthalpy and entropy equations were determined for a substantial number of points and local quadratics were fitted to these errors so that corrections could be made at intermediate points. The four equations, the error quadratics, and the results of the accuracy tests are presented and discussed in reference (3). The FORTRAN listing of the isentropic expansion program is given in Appendix A.

Input

In the present form of the program, the coefficients and limits of the error quadratics are read into the computer from a binary tape.* The enthalpy constants, listed in decimal form in Table 1, are read during the initial call of function ERRHRP. Table 2 contains the entropy constants, which are read during the initial call of function ERRSR. The binary tape containing these constants constitutes the tape input to the program and is read from tape unit 28. The card input to the program is on one card and is read as follows:

```
READ (5,5) L, NN, TPRO, TT, EMMAX, DELTAP

FORMAT (2I5, 4F10.5)
```

The symbols in the READ statement have the following meanings:

L: This should be 0, 1, or 2. If L = 2, the program gives identical BCD output both on the system tape (unit 6)

*If an input mode other than binary tape is desired, one READ statement in function ERRHRP and two in function ERRSR should be changed accordingly.

and on tape unit 17. If L = 1, the output will be on tape unit 17 only. If L = 0, the output will be on the system tape only.

NN: Identification number for the isentropic expansion table generated.

TPRO: Total (supply) pressure, [atm]

TT: Total (supply) temperature, [^{o}K]

EMMAX: Maximum Mach number desired in the expansion.

DELTAP: Fractional decrease in pressure as the computation proceeds from step to step. Typically its value is between .02 and .05.

Output

Output, whether it be on the system tape, tape 17, or both, will consist of the table number, the supply conditions (pressure, temperature, density, enthalpy, compressibility, dimensionless entropy, speed of sound), the throat conditions (temperature, sound speed, pressure, density, mass flow rate per square foot), the maximum Mach number, and the step interval in the pressure. This is followed by the table containing seven quantities: the logarithm of the pressure and density ratioed to their supply values, the enthalpy ratioed to the supply (total) enthalpy, the compressibility, the sound speed ratioed to its value at the nozzle throat, the Mach number, and the nozzle area ratioed to the throat area.

AXISYMMETRIC CORE PROGRAM

The second of the three computer programs uses the air properties compiled on tape by the isentropic expansion program to calculate an axisymmetric potential core by the method of characteristics. The derivation of the characteristic equations for real gas nozzles and a discussion of the lattice-point method of solving the equations to determine the core are given in detail by Conlan and Trytten (ref. (5)). The method of solution is described briefly, but adequately for most purposes, by Enkenhus and Maher who give the characteristic equations in an intermediate form. The final form programmed is given by Conlan and Trytten.

In addition to the exponential form for the axial Mach number distribution presented by Enkenhus and Maher, a simpler cubic form has been incorporated into the program. The cubic form is:

$$M(x) = M_e - C_1(1 + C_2 x)(x - x_t)^2 \qquad (1)$$

where M(x) is the local Mach number, M_e is the design Mach number, and x_t is the distance from the nozzle throat at which the Mach number on the centerline reaches the design value. The cubic form is applicable over a narrower range of geometries*, but it has been included because experience has shown that the simplest form applicable is usually the best to use. The program automatically changes to the exponential form if the cubic form is not consistent with the nozzle geometry.

A close examination of several nozzle contours computed using the exponential Mach number distribution revealed that the curvature of the core contours did not decrease smoothly in the region between the throat and the inflection point of the nozzle. In these nozzles, after an initial decrease from the throat value, the curvature would go through one or more cycles of increase and decrease, producing "bumps" in a plot of the curvature versus axial distance. It was found that the bumps are not due to computational errors or to nonuniformities in the real gas curve fits, but arise in satisfying the flow equations. Moreover, for given supply conditions and design Mach number, the size and position of the bumps could be changed substantially by changing the two parameters which determine the constants in the Mach number distribution. The two parameters are the Mach number gradient at the nozzle throat (EMZP) and the distance from the throat at which the centerline Mach number reaches the design value (XT). The cubic Mach number distribution could be used in only one of these cases. The curvature of the resulting contour also contained bumps and was nearly identical to that for the exponential distribution.

To make it easier to machine an accurate contour, EMZP and XT are varied until the bumps appear to be minimized. A full study has not been made, but, based on a limited number of nozzle designs, the best procedure for minimizing the bumps seems to involve increasing XT to the maximum value tolerable, then increasing EMZP until the maximum desirable contour angle at the inflection point** is reached. For a given value of XT, an increase in EMZP will move the bumps toward the throat, making

*Unless the product of x_t and $(dM/dx)_{x=o}$ is less than $3(M_e - 1)$, the quantity $(1 + C_2 x)$ in equation (1) will be negative. The Mach number M(x) will then overshoot M_e and reach a maximum before decreasing to M_e at x_t.

**In practice, it is desirable to have a maximum angle, measured with respect to the centerline, of about 10 degrees to avoid any possibility of flow separation. Angles as large as 12 degrees have been used when the bumps in the curvature were severe.

them less severe. For a given value of EMZP, an increase in XT will decrease the angle while moving the bumps away from the throat slightly. As the design Mach number increases, the bumps become substantially more severe, even when minimized. The curvature of each contour should be examined and be judged acceptable before the design is considered final.

Initial estimates for XT and EMZP which can be used to begin the optimization procedure can be obtained from figures 1 and 2, respectively. The figures, taken from reference (1), are presented here for the convenience of the user. The FORTRAN listing of the axisymmetric core program is given in Appendix B.

Input

The tape produced by the isentropic expansion program is required as input to this program. Input of this tape must be from tape unit 17. The card input is on two cards and is read as follows:

```
READ (5,1) NN, IFTH, LM, LN, KK, EMT, XT, RCT,

                EMZP, GAMA, XZ, DZX, DTX, EPSA, EPSB

1 FORMAT (5I5, 4F10.5/6E12.3)
```

The symbols in the READ statement have the following meanings:

NN: Identification number for the nozzle core computed.

IFTH: This determines the analytical form of the centerline Mach number distribution. If IFTH = 0, the exponential form applicable over a wide range of nozzle geometries will be used. If IFTH = 1, the simpler cubic form will be used. The program automatically changes IFTH from 1 to 0 if the cubic form is not consistent with the desired nozzle geometry.

LM: This should be 0, 1, or 2. If LM = 2, the program gives identical BCD output on both the system tape (unit 6) and tape unit 26. If LM = 1, the output will be on tape unit 26 only. If LM = 0, the output will be on the system tape only.

LN: This should be 0 or 1. If LN = 1, various quantities are printed on the system tape for each mesh point as well as for the wall points. This is in addition to the output governed by LM above. If LN = 0, this printing is suppressed. Normally, the program will be run with LN = 0.

KK: Number of steps to be taken at constant interval DZX.

EMT: Desired test section Mach number.

XT: Distance (in exit radii) along centerline from throat to start of test section. A suitable initial value for XT may be found from figure 1.

RCT: Radius of curvature at the throat (in exit radii). This and EMZP are related by the perfect gas equation given as equation B7 in reference (1). Given either quantity, the program will compute the other.

EMZP: Dimensionless Mach number gradient at the nozzle throat. Either this or RCT is given (see discussion for RCT). A suitable initial value for this quantity may be found from figure 2.

GAMA: Specific heat ratio γ to be used in calculating RCT or EMZP. The perfect gas value of 1.4 is normally used.

XZ: Distance (in exit radii) along the nozzle centerline from the throat to the point at which the computation will begin. A typical distance is 0.001.

DZX: Initial step size along centerline (in exit radii). A typical step is 0.001.

DTX: A spacing parameter (in exit radii) which cumulatively increases the step size at every step after the KK^{th} Typically, it is of the same order of magnitude as DZX.

EPSA: Convergence criterion for an iterative process. A typical value is 5×10^{-6}.

EPSB: Convergence criterion for a second iterative process. A typical value is 5×10^{-6}.

Output

When the printout of the mesh points is omitted (LN = 0), the output, whether on the system tape, tape 26, or both, will consist of all pertinent identification from the isentropic expansion tape used as input plus the card input quantities (with the exception of LM and LN), seven internally computed quantities (the throat radius, EMZP or RCT, four constants PA, PB, PC, PD specifying the centerline Mach number distribution, the number of characteristic lines computed along) and a table of nine quantities (NN, the number of the characteristic line, the x and y coordinates of the wall position on that characteristic

(in exit radii), the flow angle at the wall, the local wall Mach number, the local wall pressure ratioed to the total pressure, the square of the flow velocity ratioed to twice the supply enthalpy, and the local wall density ratioed to the total density). If printout at each mesh point is desired (LN = 1), in addition to the output described above, the program will include ON THE SYSTEM TAPE ONLY the following quantities along the characteristic line:

NN: Core identification number

K: Number of the characteristic line on which the computations have been made

N: Number of the point on the K^{th} characteristic at which computations have been made

L: Number of iterations needed in solving the finite difference analogue of the characteristic equations

X: x coordinate (in exit radii)

Y: y coordinate (in exit radii)

S: u/vy, where u and v are respectively the x and y components of the flow velocity

T: u/v

THETA: Flow angle

A: $(M^2 - 1)^{-\frac{1}{2}}$, where M is the local Mach number

ALPHA: Arctan A

Q: $(u^2 + v^2)/2$ HSTAG, where HSTAG is the supply enthalpy

M: Local Mach number

R: Index of streamline. (When R ≥ throat radius, we are on or are past the wall of the nozzle.)

TURBULENT BOUNDARY LAYER PROGRAM

The axisymmetric core contour computed and stored on tape by the previous program is used to calculate the turbulent boundary layer growth and the convective heat transfer to the nozzle wall from a numerical integration of the momentum integral equation, together with the application of Reynolds analogy.

The boundary layer analysis and results using different skin friction laws are presented in reference (1). The present form of the program is based on these results. Consequently, the skin friction is computed from the incompressible Blasius law with a reference enthalpy correction. The heat transfer is found from Colburn's form of the Reynolds analogy without any correction for Lewis number different from one.

The interpolation performed to determine the gas properties at the required value of S, the distance along the core contour, is done in subroutine READ using quadratics fitted to the properties at three successive core contour points. Each quadratic is used until the value of S exceeds that of the fitted point farthest downstream, then the next quadratic is determined and used. This interpolation procedure restricts the user to a constant interval of integration,* even though the integration routine and the remainder of the boundary layer program would allow the interval to be varied automatically to keep the truncation error within bounds fixed by the user.

The FORTRAN listing of the entire turbulent boundary layer program, including the integration routine, is given in Appendix C. The integration routine is discussed in detail in reference (6).

Input

The tape produced by the axisymmetric core program is required as input to this program. Input of this tape must be from tape unit 26. The card input is on two cards and is read as follows:

```
1 READ (5,2) THETA, SO, DELS, WALLT, REXIT, Z4, IP, LM,
                NN, J, NE
2 FORMAT (6F10.5/5I5)
```

*The reason for this restriction is as follows. When the interval is variable, an interpolation will sometimes be required at a value of S smaller than the value of S in the preceding interpolation. Thus, the interpolation procedure must be able to reverse direction and refit an earlier quadratic, whenever the new S value lies below the range covered by the latest quadratic. In its present form, subroutine READ will not refit an earlier quadratic when used with a variable interval, but rather will use the latest quadratic to extrapolate back to the desired S value. Appreciable errors can be introduced by such an extrapolation.

The symbols in the READ statement have the following meanings* and units:

THETA: Boundary layer momentum thickness at SO, [ft]. This initial value is used to compensate for the boundary layer growth along the nozzle wall to the first core contour point. Since the momentum thickness goes through a minimum near the nozzle throat, the initial value is small. A typical value is .0001. It cannot be zero.

SO: Distance measured along the contour from an arbitrary origin to the first core contour point, [ft]. Since the origin is arbitrary, it is usually placed at the first core contour point by setting SO equal to 0.

DELS:* Interval by which the core contour length will be incremented during the computation, [ft].

WALLT: Nozzle wall temperature, [^{o}K]. This must lie in the range from 300^{o} to 1500^{o}K to use subroutine HWALL without change.

REXIT: Radius of the core at the nozzle exit, [ft].

Z4:* Not used in present form of program. Can be left blank.

IP:* This controls the frequency of output. For example, if IP is 5, output will be written every 5th step of integration. Regardless of the value of IP selected, output will occur prior to the first step of integration (initial conditions) and after the last step (exit conditions). Usually IP = 1.

LM: This should be 0, 1, or 2. If LM = 2, the program gives identical BCD output on both the system tape (unit 6) and tape unit 16. If LM = 1, the output will be on tape unit 16 only. If LM = 0, the output will be on the system tape only.

NN: Identification number for the boundary layer computed.

*The meanings and values given are sufficient for use with a constant interval of integration. If subroutine READ is changed to permit the use of a variable interval, reference (6) should be consulted for additional meanings and values for the quantities DELS, Z4, IP, and NE. In the notation of reference (6), these quantities are G, Y(N + 3), M, and NE, respectively.

J: Integration mode; if 1, Runge-Kutta only; if 2, Runge-Kutta for first 4 and last interval, Adams-Moulton for others; if 3, Runge-Kutta repeated at each step. The Adams-Moulton mode (J = 2) is normally used.

NE:* In present form of program NE should be 0.

Output

Output, whether on the system tape, tape 16, or both, will consist of all pertinent identification from the axisymmetric core contour tape used as input plus all card input quantities except LM and WALLT and, for each step of the integration at which output is written, the following 35 quantities:

POINT: Number of the step at which computations were made

S: Distance along core contour, [ft]

X: Distance along nozzle axis from throat, [ft]

R: Radial distance from nozzle axis to core boundary, [ft]

EM: Mach number along core boundary

PE: Static pressure along core boundary, [lb/ft^2]

UE: Flow velocity along core boundary, [ft/sec]

HE: Static enthalpy along core boundary, [Btu/lb]

RHOE: Density along core boundary, [$slugs/ft^3$]

DR/DS: Core contour slope

DUE/DS: Velocity gradient, [sec^{-1}]

DRHO/DS: Density gradient, [$slugs/ft^4$]

HW: Wall enthalpy, [Btu/lb]

HO: Stagnation enthalpy, [Btu/lb]

HAD: Adiabatic wall enthalpy, [Btu/lb]

HREF: Eckert reference enthalpy, [Btu/lb]

*See footnote, page 9

PREF: Prandtl number

EMUE: Viscosity, [lb sec/ft^2]

RETH: Momentum thickness Reynolds number

WALLT: Nozzle wall temperature, [$^\circ$K]. In the present form of the program, this will equal the input WALLT.

RHOREF: Density at reference enthalpy, [slugs/ft^3]

EMUREF: Viscosity at reference enthalpy, [lb sec/ft^2]

CF: Skin friction coefficient

DTH/DS: $d\theta/ds$

HRATIO: δ^*/θ

THVDEL: θ/δ

DSVDEL: δ^*/δ

EN: N in turbulent boundary layer velocity profile law

$$\frac{u}{u_\infty} = \left(\frac{y}{\delta}\right)^{\frac{1}{N}}$$

THETA: θ, boundary layer momentum thickness, [ft]

DELTA: δ, boundary layer total thickness, [ft]

DELSTR: δ^*, boundary layer displacement thickness, [ft]

ST: Stanton number

Q: Heat transfer rate, [Btu/ft^2]

ERROR: Truncation error in the integration procedure

RWALL: Distance from nozzle axis to nozzle wall, [ft]

SUMMARY

This report presents a FORTRAN language computer program for designing contoured axisymmetric nozzles for use with high temperature air. A listing of the FORTRAN statements and the instructions necessary for running the program are given. The

details of the analysis underlying the program are given in reference (1) and are not repeated here. The FORTRAN programs and the constants for the enthalpy and entropy quadratics can be obtained on cards from the author.

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TABLE 1

CONSTANTS FOR ENTHALPY QUADRATICS

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	1	0.	1.0573629E-01	6.2956428E-01	-5.9592954E 00
2	1	-3.3212074E-01	-3.8101313E 00	-1.0911582E 01	-5.7374467E 00
3	1	-2.2023253E-01	-2.5223350E 00	-7.2061184E 00	-5.5913186E 00
4	1	-7.7975256E-01	-8.7261993E 00	-2.4401690E 01	-5.4821743E 00
5	1	1.9786674E-01	2.0948558E 00	5.5396683E 00	-5.3950240E 00
6	1	1.2999532E 00	1.3739331E 01	3.6284227E 01	-5.3224733E 00
7	1	2.1141300E-01	1.9791559E 00	4.5280620E 00	-5.2314506E 00
8	1	-8.5975540E 00	-8.9308778E 01	-2.3195609E 02	-5.1143221E 00
9	1	2.2444038E 01	2.2487190E 02	5.6293148E 02	-4.9799288E 00
10	1	-4.1645602E 01	-4.0975444E 02	-1.0080553E 03	-4.9060882E 00
11	1	4.2732854E 01	4.1724756E 02	1.0183218E 03	-4.8456977E 00
12	1	-1.4895481E 01	-1.3988578E 02	-3.2821819E 02	-4.7819110E 00
13	1	-2.1534459E 01	-2.0503644E 02	-4.8795166E 02	-4.6906040E 00
14	1	9.6836861E 00	8.8933800E 01	2.0409162E 02	-4.5681700E 00
15	1	-3.2697884E 01	-2.9544832E 02	-6.6740530E 02	-4.4726536E 00
16	1	3.1898723E 01	2.8156603E 02	6.2114923E 02	-4.3950506E 00
17	1	1.4981455E 01	1.3279753E 02	2.9408618E 02	-4.3123372E 00
18	1	-2.0506155E 01	-1.7420318E 02	-3.6986867E 02	-4.2058327E 00
19	1	7.7661794E 00	6.3604828E 01	1.3020206E 02	-4.0495523E 00
20	1	-1.2918350E 01	-1.0243989E 02	-2.0300173E 02	-3.9044819E 00
21	1	1.8733953E 01	1.4253942E 02	2.7097704E 02	-3.7980841E 00
22	1	-7.1264921E 00	-5.2001672E 01	-9.4857888E 01	-3.7205611E 00
23	1	-5.1141124E 01	-3.7932406E 02	-7.0340560E 02	-3.6562173E 00
1	2	0.	9.1295735E-02	4.5274681E-01	-4.9592955E 00
2	2	-1.6977933E-01	-1.5696090E 00	-3.6085073E 00	-4.7374467E 00
3	2	2.7507469E-01	2.5592645E 00	5.9677626E 00	-4.5913187E 00
4	2	-2.6360882E-01	-2.4743102E 00	-5.7874470E 00	-4.4821742E 00
5	2	1.2009768E 00	1.0558037E 01	2.3202447E 01	-4.3950241E 00
6	2	1.4246207E-01	1.0351614E 00	1.7956815E 00	-4.3224734E 00
7	2	-3.3898918E 00	-2.9286733E 01	-6.3272167E 01	-4.2318504E 00
8	2	-6.6167452E-01	-6.2249186E 00	-1.4536279E 01	-4.1278087E 00
9	2	-5.0636024E 00	-4.2993363E 01	-9.1306088E 01	-4.0036284E 00
10	2	3.4447921E 01	2.7491082E 02	5.4813133E 02	-3.9088608E 00
11	2	-4.7572365E 01	-3.6801409E 02	-7.1176816E 02	-3.8476810E 00
12	2	-5.9228675E 01	-4.5250610E 02	-8.6429857E 02	-3.7920426E 00
13	2	-1.7078596E 01	-1.2783076E 02	-2.3921614E 02	-3.7291581E 00
14	2	-5.3418813E 00	-4.0960406E 01	-7.8481386E 01	-3.6426750E 00
15	2	1.4764081E 01	1.0592107E 02	1.8977293E 02	-3.5353464E 00
16	2	-1.3614156E 01	-9.4274083E 01	-1.6329632E 02	-3.4049890E 00
17	2	1.1899086E 01	8.0440456E 01	1.3580514E 02	-3.3195284E 00
18	2	-8.2664272E 00	-5.3303484E 01	-8.5952024E 01	-3.2413453E 00
19	2	-8.5088357E 00	-5.5449534E 01	-9.0361444E 01	-3.1389617E 00
20	2	8.3848697E 00	5.0783265E 01	7.6644360E 01	-3.0056696E 00
21	2	-1.0625399E 01	-6.2477291E 01	-9.2039815E 01	-2.8324168E 00
22	2	2.4244710E 01	1.3306364E 02	1.8206510E 02	-2.7244813E 00
23	2	-8.9929477E 00	-4.7685655E 01	-6.3666128E 01	-2.6585060E 00

TABLE 1 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	3	0.	7.6135896E-02	3.0026446E-01	-3.9592955E 00
2	3	-2.9643819E-01	-2.2312133E 00	-4.1882410E 00	-3.7374467E 00
3	3	-1.7285375E-01	-1.2531179E 00	-2.2589625E 00	-3.5913187E 00
4	3	-7.5870100E-01	-5.4399629E 00	-9.7392427E 00	-3.4821742E 00
5	3	1.7143524E-01	1.0986741E 00	1.7510289E 00	-3.3950241E 00
6	3	-1.9053271E-01	-1.4453055E 00	-2.7136966E 00	-3.3224734E 00
7	3	-2.7112638E 00	-1.7980384E 01	-2.9825154E 01	-3.2319837E 00
8	3	1.0335273E 01	6.6136432E 01	1.0575849E 02	-3.1327329E 00
9	3	-1.7443001E 01	-1.0670929E 02	-1.6310447E 02	-3.0323443E 00
10	3	1.8118454E 01	1.0752051E 02	1.5952248E 02	-2.9226684E 00
11	3	2.1516323E-01	4.9925794E 00	1.2797256E 01	-2.8505961E 00
12	3	-3.6175390E 01	-2.0398997E 02	-2.8722361E 02	-2.7960700E 00
13	3	9.5719404E 00	5.2273389E 01	7.1653266E 01	-2.7441247E 00
14	3	-8.9641820E 00	-4.9267542E 01	-6.7404868E 01	-2.6851640E 00
15	3	-1.4017664E 00	-8.9451369E 00	-1.3658675E 01	-2.6093827E 00
16	3	1.1628052E 01	5.9262842E 01	7.5604204E 01	-2.4530011E 00
17	3	-4.2598932E-02	3.0317044E-01	1.2009276E 00	-2.3259751E 00
18	3	-4.4394957E-01	-4.6742608E-01	1.5799625E 00	-2.2544333E 00
19	3	-1.3238676E 01	-5.8286806E 01	-6.3741224E 01	-2.1821504E 00
20	3	-5.4749900E 00	-2.4600446E 01	-2.7201729E 01	-2.0931910E 00
21	3	7.0270254E 00	2.7799246E 01	2.7704137E 01	-1.9289653E 00
22	3	-1.0391880E 01	-3.8734672E 01	-3.5823328E 01	-1.7536245E 00
23	3	2.4360191E 01	8.3376671E 01	7.1444575E 01	-1.6644819E 00
1	4	0.	6.2198812E-02	1.7945568E-01	-2.9592955E 00
2	4	-4.6288294E-01	-2.6161493E 00	-3.6929030E 00	-2.7374468E 00
3	4	-0.	0.	-0.	-2.5913187E 00
4	4	-0.	0.	-0.	-2.4821743E 00
5	4	-0.	0.	-0.	-2.3950241E 00
6	4	-3.2356200E 00	-1.5429439E 01	-1.8393886E 01	-2.3224734E 00
7	4	1.0105658E 00	4.2937758E 00	4.5093152E 00	-2.2320208E 00
8	4	8.0365853E 00	3.5320601E 01	3.8758779E 01	-2.1343631E 00
9	4	1.5939915E 00	8.7678721E 00	1.1434914E 01	-2.0474932E 00
10	4	-1.4661992E 01	-5.9009286E 01	-5.9189506E 01	-1.9522969E 00
11	4	2.0447896E 01	7.8518686E 01	7.5485733E 01	-1.8627092E 00
12	4	-1.8598516E 01	-6.6235327E 01	-5.8670101E 01	-1.8005739E 00
13	4	-2.9879797E 01	-1.0780631E 02	-9.6947008E 01	-1.7504836E 00
14	4	9.7092429E 00	3.1001306E 01	2.4724376E 01	-1.7023926E 00
15	4	3.9154273E 00	1.1488338E 01	8.2974168E 00	-1.6496744E 00
16	4	2.7531595E 00	7.4639556E 00	4.8216330E 00	-1.5315936E 00
17	4	5.9679314E-01	2.1012265E 00	1.6664841E 00	-1.3560738E 00
18	4	1.1178772E 01	2.9131123E 01	1.8861413E 01	-1.2627915E 00
19	4	5.2313261E-01	2.6867318E 00	2.4596309E 00	-1.1987472E 00
20	4	-1.0410780E 01	-2.3669508E 01	-1.3422865E 01	-1.1349434E 00
21	4	-3.9843550E 00	-9.2333964E 00	-5.3165622E 00	-1.0215957E 00
22	4	5.1664985E 00	9.7747347E 00	4.5517041E 00	-8.4533260E-01
23	4	-8.4631902E 00	-1.3468356E 01	-5.3568366E 00	-7.0366393E-01

