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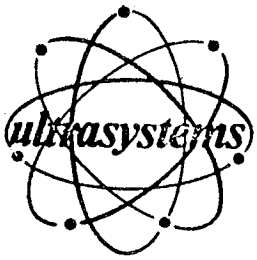

ENGINEERING AND PROGRAMMING MANUAL

TDK

TWO-DIMENSIONAL KINETIC REFERENCE COMPUTER PROGRAM

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FOREWORD

This report contains a complete engineering and programming description for the revised 12/73 version of the Two-Dimensional Kinetic Nozzle Analysis Computer Program, TDK, developed by Ultrasystems, Inc. (formerly Dynamic Science), Irvine, California. Revision of the TDK Computer Program was performed under Contract Numbers NAS9-10391 and NAS9-12652. The work performed was monitored by the NASA Manned Spacecraft Center, Houston, Texas.

The TDK Computer Program is one of a set of five computer programs selected in 1967 by the Joint Army, Navy, Air Force (JANNAF, formerly ICRPG) Liquid Rocket Performance Committee for the purpose of establishing a reference procedure for the calculation of liquid propellant rocket engine performance. These five JANNAF reference computer programs, described in References 1 through 5, are:

ODE	One-Dimensional Equilibrium Nozzle Analysis Computer Program
ODK	One-Dimensional Kinetic Nozzle Analysis Computer Program
TBL	Turbulent Boundary Layer Nozzle Analysis Computer Program
TDE	Two-Dimensional Equilibrium Nozzle Analysis Computer Program
TDK	Two-Dimensional Kinetic Nozzle Analysis Computer Program

Each of the above computer programs was selected as representing the best computer program of its type available for distribution. The reference procedure which utilizes the above computer programs is given in the Liquid Propellant Thrust Chamber Performance Evaluation Manual, Reference 6.

A further program called MABL was developed in 1971 for the purpose of computing boundary layer performance losses in nozzles having mass addition. The MABL program is restricted to H_2/O_2 systems or ideal gas systems and is described in Reference 7.

Experience with the above computer programs has led to a revised version of the TDK computer program as described in this document. This revised program contains the ODE and ODK programs (also substantially revised) as subprograms, thus eliminating the need for separate program decks and documents for ODE and ODK.

The major improvements incorporated in the revised TDK program under contract NAS9-10391 are listed below:

1) The ODE and ODK computer programs have been incorporated into TDK and are used to perform calculations required by the analysis. All calculational options of ODE and ODK have been retained so that these programs are a subset of TDK.

2) Updated JANNAF thermodynamic data has been supplied with the program in curve fit form for 415 chemical species. This data is completely compatible with the ODE version of the NASA Lewis Chemical Equilibrium Computer Program.

3) An input processor is used which allows chemical reactions to be input written in standard reaction form. A consequence of this scheme is that chemical reactions can be added or deleted simply by the addition or deletion of a single input card per reaction.

4) The number of chemical species considered per case by the program has been expanded from 19 to 40 and the number of reactions from 48 to 150.

5) The maximum number of points allowed along a left running characteristic (i.e. gas streamlines) has been increased from 60 to 151.

6) A convenient scheme for inputting and identifying third-body efficiencies has been included in the program.

7) The program is capable of analyzing chemical reactions of two general types: those which involve third body efficiencies and those which do not. Up to 10 species and 10 products per reaction are allowed.

8) An option has been added to TDK to allow the calculations to be continued to the exit plane of the nozzle.

9) The TDK program has been modified so that as many as 50 axially symmetric zones, each at a distinct mixture ratio, may be treated, thus providing a method of estimating the effect of flow striations on nozzle performance.

10) The TDK program has been modified so as to be able to calculate expansions where the downstream throat radius of curvature is arbitrarily small.

11) The transonic calculation used by TDK has been replaced by a method which gives valid results for throat geometries where the upstream radius of curvature is small. It is believed that values as small as $R/r^* = .5$ may be used without introducing significant error into the calculation of nozzle performance. This analysis, which is described in detail in Reference 18, has been derived for the purpose of estimating transonic properties for striated flow.

12) TDK has been modified to provide input parameters corresponding to the variable properties option of the TBL computer program. The TDK program will also output on option free stream fluid properties sufficient for total specification of the wall boundary layer edge conditions.

13) TDK has been modified to punch the method of characteristics initial start line in a form accepted as input for the input TDK initial line option.

14) TDK has been modified to run an ideal gas (constant gamma per zone) transonic and method of characteristics calculations.

15) Numerous changes in the details of the TDK calculations have been carried out. Check calculations for energy and continuity have been added to the computer output.

16) TDK has been modified to run a two-dimensional expansion, using for each zone, tables of Cp, R, kinetic coupling terms AA and BB, (as functions of temperature) generated from the one dimensional expansions.

The major improvements incorporated in the revised TDK program under Contract NAS9-12652 are listed below:

1) The TDK program has been modified to allow calculations to be made for engines whose nozzles have small ($< .5$) downstream radius of curvature resulting in rapid expansion of the exhaust gases. In previous versions the program problems have occurred for this case, particularly when the exhaust is near chemical equilibrium.

2) The ODE program has been replaced by the chemical equilibrium program described in NASA SP-273, Reference 9.

3) The ODE program has been modified to include an option for printing all metric or all engineering units, and the number of supersonic pressure ratios and/or area ratios selected for print has been increased from thirteen to fifty.

4) Input to TDK has been revised to allow adequate interface with the Distributed Energy Release (DER) computer program, described in Reference 10.

5) The Engineering and Programming Manual for the TDK computer program (i.e., this volume) has been revised with special emphasis placed on the Program User's Manual, Section 6. This revised document reflects modifications made under the contract plus additional explanation of all available options to the program, detailed description of all input parameters along with maximum or minimum values for each parameter and recommended values where none exist.

6) An error diagnostic sub-section has been added to the manual (Section 8).

7) TDK has been modified to allow mass flowrate to be input directly and chamber stagnation pressure calculated. The input is structured so that the mass flow can be apportioned among streamtubes to properly account for the pressure and mixture ratio effects in the multiple zone case.

8) The TDK program has been modified to permit two dimensional calculations to be performed under conditions of equilibrium chemistry. This new option of the program is called TDE. Paragraph 7) above, also applies to the TDE option. Results for this option have been compared against exact answers for source flow. The TDE option has been programmed to punch inviscid flow conditions for the JANNAF nozzle wall boundary layer computer programs.

9) The computer program has been modified to input and output with SI (Standard International) units.

Because the ODE program is contained within TDK, liberal use has been made of Reference 9. Excerpts from this document have been utilized in an attempt to document the ODE computer code contained in TDK. The authors would like to express their appreciation to Dr. Sanford Gordon, Dr. David Bittker, and Mrs. Bonnie McBride of the NASA Lewis Research Center for their assistance in providing the updated ODE program used in TDK.

Mr. Ronald Kahl of the NASA Manned Spacecraft Center as contract monitor, has been especially helpful and patient in providing overall guidance and direction to the project as well as Univac 1108 computer time.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

a	Nozzle area ratio, also reaction rate parameter
a_{ki}	Gram atoms of the k^{th} element in the i^{th} species
A	Adiabatic heat addition term linking fluid dynamic and relaxation processes, also total mass reactant in ODE
b	Reaction rate parameter
B	Energy exchange term linking fluid dynamic and relaxation processes
c	Species mass fraction
c_F	Thrust coefficient
C_p	Frozen heat capacity
C_{pe}	Equilibrium heat capacity
C^*	Characteristic exhaust velocity
$\mathcal{C}_i$	Heat capacity per mole of i^{th} species/R
f	Derivative
F	Free energy, also function defined by Equation (2.5-5)
$\mathcal{F}_i$	Free energy per mole of i^{th} species/R
G	Function defined by Equation (2.5-6)
h	Enthalpy, also integration increment
H	Total enthalpy, also function defined by Equation (2.5-7)
ΔH_F	Heat of formation
$\mathcal{H}_i$	Enthalpy per mole of i^{th} species/RT
I_{sp}	Specific impulse
k	Variable increment, also reaction rate parameter
K	Equilibrium constant
m	Reaction rate ratio
Mw	Molecular weight
M	Mach number, also third body reaction term
n	Reaction rate parameter, also summation or iteration index
n_i	Moles of i^{th} species
N_e	Average equilibrium pressure expansion coefficient
P	Pressure

r	Radial distance coordinate, from axis
r^*	Nozzle throat radius
R	Gas constant
R^*	Nozzle wall radius of curvature at throat
$\mathcal{R}$	Universal gas constant
S	Entropy, also summation term
$\mathcal{S}_i$	Entropy per mole of i^{th} species/R
T	Temperature
u	Velocity in x-direction
v	Velocity in r-direction
V	Velocity
x	Axial distance coordinate, from throat
y	Dependent variable
Y_i	Slipline height
α	Mach angle, angle between streamline and Mach line characteristics
α_i	Partial derivative, $\partial f_i/\partial x$
$\beta_{i,j}$	Partial derivative, $\partial f_i/\partial y_j$
γ	Frozen heat capacity ratio
γ_e	Equilibrium heat capacity ratio
δ_i	Incremental error
$\delta_{i,j}$	Kronecker delta
ϵ	Area ratio
ρ	Density
θ	Nozzle cone angle
ω_i	Net species production rate

Subscripts:

c	Refers to chamber conditions
i	Refers to i^{th} species or equation
j	Refers to j^{th} reaction or variable
o	Refers to reference conditions

Superscript:

$*$	Refers to throat conditions or sonic conditions

1. INTRODUCTION

The Two-Dimensional Kinetic Nozzle Analysis Computer Program (TDK) described in this report has been developed for performing reference liquid propellant rocket engine performance calculations. The TDK Computer Program calculates the inviscid two-dimensional nonequilibrium expansion of gaseous propellant exhaust mixtures through rocket exhaust nozzles. Systems of large size can be considered by the program as is indicated by Table 1-1 which gives key maximum dimensions for the program.