TABLE 1 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	5	0.	4.7864354E-02	8.9998171E-02	-1.9592955E 00
2	5	-2.3637866E-01	-8.4325948E-01	-7.4855728E-01	-1.7374468E 00
3	5	-2.5927778E-01	-8.4254491E-01	-6.7818959E-01	-1.5913188E 00
4	5	2.7373151E-01	7.8633869E-01	5.6414683E-01	-1.4821743E 00
5	5	-8.3162346E-01	-2.4271689E 00	-1.7705429E 00	-1.3950242E 00
6	5	9.6723347E-01	2.4768374E 00	1.5699275E 00	-1.3224735E 00
7	5	-1.7729053E 00	-4.7322654E 00	-3.1715957E 00	-1.2320357E 00
8	5	4.7245643E 00	1.1244712E 01	6.6500240E 00	-1.1348901E 00
9	5	8.4596297E 00	2.0035045E 01	1.1815414E 01	-1.0531647E 00
10	5	-1.5004972E 01	-2.9462562E 01	-1.4287815E 01	-9.7453027E-01
11	5	-1.4368728E 00	-3.4585104E 00	-1.8318422E 00	-8.9109687E-01
12	5	1.4975436E 01	2.6126885E 01	1.1499362E 01	-8.1553570E-01
13	5	-7.1901821E 00	-1.0055300E 01	-3.2661628E 00	-7.5820455E-01
14	5	-2.2928582E 01	-3.4558996E 01	-1.2797370E 01	-7.1105804E-01
15	5	3.7424389E 00	3.4508584E 00	7.4484995E-01	-6.6675431E-01
16	5	3.7330599E 00	3.6243474E 00	8.6469759E-01	-5.8289382E-01
17	5	5.7892900E 00	5.3927124E 00	1.1968321E 00	-4.3151665E-01
18	5	-3.7450151E-01	7.5354003E-01	3.4269088E-01	-2.9320543E-01
19	5	1.1489252E 01	7.2244058E 00	1.2200640E 00	-2.1080723E-01
20	5	-7.2458681E-01	2.3953154E 00	7.4483621E-01	-1.5189097E-01
21	5	-1.3007026E 01	-1.4827472E 00	4.3915977E-01	-6.8247285E-02
22	5	-3.2025840E 00	-3.9558675E-01	4.6768934E-01	5.8198200E-02
23	5	2.6431758E 00	-8.0199826E-01	4.7154190E-01	1.9667351E-01
1	6	0.	3.4872352E-02	2.7571673E-02	-9.5929562E-01
2	6	2.6492803E-01	5.2110049E-01	2.5020864E-01	-7.3744686E-01
3	6	-3.9043293E-02	-3.9762103E-03	2.8300605E-02	-5.9131883E-01
4	6	-2.0023916E-01	-2.4244187E-01	-5.6345257E-02	-4.8217435E-01
5	6	4.2220368E-01	2.7856100E-01	5.0155867E-02	-3.9502418E-01
6	6	6.6599407E-01	3.9514836E-01	5.8168716E-02	-3.2247351E-01
7	6	-1.1081729E 00	-7.2755015E-01	-1.1937768E-01	-2.3204309E-01
8	6	4.3060983E 00	1.8299461E 00	1.8254566E-01	-1.3505602E-01
9	6	6.1328713E 00	2.4649400E 00	2.3498481E-01	-5.5063543E-02
10	6	-5.6285239E 00	1.2014072E 00	2.0107070E-01	1.5904364E-02
11	6	-1.2762802E 01	1.3066997E 00	2.0120070E-01	8.5183501E-02
12	6	2.4270316E 00	-1.3184074E 00	3.1459561E-01	1.5551821E-01
13	6	1.8532876E 01	-6.6692899E 00	7.5722072E-01	2.2086612E-01
14	6	-4.0066795E-01	1.3239727E 00	-8.4606071E-02	2.7538047E-01
15	6	-1.0291434E 01	6.6214417E 00	-7.9336792E-01	3.2108035E-01
16	6	1.0162560E 00	-7.2689366E-01	4.0030354E-01	3.9287274E-01
17	6	-3.6704831E 00	3.1560562E 00	-4.0181081E-01	5.0265922E-01
18	6	4.0960920E 00	-4.8085904E 00	1.6393413E 00	6.3073289E-01
19	6	-2.1677747E 00	3.3868712E 00	-1.0378891E 00	7.4730301E-01
20	6	4.3481104E 00	-6.7164342E 00	2.8734795E 00	8.2836336E-01
21	6	6.0191424E 00	-9.1422386E 00	3.7362579E 00	9.1122153E-01
22	6	-9.0636606E 00	1.8052370E 01	-8.5204052E 00	1.0069792E 00
23	6	-3.2587680E 00	6.2325369E 00	-2.5043145E 00	1.1074813E 00

TABLE 1 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	7	0.	2.5138648E-02	-1.2536069E-02	4.0704374E-02
2	7	1.6954276E-01	4.7978174E-04	-1.1813251E-02	2.6255311E-01
3	7	-0.	0.	-0.	4.0868114E-01
4	7	-0.	0.	-0.	5.1782561E-01
5	7	-3.5653846E-01	3.2000073E-01	-7.0101106E-02	6.0497579E-01
6	7	-9.2004203E-01	1.0421213E 00	-3.0072670E-01	6.7752647E-01
7	7	3.4253393E-01	-6.2061564E-01	2.4624574E-01	7.6795689E-01
8	7	2.0233693E 00	-3.1946144E 00	1.2316812E 00	8.6488467E-01
9	7	2.7516808E 00	-4.4101999E 00	1.7382249E 00	9.4431977E-01
10	7	-3.0593933E-01	1.3493163E 00	-9.7399615E-01	1.0125841E 00
11	7	-6.9958768E 00	1.4901561E 01	-7.8374129E 00	1.0745604E 00
12	7	-5.6109444E 00	1.1877700E 01	-6.1872506E 00	1.1340495E 00
13	7	1.0762453E 01	-2.5768623E 01	1.5448241E 01	1.1924838E 00
14	7	6.3559601E 00	-1.5694130E 01	9.7006880E 00	1.2482676E 00
15	7	2.0602642E 00	-4.8930703E 00	2.9114954E 00	1.2988312E 00
16	7	-2.9307840E 00	8.0405526E 00	-5.4673761E 00	1.3737760E 00
17	7	3.3123299E 00	-9.0933727E 00	6.2884048E 00	1.4666155E 00
18	7	-3.8896981E 00	1.1872831E 01	-8.9696634E 00	1.5621738E 00
19	7	6.2103616E-01	-2.1988975E 00	2.0048675E 00	1.6656654E 00
20	7	-1.1919720E 00	3.9754278E 00	-3.2493971E 00	1.7656014E 00
21	7	-8.2038862E-01	2.4629768E 00	-1.7373651E 00	1.8810249E 00
22	7	6.3396788E 00	-2.4018359E 01	2.2740544E 01	1.9815060E 00
23	7	-4.8705127E 00	2.0294780E 01	-2.1050859E 01	2.0623939E 00
1	8	0.	1.7316933E-02	-3.2413706E-02	1.0407043E 00
2	8	-1.0745240E-01	2.6728735E-01	-1.7618097E-01	1.2625531E 00
3	8	-2.5927713E-01	7.1311984E-01	-4.9705343E-01	1.4086811E 00
4	8	-2.4248861E-01	6.4550930E-01	-4.3512567E-01	1.5178256E 00
5	8	4.2220216E-01	-1.4102494E 00	1.1538466E 00	1.6049757E 00
6	8	-1.3483216E 00	4.2466847E 00	-3.3646029E 00	1.6775264E 00
7	8	8.1907902E-01	-2.9123633E 00	2.5455944E 00	1.7679420E 00
8	8	1.2424701E 00	-4.3951243E 00	3.8436689E 00	1.8648491E 00
9	8	1.1073078E 00	-3.8567828E 00	3.3098038E 00	1.9440926E 00
10	8	5.5826238E-01	-1.7635460E 00	1.3154748E 00	2.0114435E 00
11	8	-3.1568440E 00	1.3228649E 01	-1.3809397E 01	2.0707395E 00
12	8	-3.6103923E 00	1.5106926E 01	-1.5754026E 01	2.1247975E 00
13	8	6.5298229E 00	-2.8455076E 01	3.1025624E 01	2.1756567E 00
14	8	9.5597436E-01	-4.6416333E 00	5.5994815E 00	2.2243517E 00
15	8	3.0744648E 00	-1.4061308E 01	1.6070441E 01	2.2709814E 00
16	8	2.6905652E 00	-1.2334085E 01	1.4127782E 01	2.3460985E 00
17	8	4.6057827E-01	-2.1078465E 00	2.4102687E 00	2.4382099E 00
18	8	2.7888851E 00	-1.3316826E 01	1.5898623E 01	2.5197623E 00
19	8	-3.6722496E 00	1.9223681E 01	-2.5072641E 01	2.5998066E 00
20	8	-9.7496186E-01	5.1313534E 00	-6.6661789E 00	2.6819554E 00
21	8	-3.1191666E-01	1.6596212E 00	-2.1244953E 00	2.8030813E 00
22	8	-4.1820283E-01	2.1633861E 00	-2.7014617E 00	2.9356684E 00
23	8	4.5412080E 00	-2.6828870E 01	3.9669246E 01	3.0293837E 00

TABLE 1 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	9	0.	1.4649335E-02	-5.2508932E-02	2.0407043E 00
2	9	7.2617597E-01	-2.9779123E 00	3.0302833E 00	2.2625530E 00
3	9	-1.0967428E-01	5.8074660E-01	-7.4253255E-01	2.4086811E 00
4	9	-5.3734608E-01	2.6197525E 00	-3.1725956E 00	2.5178255E 00
5	9	-6.8662097E-01	3.3797309E 00	-4.1397787E 00	2.6049757E 00
6	9	-9.5182798E-01	4.8626280E 00	-6.2030240E 00	2.6775264E 00
7	9	1.5921050E 00	-8.7689811E 00	1.2058140E 01	2.7679050E 00
8	9	4.1837445E-01	-2.3018447E 00	3.1500463E 00	2.8647779E 00
9	9	-2.2845050E-01	1.4575982E 00	-2.3114803E 00	2.9439344E 00
10	9	4.0619821E-01	-2.3220016E 00	3.3150729E 00	3.0109780E 00
11	9	-1.6105394E 00	9.8746997E 00	-1.5125229E 01	3.0693350E 00
12	9	-1.1417016E 00	7.0348181E 00	-1.0825575E 01	3.1213956E 00
13	9	6.9797006E 00	-4.4028054E 01	6.9434161E 01	3.1688803E 00
14	9	-5.5805683E-01	3.4238407E 00	-5.2424257E 00	3.2129595E 00
15	9	1.3176365E 00	-8.6078370E 00	1.4051833E 01	3.2544271E 00
16	9	3.6733699E 00	-2.4075551E 01	3.9440072E 01	3.3217847E 00
17	9	9.9123518E-02	-4.6631781E-01	4.5444986E-01	3.4080872E 00
18	9	9.5974704E-01	-6.4236354E 00	1.0761161E 01	3.4844990E 00
19	9	7.5813218E-01	-4.9071071E 00	7.9249241E 00	3.5542346E 00
20	9	-1.6445805E 00	1.2126373E 01	-2.2264372E 01	3.6206460E 00
21	9	-3.0800869E 00	2.2553105E 01	-4.1196817E 01	3.7179699E 00
22	9	-1.0336328E 00	7.4789821E 00	-1.3440476E 01	3.8431703E 00
23	9	-5.3530221E-01	3.6622399E 00	-6.1325443E 00	3.9532376E 00

TABLE 2

CONSTANTS FOR ENTROPY QUADRATICS

RHOL VALUES

J	RHOL(J)
1	-6.0000000E 00
2	-5.4000000E 00
3	-5.0000000E 00
4	-4.4000000E 00
5	-4.0000000E 00
6	-3.4000000E 00
7	-3.0000000E 00
8	-2.4000000E 00
9	-2.0000000E 00
10	-1.4000000E 00
11	-1.0000000E 00
12	-4.0000000E-01
13	0.
14	5.0000000E-01
15	1.0000000E 00
16	1.5000000E 00
17	2.0000000E 00

COEFFICIENTS AND LIMITS

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	1	0.	1.2628373E-01	8.3200123E-01	-5.9592954E 00
2	1	-7.2708161E-02	-7.3072549E-01	-1.6930183E 00	-5.7374467E 00
3	1	-2.6673006E-01	-2.9259195E 00	-7.9013302E 00	-5.5913186E 00
4	1	4.2155915E-01	4.7414231E 00	1.3451869E 01	-5.4821743E 00
5	1	-6.9936790E-01	-7.5268550E 00	-2.0117327E 01	-5.3950240E 00
6	1	-3.0117389E-01	-3.1589417E 00	-8.1441104E 00	-5.3224733E 00
7	1	-5.2990865E 00	-5.6628121E 01	-1.5114505E 02	-5.2314506E 00
8	1	-2.1440903E 01	-2.2652706E 02	-5.9819397E 02	-5.1143221E 00
9	1	2.4809001E 00	1.7720383E 01	2.5261998E 01	-4.9799288E 00
10	1	3.3262789E 00	3.2518895E 01	7.8000447E 01	-4.9060882E 00
11	1	4.4470721E 01	4.3449445E 02	1.0597764E 03	-4.8456977E 00
12	1	5.8709513E 01	5.7292113E 02	1.3962175E 03	-4.7819110E 00
13	1	-2.3690432E 01	-2.1635014E 02	-4.9379272E 02	-4.6906040E 00
14	1	-5.5565047E 01	-5.1561125E 02	-1.1962079E 03	-4.5681700E 00
15	1	1.9849951E 01	1.7488218E 02	3.8431133E 02	-4.4726536E 00
16	1	1.5726714E 02	1.4077600E 03	3.1495725E 03	-4.3950506E 00
17	1	-1.7238267E 02	-1.4961854E 03	-3.2457557E 03	-4.3123372E 00
18	1	3.8652473E 01	3.2023124E 02	6.6278431E 02	-4.2058327E 00
19	1	4.7301319E 00	4.1472592E 01	9.0427029E 01	-4.0495523E 00
20	1	4.7963386E 00	3.7041323E 01	7.1396807E 01	-3.9044819E 00
21	1	-4.6776965E 01	-3.5921947E 02	-6.8956230E 02	-3.7980841E 00
22	1	3.6914310E 01	2.7665847E 02	5.1827227E 02	-3.7205611E 00
23	1	-1.2306479E 02	-9.1142493E 02	-1.6875434E 03	-3.6562173E 00

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	2	0.	1.5572523E-01	5.2815716E-01	-5.3592954E 00
2	2	-1.5473049E-01	-1.4825336E 00	-3.8075336E 00	-5.1374467E 00
3	2	-6.2823633E-01	-6.2537608E 00	-1.5822038E 01	-4.9913186E 00
4	2	4.0049427E-01	4.0092497E 00	9.7752221E 00	-4.8821742E 00
5	2	-5.2803922E-01	-5.1099421E 00	-1.2614414E 01	-4.7950240E 00
6	2	-4.5996101E-01	-4.4466016E 00	-1.1001680E 01	-4.7224733E 00
7	2	-1.7591767E 00	-1.6582696E 01	-3.9336789E 01	-4.6317502E 00
8	2	1.4437681E 00	1.2815989E 01	2.8116811E 01	-4.5238642E 00
9	2	-2.7659737E 01	-2.5083276E 02	-5.6898125E 02	-4.3916270E 00
10	2	5.5044831E 01	4.7870960E 02	1.0398273E 03	-4.3071970E 00
11	2	-2.4517398E 01	-2.0889294E 02	-4.4577700E 02	-4.2469917E 00
12	2	5.2902616E 01	4.4782014E 02	9.4688232E 02	-4.1891762E 00
13	2	1.9050524E 01	1.6346395E 02	3.4972379E 02	-4.1176404E 00
14	2	-2.8133903E 01	-2.2499888E 02	-4.4982441E 02	-4.0153106E 00
15	2	-2.4459194E 01	-1.9668581E 02	-3.9538595E 02	-3.9045865E 00
16	2	1.1722586E 02	9.0778079E 02	1.7569983E 03	-3.7987940E 00
17	2	-1.0016281E 02	-7.3650562E 02	-1.3522132E 03	-3.7173778E 00
18	2	-6.0900401E 01	-4.4968157E 02	-8.2853028E 02	-3.6310811E 00
19	2	4.8472766E 01	3.4832536E 02	6.2703261E 02	-3.5089185E 00
20	2	-3.0471963E 01	-2.0826693E 02	-3.5399589E 02	-3.3617104E 00
21	2	3.3283634E 01	2.1935350E 02	3.6303118E 02	-3.2117396E 00
22	2	6.7761175E 00	4.1329318E 01	6.4697754E 01	-3.1219034E 00
23	2	-8.8101828E 00	-5.2964739E 01	-7.7763265E 01	-3.0578083E 00
1	3	0.	1.4519350E-01	7.3535345E-01	-4.9592955E 00
2	3	-1.7438330E-01	-1.5615653E 00	-3.4400851E 00	-4.7374467E 00
3	3	-3.6895678E-01	-3.3529471E 00	-7.5597923E 00	-4.5913187E 00
4	3	-1.5798937E-01	-1.4243531E 00	-3.1522948E 00	-4.4821742E 00
5	3	-6.0732189E-01	-5.4601652E 00	-1.2214417E 01	-4.3950241E 00
6	3	-9.5182831E-01	-8.4629524E 00	-1.8757190E 01	-4.3224734E 00
7	3	3.5885895E 00	3.0405622E 01	6.4418947E 01	-4.2318504E 00
8	3	-3.9302496E-01	-3.9161881E 00	-9.5207114E 00	-4.1278087E 00
9	3	-2.5464192E 01	-2.0978264E 02	-4.3211592E 02	-4.0036284E 00
10	3	5.9083658E 01	4.6620035E 02	9.1904709E 02	-3.9088608E 00
11	3	-3.9135922E 01	-3.0150691E 02	-5.8109673E 02	-3.8476810E 00
12	3	1.7445508E 01	1.3197716E 02	2.4914426E 02	-3.7920426E 00
13	3	3.1847103E 01	2.4031208E 02	4.5286847E 02	-3.7291581E 00
14	3	2.3625596E 00	2.0997215E 01	4.5036309E 01	-3.6426750E 00
15	3	-3.1303600E 01	-2.2499626E 02	-4.0431928E 02	-3.5353464E 00
16	3	3.7908448E 01	2.6216486E 02	4.5290524E 02	-3.4049890E 00
17	3	-3.8632908E 01	-2.4695568E 02	-3.9322665E 02	-3.3195284E 00
18	3	-1.1865861E 02	-7.8450406E 02	-1.2958100E 03	-3.2413453E 00
19	3	7.6844289E 01	4.8446829E 02	7.6335048E 02	-3.1389617E 00
20	3	-9.4017534E 00	-5.5298721E 01	-8.1167476E 01	-3.0056696E 00
21	3	6.7141597E 00	3.8375432E 01	5.4794002E 01	-2.8324168E 00
22	3	-4.4470029E 01	-2.4647349E 02	-3.4138736E 02	-2.7244813E 00
23	3	3.5377090E 01	1.9265103E 02	2.6231031E 02	-2.6585060E 00

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	4	0.	1.6634738E-01	8.4981117E-01	-4.3592954E 00
2	4	-1.3213727E-01	-9.6791788E-01	-1.5837508E 00	-4.1374466E 00
3	4	-2.5927539E-01	-2.0870586E 00	-4.0377448E 00	-3.9913186E 00
4	4	-2.2136621E-01	-1.7887362E 00	-3.4506789E 00	-3.8821741E 00
5	4	1.0423199E 00	7.7611379E 00	1.4578355E 01	-3.7950239E 00
6	4	-1.2377126E 00	-9.7180414E 00	-1.8917699E 01	-3.7224733E 00
7	4	2.9713172E 00	2.1605069E 01	3.9357685E 01	-3.6319549E 00
8	4	-2.4046457E 00	-1.7865403E 01	-3.3082950E 01	-3.5313720E 00
9	4	-1.1134975E 01	-7.8456936E 01	-1.3818156E 02	-3.4221636E 00
10	4	2.3890625E 01	1.5855250E 02	2.6271138E 02	-3.3148227E 00
11	4	1.8542086E 00	1.5894958E 01	3.1962596E 01	-3.2489981E 00
12	4	-3.1376144E 01	-2.0257104E 02	-3.2705265E 02	-3.1947430E 00
13	4	-3.4585088E 00	-2.5709576E 01	-4.6966962E 01	-3.1398357E 00
14	4	3.7629730E 01	2.3256815E 02	3.5891426E 02	-3.0722858E 00
15	4	-4.6651637E 00	-2.6672656E 01	-3.8328022E 01	-2.9830501E 00
16	4	-1.3094241E 01	-7.8126040E 01	-1.1680906E 02	-2.8270761E 00
17	4	7.1796762E 01	4.0619408E 02	5.7392140E 02	-2.7225741E 00
18	4	-1.5380567E 02	-8.2593954E 02	-1.1083962E 03	-2.6506447E 00
19	4	2.1122106E 01	9.9169794E 01	1.1471080E 02	-2.5694412E 00
20	4	4.9552240E 01	2.4930686E 02	3.1278420E 02	-2.4639847E 00
21	4	-2.1192991E 01	-1.0091970E 02	-1.2065905E 02	-2.2853433E 00
22	4	1.1207779E 01	5.0116886E 01	5.5288804E 01	-2.1357797E 00
23	4	5.1226805E 01	2.1428654E 02	2.2336911E 02	-2.0606305E 00
1	5	0.	1.9435373E-01	7.9149079E-01	-3.9592955E 00
2	5	-1.5531367E 00	-1.1908957E 01	-2.2782091E 01	-3.7374467E 00
3	5	-3.0009060E-01	-2.4593424E 00	-4.9678563E 00	-3.5913187E 00
4	5	-6.5396360E-01	-4.9006696E 00	-9.1713341E 00	-3.4821742E 00
5	5	-8.7171526E-01	-6.2932859E 00	-1.1380304E 01	-3.3950241E 00
6	5	-1.1423198E 00	-8.0043485E 00	-1.4070002E 01	-3.3224734E 00
7	5	-1.9693030E 01	-1.2859501E 02	-2.0995156E 02	-3.2319837E 00
8	5	1.0825449E 00	6.6123340E 00	1.0020611E 01	-3.1327329E 00
9	5	-5.0481341E 00	-3.0792154E 01	-4.6991069E 01	-3.0323443E 00
10	5	2.7025625E-01	-6.7050034E-01	-4.5547883E 00	-2.9226684E 00
11	5	3.8829648E 01	2.2734320E 02	3.3248013E 02	-2.8505961E 00
12	5	-3.0224561E 01	-1.6839128E 02	-2.3447227E 02	-2.7960700E 00
13	5	-3.7960393E 01	-2.1351531E 02	-3.0016344E 02	-2.7441247E 00
14	5	2.3802293E 01	1.2515000E 02	1.6409044E 02	-2.6851640E 00
15	5	2.4439764E 01	1.2951230E 02	1.7120810E 02	-2.6093827E 00
16	5	-1.7060343E 01	-8.7404159E 01	-1.1224169E 02	-2.4530011E 00
17	5	7.4692760E 01	3.6041024E 02	4.3414919E 02	-2.3259751E 00
18	5	-1.1223580E 02	-5.0738842E 02	-5.7301450E 02	-2.2544333E 00
19	5	-4.4852024E 01	-2.0678411E 02	-2.3779930E 02	-2.1821504E 00
20	5	6.5992916E 01	2.7946109E 02	2.9544223E 02	-2.0931910E 00
21	5	-1.4898866E 01	-5.8668149E 01	-5.7903937E 01	-1.9289653E 00
22	5	2.0365407E 01	7.3643572E 01	6.6105646E 01	-1.7536245E 00
23	5	-1.5022495E 01	-5.2948692E 01	-4.7064870E 01	-1.6644819E 00