The basic method of analysis used by TDK is the method of characteristics. The program constructs a finite-difference mesh by tracing gas streamlines and left running characteristic surfaces. The method of characteristics calculation is capable of considering striations (as many as 50) in the flow. Striated regions are separated by slipline conditions, i.e. adjacent streamlines with matched pressure and gas streamline angle, but at different mixture ratio, temperature, etc. In the present version of TDK mixing between striated zones, is not considered. The initial data line required to start the characteristic calculations can either be input or be calculated by the program using a transonic analysis provided for this purpose. The characteristic equations governing the fluid dynamic variables are integrated using a second order (modified Euler) explicit integration method while the chemical relaxation equations are integrated using a first order implicit integration method to insure numerical stability in near equilibrium flows.

The TDK Computer Program is designed for engineering use and is specified and programmed in a straight forward manner to facilitate its application. The FORTRAN IV programming language has been used in an attempt to make the compute program as machine independent as possible. A complete engineering and programming description of the TDK Computer Program is contained in this report.

Section 2 of this report contains a description of the methods of analysis used in the computer program.

Section 3 contains a description of the numerical methods used to integrate the fluid dynamic and chemical relaxation equations in the computer program.

Section 4 contains a description of the program overlay structure.

Section 5 contains a detailed engineering and programming description of the program logic and the calculations performed in the computer program.

Section 6 contains a program user's manual describing the use of the computer program with an explanation of the program input and output.

Section 7 contains input and output for a sample case using the TDK option of the program.

TABLE 1-1. MAXIMUM DIMENSIONS FOR TDK

Number of defined elements provided	102
Number of possible species per case	40
Number of species in the Master Thermodynamic Data File	415
Number of possible reactions	150
Number of possible reactions with implied third body	50
Number of reactants per reaction	10
Number of products per reaction	10
Maximum stoichiometric coefficient total	600
Number of possible third body efficiencies to be considered	2000
Maximum number of streamlines (i.e. mesh points per left running characteristic)	151
Maximum number of zones (i.e. striations)	50

2. ANALYSIS

The TDK Computer Program has been written for the purpose of evaluating two dimensional effects on the performance of liquid propellant exhaust nozzles. An important feature of the TDK program is its ability to consider nonequilibrium chemical processes. The basic method of analysis used by TDK is the method of characteristics. The program constructs a finite-difference mesh by tracing gas streamlines and left running characteristic surfaces. The mesh points are located at the intersections of these surfaces.

In order to start the method of characteristics calculation, it is necessary to approximate an initial data line across the nozzle throat. This initial data line must be supersonic and must be compatible with the mesh construction methods used by TDK. The calculations performed by TDK to generate this initial data line are carried out in two stages. First chemical information is computed by use of the ODK Computer Program. Using ODK, a one dimensional nonequilibrium calculation is performed beginning at the converging section of the nozzle and ending at an axial station located beyond the throat plane. In this calculation pressure defined relations are used to integrate the differential equations for a one dimensional streamtube. This pressure profile is obtained by computing an average value of expansion coefficient based on a chemical equilibrium gas composition at the nozzle chamber and throat. Pressure and its axial derivative are then obtained for the exact prescribed inlet geometry from the relations for isentropic expansion. Once the pressure profile has been determined the one dimensional nonequilibrium flow relations are integrated starting with an equilibrium calculation obtained at the thrust chamber contraction ratio. The advantage of using the pressure defined boundary condition is that the differential equations are not singular at Mach one so that no difficulties are encountered when integrating through the nozzle throat region. The throat (minimum area) occurs when the product of density and velocity maximize and thus determine the mass flux corresponding to the choke flow condition. Using this mass flux, the nozzle area profile can then be determined. Chemical and fluid properties, obtained from this calculation are retained in the form of tables. The second stage of the calculation makes use of this information and employs a perturbation method to estimate two dimensional effects in the transonic region of the nozzle throat. Striated flows are treated by means of a straight forward extension of the procedure described above.

The description given above is shown schematically in Figure 2-1. The TDK Computer Program is divided into subprograms corresponding to Figure 2-1. These subprograms are illustrated in the master flow chart presented in Figure 2-2. The TBL and MABL computer program referenced in Figure 2-2 are the Turbulent Boundary Layer Computer Program described in detail in Reference 3 and the Mass Addition Boundary Layer Computer Program described in detail in Reference 7. The ØDE program shown in Figure 2-2 is described in detail in Reference 9. For a description of the analysis used by TBL, ØDE, and MABL the above references should be used.

In Section 2.1 of this report the analysis for the ØDK computer program is given. In Section 2.2 a discussion of the finite rate chemistry used by both ØDK and TDK is presented. In Section 2.3 the conservation equations governing two dimensional axisymmetric inviscid flow are presented. In Section 2.4 the transonic flow method used to construct an initial data line for the method of characteristics solution is presented. The method of characteristics relations are presented in Section 2.5. Numerical methods employed are discussed in Section 3.