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	6	0.	2.2907657E-01	7.0584356E-01	-3.3592955E 00
2	6	-5.7505472E-01	-3.5615746E 00	-5.5386571E 00	-3.1374467E 00
3	6	-6.9974004E-01	-4.3227589E 00	-6.6994916E 00	-2.9913187E 00
4	6	-1.2436888E 00	-7.5063657E 00	-1.1355419E 01	-2.8821742E 00
5	6	-1.8355808E 00	-1.0868469E 01	-1.6128806E 01	-2.7950241E 00
6	6	-2.6812413E 00	-1.5469158E 01	-2.2381376E 01	-2.7224734E 00
7	6	6.1095055E 00	3.2188281E 01	4.2208973E 01	-2.6320107E 00
8	6	6.0474547E 00	3.1291542E 01	4.0278457E 01	-2.5339186E 00
9	6	5.0305182E 00	2.7126224E 01	3.6253508E 01	-2.4429983E 00
10	6	-2.1711091E 01	-1.0474987E 02	-1.2631924E 02	-2.3399412E 00
11	6	4.2731504E 01	1.9691488E 02	2.2671440E 02	-2.2558087E 00
12	6	1.2923848E 01	6.2359634E 01	7.4865234E 01	-2.1982602E 00
13	6	-5.4715936E 01	-2.3687471E 02	-2.5607028E 02	-2.1483198E 00
14	6	-2.7947101E 01	-1.2257137E 02	-1.3405647E 02	-2.0973227E 00
15	6	3.1124808E 01	1.2539196E 02	1.2615913E 02	-2.0374649E 00
16	6	2.5942799E 00	1.0182846E 01	9.8624785E 00	-1.9012178E 00
17	6	1.9942876E 01	7.1626518E 01	6.3971548E 01	-1.7384041E 00
18	6	5.1588417E 00	2.5838158E 01	2.9050829E 01	-1.6589019E 00
19	6	-9.9167839E 01	-3.2345436E 02	-2.6328849E 02	-1.5938517E 00
20	6	3.3555323E 01	9.9336697E 01	7.3412418E 01	-1.5226616E 00
21	6	1.7179970E 01	5.1781924E 01	3.8968883E 01	-1.3899150E 00
22	6	-1.4624609E 01	-4.0247183E 01	-2.7501634E 01	-1.2024831E 00
23	6	-1.2397109E 00	-4.3023928E 00	-3.6327337E 00	-1.0804721E 00
1	7	0.	2.4352639E-01	7.3293819E-01	-2.9592955E 00
2	7	-3.0124596E-01	-1.5009812E 00	-1.7914350E 00	-2.7374468E 00
3	7	-1.6596419E 00	-9.0559812E 00	-1.2293540E 01	-2.5913187E 00
4	7	-1.1884282E-02	-5.0923923E-01	-1.2108059E 00	-2.4821743E 00
5	7	-4.1030321E-01	-2.5863143E 00	-3.9117942E 00	-2.3950241E 00
6	7	1.5788564E-01	2.2104954E-01	-4.4716603E-01	-2.3224734E 00
7	7	1.2093698E 00	4.9117479E 00	4.7752993E 00	-2.2320208E 00
8	7	6.2101281E 00	2.6997441E 01	2.9157595E 01	-2.1343631E 00
9	7	1.2031259E 01	5.2566044E 01	5.7212133E 01	-2.0474932E 00
10	7	-2.6338985E 01	-1.0506292E 02	-1.0467533E 02	-1.9522969E 00
11	7	2.1925303E 01	8.2806665E 01	7.8144317E 01	-1.8627092E 00
12	7	4.3393583E 01	1.6309146E 02	1.5320329E 02	-1.8005739E 00
13	7	-3.8467278E 01	-1.3322448E 02	-1.1493665E 02	-1.7504836E 00
14	7	-5.0100299E 01	-1.7465286E 02	-1.5181210E 02	-1.7023926E 00
15	7	4.5706558E 00	1.1218516E 01	6.1708923E 00	-1.6496744E 00
16	7	2.0874575E 01	6.5884600E 01	5.1982387E 01	-1.5315936E 00
17	7	-3.8723705E 00	-1.2770908E 01	-1.0435039E 01	-1.3560738E 00
18	7	4.7237458E 01	1.2828172E 02	8.6855013E 01	-1.2627915E 00
19	7	-9.0807978E 01	-2.2116802E 02	-1.3429413E 02	-1.1987472E 00
20	7	-1.0484147E 01	-3.0022557E 01	-2.0583893E 01	-1.1349434E 00
21	7	3.9787573E 01	8.5900711E 01	4.6227639E 01	-1.0215957E 00
22	7	-2.1662193E 01	-4.1348091E 01	-1.9636668E 01	-8.4533260E-01
23	7	1.5569304E 01	2.0942422E 01	6.4143813E 00	-7.0366393E-01

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	8	0.	2.6650221E-01	8.8980268E-01	-2.3592955E 00
2	8	-1.1306168E 00	-4.9265315E 00	-5.0687683E 00	-2.1374468E 00
3	8	-6.7650247E-01	-2.8889273E 00	-2.7882467E 00	-1.9913187E 00
4	8	-1.3915590E 00	-5.7200297E 00	-5.5904301E 00	-1.8821743E 00
5	8	-1.4398260E 00	-5.8567785E 00	-5.6767220E 00	-1.7950241E 00
6	8	9.0283641E-01	2.3073781E 00	1.4297420E 00	-1.7224734E 00
7	8	4.4717029E 00	1.4008093E 01	1.0995416E 01	-1.6320294E 00
8	8	2.7454817E 00	8.0207653E 00	5.8217446E 00	-1.5347510E 00
9	8	1.3608045E 01	4.1524253E 01	3.1654928E 01	-1.4515860E 00
10	8	-1.5257398E 01	-4.1868286E 01	-2.8574099E 01	-1.3674516E 00
11	8	-4.7691595E 00	-1.3898013E 01	-9.9383199E 00	-1.2787914E 00
12	8	4.7780573E 01	1.1989493E 02	7.5219991E 01	-1.2074052E 00
13	8	5.9889331E 00	1.8316276E 01	1.3498420E 01	-1.1542448E 00
14	8	-4.6075943E 01	-1.0255611E 02	-5.6652902E 01	-1.1077662E 00
15	8	-3.6488055E 01	-8.1672121E 01	-4.5284105E 01	-1.0614452E 00
16	8	2.1017054E 01	4.0135527E 01	1.9219062E 01	-9.6673713E-01
17	8	-1.0249032E 01	-1.8644771E 01	-8.3853652E 00	-7.9857555E-01
18	8	2.5600113E 01	3.7206610E 01	1.3354361E 01	-6.7545[illegible]0E-01
19	8	-1.2408254E 01	-1.1888192E 01	-2.4659664E 00	-6.0493584E-01
20	8	-6.0472656E 01	-7.1656495E 01	-2.1032919E 01	-5.4651346E-01
21	8	3.4670729E 01	3.2234630E 01	7.3278447E 00	-4.5432184E-01
22	8	-1.1107880E 01	-7.4258518E 00	-1.2416932E 00	-3.0806137E-01
23	8	-1.2360292E 01	-9.6268874E 00	-1.8008912E 00	-1.5951752E-01
1	9	0.	2.9365901E-01	9.9601337E-01	-1.9592955E 00
2	9	-1.1150077E 00	-3.9355017E 00	-3.0098315E 00	-1.7374468E 00
3	9	-1.1634653E 00	-3.9002763E 00	-2.8023423E 00	-1.5913188E 00
4	9	-9.8095261E-01	-3.4272521E 00	-2.5117835E 00	-1.4821743E 00
5	9	-1.7170217E 00	-5.5139388E 00	-3.9876324E 00	-1.3950242E 00
6	9	-1.6821931E 00	-5.3707918E 00	-3.8558721E 00	-1.3224735E 00
7	9	2.3808125E 00	5.1489621E 00	2.9504666E 00	-1.2320357E 00
8	9	2.6502294E-01	-2.0969056E-01	-4.3999839E-01	-1.1348901E 00
9	9	7.5552409E 00	1.6373071E 01	8.9900180E 00	-1.0531647E 00
10	9	-2.9350190E 00	-5.2786055E 00	-2.1774397E 00	-9.7453027E-01
11	9	-1.1264150E 01	-2.1942852E 01	-1.0507011E 01	-8.9109687E-01
12	9	3.1540352E 01	5.3324163E 01	2.2574119E 01	-8.1553570E-01
13	9	2.8708290E 01	4.8077062E 01	2.0178541E 01	-7.5820455E-01
14	9	-2.6108865E 01	-3.5607467E 01	-1.1758469E 01	-7.1105804E-01
15	9	-4.5019542E 01	-6.2738946E 01	-2.1489241E 01	-6.6675431E-01
16	9	-6.7221526E-01	-4.1101316E 00	-2.1133489E 00	-5.8289382E-01
17	9	1.9837025E 00	1.9760289E 00	5.3185245E-01	-4.3151665E-01
18	9	3.6153277E 00	1.2216612E 00	-9.7489274E-02	-2.9320543E-01
19	9	2.5771672E 01	1.5641245E 01	2.2256429E 00	-2.1080723E-01
20	9	-4.4972596E 01	-1.4551003E 01	-9.9524795E-01	-1.5189097E-01
21	9	4.8567467E 00	-5.4334249E-01	-1.7217167E-02	-6.8247285E-02
22	9	2.5464202E-01	1.5051606E 00	1.4402279E-01	5.8198200E-02
23	9	-1.9826914E 01	2.5568845E 00	1.5083121E-01	1.9667351E-01

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	10	0.	3.5473914E-01	1.0009613E 00	-1.3592956E 00
2	10	-1.0178404E 00	-2.2832976E 00	-7.0425811E-01	-1.1374468E 00
3	10	-5.5014392E-01	-1.1574422E 00	-2.8754316E-02	-9.9131879E-01
4	10	-1.4016735E 00	-2.8184293E 00	-8.3850287E-01	-8.8217432E-01
5	10	-1.2811635E 00	-2.5733228E 00	-7.1611559E-01	-7.9502414E-01
6	10	-2.8399438E 00	-5.1228412E 00	-1.7577695E 00	-7.2247347E-01
7	10	-3.3749388E-01	-1.0514452E 00	-1.2247046E-01	-6.3204803E-01
8	10	-9.7697015E-01	-1.8120421E 00	-3.4775336E-01	-5.3501889E-01
9	10	1.5017479E-02	-7.0354213E-01	-3.8638647E-02	-4.5454442E-01
10	10	2.7039093E 00	1.8869699E 00	5.8331224E-01	-3.8136626E-01
11	10	-7.5006775E 00	-5.7605413E 00	-8.4903280E-01	-3.0707380E-01
12	10	1.3858898E 01	6.1762663E 00	8.0236166E-01	-2.3254727E-01
13	10	2.9978316E 01	1.2371523E 01	1.3713419E 00	-1.6866784E-01
14	10	6.3595409E 00	4.0263265E 00	6.3570223E-01	-1.1766333E-01
15	10	-2.6338345E 01	-3.7538511E 00	1.7295212E-01	-7.3600963E-02
16	10	-2.8096422E 01	-4.3554994E 00	1.3819370E-01	7.3768623E-04
17	10	2.3933679E 01	-3.7511940E 00	1.3771960E-01	1.2483014E-01
18	10	-1.0662100E 01	4.0713091E 00	-2.9967362E-01	2.6410915E-01
19	10	1.5945140E 01	-1.0334968E 01	1.6492042E 00	3.7055010E-01
20	10	1.1039230E 01	-5.7841377E 00	6.3651084E-01	4.3906412E-01
21	10	-2.2036372E 01	2.2802853E 01	-5.5387847E 00	5.1814528E-01
22	10	5.6227916E 00	-4.8837074E 00	1.3810955E 00	6.2250413E-01
23	10	-2.0769801E 01	2.7614432E 01	-8.6217057E 00	7.3755836E-01
1	11	0.	3.9387587E-01	8.4882928E-01	-9.5929562E-01
2	11	-9.7653754E-01	-1.3548609E 00	6.9930597E-02	-7.3744686E-01
3	11	-6.2077709E-01	-7.9065019E-01	2.9253311E-01	-5.9131883E-01
4	11	-8.2207911E-01	-1.0107678E 00	2.3276018E-01	-4.8217435E-01
5	11	-8.7173592E-01	-1.0630198E 00	2.1910825E-01	-3.9502418E-01
6	11	7.7670162E-01	2.4026109E-01	4.7670674E-01	-3.2247351E-01
7	11	1.4171578E 00	3.8459891E-01	4.5665362E-01	-2.3204309E-01
8	11	-1.1577357E 00	-8.8111997E-01	3.0159497E-01	-1.3505602E-01
9	11	-1.0311634E 00	-8.1692680E-01	3.0795610E-01	-5.5063543E-02
10	11	2.2919071E 00	-3.7692274E-01	3.2210876E-01	1.5904364E-02
11	11	-4.7240292E 00	7.3870502E-02	3.1671385E-01	8.5183501E-02
12	11	9.9761827E 00	-3.5620636E 00	5.1976737E-01	1.5551821E-01
13	11	2.0871003E 01	-8.5151876E 00	1.0265672E 00	2.2086612E-01
14	11	1.4809984E 01	-6.3981840E 00	8.5466148E-01	2.7538047E-01
15	11	-7.5555520E 00	5.9887757E 00	-8.6039147E-01	3.2108035E-01
16	11	-2.8077054E 01	1.9058927E 01	-2.9413408E 00	3.9287274E-01
17	11	2.1599845E 01	-2.0907024E 01	5.0926101E 00	5.0265922E-01
18	11	-6.2164737E 00	8.2184145E 00	-2.5193135E 00	6.3073289E-01
19	11	-1.1155378E 00	8.8522338E-01	7.6697202E-02	7.4730301E-01
20	11	1.6618465E 01	-2.5158928E 01	9.6358114E 00	8.2836336E-01
21	11	-1.2786614E 01	2.3783458E 01	-1.0728939E 01	9.1122153E-01
22	11	5.6324061E 00	-1.0484084E 01	5.2026392E 00	1.0069792E 00
23	11	-1.4433707E 01	3.0166434E 01	-1.5384430E 01	1.1074813E 00

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	12	0.	3.9437157E-01	4.3214226E-01	-3.5929562E-01
2	12	-9.1726936E-01	-1.4212806E-01	3.5779367E-01	-1.3744686E-01
3	12	-4.9442183E-01	8.0044988E-02	3.8034237E-01	8.6811570E-03
4	12	-4.3172380E-01	1.1875106E-01	3.8000163E-01	1.1782563E-01
5	12	-8.0518529E-01	2.4844081E-01	3.6990574E-01	2.0497581E-01
6	12	-4.9177623E-01	1.4079894E-01	3.7880226E-01	2.7752648E-01
7	12	-7.0043581E-01	4.4512107E-01	3.1041650E-01	3.6795197E-01
8	12	-1.3572563E 00	9.4255465E-01	2.1630906E-01	4.6490664E-01
9	12	-1.1172691E-01	-1.6733515E-01	4.6310108E-01	5.4448971E-01
10	12	3.7346088E 00	-4.2576963E 00	1.5499350E 00	6.1349295E-01
11	12	-2.6667985E 00	3.8068740E 00	-9.8828773E-01	6.7761607E-01
12	12	9.3688778E 00	-1.3698850E 01	5.3475127E 00	7.4089140E-01
13	12	1.0113398E 01	-1.6522079E 01	7.0305413E 00	8.0306087E-01
14	12	8.1990281E 00	-1.4128850E 01	6.3431846E 00	8.6011628E-01
15	12	7.4908257E 00	-1.2835703E 01	5.7549394E 00	9.0945973E-01
16	12	-1.1185681E 01	2.1246581E 01	-9.7938964E 00	9.8211739E-01
17	12	-3.3365337E-02	-1.8426922E 00	2.1254294E 00	1.0787105E 00
18	12	1.7314734E 01	-3.7781618E 01	2.0706615E 01	1.1857404E 00
19	12	-1.3408161E 01	3.4362104E 01	-2.1641325E 01	1.2991585E 00
20	12	-6.0766535E-01	9.7809330E-01	1.2495412E-01	1.3970357E 00
21	12	-6.1070153E 00	1.6810554E 01	-1.1260442E 01	1.4975516E 00
22	12	-2.6945639E 00	5.1406126E 00	-1.4370952E 00	1.5909643E 00
23	12	6.3153383E 00	-2.2375962E 01	1.9535211E 01	1.6763918E 00
1	13	0.	3.1481594E-01	1.4255800E-01	4.0704374E-02
2	13	-5.0017294E-01	4.3397990E-01	1.3853621E-01	2.6255311E-01
3	13	5.5102881E-01	-2.1931666E-01	2.3759764E-01	4.0868114E-01
4	13	3.4810928E-01	-1.6676911E-01	2.5001366E-01	5.1782561E-01
5	13	9.6384426E-01	-9.3303765E-01	4.8170103E-01	6.0497579E-01
6	13	-1.7421529E-01	4.0261810E-01	9.0190778E-02	6.7752647E-01
7	13	1.5861433E 00	-2.2389372E 00	1.0718332E 00	7.6795689E-01
8	13	-1.2726503E 00	2.0036161E 00	-5.0028058E-01	8.6488467E-01
9	13	1.1299091E 00	-2.1019615E 00	1.2533863E 00	9.4431977E-01
10	13	4.8958908E 00	-9.1393880E 00	4.5407208E 00	1.0125841E 00
11	13	-1.7182652E 00	4.4360256E 00	-2.4238632E 00	1.0745604E 00
12	13	1.0740803E 01	-2.3570866E 01	1.3284986E 01	1.1340495E 00
13	13	6.1316504E 00	-1.4828662E 01	9.2984976E 00	1.1924838E 00
14	13	2.0928319E 00	-5.8957311E 00	4.3895538E 00	1.2482676E 00
15	13	5.5022029E 00	-1.4322656E 01	9.5961854E 00	1.2988312E 00
16	13	-2.4123352E 00	6.4155585E 00	-3.9877154E 00	1.3737760E 00
17	13	-9.8353778E 00	2.6220291E 01	-1.7185846E 01	1.4666155E 00
18	13	2.6635723E 01	-8.0515947E 01	6.0907295E 01	1.5621738E 00
19	13	-7.6205077E 00	2.6872172E 01	-2.3253213E 01	1.6656654E 00
20	13	-8.5684026E 00	2.9517854E 01	-2.5030137E 01	1.7656014E 00
21	13	2.2260776E 00	-8.4368877E 00	8.3326526E 00	1.8810249E 00
22	13	-8.9880525E 00	3.3537999E 01	-3.0944619E 01	1.9815060E 00
23	13	6.5847982E 00	-2.7753697E 01	2.9360627E 01	2.0623939E 00

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	14	0.	8.4481671E-02	-2.6495493E-02	5.4070434E-01
2	14	-3.8251929E-01	5.8333517E-01	-1.8439393E-01	7.6255310E-01
3	14	3.4658819E-01	-4.4236377E-01	1.7378914E-01	9.0868113E-01
4	14	6.9622436E-01	-1.0297668E 00	4.1885329E-01	1.0178256E 00
5	14	-3.8210072E-01	1.1668331E 00	-6.9978890E-01	1.1049758E 00
6	14	-9.0371977E-01	2.2694918E 00	-1.2813350E 00	1.1775264E 00
7	14	9.8083130E-02	-6.5499642E-02	7.9135875E-02	1.2679457E 00
8	14	-1.2625974E 00	3.3071909E 00	-2.0097014E 00	1.3648698E 00
9	14	1.3184888E 00	-3.6743568E 00	2.7109871E 00	1.4441853E 00
10	14	4.1851959E 00	-1.1860016E 01	8.5535983E 00	1.5118566E 00
11	14	-5.6604542E-01	2.7051197E 00	-2.6069581E 00	1.5721394E 00
12	14	1.6072906E 01	-5.0848501E 01	4.0461641E 01	1.6283071E 00
13	14	6.5262840E 00	-2.1515043E 01	1.8009132E 01	1.6823797E 00
14	14	1.0135922E-01	-5.8372580E-01	9.8048501E-01	1.7346958E 00
15	14	7.2617948E 00	-2.5412925E 01	2.2504562E 01	1.7841677E 00
16	14	1.1101821E 01	-3.9101786E 01	3.4703711E 01	1.8608229E 00
17	14	6.0758604E-01	1.3889928E-01	-1.9780345E 00	1.9527973E 00
18	14	-9.1912694E 00	3.8139107E 01	-3.8817368E 01	2.0389775E 00
19	14	-6.9326465E 00	2.8923783E 01	-2.9417881E 01	2.1291418E 00
20	14	-2.3478937E 00	9.3831735E 00	-8.5971897E 00	2.2220398E 00
21	14	8.7146426E 00	-4.0030018E 01	4.6580246E 01	2.3473299E 00
22	14	3.8574851E 01	-1.7941073E 02	2.0922422E 02	2.4648768E 00
23	14	5.0673850E 01	-2.4969083E 02	3.0894504E 02	2.5477501E 00
1	15	0.	-2.9855713E-01	2.3404309E-01	1.0407043E 00
2	15	1.6699707E-01	-5.7996571E-01	3.4603775E-01	1.2625531E 00
3	15	2.0443983E 00	-5.3242006E 00	3.3432320E 00	1.4086811E 00
4	15	-1.2497780E-01	8.4218339E-01	-1.0383569E 00	1.5178256E 00
5	15	-6.5930091E-01	2.4030987E 00	-2.1765854E 00	1.6049757E 00
6	15	-2.3309987E 00	7.9409655E 00	-6.7585137E 00	1.6775264E 00
7	15	-1.0638932E 00	3.8844338E 00	-3.5193444E 00	1.7679420E 00
8	15	-1.7058081E 00	6.1262692E 00	-5.4763936E 00	1.8648491E 00
9	15	-4.3389462E-01	1.4613264E 00	-1.2002731E 00	1.9440926E 00
10	15	2.6740461E 00	-1.0584353E 01	1.0471195E 01	2.0114435E 00
11	15	8.3843526E-01	-3.0519205E 00	2.7468796E 00	2.0707395E 00
12	15	2.1560776E 01	-9.0163474E 01	9.4275662E 01	2.1247975E 00
13	15	8.4484878E 00	-3.6179039E 01	3.8768507E 01	2.1756567E 00
14	15	-1.8974980E 00	8.1850073E 00	-8.7797979E 00	2.2243517E 00
15	15	2.2148522E 00	-1.0112833E 01	1.1573937E 01	2.2709814E 00
16	15	5.5635878E 00	-2.5310298E 01	2.8816498E 01	2.3460985E 00
17	15	4.6899432E 00	-2.1077267E 01	2.3694117E 01	2.4382099E 00
18	15	-3.8559326E 00	2.0496139E 01	-2.6866484E 01	2.5197623E 00
19	15	-7.9345089E 00	4.1124277E 01	-5.2948547E 01	2.5998066E 00
20	15	-3.2245914E 00	1.6740346E 01	-2.1389132E 01	2.6819554E 00
21	15	-1.7208977E 00	8.7006572E 00	-1.0643480E 01	2.8030813E 00
22	15	3.0506442E 00	-1.7694938E 01	2.5854289E 01	2.9356684E 00
23	15	-7.3941533E 01	4.3629369E 02	-6.4337564E 02	3.0293837E 00

TABLE 2 (CONT'D)

I	J	A(I,J)	B(I,J)	C(I,J)	XP(I,J)
1	16	0.	-7.7835875E-01	1.0454946E 00	1.5407043E 00
2	16	1.6495990E 00	-5.8694899E 00	4.9736503E 00	1.7625531E 00
3	16	2.8937544E 00	-1.0404666E 01	9.1020540E 00	1.9086811E 00
4	16	4.0225397E-01	-9.3809148E-01	1.1009314E-01	2.0178255E 00
5	16	-1.3586905E 00	6.0261622E 00	-6.7727121E 00	2.1049757E 00
6	16	-4.1194145E-01	2.0673752E 00	-2.6344388E 00	2.1775264E 00
7	16	-1.1112031E 00	5.1610481E 00	-6.0554020E 00	2.2679223E 00
8	16	-2.2162507E 00	1.0136413E 01	-1.1655354E 01	2.3648135E 00
9	16	-1.9390845E 00	8.8921733E 00	-1.0262937E 01	2.4440135E 00
10	16	-9.2317686E-02	-9.4771322E-02	6.7015368E-01	2.5111745E 00
11	16	2.1068823E-01	-1.4640225E 00	2.1985852E 00	2.5698886E 00
12	16	2.4927992E 01	-1.2979431E 02	1.6877806E 02	2.6227008E 00
13	16	1.1360784E 01	-6.0364197E 01	7.9977751E 01	2.6714690E 00
14	16	-8.6333658E-01	4.3557189E 00	-5.6772244E 00	2.7173875E 00
15	16	1.4610142E 00	-8.2744017E 00	1.1480443E 01	2.7610855E 00
16	16	2.5901719E 00	-1.4514516E 01	2.0099653E 01	2.8324258E 00
17	16	4.1611307E 00	-2.3366958E 01	3.2570912E 01	2.9226631E 00
18	16	4.9349036E-01	-1.9847025E 00	1.4066640E 00	3.0017769E 00
19	16	-4.6417783E 00	2.8856417E 01	-4.4899399E 01	3.0755834E 00
20	16	-2.8384793E 00	1.7709214E 01	-2.7672865E 01	3.1485100E 00
21	16	-7.9579893E 00	5.0123923E 01	-7.8980556E 01	3.2578944E 00
22	16	-1.1504919E 02	7.5307079E 02	-1.2324539E 03	3.3923979E 00
23	16	-8.2541187E 02	5.5770155E 03	-9.4221036E 03	3.4986688E 00
1	17	0.	-1.2110700E 00	2.2864436E 00	2.0407043E 00
2	17	2.7525711E 00	-1.2363428E 01	1.3582109E 01	2.2625530E 00
3	17	2.1558253E 00	-9.6734536E 00	1.0550720E 01	2.4086811E 00
4	17	7.6048198E-01	-3.0868475E 00	2.7810087E 00	2.5178255E 00
5	17	-1.7143478E 00	9.5854434E 00	-1.3436482E 01	2.6049757E 00
6	17	-1.4581620E 00	8.4194942E 00	-1.2137493E 01	2.6775264E 00
7	17	-2.6497573E 00	1.4774771E 01	-2.0611323E 01	2.7679050E 00
8	17	-1.7063274E 00	9.5854321E 00	-1.3475619E 01	2.8647779E 00
9	17	-1.7963787E 00	1.0174612E 01	-1.4424457E 01	2.9439344E 00
10	17	-3.5376690E-01	1.7230984E 00	-2.0464897E 00	3.0109780E 00
11	17	-3.5492806E-01	1.8633276E 00	-2.4581144E 00	3.0693350E 00
12	17	2.4898300E 01	-1.5448039E 02	2.3950736E 02	3.1213956E 00
13	17	1.0922667E 01	-6.8898468E 01	1.0853822E 02	3.1688803E 00
14	17	-1.2513608E 00	7.7272490E 00	-1.2030559E 01	3.2129595E 00
15	17	7.7180806E-01	-5.2531870E 00	8.7908829E 00	3.2544271E 00
16	17	9.1206752E-01	-6.1780428E 00	1.0313333E 01	3.3217847E 00
17	17	2.6006274E 00	-1.7388394E 01	2.8920372E 01	3.4080872E 00
18	17	1.3379453E 00	-8.8154516E 00	1.4370241E 01	3.4844990E 00
19	17	-2.7897578E 00	2.0005582E 01	-3.5940285E 01	3.5542346E 00
20	17	-4.4702162E 00	3.2033138E 01	-5.7459522E 01	3.6206460E 00
21	17	-9.1077100E 00	6.5982313E 01	-1.1958537E 02	3.7179699E 00
22	17	-1.2199717E 02	9.1041178E 02	-1.6986425E 03	3.8431703E 00
23	17	-1.7047885E 03	1.3122011E 04	-2.5252144E 04	3.9532376E 00

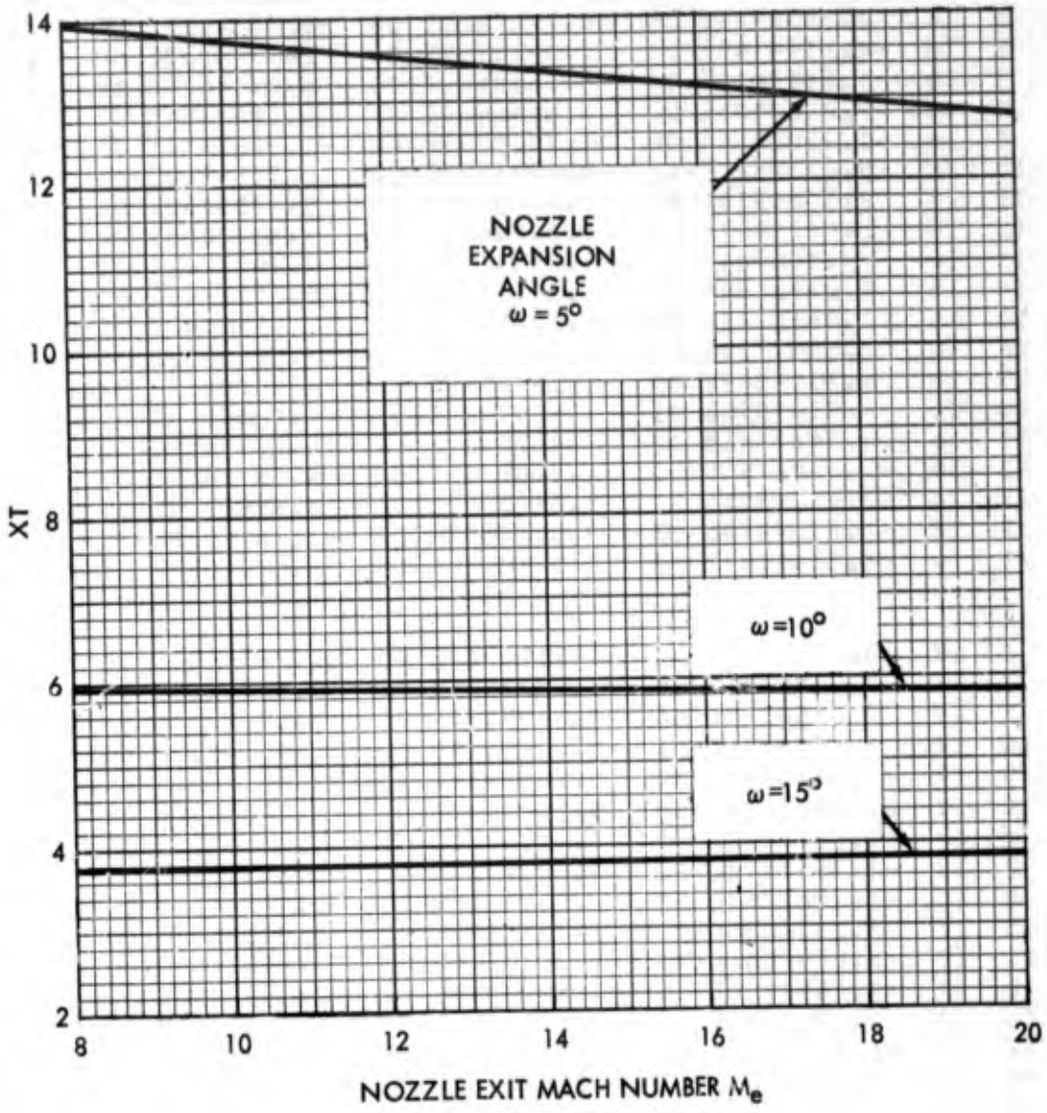

FIG. 1 DIMENSIONLESS LENGTH OF FOELSCH NOZZLE, XT

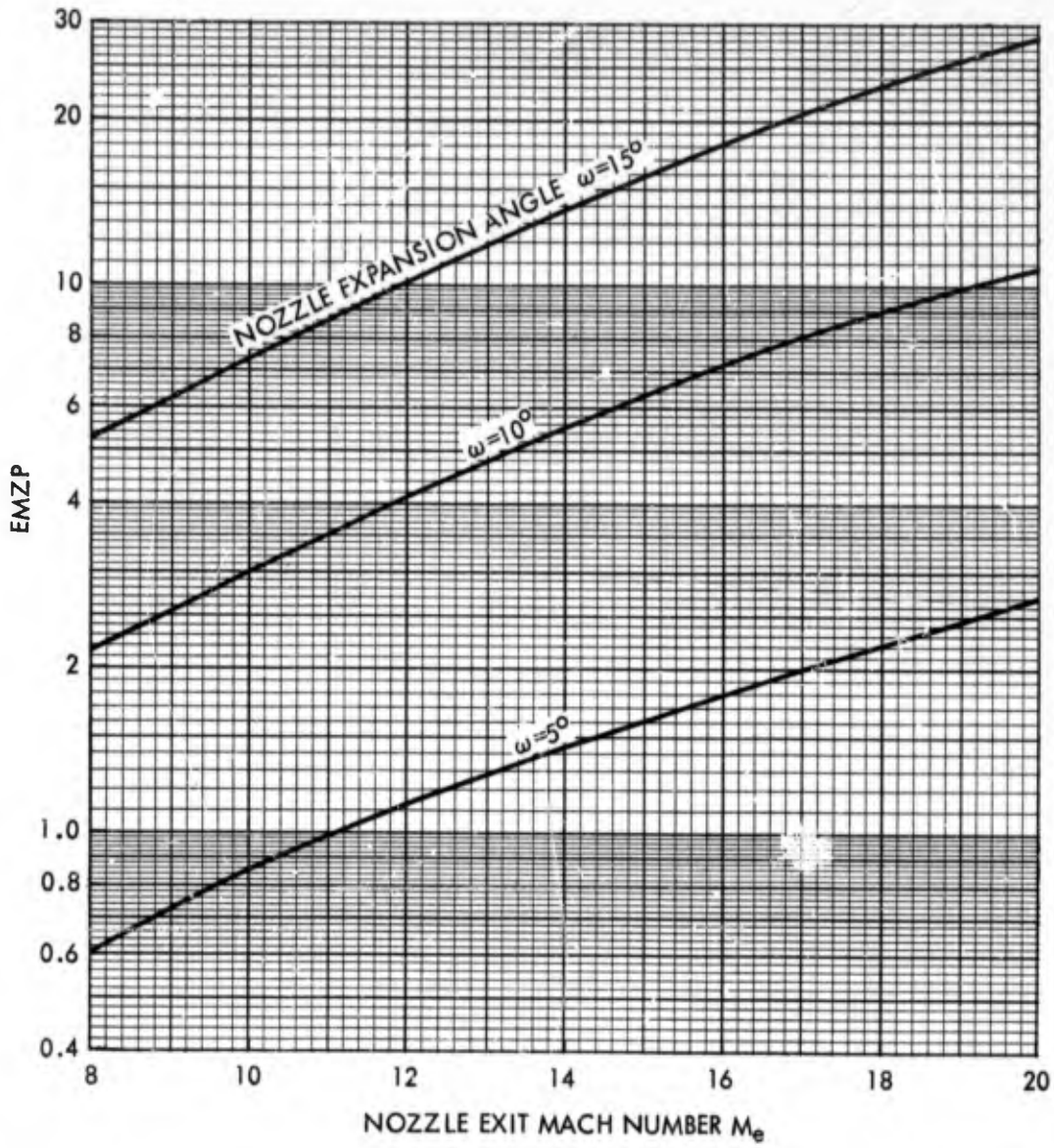

FIG. 2 DIMENSIONLESS MACH NUMBER GRADIENT AT THROAT OF FOELSCH NOZZLE, EMZP

APPENDIX A

FORTRAN LISTING OF ISENTROPIC EXPANSION PROGRAM

MAIN ROUTINE

```
C     ISENTROPIC EXPANSION PROGRAM
      READ(5,5) L,NN,TPRO,TT,EMMAX,DELTAP
    5 FORMAT(2I5,4F10.5)
      TTRO=TT/273.16
      CALL REF(SOVERR,TRHORO,TH,TZ,TAR,ASTAR,PROSTR,RROSTR,TPRO,TTRO)
      TRHO=TRHORO*2.5089296E-3
      RHOSTR=RROSTR*2.5089296E-3
      U=ALOG10(RROSTR)
      X=ALOG10(PROSTR)
      RHOQST=RHOSTR*SQRT (5.0075614E+4*(TH-ENTHLP(U,X)))
      TSTAR=PROSTR/(1.4599821*RHOSTR*COMP(U,X))
      WRITE(6,8) NN,TPRO,TT,TRHO,TH,TZ,SOVERR,TAR,TSTAR,ASTAR,PROSTR,
     1RHOSTR,RHOQST,EMMAX,DELTAP
    8 FORMAT(37H1  ISENTROPIC EXPANSION TABLE NUMBER I4//18H SUPPLY COND
     1ITIONS/9H P(ATM.)=1PE14.7,11H T(KELVIN)=1PE14.7,22H RHO(SLUGS/CUBI
     2C FT.)=1PE14.7/23H ENTHALPY(BTU/LB.MASS)=1PE14.7,4H  Z=1PE14.7,
     36H  S/R=1PE14.7,10H  A/ASTAR=1PE14.7//18H THROAT CONDITIONS/11H T(
     4KELVIN)=1PE14.7,18H  ASTAR(FT./SEC.)=1PE14.7,10H  P(ATM.)=1PE14.7/
     522H RHO(SLUGS/CUBIC FT.)=1PE14.7,30H  MASS FLOW(SLUGS/SQ.FT.SEC.)=
     61PE14.7//8H M MAX.=1PE14.7,9H  DELTAP=1PE14.7////120H     LOG10(P/
     7PT)       LOG10(RHO/RHOT)   H/HT          Z                  A/ASTA
     8R(SNDSPD)  M                AREA/AREA STAR)
      IF (L-1) 14,13,13
   13 WRITE(17,8) NN,TPRO,TT,TRHO,TH,TZ,SOVERR,TAR,TSTAR,ASTAR,PROSTR,
     1RHOSTR,RHOQST,EMMAX,DELTAP
   14 TPROL=ALOG10(TPRO)
      X=TPROL
      RHORO=TRHORO
      TRROL=ALOG10(TRHORO)
      K=0
      N=1000
   15 DELTA=ALOG10(1.-DELTAP)
      DO 30 I=1,N
      X=X+DELTA
      CALL FLSPO1(RHORO,NNI,X,SOVERR,2)
      U=ALOG10(RHORO)
      H=ENTHLP(U,X)
      Z=COMP(U,X)
      A=SNDSPD(U,X)
      Q=SQRT (5.0075614E+4*(TH-H))
      PRTL=X-TPROL
      RHORTL=U-TRROL
      HRT=H/TH
      AR=A/ASTAR
      EM=Q/A
      AREAR=RHOQST/(2.5089296E-3*RHORO*Q)
      IF (L-1) 16,19,18
```

MAIN ROUTINE (CONT'D)

```
   16 WRITE(6,17) PRTL,RHORTL,HRT,Z,AR,EM,AREAR
   17 FORMAT(1P7E17.7)
      GO TO 20
   18 WRITE(6,17) PRTL,RHORTL,HRT,Z,AR,EM,AREAR
   19 WRITE(17,17) PRTL,RHORTL,HRT,Z,AR,EM,AREAR
   20 IF(K-1)21,30,30
   21 IF(EMMAX-EM)25,30,30
   25 K=1
      N=5
      GO TO 15
   30 CONTINUE
      IF (L-1) 32,31,31
   31 END FILE 17
   32 STOP
       END
```

SUBROUTINE REF

```
      SUBROUTINE REF(SOVERR,TRHORO,TH,TZ,TAR,ASTAR,PROSTR,RROSTR,TPRO,
     1TTRO)
      CONST=2.5074678E-3*TPRO/TTRO
      TRHORO=TPRO/TTRO
      X=ALOG10(TPRO)
      CALL FLSPO1(TRHORO,NNI,CONST,X,0)
      U=ALOG10(TRHORO)
      TH=ENTHLP(U,X)
      TZ=COMP(U,X)
      SOVERR=SOVR(U,X)
      PROSTR=0.5*TPRO
      RROSTR=0.6*TRHORO
      CALL FLSPO2(PROSTR,NNI,RROSTR,SOVERR,TH,1)
      CALL FLSPO1(RROSTR,NNI,PROSTR,SOVERR,1)
      U2=ALOG10(RROSTR)
      X2=ALOG10(PROSTR)
      ASTAR=SNDSPD(U2,X2)
      TAR=SNDSPD(U,X)/ASTAR
      RETURN
       END
```

SUBROUTINE FLSPO1

```
      SUBROUTINE FLSPO1(X4,NNI,A,B,L)
      NEG=0
      X4=ABS (X4)
      CALL ORDN1(Y4,X4,A,B,L)
      X2=X4
      Y2=Y4
      X4=.95*X4
```

SUBROUTINE FLSPO1 (CONT'D)

```
      X3=X4
      CALL ORDN1(Y4,X4,A,B,L)
      Y3=Y4
      DX=X3-X2
      DY=Y3-Y2
      X4=X3-Y3*DX/DY
      IF(X4) 15,20,20
   15 X4=ABS (X4)
      NEG=1
   20 CALL ORDN1(Y4,X4,A,B,L)
      DO 6 I=1,50
      NNI=I
      X1=X2
      Y1=Y2
      X2=X3
      Y2=Y3
      X3=X4
      Y3=Y4
      DXP=DX
      DYP=DY
      DX=X3-X2
      DY=Y3-Y2
      DIV=DXP*DY-DX*DYP
      IF(DIV)1,8,1
    1 DELINV=(DX+DXP)*DXP/DIV
      RADIC=(DX+DY*DELINV)**2-4.*Y3*DX*DELINV
      IF(RADIC)9,2,2
    2 XX=SQRT (RADIC)
      XL=X3+X2-DY*DELINV
      X4=.5*(XL+XX)
      XL=.5*(XL-XX)
      XBAR=X3-Y3*DX/DY
      DXR=ABS (X4-XBAR)
      DXL=ABS (XL-XBAR)
      IF(DXR-DXL)4,4,3
    3 X4=XL
    4 IF(X4) 25,30,30
   25 X4=ABS (X4)
      NEG=1
      GO TO 5
   30 IF(NEG) 40,40,35
   35 NEG=0
      GO TO 5
   40 TEST=ABS ((X4-X3)/X4)
      IF(TEST-1.E-4)10,10,5
    5 CALL ORDN1(Y4,X4,A,B,L)
    6 CONTINUE
      WRITE(6,7) X4,A
    7 FORMAT(36H NO CONVERGENCE IN FLSPO1 NNI=50 X4=1PE14.7,3H A=1PE14.7
     1,3H B=1PE14.7,3H L=I2)
      STOP
    8 X4=X3-Y3*DX/DY
```

```
SUBROUTINE FLSPO1 (CONT'D)

      GO TO 4
    9 X4=Y3-.25*(DX+DY*DELINV)**2/(DELINV*DX)
      GO TO 4
   10 RETURN
       END


SUBROUTINE ORDN1

      SUBROUTINE ORDN1(Y4,X4,A,B,L)
      U=ALOG10(X4)
      IF(L-1)5,10,15
    5 Y4=COMP(U,B)*X4*2.5089296E-3-A
      GO TO 20
   10 IF(A) 11,11,13
   11 WRITE(6,12) Y4,X4,A,B,L
   12 FORMAT(25H LOG A UNDEFINED IN ORDN1 1P4E11.4,I3)
      STOP
   13 X=ALOG10(A)
      Y4=SOVR(U,X)-B
      GO TO 20
   15 Y4=SOVR(U,A)-B
   20 RETURN
       END


SUBROUTINE FLSPO2

      SUBROUTINE FLSPO2(X4,NNI,C,D,E,L)
      NEG=0
      X4=ABS (X4)
      CALL ORDN2(Y4,X4,C,D,E,L)
      X2=X4
      Y2=Y4
      X4=.95*X4
      X3=X4
      CALL ORDN2(Y4,X4,C,D,E,L)
      Y3=Y4
      DX=X3-X2
      DY=Y3-Y2
      X4=X3-Y3*DX/DY
      IF(X4) 15,20,20
   15 X4=ABS (X4)
      NEG=1
   20 CALL ORDN2(Y4,X4,C,D,E,L)
      DO 6 I=1,50
      NNI=I
      X1=X2
      Y1=Y2
      X2=X3
      Y2=Y3
```

SUBROUTINE FLSPO2 (CONT'D)

```
      X3=X4
      Y3=Y4
      DXP=DX
      DYP=DY
      DX=X3-X2
      DY=Y3-Y2
      DIV=DXP*DY-DX*DYP
      IF(DIV)1,8,1
    1 DELINV=(DX+DXP)*DXP/DIV
      RADIC=(DX+DY*DELINV)**2-4.*Y3*DX*DELINV
      IF(RADIC)9,2,2
    2 XX=SQRT (RADIC)
      XL=X3+X2-DY*DELINV
      X4=.5*(XL+XX)
      XL=.5*(XL-XX)
      XBAR=X3-Y3*DX/DY
      DXR=ABS (X4-XBAR)
      DXL=ABS (XL-XBAR)
      IF(DXR-DXL)4,4,3
    3 X4=XL
    4 IF(X4) 25,30,30
   25 X4=ABS (X4)
      NEG=1
      GO TO 5
   30 IF(NEG) 40,40,35
   35 NEG=0
      GO TO 5
   40 TEST=ABS ((X4-X3)/X4)
      IF(TEST-1.E-4)10,10,5
    5 CALL ORDN2(Y4,X4,C,D,E,L)
    6 CONTINUE
      WRITE(6,7) X4,C
    7 FORMAT(36H NO CONVERGENCE IN FLSPO2 NNI=50 X4=1PE14.7,3H C=1PE14.7
     1,3H D=1PE14.7,3H E=1PE14.7,3H L=I2)
      STOP
    8 X4=X3-Y3*DX/DY
      GO TO 4
    9 X4=Y3-.25*(DX+DY*DELINV)**2/(DELINV*DX)
      GO TO 4
   10 RETURN
       END
```

SUBROUTINE ORDN2

```
      SUBROUTINE ORDN2(Y4,X4,C,D,E,L)
      CALL FLSPO1(C,NNI,X4,D,1)
      U=ALOG10(C)
      X=ALOG10(X4)
      Y4=SNDSPD(U,X)-SQRT (5.0075614E+4*(E-ENTHLP(U,X)))
      RETURN
       END
```

FUNCTION SOVR

```
      FUNCTION SOVR(U,X)
      IF(U-0.5)10,5,5
    5 Y=-1.0
      GO TO 15
   10 Y=1.0
   15 AA1=6.07+U*(-.3088+U*(-.2936+U*(-4.92E-2+U*(2.367E-2+U*(8.211E-3+U
     1*(8.572E-5+U*(-2.079E-4-1.853E-5*U)))))))
      AA2=23.73+U*(-8.678+U*(.3959+U*(.3404+U*(8.723E-3+U*(-2.696E-2+U*(
     1-3.212E-3+U*(4.541E-4+6.685E-5*U)))))))
      AO=.774+1.051*U-(.188*U+.216)/(1.+EXP (-2.*(U+2.5)))
      A1=-14.27+U*(-3.747E-2+U*(-.1396+U*(-3.239E-2+U*(-3.316E-2+U*(
     18.024E-3+U*(5.188E-3+U*(7.196E-4+2.81E-5*U)))))))
      A2=1.928+U*(.2272+U*(.209+U*(6.471E-2+U*(-2.786E-3+U*(-6.389E-3+
     1U*(-1.774E-3+U*(-2.319E-4-1.234E-5*U)))))))
      CO=1.011+U*(.9836+U*(7.494E-3+U*(2.989E-2+U*(4.677E-3+U*(-4.025E-3
     1+U*(-1.6E-3+U*(-2.129E-4-9.749E-6*U)))))))
      C1=-30.32+U*(6.358+U*(.1797+U*(-.265+U*(7.801E-4+U*(4.371E-2+U*(
     19.106E-3+U*(1.831E-4-5.086E-5*U)))))))
      C2=6.803+U*(-2.416+U*(.4478+U*(4.154E-2+U*(-3.353E-2+U*(-1.133E-2
     1+U*(9.216E-4+U*(6.994E-4+6.418E-5*U)))))))
      EO=1.5+1.06*U
      E2=-13.73+U*(2.639+U*(.2221+U*(-7.91E-2+U*(-6.41E-2+U*(6.627E-3
     1+U*(6.847E-3+U*(1.094E-3+5.571E-5*U)))))))
      E3=21.03+U*(10.19+U*(-2.774+U*(-.1815+U*(2.67E-2+U*(3.078E-2+U*(
     12.708E-3+U*(-2.479E-4-2.325E-5*U)))))))
      GO=1.952+1.042*U
      G1=-22.0-U
      G2=3.26956+U*(1.59237+U*(-1.58649+U*(2.44114+U*(2.06374+U*(
     1.627211+U*(8.54131E-2+4.38097E-3*U)))))))
      G3=-5.03379+U*(-10.1141+U*(-3.01126+U*(-2.94700+U*(-2.84323+U*(
     1-.909849+U*(-.129095-6.83594E-3*U)))))))
      FIO=2.495+1.0547*U
      ZO=20.*(U+1.4948)
      IF(ZO-10.)21,20,20
   20 FI2=0.0
      GO TO 30
   21 IF(ZO+8.)22,22,23
   22 FI2=-18.48*U-27.63
      GO TO 30
   23 IF(ABS (ZO)-.01)24,24,25
   24 FI2=.924
      GO TO 30
   25 FI2=-18.48*(U+1.4948)/(1.-EXP (ZO))
   30 Z1=A1*(X-AO)
      IF(Z1-10.)32,31,31
   31 F1=0.0
      GO TO 41
   32 IF(Z1+8.)33,33,34
   33 F1=A2*(X-AO)
      GO TO 40
   34 IF(ABS (Z1)-.01)35,35,36
```