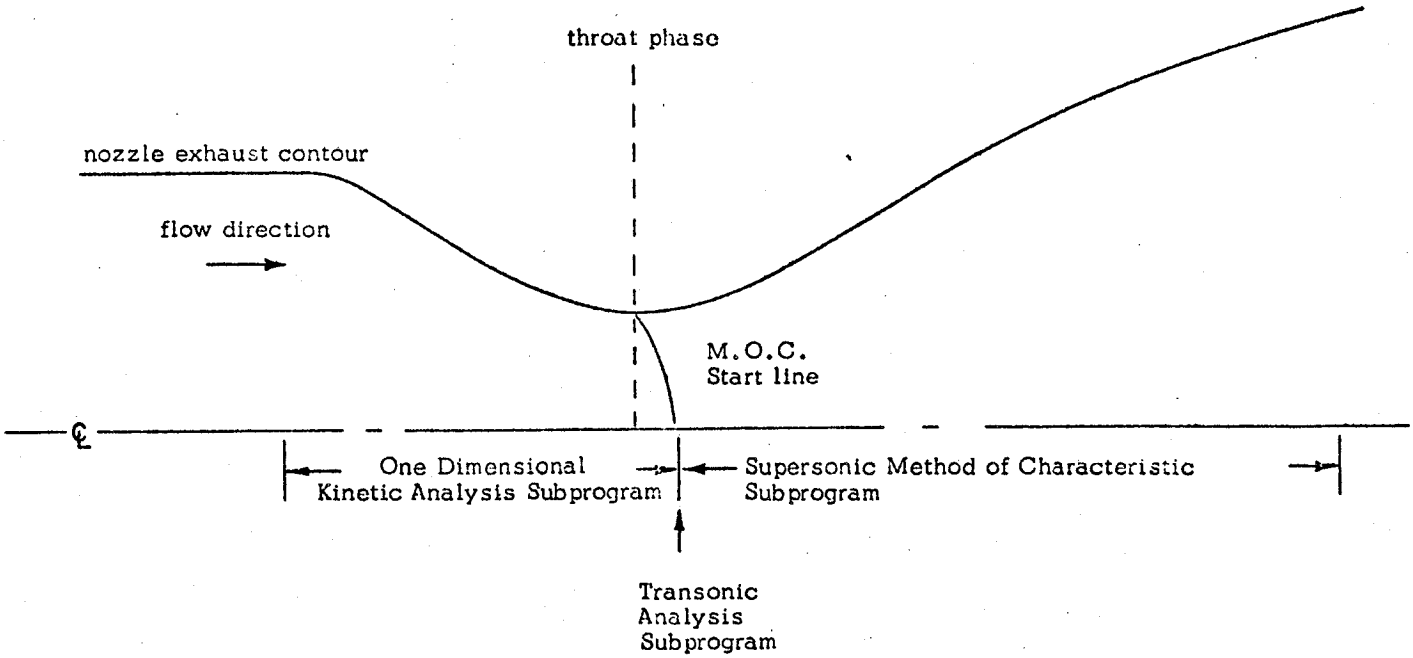


Figure 2-1. Schematic for TDK Analysis

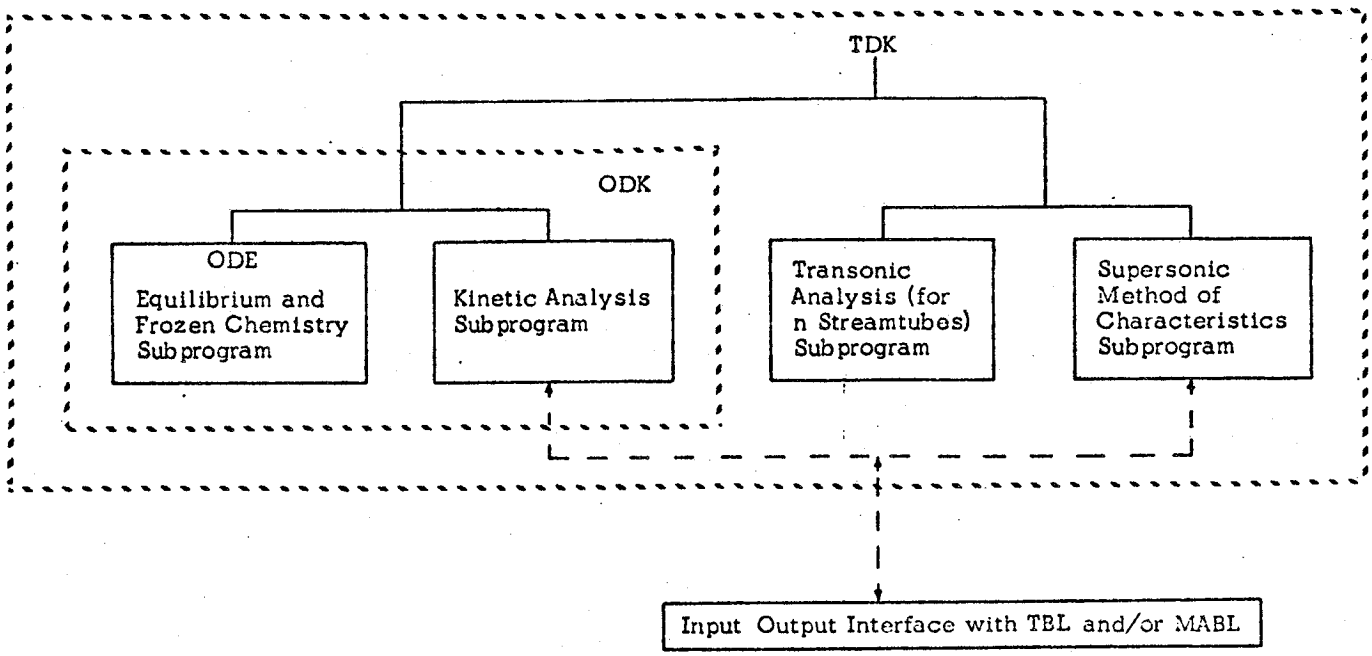


Figure 2-2. Master Flow Chart for TDK

2.1 ANALYSIS FOR THE ØDK COMPUTER PROGRAM

The One Dimensional Kinetic nozzle analysis computer program (ØDK) described in this section has been developed for performing reference liquid propellant thrust chamber performance calculations. The ODK computer program calculates the inviscid one dimensional equilibrium, frozen and nonequilibrium nozzle expansion of gaseous propellant exhaust mixtures. The ØDK program is also used as a subprogram by TDK. The ØDE computer program, which is described in Reference 9, is used to perform the equilibrium composition computations. The ØDE program computations are based on the assumption that species compositions at any pressure and enthalpy point will be distributed such that the free energy of the system is minimized. Solid and liquid phases can be included in ØDE computations, but not in ØDK or TDK computations.

The ODK one dimensional nonequilibrium calculation is performed beginning at the converging section of the nozzle and ending at an axial station located beyond the throat plane. In this calculation pressure defined relations are used to integrate the differential equations for a one dimensional streamtube until the flow becomes supersonic. This pressure profile is obtained by computing an average value of expansion coefficient based on a chemical equilibrium gas composition at the nozzle chamber and throat. These parameters are supplied automatically by ODE. Pressure and its axial derivative are then obtained for the exact prescribed inlet geometry from the relations for isentropic expansion. Once the pressure profile has been determined the one dimensional nonequilibrium flow relations are integrated starting with an equilibrium calculation obtained at the thrust chamber contraction ratio. The advantage of using the pressure defined boundary condition is that the differential equations are not singular at Mach one so that no difficulties are encountered when integrating through the nozzle throat region. The throat (minimum area) occurs when the product of density and velocity maximizes and thus determines the mass flux corresponding to the choke flow condition. Using this mass flux, the nozzle area profile can then be determined. Experience has shown good agreement between this area profile and the original input geometry. Once supersonic conditions are reached the program automatically changes over to area defined differential equations.

2.1.1 Conservation Equations for One Dimensional Kinetic Expansions

The conservation equations governing the inviscid one dimensional flow of reacting gas mixtures have been given by Hirshfelder, Curtiss and Byrd,[11] Penner[12] and others. The basic assumptions made in the derivation of these equations are:

- o There are no mass or energy losses from the system
- o The gas is inviscid
- o Each component of the gas is a perfect gas
- o The internal degrees of freedom (translational, rotational and vibrational) of each component of the gas are in equilibrium.

The conservation equations are presented here in the form used in the present analysis.

For each component of the gas the continuity equation is

$$\frac{d}{dx}\left(\rho_i \bar{V}a\right) = \omega_i r^* a$$

where the axial coordinate (x) has been normalized with the throat radius. Summi over all components of the mixture, the overall continuity equation is obtained

$$\frac{d}{dx}\left(\rho \bar{V}a\right) = 0$$

Combining the above two equations gives

$$\frac{dc_i}{dx} = \frac{\omega_i r^*}{\rho V}$$

The momentum equation is

$$\rho V \frac{dV}{dx} + \frac{dP}{dx} = 0$$

The energy equation is

$$h + \frac{1}{2} V^2 = H_c$$

where

$$h = \sum_{i=1} c_i h_i$$

and

$$h_i = \int_o^T C_{pi} dT + h_{io}$$

For each component of the gas, the equation of state is

$$P_i = \rho_i R_i T$$

Summing over all components of the mixture, the overall equation of state is obtained

$$P = \rho R T$$

where

$$R = \sum_{i=1} c_i R_i$$

Since the expansion through a nozzle can be specified either by the expansion process or by the nozzle geometry, two forms of the above equations are of interest.

If the expansion process is specified and the pressure is known as a function of distance through the nozzle, the above equations become

$$\frac{dc_i}{dx} = \frac{\omega_i r^*}{\rho V}$$

$$\frac{dV}{dx} = -\frac{1}{\rho V}\frac{dP}{dx}$$

$$\frac{d\rho}{dx} = \left[\frac{1}{\gamma P}\frac{dP}{dx} - A\right]\rho$$

$$\frac{dT}{dx} = \left[\frac{\gamma - 1}{\gamma}\frac{1}{P}\frac{dP}{dx} - B\right]T$$

while if the nozzle geometry is specified, the above equations become

$$\frac{dc_i}{dx} = \frac{\omega_i r^*}{\rho V}$$

$$\frac{dV}{dx} = \left[\frac{1}{\tilde{a}}\frac{d\tilde{a}}{dx} - A\right]\frac{V}{M^2 - 1}$$

$$\frac{d\rho}{dx} = -\left\{\left[\frac{1}{\tilde{a}}\frac{d\tilde{a}}{dx} - A\right]\frac{M^2}{M^2 - 1} + A\right\}\rho$$

$$\frac{dT}{dx} = -\left\{\left[\frac{1}{\tilde{a}}\frac{d\tilde{a}}{dx} - A\right]\frac{(\gamma - 1)M^2}{M^2 - 1} + B\right\}T$$

$$P = \rho R T$$

where

$$A = \frac{r^*}{PV}\left[\sum_{i=1} \omega_i R_i T - \frac{\gamma - 1}{\gamma} \sum_{i=1} \omega_i h_i\right]$$

$$B = \frac{\gamma - 1}{\gamma} \frac{r^*}{PV} \sum_{i=1} \omega_i h_i$$

$$M = \frac{V}{\sqrt{\gamma R T}}$$

$$\gamma = \frac{C_p}{C_p - R}$$

and

$$C_p = \sum_{i=1} c_i C_{pi}.$$

The first set of equations is completely specified at the sonic point while the second set of equations is singular. Thus, if the expansion through the nozzle is specified by the pressure distribution, the equations governing the expansion can be directly integrated through the sonic point without mathematical difficulty.