FUNCTION SOVR (CONT'D)

```
   35 F1=-A2/A1
      GO TO 41
   36 F1=A2*(X-A0)/(1.-EXP (Z1))
   40 Z2=C1*(X-C0)
      IF(Z2-10.)42,41,41
   41 F2=0.0
      GO TO 51
   42 IF(Z2+8.)43,43,44
   43 F2=C2*(X-C0)
      GO TO 50
   44 IF(ABS (Z2)-.01)45,45,46
   45 F2=-C2/C1
      GO TO 51
   46 F2=C2*(X-C0)/(1.-EXP (Z2))
   50 Z3=-18.*(X-E0)
      IF(Z3-10.)52,51,51
   51 F3=0.0
      GO TO 71
   52 IF(Z3+8.)53,53,54
   53 F3=E2*X+E3
      GO TO 70
   54 IF(Y) 55,60,60
   55 IF(ABS (Z3)-.01)56,56,57
   56 F3=E2/18.
      GO TO 71
   57 F3=E2*(X-E0)/(1.-EXP (Z3))
      GO TO 70
   60 F3=(E2*X+E3)/(1.+EXP (Z3))
   70 Z4=G1*(X-G0)
      IF(Z4-10.)72,71,71
   71 F4=0.0
      GO TO 81
   72 IF(Z4+8.)73,73,74
   73 F4=G2*X+G3
      GO TO 80
   74 F4=(G2*X+G3)/(1.+EXP (Z4))
   80 Z5=-66.*(X-FI0)
      IF(Z5-10.) 82,81,81
   81 F5=0.0
      GO TO 90
   82 IF(Z5+8.)83,83,84
   83 F5=FI2*(X-FI0)
      GO TO 90
   84 IF(ABS (Z5)-.01)85,85,86
   85 F5=FI2/66.
      GO TO 90
   86 F5=FI2*(X-FI0)/(1.-EXP (Z5))
   90 SOVR=AA1*X+AA2+F1+F2-F3-F4-F5-ERRSR(U,X)
      RETURN
       END
```

FUNCTION ERRSR

```
      FUNCTION ERRSR(U,X)
      DIMENSION A(23,17),B(23,17),C(23,17),XP(23,17),RHOL(17)
      N=0
      IF(M-123) 5,10,5
    5 M=123
      READ(28) (RHOL(J),J=1,17)
      DO 6 J=1,17
    6 READ(28) (A(I,J),B(I,J),C(I,J),XP(I,J),I=1,23)
   10 IF(U+6.)70,16,15
   15 IF(U-2.)16,16,70
   16 JJ=0
      J=U+7.
      UJ=J
      DEL=U+7.-UJ
      IF(J-7)19,17,17
   17 IF(DEL-.5)24,18,18
   18 JJ=1
      GO TO 24
   19 IF(DEL-.6)24,18,18
   24 J=J+(J-1)+JJ
      L=12
      LL=11
      XTR=X-1.03*U
      U1=RHOL(J)
      XINT=XTR+1.03*U1
      IF(XINT-XP(12,J))30,25,40
   25 I=12
      GO TO 50
   30 DO 35 K=1,LL
      I=L-K
      IF(XINT-XP(I,J))35,50,32
   32 I=I+1
      GO TO 50
   35 CONTINUE
      GO TO 50
   40 DO 45 K=1,LL
      I=L+K
      IF(XINT-XP(I,J))50,50,45
   45 CONTINUE
      GO TO 72
   50 IF(N-123) 55,60,55
   55 ERR1=A(I,J)*XINT**2+B(I,J)*XINT+C(I,J)
      N=123
      L=I
      IF(J-16)95,95,90
   90 DU=0
      GO TO 85
   95 J=J+1
      U2=RHOL(J)
      XINT=XTR+1.03*U2
      IF(XINT-XP(I,J))56,60,58
   56 IF(I-1)60,60,57
```

FUNCTION ERRSR (CONT'D)

```
   57 LL=I-1
      GO TO 30
   58 IF(23-I)72,72,59
   59 LL=23-I
      GO TO 40
   60 ERR2=A(I,J)*XINT**2+B(I,J)*XINT+C(I,J)
      GO TO 80
   70 WRITE(6,71) U,X
   71 FORMAT(24H U OUT OF RANGE IN ERRSR ,3H U=1PE14.7,3H X=1PE14.7)
      GO TO 74
   72 WRITE(6,73) U,X,N,I,J,XINT,XP(I,J)
   73 FORMAT(24H X OUT OF RANGE IN ERRSR ,3H U=1PE14.7,3H X=1PE14.7,3H N
     1=I4,3H I=I4,3H J=I4,6H XINT=1PE13.6,9H XP(I,J)=1PE13.6)
   74 DU=0
      ERR1=0
      GO TO 85
   80 DU=(U-U1)/(U2-U1)
   85 ERRSR=ERR1+DU*(ERR2-ERR1)
      RETURN
       END
```

FUNCTION ENTHLP

```
       FUNCTION ENTHLP(U,X)
       AA1=2.4876733E-2+U*(-8.2553890E-3+U*(9.3531968E-4+U*(-6.9802146E-4
      1+U*(-7.0256556E-5+U*(1.1449208E-4+U*(3.5362594E-5+U*(3.4741999E-6
      2+8.9880020E-8*U)))))))
       AA2=3.4894155+U*(-2.9193911E-2+U*(1.0481798E-2+U*(-2.6714733E-4
      1+U*(-2.6951449E-4+U*(-2.3151119E-4+U*(-6.2749893E-5+U*(-
      27.5707012E-6-3.6330450E-7*U)))))))
       AO=.36547857+U*(1.0189210+U*(-5.4844838E-3+U*(-2.7426243E-2+U*(
      1-7.7107391E-3+U*(2.4202901E-3+U*(1.4256573E-3+U*(2.2860249E-4+
      21.2352353E-5*U)))))))
       A1=-23.014062+U*(.46035662+U*(3.0044637E-2+U*(2.8921658E-2+U*(
      1-4.4337102E-3+U*(1.8974229E-4+U*(2.8921472E-3+U*(8.1853124E-4+
      26.2730577E-5*U)))))))
       A2=.71774971+U*(-6.9915246E-2+U*(-4.7677628E-2+U*(-7.2328367E-3
      1+U*(4.6877100E-3+U*(2.1195796E-3+U*(2.6545771E-4+U*(-4.6416051E-7
      2-1.4305115E-6*U)))))))
       CO=.94993342+U*(1.0187300+U*(-2.7831274E-2+U*(-3.3968208E-2+U*(
      1-7.5758964E-3+U*(4.3377145E-3+U*(2.3585523E-3+U*(3.9680529E-4+
      22.2767082E-5*U)))))))
       C1=-56.5+44.6/(1.+EXP (-U-1.75))
       C2=4.2598137+U*(-1.8016141+U*(.28493805+U*(2.5524034E-2+U*(
      1-2.8069440E-4+U*(-1.8133469E-3+U*(-9.7441476E-4+U*(-1.8356511E-4
      2-1.1383541E-5*U)))))))
       EO=1.374+1.046*U
       E1=-20.616464+U*(.99527941+U*(.36318074+U*(7.4026954E-2+U*(
      1-9.5602994E-3+U*(-6.8683405E-3+U*(-8.0744407E-4+U*(2.9434846E-5+
      27.0238870E-6*U)))))))
       E2=-.22188469+U*(-5.5351400E-2+U*(-8.3290583E-3+U*(-6.5111980E-4
```

```
FUNCTION ENTHLP (CONT'D)

     1+U*(1.3836166E-3+U*(8.2097136E-4+U*(1.9030699E-4+U*(2.0702239E-5+
     28.9265052E-7*U))))))
      E3=.48990558+U*(.30389535+U*(7.2574817E-2+U*(-6.9748615E-3+U*(
     1-6.4693200E-3+U*(-5.8788707E-4+U*(7.7232629E-5+U*(5.3091414E-6-
     26.6747741E-7*U))))))
      GO=1.835+1.043*U
      G1=-11.591952+U*(1.8211028+U*(1.8682006E-2+U*(3.8627552E-2+U*(
     11.7205973E-2+U*(-3.7323972E-3+U*(-2.2956386E-3+U*(-3.0764239E-4-
     21.2352353E-5*U))))))
      G2=1.3480705+U*(.21904060+U*(-6.7552429E-3+U*(1.6563452E-2+U*(
     19.1140456E-3+U*(-2.3675397E-3+U*(-1.7376722E-3+U*(-2.9616734E-4-
     21.6477373E-5*U))))))
      G3=-2.2628366+U*(-1.8824979+U*(-.28388494+U*(1.2905525E-2+U*(
     11.4367226E-2+U*(6.8502795E-6+U*(-9.3289221E-4+U*(-1.7551892E-4
     2-1.0293628E-5*U))))))
      HO=2.376+1.046*U
      H1=-28.86+.507*U
      H2=.95+.38/(1.+EXP (2.5*(U+4.2)))
      Z1=E1*(X-EO)
      IF(Z1-10.)11,10,10
   10 FX1=0.0
      GO TO 21
   11 IF(Z1+8.)12,12,13
   12 FX1=E2*X+E3
      GO TO 20
   13 FX1=(E2*X+E3)/(1.+EXP (Z1))
   20 Z2=G1*(X-GO)
      IF(Z2-10.)22,21,21
   21 FX2=0.0
      GO TO 31
   22 IF(Z2+8.)23,23,24
   23 FX2=G2*X+G3
      GO TO 30
   24 FX2=(G2*X+G3)/(1.+EXP (Z2))
   30 Z3=H1*(X-HO)
      IF(Z3-10.)32,31,31
   31 FX3=0.0
      GO TO 40
   32 IF(Z3+8.)33,33,34
   33 FX3=H2*(X-HO)
      GO TO 40
34 IF(ABS (Z3)-.01)35,35,36
      GO TO 40
   35 FX3=-H2/H1
   36 FX3=H2*(X-HO)/(1.-EXP (Z3))
   40 XX=X-FX1-FX2-FX3
   50 Z4=A1*(XX-AO)
      IF(Z4-10.)52,51,51
   51 F1=0.0
      GO TO 61
   52 IF(Z4+8.)53,53,54
   53 F1=A2*(XX-AO)
```

```
FUNCTION ENTHLP (CONT'D)

      GO TO 60
   54 IF(ABS (Z4)-.01)55,55,56
   55 F1=-A2/A1
      GO TO 61
   56 F1=A2*(XX-AO)/(1.-EXP (Z4))
   60 Z5=C1*(XX-CO)
      IF(Z5-10.)62,61,61
   61 F2=0.0
      GO TO 70
   62 IF(Z5+8.)63,63,64
   63 F2=C2*(XX-CO)
      GO TO 70
   64 IF(ABS (Z5)-.01)65,65,66
   65 F2=-C2/C1
      GO TO 70
   66 F2=C2*(XX-CO)/(1.-EXP (Z5))
   70 HRHOVP=AA1*XX+AA2+F1+F2-ERRHRP(U,X)
   75 ENTHLP=33.687746*HRHOVP*10.**(X-U)
      RETURN
       END

FUNCTION ERRHRP

      FUNCTION ERRHRP(U,X)
      DIMENSION A(23,9),B(23,9),C(23,9),XP(23,9)
      N=0
      IF(M-123)5,10,5
    5 M=123
      DO 6 J=1,9
    6 READ(28) (A(I,J),B(I,J),C(I,J),XP(I,J),I=1,23)
   10 IF(U+6.)70,20,15
   15 IF(U-2.)20,20,70
   20 J=U+7.
      L=12
      LL=11
      XTR=X-1.03*U
      U1=J-7
      XINT=XTR+1.03*U1
      IF(XINT-XP(12,J))30,25,40
   25 I=12
      GO TO 50
   30 DO 35 K=1,LL
      I=L-K
      IF(XINT-XP(I,J))35,50,32
   32 I=I+1
      GO TO 50
   35 CONTINUE
      GO TO 50
   40 DO 45 K=1,LL
      I=L+K
      IF(XINT-XP(I,J))50,50,45
```

```
FUNCTION ERRHRP (CONT'D)

   45 CONTINUE
      GO TO 72
   50 IF(N-123)55,60,55
   55 ERR1=A(I,J)*XINT**2+B(I,J)*XINT+C(I,J)
      N=123
      L=I
      J=J+1
      XINT=XINT+1.03
      IF(XINT-XP(I,J))56,60,58
   56 IF(I-1)60,60,57
   57 LL=I-1
      GO TO 30
   58 IF(23-I)72,72,59
   59 LL=23-I
      GO TO 40
   60 ERR2=A(I,J)*XINT**2+B(I,J)*XINT+C(I,J)
      GO TO 80
   70 WRITE(6,71) U,X
   71 FORMAT(25H U OUT OF RANGE IN ERRHRP,3H U=1PE14.7,3H X=1PE14.7)
      GO TO 74
   72 WRITE(6,73) U,X,N,I,J,XINT,XP(I,J)
   73 FORMAT(25H X OUT OF RANGE IN ERRHRP,3H U=1PE14.7,3H X=1PE14.7,3H N
     1=I4,3H I=I4,3H J=I4,6H XINT=1PE13.6,9H XP(I,J)=1PE13.6)
   74 DU=0
      ERR1=0
      GO TO 85
   80 DU=U-U1
   85 ERRHRP=ERR1+DU*(ERR2-ERR1)
      RETURN
       END


FUNCTION COMP

      FUNCTION COMP(U,X)
      IF(U-0.5)10,5,5
    5 Y=-1.0
      GO TO 15
   10 Y=1.0
   15 AO=1.042+U*(1.069+U*(6.354E-3+U*(-3.3E-3+U*(-9.155E-4+U*(5.952E-4
     1+U*(2.866E-4+U*(4.287E-5+2.18E-6*U))))))
      A1=-44.71+U*(8.358+U*(-.2318+U*(-.107+U*(-.1176+U*(1.642E-2+U*(
     12.461E-2+U*(5.21E-3+3.362E-4*U))))))
      CO=1.137+U*(.063+U*(2.836E-2+U*(1.698E-2+U*(-2.23E-4+U*(-2.836E-3
     1+U*(-8.384E-4+U*(-9.259E-5-3.451E-6*U))))))
      C2=.1805+U*(-9.217E-2+U*(1.075E-2+U*(3.633E-3+U*(-1.602E-4+U*(
     1-4.084E-4+U*(-9.916E-5+U*(-8.743E-6-2.119E-7*U))))))
      EO=1.435+U*(1.1+U*(3.016E-2+U*(1.447E-3+U*(-6.107E-3+U*(-2.075E-3
     1+U*(-1.37E-4+U*(2.689E-5+3.088E-6*U))))))
      ZO=-15.*(U-.5)
      IF(ZO-10.)21,20,20
   20 E1=-22.0
```

FUNCTION COMP (CONT'D)

```
      GO TO 30
   21 IF(ZO+8.)22,22,23
   22 E1=-56.6+9.8*U
      GO TO 30
   23 E1=-22.0+(9.8*U-34.6)/(1.+EXP (ZO))
   30 E2=-.2476+U*(-4.858E-2+U*(1.217E-2+U*(3.934E-3+U*(-3.705E-4+U*(
     1-5.415E-4+U*(-1.095E-4+U*(-5.681E-6+1.694E-7*U)))))))
      E3=.3904+U*(.3021+U*(4.053E-2+U*(-1.283E-2+U*(-1.935E-3+U*(
     15.477E-4+U*(2.667E-4+U*(4.022E-5+2.142E-6*U)))))))
      GO=1.87016+U*(1.08549+U*(2.39061E-2+U*(2.06972E-2+U*(1.71414E-2+U
     1*(6.45427E-3+U*(1.05835E-3+6.27306E-5*U))))))
      G1=-13.9930+U*(2.33941+U*(.431717+U*(.162394+U*(5.00809E-2+U*(
     17.94148E-3+4.80406E-4*U)))))
      G2=.408955+U*(-1.83205E-2+U*(-9.92156E-3+U*(5.94758E-3+U*(
     14.30655E-3+U*(9.39536E-4+U*(8.33593E-5+2.33120E-6*U))))))
      G3=-.718311+U*(-.423658+U*(2.64678E-2+U*(1.17670E-2+U*(
     11.67085E-3+U*(5.85089E-5-2.21499E-6*U)))))
      FIO=2.462+U*(1.035+U*(-7.083E-3+U*(6.893E-3+U*(3.469E-3+U*(
     1-1.743E-4+U*(-4.025E-4+U*(-8.534E-5-5.571E-6*U)))))))
      FI1=-16.37+U*(1.561+U*(-.2057+U*(-5.558E-2+U*(4.067E-2+U*(1.993E-2
     1+U*(-2.783E-3+U*(-1.926E-3-1.952E-4*U)))))))
      FI2=.1986+U*(-8.448E-2+U*(-6.44E-4+U*(2.533E-4+U*(-6.545E-4+U*(
     1-5.846E-5+U*(8.109E-5+U*(2.085E-5+1.431E-6*U)))))))
   40 Z1=A1*(X-AO)
      IF(Z1-10.)42,41,41
   41 F1=0.0
      GO TO 51
   42 IF(Z1+8.)43,43,44
   43 F1=.3468*(X-AO)
      GO TO 50
   44 IF(ABS (Z1)-.01)45,45,46
   45 F1=-.3468/A1
      GO TO 51
   46 F1=.3468*(X-AO)/(1.-EXP (Z1))
   50 Z2=-100.*(X-CO)
      IF(Z2-10.)52,51,51
   51 F2=0.0
      GO TO 61
   52 IF(Z2+8.)53,53,54
   53 F2=C2*(X-CO)
      GO TO 60
   54 IF(ABS (Z2)-.01)55,55,56
   55 F2=.01*C2
      GO TO 61
   56 F2=C2*(X-CO)/(1.-EXP (Z2))
   60 Z3=E1*(X-EO)
      IF(Z3-10.)62,61,61
   61 F3=0.0
      GO TO 81
   62 IF(Z3+8.)63,63,64
   63 F3=E2*X+E3
      GO TO 80
```

FUNCTION COMP (CONT'D)

```
   64 IF(Y) 65,70,70
   65 IF(ABS (Z3)-.01) 66,66,67
   66 F3=-E2/E1
      GO TO 81
   67 F3=E2*(X-EO)/(1.-EXP (Z3))
      GO TO 80
   70 F3=(E2*X+E3)/(1.+EXP (Z3))
   80 Z4=G1*(X-GO)
      IF(Z4-10.)82,81,81
   81 F4=0.0
      GO TO 91
   82 IF(Z4+8.)83,83,84
   83 F4=G2*X+G3
      GO TO 90
   84 F4=(G2*X+G3)/(1.+EXP (Z4))
   90 Z5=FI1*(X-FIO)
      IF(Z5-10.)92,91,91
   91 F5=0.0
      GO TO 100
   92 IF(Z5+8.)93,93,94
   93 F5=FI2*(X-FIO)
      GO TO 100
   94 IF(ABS (Z5)-.01)95,95,96
   95 F5=-FI2/FI1
      GO TO 100
   96 F5=FI2*(X-FIO)/(1.-EXP (Z5))
  100 RECIP=1.-F1-F2+F3+F4+F5
      COMP=1./RECIP
      RETURN
       END
```

FUNCTION SNDSPD

```
      FUNCTION SNDSPD(U,X)
      IF(U-0.5)10,5,5
    5 Y=-1.0
      GO TO 15
   10 Y=1.0
   15 AA1=6.07+U*(-.3088+U*(-.2936+U*(-4.92E-2+U*(2.367E-2+U*(8.211E-3+U
     1*(8.572E-5+U*(-2.079E-4-1.853E-5*U)))))))
      DAA1U=-.3088+U*(-.5872+U*(-.1476+U*(9.468E-2+U*(4.1055E-2+U*(
     15.1432E-4+U*(-1.4553E-3-1.4824E-4*U)))))
      DAA2U=-8.678+U*(.7918+U*(1.0212+U*(3.4892E-2+U*(-.1348+U*(-1.9272E
     1-2+U*(3.1787E-3+5.348E-4*U)))))
      EXPO=EXP (-2.*(U+2.5))
      AO=.774+1.051*U-(.188*U+.216)/(1.+EXPO)
      DAOU=1.051-(.188*(1.+EXPO)+(.432+.376*U)*EXPO)/(1.+EXPO)**2
      A1=-14.27+U*(-3.747E-2+U*(-.1396+U*(-3.239E-2+U*(-3.316E-2+U*(
     18.024E-3+U*(5.188E-3+U*(7.196E-4+2.81E-5*U)))))))
      DA1U=-3.747E-2+U*(-.2792+U*(-9.717E-2+U*(-.13264+U*(4.012E-2+U*(
     13.1128E-2+U*(5.0372E-3+2.248E-4*U)))))
```

```
FUNCTION SNDSPD (CONT'D)

      A2=1.928+U*(.2272+U*(.209+U*(6.471E-2+U*(-2.786E-3+U*(-6.389E-3+
     1U*(-1.774E-3+U*(-2.319E-4-1.234E-5*U)))))))
      DA2U=.2272+U*(.418+U*(.19413+U*(-1.1144E-2+U*(-3.1945E-2+U*(
     1-1.0644E-2+U*(-1.6233E-3-9.872E-5*U)))))
      CO=1.011+U*(.9836+U*(7.494E-3+U*(2.989E-2+U*(4.677E-3+U*(-4.025E-3
     1+U*(-1.6E-3+U*(-2.129E-4-9.749E-6*U)))))))
      DCOU=.9836+U*(1.4988E-2+U*(8.967E-2+U*(1.8708E-2+U*(-2.0125E-2+U*(
     1-9.6E-3+U*(-1.4903E-3-7.7992E-5*U)))))
      C1=-30.32+U*(6.358+U*(.1797+U*(-.265+U*(7.801E-4+U*(4.371E-2+U*(
     19.106E-3+U*(1.831E-4-5.086E-5*U)))))))
      DC1U=6.358+U*(.3594+U*(-.795+U*(3.1204E-3+U*(.21855+U*(5.4636E-2
     1+U*(1.2817E-3-4.0688E-4*U)))))
      C2=6.803+U*(-2.416+U*(.4478+U*(4.154E-2+U*(-3.353E-2+U*(-1.133E-2
     1+U*(9.216E-4+U*(6.994E-4+6.418E-5*U)))))))
      DC2U=-2.416+U*(.8956+U*(.12462+U*(-.13412+U*(-5.665E-2+U*(5.5296E
     1-3+U*(4.8958E-3+5.1344E-4*U)))))
      EO=1.5+1.06*U
      E2=-13.73+U*(2.639+U*(.2221+U*(-7.91E-2+U*(-6.41E-2+U*(6.627E-3
     1+U*(6.847E-3+U*(1.094E-3+5.571E-5*U)))))))
      DE2U=2.639+U*(.4442+U*(-.2373+U*(-.2564+U*(3.3135E-2+U*(4.1082E-2
     1+U*(7.658E-3+4.4568E-4*U)))))
      E3=21.03+U*(10.19+U*(-2.774+U*(-.1815+U*(2.67E-2+U*(3.078E-2+U*(
     12.708E-3+U*(-2.479E-4-2.325E-5*U)))))))
      DE3U=10.19+U*(-5.548+U*(-.5445+U*(.1068+U*(.1539+U*(1.6248E-2+U*(
     1-1.7353E-3-1.86E-4*U)))))
      GO=1.952+1.042*U
      G1=-22.0-U
      G2=3.26956+U*(1.59237+U*(-1.58649+U*(2.44114+U*(2.06374+U*(
     1.627211+U*(8.54131E-2+4.38097E-3*U)))))
      DG2U=5.04594+U*(-.705604-6.5454E-2*U)
      G3=-5.03379+U*(-10.1141+U*(-3.01126+U*(-2.94700+U*(-2.84323+U*(
     1-.909849+U*(-.129095-6.83594E-3*U)))))
      DG3U=-14.4934+U*(-9.40764+.656448*U)
      FIO=2.495+1.0547*U
      ZO=20.*(U+1.4948)
      IF(ZO-10.)21,20,20
   20 FI2=0.0
      DFI2U=0.0
      GO TO 30
   21 IF(ZO+8.)22,22,23
   22 FI2=-18.48*U-27.63
      DFI2U=-18.48
      GO TO 30
   23 IF(ABS (ZO)-.01)24,24,25
   24 FI2=.924
      DFI2U=-9.24
      GO TO 30
   25 EXPO=EXP (ZO)
      FI2=-18.48*(U+1.4948)/(1.-EXPO)
      DFI2U=(-18.48*(EXPO*(ZO-1.)+1.))/(1.-EXPO)**2
   30 Z1=A1*(X-AO)
      IF(Z1-10.)32,31,31
```

FUNCTION SNDSPD (CONT'D)

```
   31 DF1U=0.0
      DF1X=0.0
      GO TO 41
   32 IF(Z1+8.)33,33,34
   33 DF1U=(X-AO)*DA2U-A2*DAOU
      DF1X=A2
      GO TO 40
   34 IF(ABS (Z1)-.005)35,35,36
   35 DF1U=-(A1*DA2U-A2*DA1U)/A1**2-.5*A2*DAOU
      DF1X=.5*A2
      GO TO 41
   36 EXPO=EXP (Z1)
      DEL=X-AO
      DF1U=((1.-EXPO)*(DEL*DA2U-A2*DAOU)+A2*DEL*EXPO*(DEL*DA1U-A1*DAOU))
     1/(1.-EXPO)**2
      DF1X=(A2*(EXPO*(A1*DEL-1.)+1.))/(1.-EXPO)**2
   40 Z2=C1*(X-CO)
      IF(Z2-10.)42,41,41
   41 DF2U=0.0
      DF2X=0.0
      GO TO 51
   42 IF(Z2+8.)43,43,44
   43 DF2U=(X-CO)*DC2U-C2*DCOU
      DF2X=C2
      GO TO 50
   44 IF(ABS (Z2)-.005)45,45,46
   45 DF2U=-(C1*DC2U-A2*DC1U)/C1**2-.5*C2*DCOU
      DF2X=.5*C2
      GO TO 51
   46 EXPO=EXP (Z2)
      DEL=X-CO
      DF2U=((1.-EXPO)*(DEL*DC2U-C2*DCOU)+C2*DEL*EXPO*(DEL*DC1U-C1*DCOU))
     1/(1.-EXPO)**2
      DF2X=(C2*(EXPO*(C1*DEL-1.)+1.))/(1.-EXPO)**2
   50 Z3=-18.*(X-EO)
      IF(Z3-10.)52,51,51
   51 DF3U=0.0
      DF3X=0.0
      GO TO 71
   52 IF(Z3+8.)53,53,54
   53 DF3U=X*DE2U+DE3U
      DF3X=E2
      GO TO 70
   54 IF(Y)55,60,60
   55 IF(ABS (Z3)-.005)56,56,57
   56 DF3U=DE2U/18.-.53*E2
      DF3X=.5*E2
      GO TO 71
   57 EXPO=EXP (Z3)
      DEL=X-EO
      DF3U=((1.-EXPO)*(DEL*DE2U-1.06*E2)+19.08*E2*DEL*EXPO)/(1.-EXPO)**2
      DF3X=(E2*(EXPO*(-18.*DEL-1.)+1.))/(1.-EXPO)**2
```

FUNCTION SNDSPD (CONT'D)

```
      GO TO 70
   60 EXPO=EXP (Z3)
      DF3U=((X*DE2U+DE3U)*(1.+EXPO)-19.08*(E2*X+E3)*EXPO)/(1.+EXPO)**2
      DF3X=(E2*(1.+EXPO)+18.*(E2*X+E3)*EXPO)/(1.+EXPO)**2
   70 Z4=G1*(X-GO)
      IF(Z4-10.)72,71,71
   71 DF4U=0.0
      DF4X=0.0
      GO TO 81
   72 IF(Z4+8.)73,73,74
   73 DF4U=X*DG2U+DG3U
      DF4X=G2
      GO TO 80
   74 EXPO=EXP (Z4)
      DF4U=((X*DG2U+DG3U)*(1.+EXPO)-(G2*X+G3)*EXPO*(-X+GO-1.042*G1))
     1/(1.+EXPO)**2
      DF4X=(G2*(1.+EXPO)-G1*(G2*X+G3)*EXPO)/(1.+EXPO)**2
   80 Z5=-66.*(X-FIO)
      IF(Z5-10.)82,81,81
   81 DF5U=0.0
      DF5X=0.0
      GO TO 90
   82 IF(Z5+8.)83,83,84
   83 DF5U=(X-FIO)*DFI2U-1.0547*FI2
      DF5X=FI2
      GO TO 90
   84 IF(ABS (Z5)-.005)85,85,86
   85 DF5U=DFI2U/66.-.52735*FI2
      DF5X=.5*FI2
      GO TO 90
   86 EXPO=EXP (Z5)
      DEL=X-FIO
      DF5U=((1.-EXPO)*(DEL*DFI2U-1.0547*FI2)+69.6102*FI2*DEL*EXPO)/
     1(1.-EXPO)**2
      DF5X=(FI2*(EXPO*(-66.*DEL-1.)+1.))/(1.-EXPO)**2
   90 DSOVRU=X*DAA1U+DAA2U+DF1U+DF2U-DF3U-DF4U-DF5U
      DSOVRX=AA1+DF1X+DF2X-DF3X-DF4X-DF5X
      IF(DSOVRX)95,91,95
   91 CHECK=1.
      WRITE(6,501) CHECK,U,X,DSOVRU
      STOP
   95 POVRHO=843467.28*10.**(X-U)
      IF(-POVRHO*DSOVRU/DSOVRX)96,97,97
   96 CHECK=2.
      WRITE(6,502) CHECK,U,X,POVRHO,DSOVRU,DSOVRX
      STOP
   97 SNDSPD=SQRT (-POVRHO*DSOVRU/DSOVRX)
  501 FORMAT(7H CHECK=F3.0,4H  U=1PE14.7,4H  X=1PE14.7,9H  DSOVRU=1PE14.
     17)
  502 FORMAT(7H CHECK=F3.0,4H  U=1PE14.7,4H  X=1PE14.7,9H  POVRHO=1PE14.
     17,9H  DSOVRU=1PE14.7,9H  DSOVRX=1PE14.7)
      RETURN
       END
```

APPENDIX B

FORTRAN LISTING OF AXISYMMETRIC CORE PROGRAM

MAIN ROUTINE

```
C      AXISYMMETRIC CORE PROGRAM
C      COEFFICIENTS B, E, AND G
       BEEF(A,S,Y)=(S*Y+A)/(1.-S*Y*A)
       EEEF(A,S,Y,Q)=    A*Q/(1.+(S*Y)**2)
       GEEF(A,S,Y,Q)=    Q*S*A**2/(1.-S*Y*A)
       DIMENSION X(2,500),Y(2,500),S(2,500),Q(2,500),A(2,500),T(2,500),
      1EM(2,500),R(2,500),XW(500),YW(500),TW(500),EMW(500),PW(500),THETAW
      2(500),RORSTG(500),QW(500),KP(500),XX(4),YY(4),SS(4),QQ(4),AA(4)
C      INITIALIZING
       COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
       REWIND 17
       KW=0
       READ(5,1) NN,IFTH,LM,LN,KK,EMT,XT,RCT,EMZP,GAMA,XZ,DZX,DTX,EPSA,
      1EPSB
     1 FORMAT(5I5,4F10.5/6E12.3)
       CALL TABL(EMT,Y,LM,0,YP)
       CALL REFT(RSTAR,QT,AT,ALPHAT,RHOSTR,QSTAR,EMT)
       CALL CLP(EMZP,PA,PB,PC,PD,EMT,XT,RCT,IFTH,RSTAR,EPSB,GAMA)
       IF (LN) 4,4,2
     2 WRITE(6,3) NN,EMT,RSTAR,XT,RCT,EMZP,IFTH,PA,PB,PC,PD,KK,GAMA,XZ,
      1DZX,DTX,EPSA,EPSB
     3 FORMAT(46H0AXIALLY SYMMETRIC NOZZLE WALL CONTOUR NUMBER I3///23H T
      1ERMINAL MACH NUMBER =F10.6,16H THROAT RADIUS =1PE14.7//5H XT =1PE1
      24.7,10H     RCT =1PE14.7,11H     EMZP =1PE14.7//6H IFTH=I2,7H    P
      3A=1PE14.7,7H    PB=1PE14.7,7H    PC=1PE14.7,7H    PD=1PE14.7,4X,3H
      4KK=I3//6H GAMA=1PE10.3,4X,3HXZ=1PE10.3,4X,4HDZX=1PE10.3,4X,4HDTX=1
      5PE10.3,4X,5HEPSA=1PE10.3,4X,5HEPSB=1PE10.3)
C      MAIN DO LOOP
     4 X(2,1) = XZ
       DO 41 K=1,500
       M=2
       KP(K)=K
       IF (K-1) 13,13,5
C      TEST OLD X
     5 IF(XT-X(1,1)) 6,6,10
C      INCREASE X ON TERMINAL LINE
     6 J=J+1
       N=J
       X(2,N) = XINC(X(1,N-1), DZX/2., DTX/2., K, KK)
C      TERMINAL LINE
       S(2,N)=0.0
       A(2,N)=AT
       EM(2,N)=EMT
       Q(2,N)=QT
       Y(2,N)=AT*(X(2,N)-XT)
       R(2,N)=RSTAR*Y(2,N)
       BR=-AT
```

MAIN ROUTINE (CONT'D)

```
      GR=0.0
      ER=-AT*QT
      GR=0.0
      T(2,N)=0.0
      THETA=0.0
      ALPHA=ALPHAT*57.295780
      IF (LN) 16,16,7
C     PRINT COLUMN HEADINGS FOR EACH CHARACTERISTIC
    7 WRITE(6,8)
    8 FORMAT(1H1 NN  K   N L      X          Y          S          T
     1          THETA    A        ALPHA  Q            M        R     )
C     PRINT CHARACTERISTIC POINTS
      WRITE(6,9) NN,K,N,LZ,X(2,N),Y(2,N),S(2,N),T(2,N),THETA,A(2,N),
     1ALPHA,Q(2,N),EM(2,N),R(2,N)
    9 FORMAT (1H0I3,2I4,I3,F12.6,F11.7,F11.6,F11.7,F8.3,F11.5,F8.3,F11.8
     1,F11.6,F11.8)
      GO TO 16
C     INCREASE X ON CENTER LINE
   10 X(2,1) = XINC (X(1,1), DZX, DTX, K, KK)
C     TEST NEW X ON CENTER LINE
      IF(XT-X(2,1)) 12,12,11
   11 IF (XT-X(2,1)-(X(2,1)-X(1,1))/2.) 12,13,13
   12 X(2,1)=XT
   13 N=1
      CALL CL(EMT,XT,PA,PB,PC,PD,EM(2,1),EMP,X(2,1), IFTH)
C     CENTER LINE
      Y(2,1)=0.0
      R(2,1)=0.0
      T(2,1)=0.0
      THETA=0.0
      CALL QEMCAL(Q(2,1),EM(2,1))
      A(2,1)=1./SQRT (EM(2,1)**2-1.)
      CALL SONCL(S(2,1),EM(2,1),Q(2,1),EMP)
      ALPHA=ATAN (A(2,1))*57.295780
      BR=-A(2,1)
      ER=   -A(2,1)*Q(2,1)
      GR=   A(2,1)**2*Q(2,1)*S(2,1)
      L=1
      LZ=0
      IF (LN) 15,15,14
C     PRINT COLUMN HEADINGS FOR EACH CHARACTERISTIC
   14 WRITE(6,8)
C     PRINT CHARACTERISTIC POINTS
      WRITE(6,9) NN,K,N,LZ,X(2,1),Y(2,1),S(2,1),T(2,1),THETA,A(2,1),
     1ALPHA,Q(2,1),EM(2,1),R(2,1)
   15 J=1
      IF (K-1) 39,39,16
C      DO LOOP FOR ONE CHARACTERISTIC
   16 JJ=J+1
      DO 26  N=JJ,K
      I=1
      BL=BEEF(A(1,N-1),S(1,N-1),Y(1,N-1))
```

MAIN ROUTINE (CONT'D)

```
      EL=EEEF(A(1,N-1),S(1,N-1),Y(1,N-1),Q(1,N-1))
      GL=GEEF(A(1,N-1),S(1,N-1),Y(1,N-1),Q(1,N-1))
      IF (N-2) 18,18,17
C     STARTING VALUES FOR GENERAL POINTS
   17 QQ(1)=Q(1,N-1)+Q(2,N-1)-Q(1,N-2)
      SS(1)=S(1,N-1)+S(2,N-1)-S(1,N-2)
      XX(1)=X(1,N-1)+X(2,N-1)-X(1,N-2)
      YY(1)=Y(1,N-1)+Y(2,N-1)-Y(1,N-2)
      GO TO 19
C     STARTING VALUES FOR FIRST POINT AWAY FROM CENTER LINE
   18 QQ(1)=(Q(1,1)+Q(2,1))/2.
      SS(1)=(S(1,1)+S(2,1))/2.
      XX(1)=(X(1,1)+X(2,1))/2.
      YY(1)=A(1,1)*A(2,1)*(X(2,1)-X(1,1))/(A(1,1)+A(2,1))
C     LOOP WHICH COUNTS SHANKS TRANSFORMS
   19 DO 21 L=1,15
       LL = L
C     LOOP WHICH ITERATES AT EACH POINT
      DO 20 I=2,4
      CALL AY(AA(I-1),QQ(I-1))
C     AVERAGE COEFFICIENTS ON LEFT AND RIGHT
      BBL = BEEF( AA(I-1), SS(I-1), YY(I-1))+ BL
      BBR = BEEF(-AA(I-1), SS(I-1), YY(I-1))+ BR
      EBLS = EEEF( AA(I-1), SS(I-1), YY(I-1), QQ(I-1)) *SS(I-1) +
     1  EL*S(1,N-1)
      EBLY = EEEF( AA(I-1), SS(I-1), YY(I-1), QQ(I-1)) *YY(I-1) +
     1  EL*Y(1,N-1)
      EBRS = EEEF(-AA(I-1), SS(I-1), YY(I-1), QQ(I-1)) * SS(I-1) +
     1   ER*S(2,N-1)
      EBRY = EEEF(-AA(I-1), SS(I-1), YY(I-1), QQ(I-1)) * YY(I-1) +
     1   ER*Y(2,N-1)
      GBL = GEEF( AA(I-1), SS(I-1), YY(I-1), QQ(I-1)) + GL
      GBR = GEEF(-AA(I-1), SS(I-1), YY(I-1), QQ(I-1)) + GR
C     CHARACTERISTICS EQUATIONS
      XX(I)=(2.*(Y(2,N-1)-Y(1,N-1))+X(1,N-1)*BBL-X(2,N-1)*BBR)/(BBL-
     1BBR)
      YY(I)=Y(1,N-1)+BBL*(XX(I)-X(1,N-1))/2.
C     COMPATIBILITY EQUATIONS
      SS(I)=(Q(2,N-1)-Q(1,N-1)+EBRS*(YY(I)-Y(2,N-1))-EBLS*(YY(I)-Y(I
     1,N-1))+GBR*(XX(I)-X(2,N-1))-GBL*(XX(I)-X(1,N-1))-EBRY*S(2,N-1)+
     2EBLY*S(1,N-1))/(EBLY-EBRY)
      QQ(I)=Q(2,N-1)+EBRY*(SS(I)-S(2,N-1))+EBRS*(YY(I)-Y(2,N-1))+GBR*(XX
     1(I)-X(2,N-1))
C     TEST SUCCESSIVE VALUES OF S
      IF(ABS (SS(I)-SS(I-1))-EPSA) 23,23,20
   20 CONTINUE
C     SHANKS TRANSFORM ON X,Y,S AND Q
      I=1
      SS(1)=SHANKS (SS(2),SS(3),SS(4))
      QQ(1)=SHANKS (QQ(2),QQ(3),QQ(4))
      XX(1)=SHANKS (XX(2),XX(3),XX(4))
      YY(1)=SHANKS (YY(2),YY(3),YY(4))
```

MAIN ROUTINE (CONT'D)

```
   21 CONTINUE
C     IF SHANKS IS DONE 15 TIMES
      LL = 15
C     PRINT ITERATIONS OF CHARACTERISTIC RESULTS
      WRITE(6,22) (NN,K,N,LL,XX(I),YY(I),SS(I),QQ(I),I=2,4)
   22 FORMAT(14H0   ITERATIONS/1H I3,2I4,I3,F12.6,F11.7,F11.6,F49.8)
      I = 1
C     PUT LAST ITERATED VALUES IN CHARACTERISTIC GRID
   23 X(2,N)=XX(I)
      Y(2,N)=YY(I)
      S(2,N)=SS(I)
      Q(2,N)=QQ(I)
      CALL AY(A(2,N),Q(2,N))
      T(2,N)=SS(I)*YY(I)
C     COMPUTE MASS FLOW
      CALL MASS(R(2,N),R(2,N-1),X(2,N),X(2,N-1),Y(2,N),Y(2,N-1),A(2,N),
     1A(2,N-1),Q(2,N),Q(2,N-1),RHOSTR,QSTAR)
      BR = BEEF(-A(2,N), SS(I), YY(I))
      ER = EEEF(-A(2,N), SS(I), YY(I), QQ(I))
      GR = GEEF(-A(2,N), SS(I), YY(I), QQ(I))
C     ADDITIONAL RESULTS TO PRINT
      EM(2,N)=SQRT (A(2,N)**2+1.)/A(2,N)
      THETA=ATAN (T(2,N))*57.295780
      ALPHA=ATAN (A(2,N))*57.295780
      IF (LN) 25,25,24
C     PRINT CHARACTERISTIC POINTS
   24 WRITE(6,9) NN,K,N,LL,X(2,N),Y(2,N),S(2,N),T(2,N),THETA,A(2,N),
     1ALPHA,Q(2,N),EM(2,N),R(2,N)
C     WALL TEST
   25 IF(RSTAR-R(2,N)) 27,27,26
   26 CONTINUE
      N = K
      GO TO 39
   27 IF(N-J-2) 28,29,29
   28 IF(J-1) 39,39,42
C     INTERPOLATE AT WALL
   29 KW=KW+1
      IF(KW-1) 30,30,32
   30 KLESS1=K-1
      DO 31 KEEL=1,KLESS1
      XW(KEEL)=0.0
   31 CONTINUE
   32 XW(K)=VINTP(X(2,N),X(2,N-1),X(2,N-2),R(2,N),R(2,N-1),R(2,N-2),
     1RSTAR)
      YW(K)=VINTP(Y(2,N),Y(2,N-1),Y(2,N-2),R(2,N),R(2,N-1),R(2,N-2),
     1RSTAR)
      EMW(K)=VINTP(EM(2,N),EM(2,N-1),EM(2,N-2),R(2,N),R(2,N-1),R(2,N-2),
     1RSTAR)
      THETAW(K)=ATAN (VINTP(T(2,N),T(2,N-1),T(2,N-2),R(2,N),R(2,N-1),
     1R(2,N-2),RSTAR))*57.295780
      CALL QEMCAL(QW(K),EMW(K))
      CALL PCAL(PW(K),QW(K))
```

MAIN ROUTINE (CONT'D)

```
      CALL RHOCAL(RHO,QW(K))
      RORSTG(K)=RHO/RHOSTG
      IF (LN) 36,36,33
C     PRINT WALL HEADINGS
   33 WRITE(6,34)
   34 FORMAT(106H  NN  K   N   J    XW          YW          THETAW    MW
     1          PW/P STAG    QW              RHO/RHO STAG )
C     PRINT WALL RESULTS
      WRITE(6,35) NN,K,N,J,XW(K),YW(K),THETAW(K),EMW(K),PW(K),QW(K),
     1RORSTG(K)
   35 FORMAT(1H I3,3I4,2F12.7,F8.3,2F12.6,2F15.8)
   36 IF(XW(K)-XW(K-1)) 37,37,39
C     ERROR PRINT
   37 WRITE(6,38)
   38 FORMAT (28HOCHARACTERISTICS INTERSECTED)
      STOP
C     PUT NEW CHARACTERISTIC IN PLACE OF OLD
   39 DO 40 I=J,N
      X(1,I)=X(2,I)
      Y(1,I)=Y(2,I)
      S(1,I)=S(2,I)
      Q(1,I)=Q(2,I)
      A(1,I)=A(2,I)
   40 CONTINUE
   41 CONTINUE
C      END POINT VALUES
   42 XW(K)=XT+SQRT (EMT**2-1.)
       KT = K
      YW(K)=1.0
      TW(K)=0.0
      EMW(K)=EMT
      THETAW(K)=0.0
      QW(K)=QT
      CALL PCAL(PW(K),QT)
      CALL RHOCAL(RHO,QT)
      RORSTG(K)=RHO/RHOSTG
      IF (LN) 45,45,43
C     PRINT WALL HEADINGS
   43 WRITE(6,34)
C     PRINT WALL RESULTS
      WRITE(6,35) NN,K,N,J,XW(K),YW(K),THETAW(K),EMW(K),PW(K),QW(K),
     1RORSTG(K)
      WRITE(6,44)
   44 FORMAT (1H1)
   45 WRITE(6,46)NN,EMT,RSTAR,XT,RCT,EMZP,IFTH,PA,PB,PC,PD,KT,KK,GAMA,
     1XZ,DZX,DTX,EPSA,EPSB
   46 FORMAT(46HOAXIALLY SYMMETRIC NOZZLE WALL CONTOUR NUMBER I3///23H T
     1ERMINAL MACH NUMBER =F10.6,16H THROAT RADIUS =1PE14.7//5H XT =1PE1
     24.7,10H      RCT =1PE14.7,11H      EMZP =1PE14.7//6H IFTH=I2,7H    P
     3A=1PE14.7,7H    PB=1PE14.7,7H    PC=1PE14.7,7H    PD=1PE14.7,7H
     4 KT=I3,4X,3HKK=I3//6H GAMA=1PE10.3,4X,3HXZ=1PE10.3,4X,4HDZX=1PE10.
     53,4X,4HDTX=1PE10.3,4X,5HEPSA=1PE10.3,4X,5HEPSB=1PE10.3/13H1 NN  K
```

MAIN ROUTINE (CONT'D)

```
     6   XW 14X,2HYW 14X,6HTHETAW 10X,2HMW 14X,9HPW/P STAG 7X,2HQW 14X,
     712HRHO/RHO STAG)
      IF (LM-1) 47,50,49
C     PRINT WALL RESULTS
   47 WRITE(6,48) (NN,KP(K),XW(K),YW(K),THETAW(K),EMW(K),PW(K),QW(K),
     1RORSTG(K),K=1,KT)
   48 FORMAT(1H I3,I4,1P7E16.7)
      GO TO 53
C     PRINT WALL RESULTS
   49 WRITE(6,48) (NN,KP(K),XW(K),YW(K),THETAW(K),EMW(K),PW(K),QW(K),
     1RORSTG(K),K=1,KT)
   50 DO 51 KEY=1,KT
      IF(XW(KEY)) 51,51,52
   51 CONTINUE
C     PREPARE INPUT TAPE FOR TURBULENT BOUNDARY LAYER PROGRAM
   52 WRITE(26,46) NN,EMT,RSTAR,XT,RCT,EMZP,IFTH,PA,PB,PC,PD,KT,KK,GAMA,
     1XZ,DZX,DTX,EPSA,EPSB
      WRITE(26,48) (NN,KP(K),XW(K),YW(K),THETAW(K),EMW(K),PW(K),QW(K),
     1RORSTG(K),K=KEY,KT)
      END FILE 26
   53 STOP
       END
```

SUBROUTINE TABL

```
      SUBROUTINE TABL(X,Y,N,M,YP)
      DIMENSION GAS(7,1000),A(4,7)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
      J=HIJ
      IF (M) 21,1,12
    1 READ(17,2) NN,PSTAG,TT,RHOSTG,HSTAG,TZ,SSTAG,TAR,TSTAR,ASTAR,
     1PROSTR,RHOSTR,RHOQST,EMMAX,DELTAP
    2 FORMAT(37H1  ISENTROPIC EXPANSION TABLE NUMBER I4//18H SUPPLY COND
     1ITIONS/9H P(ATM.)=1PE14.7,11H T(KELVIN)=1PE14.7,22H RHO(SLUGS/CUBI
     2C FT.)=1PE14.7/23H ENTHALPY(BTU/LB.MASS)=1PE14.7,4H  Z=1PE14.7,
     36H  S/R=1PE14.7,10H  A/ASTAR=1PE14.7//18H THROAT CONDITIONS/11H T(
     4KELVIN)=1PE14.7,18H  ASTAR(FT./SEC.)=1PE14.7,10H  P(ATM.)=1PE14.7/
     522H RHO(SLUGS/CUBIC FT.)=1PE14.7,30H  MASS FLOW(SLUGS/SQ.FT.SEC.)=
     61PE14.7//8H M MAX.=1PE14.7,9H  DELTAP=1PE14.7////120H     LOG10(P/
     7PT)        LOG10(RHO/RHOT)    H/HT            Z                  A/ASTA
     8R(SNDSPD)  M                 AREA/AREA STAR)
      IF (N-1) 5,3,3
    3 WRITE(26,4) NN,PSTAG,TT,RHOSTG,HSTAG,TZ,SSTAG,TAR,TSTAR,ASTAR,
     1PROSTR,RHOSTR,RHOQST,EMMAX,DELTAP
    4 FORMAT(37H1  ISENTROPIC EXPANSION TABLE NUMBER I4//18H SUPPLY COND
     1ITIONS/9H P(ATM.)=1PE14.7,11H T(KELVIN)=1PE14.7,22H RHO(SLUGS/CUBI
     2C FT.)=1PE14.7/23H ENTHALPY(BTU/LB.MASS)=1PE14.7,4H  Z=1PE14.7,
     36H  S/R=1PE14.7,10H  A/ASTAR=1PE14.7//18H THROAT CONDITIONS/11H T(
     4KELVIN)=1PE14.7,18H  ASTAR(FT./SEC.)=1PE14.7,10H  P(ATM.)=1PE14.7/
     522H RHO(SLUGS/CUBIC FT.)=1PE14.7,30H  MASS FLOW(SLUGS/SQ.FT.SEC.)=
```