The expansion from the chamber through the sonic point is specified by the pressure distribution in the present program in order to eliminate numerical difficulties at the sonic point. In the expansion section downstream of the sonic point, however, the area variation is specified and the second set of equations is integrated through the supersonic expansion section.

In specifying the nozzle pressure distribution from the chamber through the sonic point, rather than the known area distribution, a question naturally arises regarding how accurately the calculation represents the flow through a specified nozzle geometry. It has been shown by Bray [13] and others that the pressure distribution through a nozzle is essentially identical with the equilibrium pressure distribution up to the freeze point which generally occurs downstream of the throat (or sonic point). Thus, the difference in the expansion and predicted performance caused by utilizing the equilibrium pressure distribution rather than the nozzle geometry to specify the expansion from the chamber to the sonic point is negligible. If a case does arise in which the equilibrium pressure distribution is not an adequate representation of the expansion, the pressure distribution can be iterated to obtain the correct pressure distribution. Experience has shown that this is rarely if ever required.

In the above analysis the chemistry is brought into the conservation equations through the net species production rates, ω_i. The analysis pertaining to the chemistry is given in the following section.

2.2 CHEMISTRY

The method by which the net species production rate, $\dot{\omega}_i$, required by the preceeding analysis is determined is described below.

A chemical reaction can be written in terms of its stoichiometric coefficients (ν_{ij} and ν'_{ij}) as

$$\sum_{i=1} \nu_{ij} \; \bar{M}_i \rightleftarrows \sum_{i=1} \nu'_{ij} \; \bar{M}_i$$

where $\bar{M}_i$ represents the i^{th} chemical species name and j represents the j^{th} reaction.

Given a system of chemical reactions, the net species production rate ω_i for each species (component) is calculated from

$$\omega_i = m_{w_i} \sum_{j=1} \rho^{\sum_{\ell=1} \nu_{\ell j}} (\nu'_{ij} - \nu_{ij}) \; X_j$$

where

$$X_j = [K_j \prod_{i=1} \bar{c}_i^{\,\nu_{ij}} - \rho^{\lambda_j} \prod_{i=1} \bar{c}_i^{\,\nu'_{ij}}] \; k_j \; M_j \qquad (2.2\text{-}1)$$

The reaction rate, k_j, is from right to left (reverse) in the above equation and is represented by the Arrhenius form

$$k_j = a_j T^{-n_j} \, e^{(-b_j/\Re T)}$$

where

a_j	is the pre-exponential coefficient
n_j	is the temperature dependence of the pre-exponential factor
b_j	is the activation energy

The term M_j is provided so that the reaction rate can be modified for reactions involving a third body, i.e.

$M_j = \sum_{i=1} m_{j,i} \, \bar{c}_i$ for reactions requiring a third body

$M_j = 1$ for all other reactions

where the constants $m_{j,i}$ are specified and

$$\bar{c}_i = \bar{c}_i / Mw_i$$

The integer, λ_j, is determined for a given reaction from the stoichometric coefficients

$$\lambda_j = \sum_{i=1} (\nu'_{ij} - \nu_{ij})$$

The equilibrium constant, K_j, is*

$$K_j = e^{-\Delta F/\Re T} \quad (\Re T)^{-\lambda_j}$$

where

$$\Delta F = \sum_{i=1} f_i \nu_{ij} - \sum_{i=1} f_i \nu'_{ij}$$

Reactions involving a third body have a distinct reaction rate for each particular third body, so that the net production rate should be calculated from

$$\dot{X}_j = \sum_{k=1} \left[K_j \prod_{i=1} \bar{c}_i^{\nu_{ij}} - \rho^{\lambda_j} \prod_{i=1} \bar{c}_i^{\nu'_{ij}} \right] \bar{c}_k \, k_{kj} \qquad (2.2\text{-}2)$$

rather than Equation (2.2-1). Benson and Fueno[14] have shown theoretically that the temperature dependence of recombination rates is approximately independent of the third body. Available experimental recombination rate data also indicates that the temperature dependence of recombination rates is independent of the third body within the experimental accuracy of the measurements. Assuming that the temperature dependence of recombination rates is independent of the third body, the recombination rate associated with the k^{th} species (third body) can be represented as

$$k_{kj} = a_{kj} T^{-n_j} e^{(-b_j/\Re T)} \qquad (2.2\text{-}3)$$

where only the constant a_{kj} is different for different species (third bodies). From Equation (2.2-2) it can be shown that

$$\dot{X}_j = \left[K_j \prod_{i=1} \bar{c}_i^{\nu_{ij}} - \rho^{\lambda_j} \prod_{i=1} \bar{c}_i^{\nu'_{ij}} \right] \sum_{k=1} a_{kj} \bar{c}_k \, T^{-n_j} e^{-b_j/\Re T}$$

$$= \left[K_j \prod_{i=1} \bar{c}_i^{\nu_{ij}} - \rho^{\lambda_j} \prod_{i=1} \bar{c}_i^{\nu'_{ij}} \right] \left[\sum_{i=1} \frac{a_{ij}}{a_{kj}} \bar{c}_i \right] a_{kj} \, T^{-n_j} e^{-b_j/\Re T}$$

---

*K_j is also the ratio of the forward to reverse reaction rates.

Thus the recombination rates associated with each third body can be considered as in Equation (2.2-1) by calculating the general third body term (M_j) as

$$M_j = \sum_{i=1} m_{j,i} \bar{c}_i$$

where $m_{j,i}$ is the ratio $\left(\frac{a_{ij}}{a_{kj}}\right)$ of the recombination rate associated with the i^{th} species (third body) to the recombination rate associated with the k^{th} species (third body) which is the reference species (third body) whose rate in the form of Equation (2.2-3) is specified in the program input.

An extensive survey of chemical reactions and rate data for the kinetic expansion of exhaust products of typical liquid rocket propulsion systems has been carried out by Cherry, Reference 15. This survey established 19 chemical species and 48 chemical reactions which must be considered to predict thrust chamber performance within a prescribed tolerance of $\pm$.5 second of specific impulse at an expansion ratio of 40 for the systems studied. (Additional reactions are presented in Reference 16 for systems containing solid phase Al, B, Be, or Li, however, the analysis used here does not consider two phase flow effects). Updated reaction rate data has been recommended by the JANNAF Performance Standardization Working Group Reaction Rate Constant Sub-Committee. This data is presented in Reference 16. Care should be exercised in selecting rate data for a given propellant system and References 15 and 16 should be referred to for further information.

Reaction cards suitable for input the computer program for the 48 reactions refered to above are listed in Table 2-1. The reaction rates listed on these cards have been taken from Reference 16. These rates include the rate data selected by Baulch, et.al. at the University of Leeds as given in Reference 17. Rates for dissociation-recombination reactions are given first in Table 2-1. (i.e. before the first END card) A third body is implied in these reactions and the type of third body is indicated in parenthesis as a comment to the right of the reaction in Table 2-1 (e.g. AR is argon, M is generalized third

body). The second set of reactions listed in Table 2-1 are all binary exchange reactions and no third body is implied. Cards can be abstracted from Table 2-1 for input to the computer program. Note that the reaction rates are those in the forward direction, left to right, as the reaction is written.

In order to use the computer program for systems for which rate data and reactions of importance have not been studied, it is necessary to conduct a screening study. The computer program can be used for this purpose since the chemistry is easily modified by input.

In the case of low pressure systems, the condition of equilibrium is sometime never achieved in the thrust chamber. Systems of this type are discussed in Reference 18. The computer program, however, contains an option for starting with prescribed initial composition so that any gas phase system can be studied provided initial conditions are known.