SUBROUTINE TABL (CONT'D)

```
     61PE14.7//8H M MAX.=1PE14.7,9H  DELTAP=1PE14.7////120H * * * * * *
     7* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     8* * * * * * * * * * * * * * * * * * * * * *)
    5 WRITE(6,4) NN,PSTAG,TT,RHOSTG,HSTAG,TZ,SSTAG,TAR,TSTAR,ASTAR,
     1PROSTR,RHOSTR,RHOQST,EMMAX,DELTAP
    6 DO 8 J=1,997
      READ(17,7) (GAS(I,J),I=1,7)
    7 FORMAT (1P7E17.7)
      IF (GAS(6,J)-X) 8,9,9
    8 CONTINUE
      GO TO 21
    9 DO 10 K=1,3
      KJ=K+J
   10 READ(17,7) (GAS(I,KJ),I=1,7)
   11 HIJ=5
      GO TO 30
   12 NN=-1
      IF(N-5) 14,14,13
   13 NN=1
   14 IF(GAS(N,J)-X) 17,18,15
   15 J=J-NN
      IF(J*(J-1000)) 14,21,21
   16 IF(GAS(N,J)-X) 17,18,18
   17 J=J+NN
      IF(J*(J-1000)) 16,21,21
   18 IF(NN) 19,21,20
   19 JJ=J
      GO TO 23
   20 JJ=J-1
      GO TO 23
   21 WRITE(6,22) J,N,M,JJ,X,Y,YP,NN
   22 FORMAT(2H Z 4I5,1P3E14.7, I5)
      STOP
   23 A(1,N)=GAS(N,JJ-1)
      A(2,N)=GAS(N,JJ)
      A(3,N)=GAS(N,JJ+1)
      A(4,N)=GAS(N,JJ+2)
      A(1,M)=GAS(M,JJ-1)
      A(2,M)=GAS(M,JJ)
      A(3,M)=GAS(M,JJ+1)
      A(4,M)=GAS(M,JJ+2)
      HIJ=J
      F1=X-A(1,N)
      F2=X-A(2,N)
      F3=X-A(3,N)
      F4=X-A(4,N)
      F12=A(1,N)-A(2,N)
      F13=A(1,N)-A(3,N)
      F14=A(1,N)-A(4,N)
      F21=-F12
      F23=A(2,N)-A(3,N)
      F24=A(2,N)-A(4,N)
```

SUBROUTINE TABL (CONT'D)

```
      F31=-F13
      F32=-F23
      F34=A(3,N)-A(4,N)
      F41=-F14
      F42=-F24
      F43=-F34
      P1=F2*F3*F4
      P2=F1*F3*F4
      P3=F1*F2*F4
      P4=F1*F2*F3
      Q1=F12*F13*F14
      Q2=F21*F23*F24
      Q3=F31*F32*F34
      Q4=F41*F42*F43
      Y=P1*A(1,M)/Q1+P2*A(2,M)/Q2+P3*A(3,M)/Q3+P4*A(4,M)/Q4
      YP=(A(3,M)-A(2,M))/(A(3,N)-A(2,N))
   30 RETURN
       END
```

SUBROUTINE CLP

```
      SUBROUTINE CLP(EMZP,PA,PB,PC,PD,EMT,XT,RCT,IFTH,RSTAR,EPSB,GAMA)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
      IF(EMZP) 5,5,10
    5 EMZP=SQRT (((GAMA+1.)/2.)/RSTAR/RCT)
   10 IF(RCT) 15,15,20
   15 RCT=((GAMA+1.)/2.)/(RSTAR*EMZP**2)
   20 IF(IFTH) 30,30,25
C     THICKSTUN CENTER LINE
   25 PA=(EMT-1.)/XT**2
      PB=2./XT-EMZP/(EMT-1.)
      PC=0.0
      PD=0.0
      IF(PB+1./XT) 30,30,45
C     SCHAAF CENTER LINE
   30 IFTH=0
      PB=0.1
      DO 35 L=1,25
      PT = PB*XT
      EBX = EXP (PT*XT)
      EMX = EMZP/(2.*PT)
      PC = EMX*(1.-EBX) +EBX*(EMT - 1.)
      PCP = EMX*(EBX-1.)/PB + EBX*XT**2*(EMT-1.-EMX)
      HB = PC/PCP
      PB = PB - HB
      PD = L
      IF(ABS (HB) - EPSB) 40,40,35
   35 CONTINUE
   40 PA = EMZP/(2.*XT*PB) + 1. - EMT
   45 RETURN
       END
```

SUBROUTINE CL

```
      SUBROUTINE CL (EMT, XT, PA, PB, PC, PD, EM, EMP, X, IFTH)
      IF (IFTH) 15,10,5
    5 EM=EMT-PA*(1.+PB*X)*(X-XT)**2
      EMP=-PA*(X-XT)*(PB*(3.*X-XT)+2.)
      GO TO 15
   10  EBX = EXP (PB*(X-XT)**2)
      EM = EMT - PA*(EBX-1.)
       EMP = -2.*PA*PB*(X-XT)*EBX
   15 RETURN
       END
```

SUBROUTINE REFT

```
      SUBROUTINE REFT(RSTAR,QT,AT,ALPHAT,RHOSTR,QSTAR,EMT)
    5 CALL QEMCAL(QSTAR,1.0)
   10 CALL RHOCAL(RHOSTR,QSTAR)
   15 CALL QEMCAL(QT,EMT)
   20 CALL RHOCAL(RHOT,QT)
   25 RSTAR=SQRT ((RHOT/RHOSTR)*SQRT (QT/QSTAR))
   35 AT=SQRT (1./(EMT**2-1.))
   40 ALPHAT=ATAN (AT)
   45 RETURN
       END
```

SUBROUTINE MASS

```
      SUBROUTINE MASS(R2,R1,X2,X1,Y2,Y1,A2,A1,Q2,Q1,RHOSTR,QSTAR)
    5 YAV=(Y2+Y1)/2.
   10 CALL RHOCAL(RHO2,Q2)
   15 CALL RHOCAL(RHO1,Q1)
   20 RHOAV=(RHO2+RHO1)/2.
   25 QAV=(Q2+Q1)/2.
   30 SINAV=(A2/(SQRT (A2**2+1.))+A1/(SQRT (A1**2+1.)))/2.
   35 R2=SQRT (R1**2+(2./(RHOSTR*SQRT (QSTAR)))*YAV*RHOAV*SQRT (QAV)*
     1SINAV*SQRT ((X2-X1)**2+(Y2-Y1)**2))
   40 RETURN
       END
```

SUBROUTINE SNDVEL

```
      SUBROUTINE SNDVEL(C,Q)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
    5 HRT=1.-Q
   10 CALL TABL(HRT,EM,3,6,EMP)
   15 C=Q/(EM)**2
   20 RETURN
       END
```

SUBROUTINE SNDVLP

```
      SUBROUTINE SNDVLP(CP,Q)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
    5 HRT=1.-Q
      CALL TABL(HRT,AR,3,5,ARP)
      CP=-2.*AR*ARP*(ASTAR**2/(50060.*HSTAG))
   15 RETURN
       END
```

SUBROUTINE SONCL

```
      SUBROUTINE SONCL(S,EM,Q,EMP)
    5 CALL SNDVEL(C,Q)
   10 CALL SNDVLP(CP,Q)
   15 S=(EM*(EM**2-1.)*EMP*C**2)/(2.*Q*(C-Q*CP))
   20 RETURN
       END
```

SUBROUTINE PCAL

```
      SUBROUTINE PCAL(P,Q)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
    5 HRT=1.-Q
   10 CALL TABL(HRT,PRTL,3,1,PRTLP)
   15 P=(10.**PRTL)
   20 RETURN
       END
```

SUBROUTINE RHOCAL

```
      SUBROUTINE RHOCAL(RHO,Q)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
    5 HRT=1.-Q
   10 CALL TABL(HRT,RHORTL,3,2,RORTLP)
   15 RHO=(10.**RHORTL)*RHOSTG
   20 RETURN
       END
```

SUBROUTINE QEMCAL

```
      SUBROUTINE QEMCAL(Q,EM)
      COMMON HSTAG,SSTAG,PSTAG,RHOSTG,ASTAR
    5 CALL TABL(EM,HRT,6,3,HRTP)
   10 Q=1.-HRT
   15 RETURN
       END
```

SUBROUTINE AY

```
      SUBROUTINE AY(A,Q)
    5 CALL SNDVEL(C,Q)
   10 A=SQRT (C/(Q-C))
   15 RETURN
      END
```

FUNCTION SHANKS

```
      FUNCTION SHANKS (A,B,C)
      SHANKS = B + (A-B)*(C-B)/((A-B)+(C-B))
      CALL DVCHK(J)
      GO TO (5,10),J
    5 SHANKS = B
   10 RETURN
      END
```

FUNCTION XINC

```
      FUNCTION XINC (PX, DZX, DTX, K, KK)
      IF (K-KK) 5,5,10
    5 CF=0.0
      GO TO 15
   10 CF=K-KK
   15 XINC=PX+DZX+CF*DTX
      RETURN
      END
```

FUNCTION VINTP

```
      FUNCTION VINTP (VA,VB,VC,HA,HB,HC,HW)
      HD=(HW-HB)/(HA-HC)
      HE=(HW-HA)/(HA-HB)*(HD+1.)
      HF=(HW-HA)/(HB-HC)*HD
      VINTP=VA+(VA-VB)*HE-(VB-VC)*HF
      RETURN
      END
```

APPENDIX C

FORTRAN LISTING OF TURBULENT BOUNDARY LAYER PROGRAM

MAIN ROUTINE

```
C       TURBULENT BOUNDARY LAYER PROGRAM
        DIMENSION Y(200),D(4),QP(20),DQPDS(20),Z(4)
        COMMON Y
        REWIND 26
      1 READ(5,2) THETA,SO,DELS,WALLT,REXIT,Z4,IP,LM,NN,J,NE
      2 FORMAT (6F10.5/5I5)
        Z(1)=THETA
        Z(3)=DELS
        Z(4)=Z4
        IF (IP) 20,3,4
      3 IP1=1
        GO TO 5
      4 IP1=IP
      5 Y(50)=LM
        Y(92)=1-IP1
      6 Y(93)=REXIT
        Y(94)=SO
      7 Y(96)=REXIT
      8 Y(97)=0.0
      9 Y(98)=0.0
     10 Y(99)=IP1
     11 Y(117)=WALLT
     12 S=Y(94)
     13 LMN=LM-3
C       CALL READ WILL CHANGE Y(96) TO XEXIT
        CALL READ (LMN,Y(96),S,QP,DQPDS,SO)
     14 WRITE(6,15) NN,THETA,SO,DELS,REXIT,Z4,IP,J,NE
     15 FORMAT (41HOREAL GAS TURBULENT BOUNDARY LAYER NUMBER I4///7H THETA
       1=0PF9.7,5X,3HSO=F8.5,5X,5HDELS=F8.5,5X,6HREXIT=F8.5,5X,3HZ4=F8.5,5
       2X,3HIP=I3,5X,2HJ=I2,5X,3HNE=I3/1H1 5X,5HPOINT 12X,1HS 14X,1HX 14X,
       31HR 13X,2HEM 13X,2HPE 13X,2HUE/7X,2HHE 12X,4HRHOE 10X,64H DR/DS
       4        DUE/DS         DRHO/DS            HW                HO/101H
       5HAD             HREF             PREF             EMUE             RETH
       6          WALLT          RHOREF/ 10H     EMUREF 12X,2HCF 11X,6HDTH/DS
       7 10X,6HHRATIO 9X,6HTHVDEL 9X,6HDSVDEL 10X,2HEN/9H     THETA 11X,5HD
       8ELTA 10X,6HDELSTR 11X,2HST 14X,1HQ 10X,7H  ERROR 10X,5HRWALL///)
     16 IF (LM-1) 18,17,17
     17 WRITE(16,15) NN,THETA,SO,DELS,REXIT,Z4,IP,J,NE
        EXTERNAL DER,TERM,OUT
     18 CALL FNOL2 (J,1,DELS,0,IP,NE,S,Z,D,DER,TERM,OUT)
        IF (LM-1) 20,19,19
     19 END FILE 16
     20 STOP
         END
```

SUBROUTINE READ

```
      SUBROUTINE READ (L,EXIT,S,QP,DQPDS,SO)
      DIMENSION Q(20),Q1(20),Q2(20),Q3(20),QP(20),DQPDS(20),A(20),B(20),
     1KP(999),XW(999),YW(999),EMW(999),PW(999),QW(999),RORSTG(999)
C     Q(1)=S,Q(2)=X,Q(3)=R,Q(4)=EM,Q(5)=PE,Q(6)=UE,Q(7)=HE,Q(8)=RHOE
      IF (L+1) 1,1,9
    1 READ(26,2) NN,PSTAG,TT,RHOSTG,HSTAG,TZ,SSTAG,TAR,TSTAR,ASTAR,
     1PROSTR,RHOSTR,RHOQST,EMMAX,DELTAP
    2 FORMAT(37H1  ISENTROPIC EXPANSION TABLE NUMBER I4//18H SUPPLY COND
     1ITIONS/9H P(ATM.)=1PE14.7,11H T(KELVIN)=1PE14.7,22H RHO(SLUGS/CUBI
     2C FT.)=1PE14.7/23H ENTHALPY(BTU/LB.MASS)=1PE14.7,4H  Z=1PE14.7,
     36H  S/R=1PE14.7,10H  A/ASTAR=1PE14.7//18H THROAT CONDITIONS/11H T(
     4KELVIN)=1PE14.7,18H  ASTAR(FT./SEC.)=1PE14.7,10H  P(ATM.)=1PE14.7/
     522H RHO(SLUGS/CUBIC FT.)=1PE14.7,30H  MASS FLOW(SLUGS/SQ.FT.SEC.)=
     61PE14.7//8H M MAX.=1PE14.7,9H  DELTAP=1PE14.7////120H * * * * * *
     7* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     8* * * * * * * * * * * * * * * * * * * *)
      READ(26,3) NNN,EMT,RSTAR,XT,RCT,EMZP,IFTH,PA,PB,PC,PD,KT,KK,GAMA,
     1XZ,DZX,DTX,EPSA,EPSB
    3 FORMAT(46H0AXIALLY SYMMETRIC NOZZLE WALL CONTOUR NUMBER I3///23H T
     1ERMINAL MACH NUMBER =F10.6,16H THROAT RADIUS =1PE14.7//5H XT =1PE1
     24.7,10H      RCT =1PE14.7,11H      EMZP =1PE14.7//6H IFTH=I2,7H    P
     3A=1PE14.7,7H    PB=1PE14.7,7H    PC=1PE14.7,7H    PD=1PE14.7,7H
     4 KT=I3,4X,3HKK=I3//6H GAMA=1PE10.3,4X,3HXZ=1PE10.3,4X,4HDZX=1PE10.
     53,4X,4HDTX=1PE10.3,4X,5HEPSA=1PE10.3,4X,5HEPSB=1PE10.3/13H1 NN  K
     6   XW 14X,2HYW 14X,6HTHETAW 10X,2HMW 14X,9HPW/P STAG 7X,2HQW 14X,
     712HRHO/RHO STAG)
      WRITE(6,2) NN,PSTAG,TT,RHOSTG,HSTAG,TZ,SSTAG,TAR,TSTAR,ASTAR,
     1PROSTR,RHOSTR,RHOQST,EMMAX,DELTAP
      WRITE(6,4) NNN,EMT,RSTAR,XT,RCT,EMZP,IFTH,PA,PB,PC,PD,KT,KK,GAMA,
     1XZ,DZX,DTX,EPSA,EPSB
    4 FORMAT(46H0AXIALLY SYMMETRIC NOZZLE WALL CONTOUR NUMBER I3///23H T
     1ERMINAL MACH NUMBER =F10.6,16H THROAT RADIUS =1PE14.7//5H XT =1PE1
     24.7,10H      RCT =1PE14.7,11H      EMZP =1PE14.7//6H IFTH=I2,7H    P
     3A=1PE14.7,7H    PB=1PE14.7,7H    PC=1PE14.7,7H    PD=1PE14.7,7H
     4 KT=I3,4X,3HKK=I3//6H GAMA=1PE10.3,4X,3HXZ=1PE10.3,4X,4HDZX=1PE10.
     53,4X,4HDTX=1PE10.3,4X,5HEPSA=1PE10.3,4X,5HEPSB=1PE10.3/120H * * *
     6* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     7* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *)
      I=0
      J=0
      REXIT=EXIT
      IF (L+2) 6,5,5
    5 WRITE(16,2) NN,PSTAG,TT,RHOSTG,HSTAG,TZ,SSTAG,TAR,TSTAR,ASTAR,
     1PROSTR,RHOSTR,RHOQST,EMMAX,DELTAP
      WRITE(16,4) NNN,EMT,RSTAR,XT,RCT,EMZP,IFTH,PA,PB,PC,PD,KT,KK,
     1GAMA,XZ,DZX,DTX,EPSA,EPSB
    6 IF (999-I) 54,54,7
    7 I=I+1
      READ(26,8) NN,KP(I),XW(I),YW(I),THETAW,EMW(I),PW(I),QW(I),
     1RORSTG(I)
    8 FORMAT (2I4,7E16.7)
      IF (KT-KP(I)) 56,56,6
```

SUBROUTINE READ (CONT'D)

```
    9 IF (L-3) 10,38,38
   10 J=J+1
      IF (EMW(J)) 11,11,12
   11 L=0
      GO TO 10
   12 Q(2)=REXIT*XW(J)
      Q(3)=REXIT*YW(J)
      Q(4)=EMW(J)
      Q(5)=2116.0*PSTAG*PW(J)
      Q(6)=SQRT (50060.0*HSTAG*QW(J))
      Q(7)=HSTAG*(1.0-QW(J))
      Q(8)=RHOSTG*RORSTG(J)
   13 IF(L-1)14,19,24
   14 DO 15 I=2,8
   15 Q1(I)=Q(I)
   16 Q1(1)=S0
   17 L=1
   18 GO TO 10
   19 DO 20 I=2,8
   20 Q2(I)=Q(I)
   21 Q2(1)=SQRT ((Q2(2)-Q1(2))**2+(Q2(3)-Q1(3))**2)+Q1(1)
   22 L=2
   23 GO TO 10
   24 L=3
      DO 25 I=2,8
   25 Q3(I)=Q(I)
   26 Q3(1)=Q2(1)+SQRT ((Q3(2)-Q2(2))**2+(Q3(3)-Q2(3))**2)
C     QP(I)=A(I)*R**2+B(I)*R+Q1(I)
   29 A1=Q2(1)-Q3(1)
   30 A2=Q1(1)-Q3(1)
   31 A3=Q1(1)-Q2(1)
   32 B2=A2**2
   33 B3=A3**2
   34 B1=B2-B3
   35 DEN=A1*A2*A3
   36 DO 37 I=2,8
      A(I)=(Q1(I)*A1-Q2(I)*A2+Q3(I)*A3)/DEN
   37 B(I)=(Q1(I)*B1-Q2(I)*B2+Q3(I)*B3)/DEN
   38 QP(1)=S
   39 IF(QP(1)-Q3(1)) 40,40,45
   40 R=QP(1)-Q1(1)
   41 DO 43 I=2,8
   42 QP(I)=A(I)*R**2+B(I)*R+Q1(I)
   43 DQPDS(I)=2.0*A(I)*R+B(I)
   44 GO TO 57
   45 IF(KT-KP(J)) 40,40,46
   46 J=J+1
      Q(2)=REXIT*XW(J)
      Q(3)=REXIT*YW(J)
      Q(4)=EMW(J)
      Q(5)=2116.0*PSTAG*PW(J)
      Q(6)=SQRT (50060.0*HSTAG*QW(J))
```

SUBROUTINE READ (CONT'D)

```
      Q(7)=HSTAG*(1.0-QW(J))
      Q(8)=RHOSTG*RORSTG(J)
   48 Q(1)=Q3(1)+SQRT ((Q(2)-Q3(2))**2+(Q(3)-Q3(3))**2)
   49 DO 52 I=1,8
   50 Q1(I)=Q2(I)
   51 Q2(I)=Q3(I)
   52 Q3(I)=Q(I)
   53 IF(QP(1)-Q3(1))29,29,45
   54 WRITE(6,55)
   55 FORMAT (60H     STORAGE REQUIRED BY INPUT DATA EXCEEDS ASSIGNED ST
     1ORAGE)
   56 EXIT=XW(I)*REXIT
   57 RETURN
       END
```