TABLE 2-1 REACTIONS AND RATE DATA FOR C,CL,F,H,N, AND O SYSTEMS (FROM REFERENCE 16)

```
REACTIONS CCLFHNO   MAY 3-4 1972  JANNAF PSWG     K=AT**-N EXP(-1000B/RT)
   H + OH   = H2O       , A=7.5E23 , N=2.6 , B=0.,                    (AR) NO.
   O + H    = OH        , A=4.0E18 , N=1.  , B=0.,                    (AR) NO.
   O + O    = O2        , A=1.2E17 , N=1.  , B=0.,                    (AR) NO.
   F + F    = F2        , A=5.7E15 , N=1.  , B=0.,                    (AR) NO.
   H + F    = HF        , A=2.5E18 , N=1.  , B=0.,                    (AR) NO.
   H + H    = H2        , A=6.4E17 , N=1.  , B=0.,                    (AR) NO.
      CO2   = O + CO    , A=2.7E32 , N=4.5 , B=127.555,               (N2) NO.
   C + O    = CO        , A=3.0E16 , N=.5  , B=0.,                    (M)  NO.
   N + N    = N2        , A=1.0E18 , N=1.  , B=0.,                    (M)  NO.
   N + O    = NO        , A=6.4E16 , N=.5  , B=0.,          BAULCH    (N2) NO.
  CL + F    = CLF       , A=3.0E16 , N=.5  , B=0.,                    (M)  NO.
   H + CL   = HCL       , A=3.0E16 , N=.5  , B=0.,                    (M)  NO.
  CL + CL   = CL2       , A=1.1E19 , N=1.  , B=0.,                    (M)  NO.
END THR REAX
  H2 + OH   = H + H2O   , A=2.19E13, N=0.  , B=5.15,          BAULCH  NO.
  OH + OH   = O + H2O   , A=5.75E12, N=0.  , B=.780,          BAULCH  NO.
   H + OH   = O + H2    , A=7.33E12, N=0.  , B=7.300,         BAULCH  NO.
   O + OH   = H + O2    , A=1.3E13 , N=0.  , B=0.,            BAULCH  NO.
  OH + CO   = H + CO2   , A=5.6E11 , N=0.  , B=1.080,         BAULCH  NO.
  O2 + CO   = O + CO2   , A=8.85E9 , N=-.656,B=45.920,        BAULCH  NO.
   N + NO   = O + N2    , A=3.1E13 , N=0.  , B=.334,          BAULCH  NO.
   N + O2   = O + NO    , A=6.43E9 , N=-1. , B=6.250,         BAULCH  NO.
  OH + OH   = H2+ O2    , A=1.41E13, N=.015, B=49.264,                NO.
   H + F2   = HF+ F     , A=5.3E12 , N=-.5 , B=4.000,                 NO.
  H2 + F    = HF+ H     , A=5.0E12 , N=0.  , B=5.700,                 NO.
  H2 + F2   = HF+ HF    , A=1.75E10, N=-.5 , B=39.739,                NO.
   H + CL2  = HCL+CL    , A=3.0E14 , N=0.  , B=3.000,                 NO.
  H2 + CL2  = HCL+HCL   , A=1.75E10, N=-.5 , B=45.375                 NO.
  HCL+ H    = H2+CL     , A=6.2E11 , N=-.5 , B=3.100,                 NO.
  HCL+ F    = HF+CL     , A=1.9E12 , N=-.68, B=.600,                  NO.
  CL2+ F    = CL+CLF    , A=6.2E12 , N=-.68, B=.500,                  NO.
  CL + F2   = F +CLF    , A=7.6E12 , N=-.68, B=.300,                  NO.
  CLF+ H    = HF+CL     , A=1.8E12 , N=-.68, B=3.200,                 NO.
  CLF+ H    = HCL+F     , A=5.6E12 , N=-.68, B=1.900,                 NO.
  CLF+ H2   = HCL+HF    , A=1.8E10 , N=-.5 , B=46.337,                NO.
  F2 + HCL  = HF+CLF    , A=1.8E10 , N=-.5 , B=39.427,                NO.
  CLF+ HCL  = HF+CL2    , A=1.8E10 , N=-.5 , B=46.025,                NO.
  F2 + CL2  = CLF+CLF   , A=1.8E10 , N=-.5 , B=26.758,                NO.
  CO2+ C    = CO+CO     , A=1.1E11 , N=-.5 , B=6.995,                 NO.
   C + OH   = CO+ H     , A=5.3E11 , N=-.5 , B=5.628,                 NO.
   C + NO   = CO+ N     , A=5.3E11 , N=-.5 , B=8.303,                 NO.
  CO2+ N    = CO+NO     , A=1.1E11 , N=-.5 , B=59.618,                NO.
   C + O2   = CO+ O     , A=5.3E11 , N=-.5 , B=6.552,                 NO.
  NO + NO   = N2+O2     , A=1.0E13 , N=0.  , B=79.490,                NO.
   N + OH   = NO+ H     , A=5.3E11 , N=-.5 , B=5.628,                 NO.
  OH + F    = HF+ O     , A=2.9E12 , N=-.68, B=.200,                  NO.
  H2O+ F    = HF+OH     , A=1.4E10 , N=-.68, B=.600,                  NO.
  HCL + OH  = H2O+CL    , A=1.0E11 , N=-.5 , B=6.0,
  OH + CL   = HCL+O     , A=5.0E11 , N=-.5 , B=6.0,
LAST REAX
```

2.3 CONSERVATION EQUATIONS FOR TWO DIMENSIONAL KINETIC EXPANSIONS

The conservation equations governing the axisymmetric inviscid flow of reacting gas mixtures have been given by Hirshfelder, Curtiss and Bird,[11] Penner[12] and others. The basic assumptions made in the derivation of these equations are:

- o There are no mass or energy losses from the system
- o The gas is inviscid
- o Each component of the gas is a perfect gas
- o The internal degrees of freedom (translational, rotational, and vibrational) of each component of the gas are in equilibrium.

The conservation equations are presented here in the form used in the present analysis.

For each component of the gas, the continuity equation is

$$\left(\rho_i u\right)_x + \frac{1}{r}\left(r\rho_i v\right)_r = \omega_i r^* \qquad (2.3\text{-}1)$$

where the coordinates (r,x) have been normalized with the throat radius. Summing over all components of the mixture, the overall continuity equation is obtained

$$(\rho u)_x + \frac{1}{r}(r\rho v)_r = 0 \qquad (2.3\text{-}2)$$

Combining the above two equations gives

$$u\left(c_i\right)_x + v\left(c_i\right)_r = \frac{\omega_i r^*}{\rho} \qquad (2.3\text{-}3)$$

The momentum equations are

$$\rho(uu_x + vu_r) + P_x = 0 \qquad (2.3\text{-}4)$$

$$\rho(uv_x + vv_r) + P_r = 0 \qquad (2.3\text{-}5)$$

The energy equation is

$$h + \frac{1}{2}(u^2 + v^2) = H_c \tag{2.3-6}$$

where

$$h = \sum_{i=1} c_i h_i \tag{2.3-7}$$

and

$$h_i = \int_o^T C_{pi}\, dT + h_{io} \tag{2.3-8}$$

For each component of the gas, the equation of state is

$$P_i = \rho_i R_i T \tag{2.3-9}$$

Summing over all components of the mixture, the overall equation of state is obtained

$$P = \rho R T \tag{2.3-10}$$

where

$$R = \sum_{i=1} c_i R_i \tag{2.3-11}$$

2.4 INITIAL LINE CONSTRUCTION

The solution to equations 2.3-1 through 2.3-11 becomes highly complex in the subsonic-transonic domain. Because of the elliptic character of the partial differential equations for the case of steady-state, choked flow in a rocket nozzle, the known boundary conditions are improperly set. Thus, it is necessary to construct by approximate means an initial data line suitable for the calculation by method of characteristics of the flow field in the supersonic domain. The method used by the TDK Computer Program in constructing this initial line is summarized below.

2.4.1 Uniform Expansions

For the purpose of calculating a transonic solution in the region of the nozzle throat, an average expansion coefficient is determined. To accomplish this, a one-dimensional calculation is performed from the chamber to throat for the propellant system and nozzle geometry specified using the ODK subprogram.

Tables of flow properties (ρ, V, T, c_i) are constructed as a function of pressure. These tables span the nozzle throat region. An average expansion coefficient is computed using these tables as*

$$\gamma = \frac{\ln(P_\ell / P_1)}{\ln(\rho_\ell / \rho_1)}$$

where the subscripts 1 and ℓ refer to the first and last table entries, respectively.

Using the above expansion coefficient and the throat wall geometry, the transonic flow field is constructed using the method of Sauer in a somewhat modified form as described in section 2.4.3. The initial line calculated by this method is an approximation to the constant pressure surface emanating from the throat minimum point. Along a constant property line it is a reasonable assumption that a constant value for expansion coefficient can be used.

---

* $\gamma \equiv \frac{d\,\ell n P}{d\,\ell n \rho} \doteq \frac{\ell n\, P_\ell - \ell n\, P_1}{\ell n\, \rho_\ell - \ell n\, \rho_1} = \frac{\ell n(P_\ell / P_1)}{\ell n(\rho_\ell / \rho_1)}$

The TDK transonic analysis computes the pressure value at the throat minimum point, the location of the corresponding isobar, and the variation of streamline flow angle along this isobar. This particular surface has been chosen because it is advantageous from the standpoint of the assumptions made in the transonic analysis. It satisfies boundary conditions exactly at the wall, as well as at the axis and will yield a constant Mach number which is usually slightly greater than unity. If supersonic, this surface will be upstream of its characteristics, both left and right running. Should this surface be subsonic due to nonequilibrium effects, a provision exists for displacing the initial line downstream. Once the pressure surface described above has been calculated, all of the other gas dynamic properties are obtained by interpolation from the tables constructed by ODK.

2.4.2 Zoned Expansions

Many rocket thrust chambers are designed to operate with a cool (fuel rich) barrier zone near the wall to help shield the wall from excessive heat transfer. In addition thrust chamber and injector design usually result in a mal-distribution of the fuel/oxidizer ratio so that the resultant flow is striated into numerous zones of varying mixture ratio. In order to obtain an estimate of the effect of these phenomena on engine performance, a zoned expansion capability is included in the TDK computer program. Each zone is assumed to have a distinct mixture ratio and to contain a specified fraction of the total nozzle mass flow rate. The zones are assumed to be axially symmetric and are distributed radially from the nozzle axis to the nozzle wall.

The procedure used in constructing an initial line for zoned expansions is analogous to that described above for uniform expansions. For the purpose of calculating a transonic solution in the region of the nozzle throat, an average expansion coefficient is determined for each zone. To accomplish this, a one dimensional calculation is performed from the chamber to throat for the propellant system and nozzle geometry specified using the ODK Computer Program. One such calculation is performed for each zone (i.e. for each mixture ratio).

Tables of flow properties (ρ, V, T, c_i) are constructed as a function of pressure for each zone. These tables span the nozzle throat region. An average expansion coefficient, $\bar{\gamma}_n$, is computed for each of N zones using these tables as

$$\bar{\gamma}_n = \frac{\ln(P_\ell / P_1)_n}{\ln(\rho_\ell / \rho_1)_n} \qquad n = 1, \ldots, N$$

where the subscripts 1 and ℓ refer to the first and last table entries, respectively.

Using the above expansion coefficient vector and the throat wall geometry, the transonic flow field is constructed using the method described in section 2.4.3. The initial line calculated by this method is an approximation to the constant pressure surface emanating from the throat minimum point. Along this line each zone is separated by a double point defining the properties on either side of the contact discontinuity.

These points, which have equal pressure and gas streamline angle, become dividing streamline points in the method of characteristics calculation (see subroutine DSPT, Section 5). Properties other than pressure and flow angle are discontinuous across a dividing streamline and these discontinuities may be large. Within a given zone only the gas streamline angle will vary with location (r,x) along the start line. Properties other than pressure and flow angle are obtained by interpolation on pressure from the tables constructed as described above by use of the ODK subprogram.

2.4.3 Transonic Analysis

The basic assumptions made in carrying out the transonic analysis are summarized below (see Reference 8 for a more complete discussion):

- The flow is inviscid and compressible
- The flow is near the sonic speed and directed nearly along the nozzle axis
- The flow is axially symmetric
- The flow is divided into annular zones, each of which is characterized by a single adiabatic expansion coefficient, γ.
- In the nozzle throat region the flow is dependent only on the local wall geometry

With the above assumptions equations 2.3-1 through 2.3-11 reduce to the equations governing the irrotational flow of a perfect gas, i.e.:

$$\frac{\partial v}{\partial x} - \frac{\partial u}{\partial r} = 0$$

and

$$(a^2 - u^2)\ \frac{\partial u}{\partial x} - 2uv\ \frac{\partial u}{\partial r} + (a^2 - v^2)\ \frac{\partial v}{\partial r} + \frac{a^2 v}{r} = 0$$

The method of analysis used to approximate a transonic solution to these equations is a small perturbation technique. For a one zone expansion the method reduces to that given by Sauer.[19] The method consists of normalizing the velocity to the critical speed of sound

$$\tilde{u} = \frac{u}{a^*}$$

$$\tilde{v} = \frac{v}{a^*}$$

Perturbation variables u' and v' (both of which are assumed of small magnitude with respect to unity) are then introduced.

$$\tilde{u} = 1 + u'$$

$$\tilde{v} = v'$$

It can be shown that substituting these relations into the governing equations and retaining only terms through first order gives*

$$\frac{\partial v'}{\partial x} - \frac{\partial u'}{\partial r} = 0$$

$$(\gamma + 1)\, u' \frac{\partial u'}{\partial x} - \frac{\partial v'}{\partial r} - v'/r = 0$$

An exact solution for the above equations can be constructed and is found to be

$$u' = \frac{1}{4}(\gamma + 1) B_1^2 r^2 + C_1 \ln r + B_0 + B_1 x$$

$$v' = \frac{1}{16}(\gamma + 1)^2 B_1^3 r^3 + \frac{1}{2}(\gamma + 1) B_1 C_1 r (\ln r - \frac{1}{2})$$

$$+ \frac{1}{2}(\gamma + 1) B_1 B_0 r + C_2/r$$

$$+ \left[\frac{1}{2}(\gamma + 1) B_1^2 r + C_1/r\right] x$$

where B_0, B_1, C_1, and C_2 are constant coefficients which must be determined from boundary conditions. For the case of a nozzle throat with constant radius of curvature, R, (i.e. a circular arc, see Figure 2.4-1) these coefficients are found to be

$$B_0 = -\frac{1}{4R}$$

$$B_1 = +\left(\frac{2}{(\gamma + 1)R}\right)^{\frac{1}{2}}$$

$$C_1 = C_2 = 0$$

which is the classical solution given by Sauer.[19]

*A complete derivation of the material presented here is given in Reference 8.

Nearly all exhaust nozzles for engines using liquid propellants are constructed with a radius of curvature smaller than appropriate to the small perturbation methods of analysis. Fortunately a simple modification to the method yields results which compare favorably both with experimental measurement and with the results of other analysis when applied to throat geometries such as occur in rocket exhaust nozzles of practical interest. The basis for this modification is to bound the method such that the computed pressure proceeds to a physically reasonable limit for a zero radius of curvature throat. The bound is applied at the wall boundary condition and is chosen such that the ratio of pressure to sonic pressure be zero at this limit. This assumption leads to the result that

$$P/P^* \Big|_{\text{throat}} = 1 - (\gamma/4) \; / \; (R + \gamma/4)$$

rather than the usual result

$$P/P^* \Big|_{\text{throat}} = 1 - (\gamma/4) \; / \; R$$

which is divergent for $R = 0$. Results obtained from the transonic analysis (see Reference 8) have been found to compare favorably to both available experimental data and to the results of other, more complex, analytical methods.