SUBROUTINE FNOL2

```
      SUBROUTINE FNOL2(J,N,G,L,M,NE,X,Y,D,DERIV,TERM,OUTPUT)
C     FORTRAN IV      11-63
      DIMENSION Y(50),D(50),YB(30,6),GI2(30),GI3(30),GI4(30),EF(30),
     1EF1(30),EF2(30),EF3(30),Y1(30),ERROR(30),HA(30),YA(50),DA(50),
     2YC(30),YP(30),YD(50)
      DOUBLE PRECISION XD,YD,YA,YC,YP,Y1
      EC=Y(N+3)
    1 H=G
    2 HZ=H
    3 LN=N+MAX0(L,3)
    4 NA=0
    5 NB=1
    6 NF=0
    7 NG=0
    8 F=0.
    9 FA=0.
   10 FB=0.
   11 FC=0.
   12 FD=0.
   13 ENE=NE
      DO 200 I=1,LN
  200 YD(I)=DBLE(Y(I))
      XD=DBLE(X)
   14 IF(J-3)15,21,15
   15 IF(NE)18,16,18
   16 JA=4
   17 GO TO 22
   18 RE1=10.**(-ENE)
   19 RE2=10.**(-ENE-3.0)
   20 REM=10.**(-ENE-1.5)
   21 JA=1
   22 DO 25 I=1,N
   23 DO 24 IC=1,5
```

```
SUBROUTINE FNOL2 (CONT'D)

   24 YB(I,IC)=0.
   25 ERROR(I)=0.
   26 CALL DERIV(X,Y,D)
      DO 300 I=1,N
      GI2(I)=D(I)
      GI3(I)=D(I)
      GI4(I)=D(I)
  300 EF(I)=D(I)
   27 CALL OUTPUT(X,Y,D,ERROR,N,L,H)
   28 FD=Y(N+1)
   29 IF(J-2) 30,129,30
   30 GO TO(31,37,35,37),JA
   31 DO 33 I=1,LN
   32 YA(I)=YD(I)
   33 DA(I)=D(I)
   34 GO TO 37
   35 HB=H
   36 H=2.*H
   37 HD2 = .5*H
      DO 39 I=1,N
   38 YB(I,NB)=D(I)
      XL = D(I) * HD2
   39 Y(I)=SNGL(YD(I)+XL)
      X=SNGL(XD+HD2)
   40 CALL DERIV (X,Y,GI2)
   41 DO 42 I=1,N
      XL = GI2(I)*HD2
   42 Y(I)=SNGL(YD(I)+XL)
   43 CALL DERIV (X,Y,GI3)
   44 DO 45 I=1,N
      XL=GI3(I)*H
   45 Y(I)=SNGL(YD(I)+XL)
      X=SNGL(XD+H)
   46 CALL DERIV(X,Y,GI4)
   47 HD6 =H/6.
      GO TO(48,55,60,66),JA
   48 DO 52 I=1,N
      XL=(D(I) + 2.*(GI2(I) + GI3(I)) +GI4(I))*HD6
   49 YC(I)=YD(I)+XL
   51 YD(I)=YA(I)
   52 ERROR(I)=0.
   53 JA=3
   54 GO TO 35
   55 DO 57 I=1,N
      XL=(D(I) + 2.*(GI2(I) + GI3(I)) +GI4(I))*HD6
   56 YD(I)=YD(I)+XL
   57 ERROR(I)=SNGL(YD(I)-YP(I))/15.
   58 JA=1
   59 GO TO 681
   60 DO 62 I=1,N
   61 YD(I)=YC(I)
      XL=(D(I) + 2.*(GI2(I) + GI3(I)) +GI4(I))*HD6
```

```
SUBROUTINE FNOL2 (CONT'D)

   62 YP(I)=YA(I)+XL
   63 H=HB
   64 JA=2
   65 GO TO 681
   66 DO 68 I=1,N
      XL=(D(I) + 2.*(GI2(I) + GI3(I)) +GI4(I))*HD6
   67 YD(I)=YD(I)+XL
   68 ERROR(I)=0.
  681 DO 69 I=1,N
   69 Y(I)=SNGL(YD(I))
      XD=XD+H
      X=SNGL(XD)
   70 CALL DERIV(X,Y,D)
   71 FC=F
   72 CALL TERM(X,Y,D,F)
   73 IF(ABS(F)-1.0E-5 )731,731,733
  731 NF=5
  732 GO TO 124
  733 IF(F)74,124,76
   74 FA=1.
   75 GO TO 77
   76 FB=1.
   77 IF(FA-FB)83,78,83
   78 NF=NF+1
   79 JA=4
   80 NB=1
   81 H=H*F/(FC-F)
   82 IF(NF-4)37,37,124
   83 IF(NE)84,117,84
   84 IF(JA-1)117,85,117
   85 IF(J-3)86,117,86
   86 DO 95 I=1,N
      IF(Y(I))886,885,886
  885 HA(I)=1000.
      GO TO 95
  886 IF(EC)880,890,87
   87 IF(ABS(Y(I))-EC) 880,880,890
  880 IF(ABS(ERROR(I))-RE2) 882,94,881
  881 IF(ABS(ERROR(I))-RE1)94,94,882
  882 HA(I)=H*(REM/(ABS(ERROR(I))+.0000000001))**(.2)
  883 GO TO 95
  890 IF(ABS(ERROR(I)/Y(I))-RE2)892,94,891
  891 IF(ABS(ERROR(I)/Y(I))-RE1)94,94,892
  892 HA(I)=H*(REM/(ABS(ERROR(I)/Y(I))+.0000000001))**(.2)
  893 GO TO 95
   94 HA(I)=H
   95 CONTINUE
   96 HB=HA(N)
   97 DO 98 I=1,N
   98 HB=AMIN1(HA(I),HB)
   99 IF(H-HB)100,117,101
  100 IF(HZ-H)101,101,116
```

```
      SUBROUTINE FNOL2 (CONT'D)

        101 DO 103 I=1,LN
        102 YD(I)=YA(I)
            Y(I)=SNGL(YD(I))
        103 D(I)=DA(I)
        104 IF(NB-6)107,105,105
        105 XD=XD-H
        106 GO TO 109
        107 XD=XD-2.*H
        108 HZ=H
        109 H=HB
            X=SNGL(XD)
            CALL DERIV(X,Y,D)
        110 NB=1
        111 XABS=ABS(.000001*X)
        112 IF(ABS(H)-XABS)113,113,117
        113 NG=NG+1
        114 H=SIGN(XABS,HB)
        115 IF(NG-10)124,126,126
        116 HZ=H
        117 IF(M)118,118,121
        118 IF(ABS(Y(N+1)-FD)-Y(N+2))29,119,119
        119 FD=Y(N+1)
        120 GO TO 124
        121 NA=NA+1
        122 IF(M-NA)123,123,29
        123 NA=0
       124  CALL OUTPUT(X,Y,D,ERROR,N,L,H)
        125 IF(NF-4)29,29,126
        126 WRITE (6,127)
        127 FORMAT(1H0)
        128 RETURN
        129 NB=NB+1
        130 IF(NB-6)30,131,136
        131 DO 134 I=1,N
        132 EF3(I)=YB(I,3)
        133 EF2(I)=YB(I,4)
        134 EF1(I)=YB(I,5)
        135 GO TO 137
        136 NB=10
        137 HD24 =H/24.
            DO 138 I=1,N
            XL =(55.*D(I) -59.*EF1(I) +37.*EF2(I) -9.*EF3(I))*HD24
            YP(I)=YD(I)+XL
        138 Y(I)=SNGL(YP(I))
            X=SNGL(XD+H)
        139 CALL DERIV(X,Y,EF)
        140 DO 142 I=1,LN
        141 YA(I)=YD(I)
        142 DA(I)=D(I)
        143 DO 148 I=1,N
            XL = (9.*EF(I) +19.*D(I) -5.*EF1(I) +EF2(I))*HD24
        144 YD(I)=YD(I)+XL
```

```
SUBROUTINE FNOL2 (CONT'D)

  145 ERROR(I)=-SNGL(YD(I)-YP(I))/14.
  146 EF3(I)=EF2(I)
  147 EF2(I)=EF1(I)
  148 EF1(I)=D(I)
  149 GO TO 681
      END


SUBROUTINE DER

      SUBROUTINE DER(S,Z,D)
      DIMENSION Y(200),D(4),QP(20),DQPDS(20),Z(4)
      COMMON Y
      Z(2)=S
      XEXIT=Y(96)
      SO=Y(94)
      LL=Y(97)
      L=Y(98)
      THETA=Z(1)
      CALL READ(L,XEXIT,S,QP,DQPDS,SO)
      Y(98)=L
   10 S=QP(1)
   11 X=QP(2)
   12 R=QP(3)
   13 EM=QP(4)
   14 PE=QP(5)
   15 UE=QP(6)
   16 HE=QP(7)
   17 RHOE=QP(8)
   18 DRDS=DQPDS(3)
   19 DUEDS=DQPDS(6)
   20 DRHODS=DQPDS(8)
      WALLT=Y(117)
   21 CALL HWALL(S,WALLT,HW)
   22 HO=HE+(UE**2)/50060.0
   23 PREF=0.72
   24 PRN=PREF**0.333333333
   25 HAD=HE+(HO-HE)*PRN
   26 HREF=0.5*(HW+HE)-0.22*(HAD-HE)
   27 CALL PRANDL(HREF,PE,PR)
   28 IF(ABS ((PR-PREF)/PR)-1.0E-03)31,29,29
   29 PREF=PR
   30 GO TO 24
   31 CALL VISC(PE,HE,EMUE)
   32 RETH=UE*RHOE*THETA/EMUE
   33 CALL ENVAL(RETH,EN)
   34 CALL BOUND(LL,UE,HO,HE,HW,PREF,HAD,THVDEL,DSVDEL,HRATIO,EN,PE)
      Y(97)=LL
   35 DELTA=THETA/THVDEL
   36 DELSTR=THETA*HRATIO
   37 CALL SKIN (UE,RHOREF,RHOE,HE,HW,HO,HI,HREF,THETA,PE,EMUREF,EMUE,
```

```
      SUBROUTINE DER (CONT'D)

           1HRATIO,CF)
      C     LISTING OF EQUIVALENT QUANTITIES
          38 Y(100)=X
          39 Y(101)=R
          40 Y(102)=EM
          41 Y(103)=PE
          42 Y(104)=UE
          43 Y(105)=HE
          44 Y(106)=RHOE
          45 Y(107)=DRDS
          46 Y(108)=DUEDS
          47 Y(109)=DRHODS
          48 Y(110)=HW
          49 Y(111)=HO
          50 Y(112)=HAD
          51 Y(113)=HREF
          52 Y(114)=PREF
          53 Y(115)=EMUE
          54 Y(116)=RETH
          55 Y(117)=WALLT
          56 Y(118)=RHOREF
          57 Y(119)=EMUREF
          58 Y(120)=CF
          59 D(1)=CF/2.0-THETA*((2.0+HRATIO)*DUEDS/UE+DRHODS/RHOE+DRDS/R)
          60 Y(121)=D(1)
          61 Y(122)=HRATIO
          62 Y(123)=THVDEL
          63 Y(124)=DSVDEL
          64 Y(125)=EN
          65 Y(126)=Z(1)
          66 Y(127)=DELTA
          67 Y(128)=DELSTR
          68 CALL HEAT(UE,THETA,EMUREF,RHOREF,PREF,RHOE,HE,HREF,HAD,HW,ST,Q,CF)
          69 Y(129)=ST
          70 Y(130)=Q
          71 Y(132)=R+DELSTR/SQRT  (1.0-DRDS**2)
          72 RETURN
              END


      SUBROUTINE TERM

             SUBROUTINE TERM(S,Z,D,F)
             DIMENSION Y(200),D(4),Z(4)
             COMMON Y
      C      F=XEXIT-X
             F=Y(96)-Y(100)
             RETURN
              END
```

SUBROUTINE OUT

```
      SUBROUTINE OUT (S,Z,D,ERROR,N,L,H)
      DIMENSION Y(200),D(4),ERROR(30),Z(4)
      COMMON Y
      Y(131)=ERROR(1)
      Y(92)=Y(92)+Y(99)
    1 LM=Y(50)
    2 IF(LM-1) 3,7,6
    3 WRITE(6,4) Y(92),S,(Y(I),I=100,132)
    4 FORMAT(1H0F9.0,1PE20.5,1P5E15.5/(1P7E15.5))
    5 GO TO 8
    6 WRITE(6,4) Y(92),S,(Y(I),I=100,132)
    7 WRITE(16,4) Y(92),S,(Y(I),I=100,132)
    8 RETURN
       END
```

SUBROUTINE PRANDL

```
      SUBROUTINE PRANDL(H,P,PR)
    9 PR=0.72
   10 RETURN
       END
```

SUBROUTINE HWALL

```
      SUBROUTINE HWALL (S,WALLT,HW)
      DIMENSION Y(200)
      COMMON Y
C     HOVRT=H/RT
    2 HOVRT=3.48+.00033175*(WALLT-499.17)/(1.0-EXP (-.012287*(WALLT-499.
     117)))
    3 HW=.123406*HOVRT*WALLT
    4 RETURN
       END
```

SUBROUTINE VISC

```
      SUBROUTINE VISC(P,H,EMU)
   11 EMUSTR=(4.654E-08*SQRT (H))/(1.0+48.47/H)
   12 IF(H-100.0)13,13,15
   13 EMU=EMUSTR
   14 GO TO 100
   15 IF(H-600.0)16,16,19
   16 X=ALOG10(H)-2.0
   17 EMU=EMUSTR*(1.0-0.066*X*X)
   18 GO TO 100
   19 Y=ALOG10(P/2116.0)+4.0
```

SUBROUTINE VISC (CONT'D)

```
   20 Y2=Y*Y
   21 Y3=Y2*Y
   22 IF(H-2500.0)23,23,32
   23 X=ALOG10(H)-2.77815
   24 X2=X*X
   25 X3=X2*X
   26 A=2.9345-0.018506*Y3+0.34156*Y2-1.8930*Y
   27 B=-3.0797+0.012489*Y3-0.24747*Y2+1.5311*Y
   28 C=0.26833-0.0016713*Y3+0.032455*Y2-0.19542*Y
   29 D=0.960
   30 GO TO 99
   32 IF(H-5000.0)33,33,41
   33 X=ALOG10(H)-3.39794
   34 X2=X*X
   35 X3=X2*X
   36 A=-15.510-0.31453*Y3+2.9963*Y2-4.3024*Y
   37 B=6.1722+0.13513*Y3-1.3980*Y2+2.6807*Y
   38 C=-0.59538-0.010095*Y3+0.13061*Y2-0.38801*Y
   39 D=0.642-0.00058325*Y3+0.005875*Y2+0.017082*Y
   40 GO TO 99
   41 IF(H-15000.0)44,44,42
   42 WRITE(6,43)
   43 FORMAT(53H   H EXCEEDS 15000 BTU/LB, SUBROUTINE VISC IS INVALID)
   44 X=ALOG10(H)-3.69897
   45 X2=X*X
   46 X3=X2*X
   47 A=0.69954+0.0214412*Y3-0.21721*Y2+0.65378*Y
   48 B=-0.12931-0.0056775*Y3+0.057196*Y2-0.25586*Y
   49 C=-0.42031-0.001909*Y3+0.024503*Y2-0.013625*Y
   50 D=0.599+4.175E-05*Y3+2.500E-04*Y2+2.5833E-02*Y
   99 EMU=EMUSTR*(A*X3+B*X2+C*X+D)
  100 RETURN
      END
```

SUBROUTINE SKIN

```
      SUBROUTINE SKIN (UE,RHOREF,RHOE,HE,HW,HO,HI,HREF,THETA,PE,EMUREF,
     1EMUE,HRATIO,CF)
C     INCOMPRESSIBLE BLASIUS LAW WITH REFERENCE ENTHALPY
      CALL VISC (PE,HREF,EMUREF)
      CALL RHO (PE,HREF,RHOREF)
      CALL RHO (PE,HE,RHOE)
    9 RETHR=RHOREF*UE*THETA/EMUREF
   10 DENR=(RHOREF/RHOE)**1.25
   11 CF=0.0246*DENR/(RETHR**0.25)
   12 RETURN
      END
```

SUBROUTINE ENVAL

```
      SUBROUTINE ENVAL(RETH,EN)
    9 EN=2.05*ALOG10(RETH)-1.65
   10 RETURN
      END
```

SUBROUTINE HEAT

```
      SUBROUTINE HEAT(UE,THETA,EMUREF,RHOREF,PREF,RHOE,HE,HREF,HAD,HW,ST
     1,Q,CF)
    9 ST=CF/(2.0*PREF**0.666666667)
   10 Q=RHOE*UE*ST*(HAD-HW)*32.174
   11 RETURN
      END
```

SUBROUTINE BOUND

```
      SUBROUTINE BOUND(LL,UE,HO,HE,HW,PR,HAD,THVDEL,DSVDEL,HRATIO,EN,PE)
      DIMENSION C(16),Z(16),ZLN(16),ZC(16),ZSQC(16)
   10 IF(LL)11,11,41
C     COEFFICIENTS FOR 16 POINT GAUSSIAN INTEGRATION
   11 C(1)=.01357623
   12 C(2)=.031126762
   13 C(3)=.047579256
   14 C(4)=.062314485
   15 C(5)=.074797995
   16 C(6)=.084578260
   17 C(7)=.091301710
   18 C(8)=.094725305
   19 DO 21 I=1,8
   20 K=17-I
   21 C(K)=C(I)
   22 Z(1)=.005299535
   23 Z(2)=.02771249
   24 Z(3)=.0671844
   25 Z(4)=.1222978
   26 Z(5)=.19106188
   27 Z(6)=.27099161
   28 Z(7)=.35919822
   29 Z(8)=.45249374
   30 Z(9)=.54750626
   31 Z(10)=.64080178
   32 Z(11)=.72900839
   33 Z(12)=.80893812
   34 Z(13)=.8777022
   35 Z(14)=.9328156
   36 Z(15)=.97228751
   37 Z(16)=.99470046
   38 DO 39 I=1,16
```

SUBROUTINE BOUND (CONT'D)

```
  381 ZC(I)=1.0-Z(I)
  382 ZSQC(I)=1.0-Z(I)*Z(I)
   39 ZLN(I)=ALOG (Z(I))
   40 LL=1
   41 PRN=PR**0.333333333
   43 D1=PRN*(H0/HE-1.0)
   44 D2=(HW-HAD)/HE
   46 SUM0=0.0
   47 SUM1=0.0
   48 EN1=EN+1.0
  483 CALL RHO(PE,HE,RHOE)
   49 DO 64   I=1,16
   50 H=HE*(1.0+D1*ZSQC(I)+D2*ZC(I))
   51 CALL RHO(PE,H,R)
   52 GAMMA=R/RHOE
   61 GIZM0=GAMMA*(EXP (ZLN(I)*EN))*C(I)
   62 SUM0=SUM0+GIZM0
   63 GIZM1=GAMMA*(EXP (ZLN(I)*EN1))*C(I)
   64 SUM1=SUM1+GIZM1
   65 THVDEL=EN*(SUM0-SUM1)
   66 DSVDEL=1.0-EN*SUM0
   67 HRATIO=DSVDEL/THVDEL
   68 RETURN
       END
```

SUBROUTINE RHO

```
      SUBROUTINE RHO(P,H,R)
    7 IF(H-100.0)8,10,10
    8 RHO=P/(7147.3*H)
    9 GO TO 14
   10 REFR=7.34412E-05*(P/2117.0)**0.965
   11 HPOW=(H/8465.0)**0.6123
   12 TT=1.0-1.0477*(1.0-HPOW)
   13 RHO=REFR/TT
   14 X4=0.43429448*ALOG (RHO/0.0025089296)
   15 X=0.43429448*ALOG (P/2116.0)
      Y4=H-ENTHLP(X4,X)
      X2=X4
      Y2=Y4
      X4=0.95*X4
      X3=X4
      Y4=H-ENTHLP(X4,X)
      Y3=Y4
      DX=X3-X2
      DY=Y3-Y2
      X4=X3-Y3*DX/DY
      Y4=H-ENTHLP(X4,X)
      DO 20 I=1,15
      X1=X2
```

SUBROUTINE RHO (CONT'D)

```
      Y1=Y2
      X2=X3
      Y2=Y3
      X3=X4
      Y3=Y4
      DXP=DX
      DYP=DY
      DX=X3-X2
      DY=Y3-Y2
      DIV=DXP*DY-DX*DYP
      IF(DIV) 16,22,16
   16 DELINV=(DX+DXP)*DXP/DIV
      RADIC=(DX+DY*DELINV)**2-4.*Y3*DX*DELINV
      IF(RADIC) 23,17,17
   17 XX=SQRT (RADIC)
      XL=X3+X2-DY*DELINV
      X4=.5*(XL+XX)
      XL=.5*(XL-XX)
      XBAR=X3-Y3*DX/DY
      DXR=ABS (X4-XBAR)
      DXL=ABS (XL-XBAR)
      IF(DXR-DXL) 19,19,18
   18 X4=XL
   19 Y4=H-ENTHLP(X4,X)
      TEST=ABS ((X4-X3)/X4)
      IF(TEST-1.0E-03) 24,24,20
   20 CONTINUE
      WRITE(6,21)
   21 FORMAT(55H  SUBROUTINE RHO FAILED TO CONVERGE AFTER 15 ITERATIONS)
      GO TO 24
   22 X4=X3-Y3*DX/DY
      GO TO 19
   23 X4=Y3-.25*(DX+DY*DELINV)**2/(DELINV*DX)
      GO TO 19
   24 R=0.0025089296*EXP (X4/0.43429448)
      RETURN
       END
```

FUNCTION ENTHLP

```
       FUNCTION ENTHLP(U,X)
       AA1=2.4876733E-2+U*(-8.2553890E-3+U*(9.3531968E-4+U*(-6.9802146E-4
      1+U*(-7.0256556E-5+U*(1.1449208E-4+U*(3.5362594E-5+U*(3.4741999E-6
      2+8.9880020E-8*U))))))
       AA2=3.4894155+U*(-2.9193911E-2+U*(1.0481798E-2+U*(-2.6714733E-4
      1+U*(-2.6951449E-4+U*(-2.3151119E-4+U*(-6.2749893E-5+U*(-
      27.5707012E-6-3.6330450E-7*U))))))
       AO=.36547857+U*(1.0189210+U*(-5.4844838E-3+U*(-2.7426243E-2+U*(
      1-7.7107391E-3+U*(2.4202901E-3+U*(1.4256573E-3+U*(2.2860249E-4+
      21.2352353E-5*U))))))
```

FUNCTION ENTHLP (CONT'D)

```
      A1=-23.014062+U*(.46035662+U*(3.0044637E-2+U*(2.8921658E-2+U*(
     1-4.4337102E-3+U*(1.8974229E-4+U*(2.8921472E-3+U*(8.1853124E-4+
     26.2730577E-5*U))))))))
      A2=.71774971+U*(-6.9915246E-2+U*(-4.7677628E-2+U*(-7.2328367E-3
     1+U*(4.6877100E-3+U*(2.1195796E-3+U*(2.6545771E-4+U*(-4.6416051E-7
     2-1.4305115E-6*U))))))))
      C0=.94993342+U*(1.0187300+U*(-2.7831274E-2+U*(-3.3968208E-2+U*(
     1-7.5758964E-3+U*(4.3377145E-3+U*(2.3585523E-3+U*(3.9680529E-4+
     22.2767082E-5*U))))))))
      C1=-56.5+44.6/(1.+EXP (-U-1.75))
      C2=4.2598137+U*(-1.8016141+U*(.28493805+U*(2.5524034E-2+U*(
     1-2.8069440E-4+U*(-1.8133469E-3+U*(-9.7441476E-4+U*(-1.8356511E-4
     2-1.1383541E-5*U))))))))
      E0=1.374+1.046*U
      E1=-20.616464+U*(.99527941+U*(.36318074+U*(7.4026954E-2+U*(
     1-9.5602994E-3+U*(-6.8683405E-3+U*(-8.0744407E-4+U*(2.9434846E-5+
     27.0238870E-6*U))))))))
      E2=-.22188469+U*(-5.5351400E-2+U*(-8.3290583E-3+U*(-6.5111980E-4
     1+U*(1.3836166E-3+U*(8.2097136E-4+U*(1.9030699E-4+U*(2.0702239E-5+
     28.9265052E-7*U))))))))
      E3=.48990558+U*(.30389535+U*(7.2574817E-2+U*(-6.9748615E-3+U*(
     1-6.4693200E-3+U*(-5.8788707E-4+U*(7.7232629E-5+U*(5.3091414E-6-
     26.6747741E-7*U))))))))
      G0=1.835+1.043*U
      G1=-11.591952+U*(1.8211028+U*(1.8682006E-2+U*(3.8627552E-2+U*(
     11.7205973E-2+U*(-3.7323972E-3+U*(-2.2956386E-3+U*(-3.0764239E-4-
     21.2352353E-5*U))))))))
      G2=1.3480705+U*(.21904060+U*(-6.7552429E-3+U*(1.6563452E-2+U*(
     19.1140456E-3+U*(-2.3675397E-3+U*(-1.7376722E-3+U*(-2.9616734E-4-
     21.6477373E-5*U))))))))
      G3=-2.2628366+U*(-1.8824979+U*(-.28388494+U*(1.2905525E-2+U*(
     11.4367226E-2+U*(6.8502795E-6+U*(-9.3289221E-4+U*(-1.7551892E-4
     2-1.0293628E-5*U))))))))
      H0=2.376+1.046*U
      H1=-28.86+.507*U
      H2=.95+.38/(1.+EXP (2.5*(U+4.2)))
      Z1=E1*(X-E0)
      IF(Z1-10.)11,10,10
   10 FX1=0.0
      GO TO 21
   11 IF(Z1+8.)12,12,13
   12 FX1=E2*X+E3
      GO TO 20
   13 FX1=(E2*X+E3)/(1.+EXP (Z1))
   20 Z2=G1*(X-G0)
      IF(Z2-10.)22,21,21
   21 FX2=0.0
      GO TO 31
   22 IF(Z2+8.)23,23,24
   23 FX2=G2*X+G3
      GO TO 30
   24 FX2=(G2*X+G3)/(1.+EXP (Z2))
```

FUNCTION ENTHLP (CONT'D)

```
   30 Z3=H1*(X-HO)
      IF(Z3-10.)32,31,31
   31 FX3=0.0
      GO TO 40
   32 IF(Z3+8.)33,33,34
   33 FX3=H2*(X-HO)
      GO TO 40
   34 IF(ABS (Z3)-.01)35,35,36
   35 FX3=-H2/H1
      GO TO 40
   36 FX3=H2*(X-HO)/(1.-EXP (Z3))
   40 XX=X-FX1-FX2-FX3
   50 Z4=A1*(XX-AO)
      IF(Z4-10.)52,51,51
   51 F1=0.0
      GO TO 61
   52 IF(Z4+8.)53,53,54
   53 F1=A2*(XX-AO)
      GO TO 60
   54 IF(ABS (Z4)-.01)55,55,56
   55 F1=-A2/A1
      GO TO 61
   56 F1=A2*(XX-AO)/(1.-EXP (Z4))
   60 Z5=C1*(XX-CO)
      IF(Z5-10.)62,61,61
   61 F2=0.0
      GO TO 70
   62 IF(Z5+8.)63,63,64
   63 F2=C2*(XX-CO)
      GO TO 70
   64 IF(ABS (Z5)-.01)65,65,66
   65 F2=-C2/C1
      GO TO 70
   66 F2=C2*(XX-CO)/(1.-EXP (Z5))
   70 HRHOVP=AA1*XX+AA2+F1+F2
   75 ENTHLP=33.687746*HRHOVP*10.**(X-U)
      RETURN
       END
```

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13. ABSTRACT: A computer program is presented for designing contoured axisymmetric nozzles when the supply air temperature is high enough to produce real gas effects. The real gas properties of high temperature air in thermodynamic equilibrium are computed using empirical equations and assuming that the air undergoes an isentropic expansion. These properties are used to determine the potential core contour by solving the inviscid flow equations by the method of characteristics. The turbulent boundary layer growth is computed from a numerical integration of the momentum integral equation and is added to the potential core to obtain the nozzle contour. The heat transfer rate is calculated from a form of Reynolds analogy. The computer program covering these phases of nozzle design is presented with the instructions necessary for using it.

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(NOL technical report 64-219)
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1. Nozzles, Axisymmetric
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