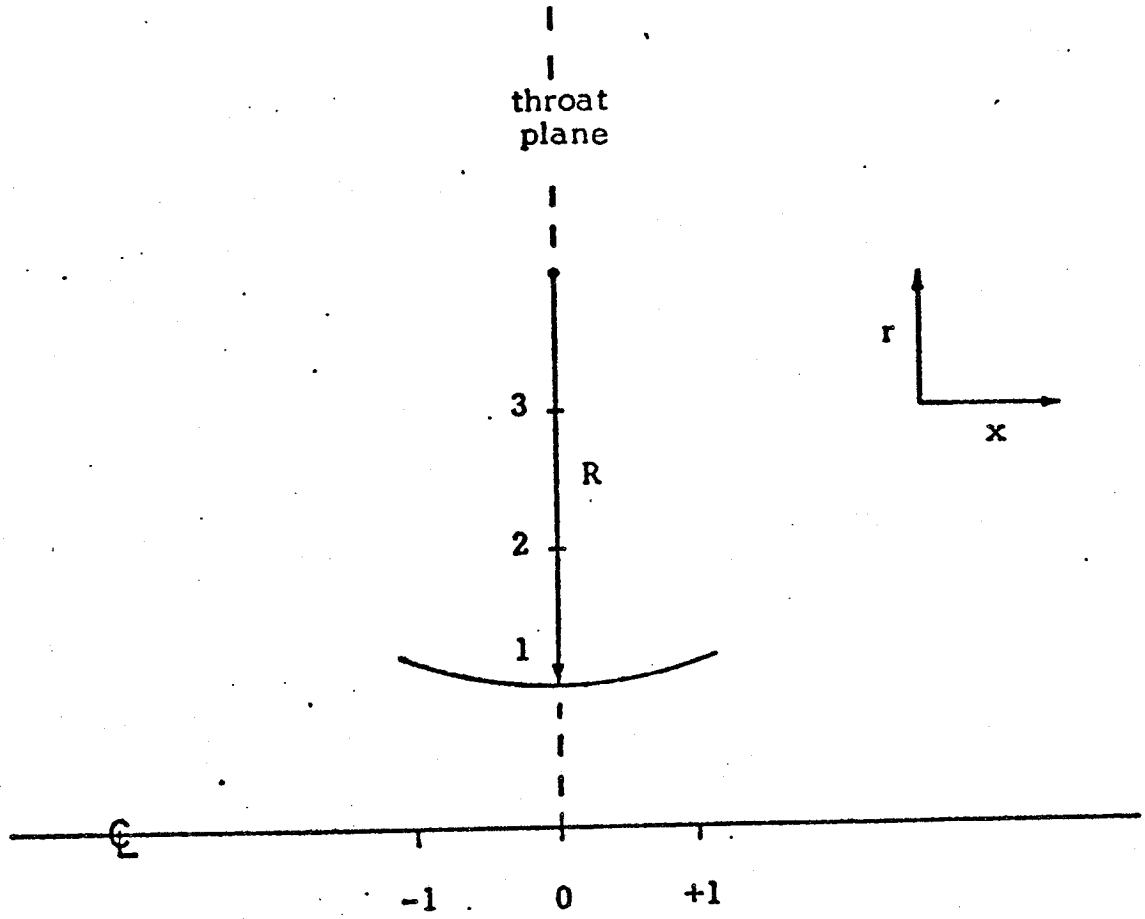


Figure 2.4-1. Nozzle Throat Geometry

To apply the small perturbation analysis to striated flow the analysis assumes that the nozzle flow is divided into N axially symmetric zones, each of which is characterized by a constant (i.e. average) specific heat ratio. These N zones are bounded by N-1 sliplines, i.e. dividing streamlines, such that pressure and streamline angle are matched but other properties such as velocity, temperature, and Mach number are discontinuous. A first order method is used to determine the radial coordinate location, Y_n, of each slipline. Once these locations are known, boundary conditions are applied at the wall, axis, and each slipline to complete the solution.

The indices n = 0, 1, . . . N identifying each zone and slipline boundary are taken numbered from nozzle axis to wall as shown in Figure 2.4-2. The sliplines are located at

$$Y_n \; ; n = 0, 1, \ldots, N$$

The total mass flow rate for the nozzle is

$$\dot{M}$$

and for each zone the partial mass flow rate is

$$\dot{m}_n = \frac{\text{mass flow rate, zone n}}{\dot{M}} \qquad , n = 1, 2, \ldots N$$

so that

$$\sum_{n=1}^{N} \dot{m}_n = 1 = \dot{m}_1 + \dot{m}_2 + \ldots + \dot{m}_n$$

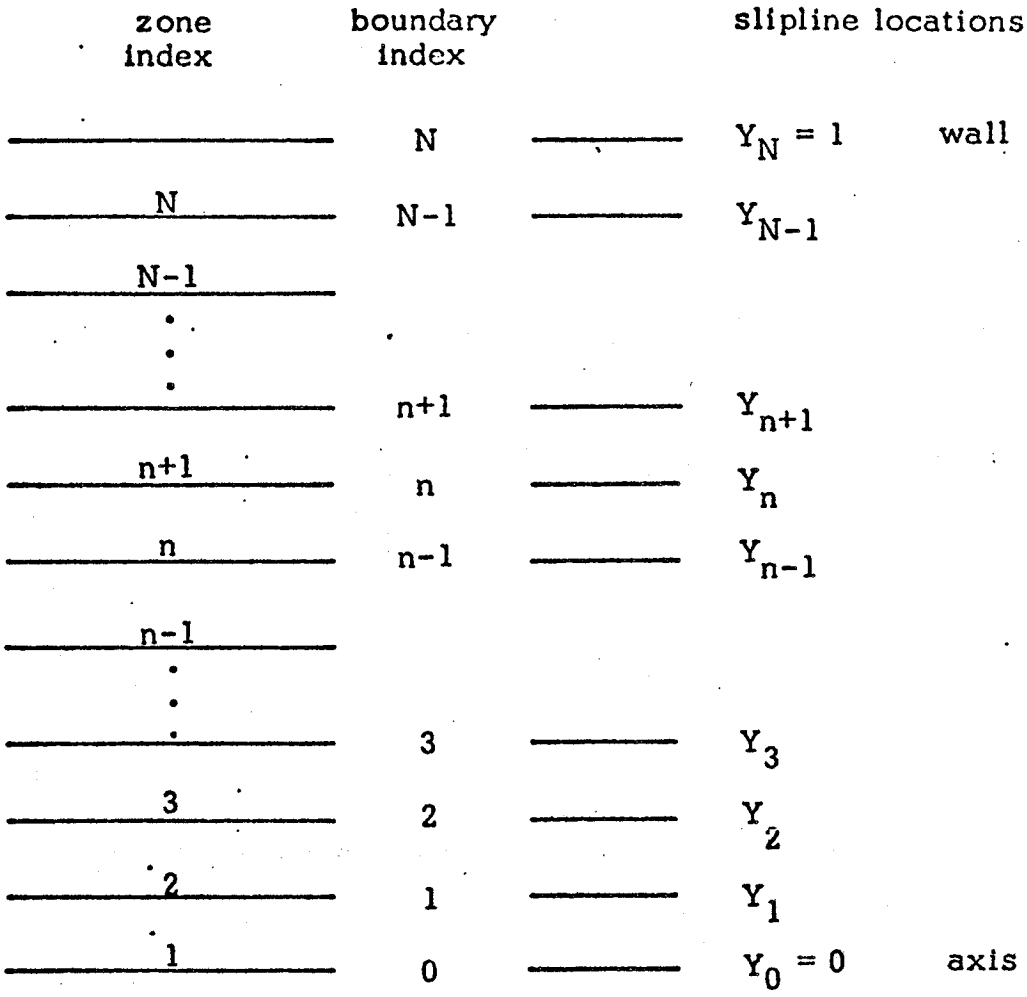


Figure 2.4-2. Nomenclature for the Numbering of Zones

Applying the continuity relation it can be shown that to first order the Y_n^2 are solutions to the tridiagonal system shown below.

$$\begin{bmatrix} (1 + A_1K_1) & -1 & & & \\ -A_2K_2 & (1 + A_2K_2) & -1 & & \\ & \ddots & \ddots & \ddots & \\ & & -A_{N-1}K_{N-1} & (1 + A_{N-1}K_{N-1}) \end{bmatrix} \begin{bmatrix} Y_1^2 \\ Y_2^2 \\ \vdots \\ Y_{N-1}^2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{bmatrix}$$

where

$$K_n \equiv \frac{\dot{m}_{n+1}}{\dot{m}_n} \qquad n = 1, 2, \ldots N-1.$$

$$A_n \equiv \frac{\rho^*_n \, a^*_n}{\rho^*_{n+1} \, a^*_{n+1}} \qquad n = 1, 2, \ldots N-1$$

Once the slipline locations Y_n, are known it is necessary to apply boundary conditions sufficient to determine the constant coefficients B_{0_n}, B_{1_n}, C_{1_n}, C_{2_n}. The conditions applied are:

at the axis;

the radial velocity component is zero.

at the sliplines;

the gas pressure and streamline angle match through first order.

at the wall;

the gas streamline follows the wall streamline through first order.

These conditions require that the following relations be satisfied by the constant coefficients:

at the axis (for n-1);

$$C_{1_1} = C_{2_1} = 0$$

at the sliplines (for n=2, ..., N=1);

$$\frac{1}{16}(\gamma_n+1)^2 B_{1_n}^3 Y_n^3 + \frac{1}{2}(\gamma_n+1) B_{1_n} C_{1_n} Y_n (\ln Y_n - \tfrac{1}{2}) + \frac{1}{2}(\gamma_n+1) B_{1_n} B_{0_n} Y_n + C_{2_n} Y_n^{-1} =$$

$$\frac{1}{16}(\gamma_{n+1}+1)^2 B_{1_{n+1}}^3 Y_n^3 + \frac{1}{2}(\gamma_{n+1}+1) B_{1_{n+1}} C_{1_{n+1}} Y_n (\ln Y_n - \tfrac{1}{2}) + \frac{1}{2}(\gamma_{n+1}+1) B_{1_{n+1}} B_{0_{n+1}} Y_n + C_{2_{n+1}} Y_n^{-1}$$

and

$$\frac{1}{2}(\gamma_n+1) B_{1_n}^2 Y_n + C_{1_n} Y_n^{-1} = \frac{1}{2}(\gamma_{n+1}+1) B_{1_{n+1}}^2 Y_n + C_{1_{n+1}} Y_n^{-1}$$

and

$$P_n^* \left\{1-\gamma_n \left[\frac{1}{4}(\gamma_n+1) B_{1_n}^2 Y_n^2 + C_{1_n} \ln Y_n + B_{0_n}\right]\right\} =$$

$$P_{n+1}^* \left\{1-\gamma_{n+1}\left[\frac{1}{4}(\gamma_{n+1}+1) B_{1_{n+1}}^2 Y_n^2 + C_{1_{n+1}} \ln Y_n + B_{0_{n+1}}\right]\right\}$$

and

$$P_n^* \gamma_n B_{1_n} = P_{n+1}^* \gamma_{n+1} B_{1_{n+1}}.$$

at the wall (n = N);

$$\frac{1}{16}(\gamma_N+1)^2 B_{1_N}^3 - \frac{1}{4}(\gamma_N+1) B_{1_N} C_{1_N}$$

$$+ \frac{1}{2}(\gamma_N+1) B_{1_N} B_{0_N} + C_{2_N} = 0$$

and

$$\frac{1}{2}(\gamma_N+1) B_{1_N}^2 + C_{1_N} = 1/R$$

The above equations form a system of 4N non-linear equations in 4N unknowns (B_{0_n}, B_{1_n}, C_{1_n}, C_{2_n}). For given values of R and of the vectors $\dot{m}_n$, A_n, γ_n, and Y_n the above system of equations can be used to determine the 4N unknown coefficients by employing standard numerical technique.

To apply a numerical method (such as the Newton method) to obtain a solution to the above system of equations requires an estimate for the solution vector (B_{0_n}, B_{1_n}, C_{1_n}, C_{2_n}). The TDK program uses the one zone solution to provide a first estimate. A good estimate is obtained since if

$$\gamma_n = \gamma_{n+1} \qquad n = 1, 2, \ldots, N-1$$

the one zone solution satisfies the above system identically. The program also takes advantage of the banded property of the Jacobian, J, for the above system in using Newton's Method, $x^{(k+1)} = x^{(k)} - J^{(k)^{-1}} f^{(k)}$, to obtain solutions.

The method described above has also been bounded so as to give reasonable answers for nozzle geometries where R is small.

2.5 METHOD OF CHARACTERISTICS FOR KINETIC EXPANSIONS

By standard methods[20] the characteristic relationships for the conservation equations 2.3-1 through 2.3-11 can be shown to be

$$\frac{dr}{dx} = \tan\theta$$

$$d\frac{V^2}{2} + \frac{dP}{\rho} = 0$$

$$\frac{dP}{\gamma P} - \frac{d\rho}{\rho} = \frac{A}{\cos\theta}\,dx$$

$$\frac{\gamma - 1}{\gamma}\frac{dP}{P} - \frac{dT}{T} = \frac{B\,dx}{\cos\theta}$$

$$dc_i = \frac{\omega_i r^*}{\rho V \cos\theta}\,dx$$

along streamlines,

$$\frac{dx}{dr} = \cot(\theta + \alpha) \qquad (2.5\text{-}1)$$

$$\frac{dP}{P} = G\left[\left(A - \frac{\sin\theta}{r}\right)F\,dr - d\theta\right] \qquad (2.5\text{-}2)$$

along left running characteristics, and

$$\frac{dr}{dx} = \tan(\theta - \alpha) \qquad (2.5\text{-}3)$$

$$\frac{dP}{P} = -G\left[\left(A - \frac{\sin\theta}{r}\right)H\,dx - d\theta\right] \qquad (2.5\text{-}4)$$

along right running characteristics, where

$$A = \frac{r^*}{PV}\left(\sum_{i=1} \omega_i R_i T - \frac{\gamma - 1}{\gamma} \sum_{i=1} \omega_i h_i\right)$$

$$B = \frac{r^*}{PV} \frac{\gamma - 1}{\gamma} \sum_{i=1} \omega_i h_i$$

$$V = \left(u^2 + v^2\right)^{1/2}$$

$$\theta = \tan^{-1}\left(\frac{v}{u}\right)$$

$$\alpha = \sin^{-1}\left(\frac{1}{M}\right)$$

$$M = \frac{V}{(\gamma R T)^{1/2}}$$

$$\gamma = \frac{C_p}{C_p - R}$$

$$C_p = \sum_{i=1} c_i C_{pi}$$

$$F = \cos\theta - \sin\theta \cot(\theta + \alpha) \qquad (2.5\text{-}5)$$

$$G = \frac{\gamma}{\sin\alpha \cos\alpha} \qquad (2.5\text{-}6)$$

$$H = \cos\theta \tan(\theta - \alpha) - \sin\theta \qquad (2.5\text{-}7)$$

The above form of the characteristic relationships remains determinant when the streamline is horizontal, when the left running characteristic is vertical, or when the right running characteristic is horizontal. Rarely (if ever) will the inverse of the three situations occur in nozzle flow field calculations.

In the analysis above the chemistry is brought into the conservation equations through the net species production rates, ω_i. The anslysis pertaining to the chemistry is identical to that used by the ODK program as presented in Section 2.2.

3. NUMERICAL METHODS

In this Section numerical methods used by the ODK and TDK programs are discussed. The ODK subprogram integrates the system of differential equations presented in Section 2.1.1. Standard integration methods, such as Runge-Kutta, are impractical when applied to these differential equations because of the very small step sizes often required for stability. Consequently a fully stable integration method has been developed and applied as described in Section 3.1.

Solution of the characteristic differential equations presented in Section 2.5 also requires a numerically stable integration method. A highly stable implicit finite difference method is presented in Section 3.2 for integration of these characteristic relationships.

3.1 ODK NUMERICAL INTEGRATION METHOD

It has been shown by Tyson[21] that in the numerical integration of relaxation equations in near equilibrium flow regions (such as the chamber and nozzle inlet in rocket engines), explicit integration methods are unstable unless the integration step size is of the order of the characteristic relaxation distance of the relaxation equations. Since the characteristic relaxation distance is orders of magnitude smaller than the characteristic physical dimensions of the system of interest (such as the nozzle throat diameter and length) in near equilibrium flow regions, the use of explicit methods to integrate relaxation equations in these regions results in excessively long computation times. Implicit integration methods were shown to be inherently stable in integrating relaxation equations in all flow situations (whether near equilibrium or frozen) and can thus be used to integrate with step sizes of the order of the physical dimensions of the system of interest throughout the integration reducing the computation time per case several orders of magnitude. Since it has been demonstrated that there are significant advantages in using implicit rather than explicit integration of the relaxation equations, a second order implicit integration method has been chosen for use in the ODK computer program.

3.1.1 Stability Considerations

The numerical considerations leading to the above conclusions can be illustrated by considering the simple relaxation equation.

$$\frac{dy}{dx} = -\frac{y - y_e}{\tau} \qquad (3.1\text{-}1)$$

which represents the relaxation toward equilibrium of chemical reactions, gas particle lags, etc. In this equation y_e is the equilibrium condition and τ is the characteristic relaxation distance of the equation. In the equilibrium limit, τ is very small compared to the physical dimensions of the system of interest while in the frozen limit, τ, is very large compared to the physical dimensions of the system of interest. The mathematical behavior of solutions to the above equation can be found by considering the simple case where τ is constant and

$$y_e = y_{eo} + a(x - x_o)$$

which is equivalent to terminating the Taylor series for y_e after the first term. The exact solution of Equation (5-4) for this case can be shown to be

$$y(x_o + h) = y(x_o) + \left[y_{eo} - y(x_o) - a\tau\right]\left[1 - e^{-h/\tau}\right] + ah$$

where $y(x_o)$ is the initial value of y and h is the integration step.

It is seen that the solution consists of two parts, a term which varies slowly with x and a term which exponentially decays with a relaxation length of τ, the characteristic relaxation length of Equation (3.1-1). Thus after a few relaxation lengths

$$y(x) \simeq y_{eo} + ah, \quad h >> \tau$$

which is independent of $y(x_o)$ the initial condition. Since explicit integration methods construct the solution of Equation (3.1-1) as a Taylor series about the initial condition $y(x_o)$, the above example indicated that explicit integration methods should be limited to step sizes of the order of a few relaxation lengths.

That this is indeed the case can be shown by explicitly integrating Equation (5-4) using Euler's method. The explicit finite difference form of Equation (5-4) is then

$$\frac{y(x_o + h) - y(x_o)}{h} = - \frac{y(x_o) - y_{eo}}{\tau}$$

which yields the truncated Taylor series

$$y(x_o + h) = y(x_o) \left(1 - \frac{h}{\tau}\right) + y_{eo} \frac{h}{\tau}$$

when solved for $y(x_o + h)$. After n integration steps, it is found that

$$y(x_o + nh) = y(x_o) \left[1 - \frac{h}{\tau}\right]^n + \sum_{i=1}^{n} \left[y_{oo} + (i - 1)\, ah\right] \left[1 - \frac{h}{\tau}\right]^{n-i} \frac{h}{\tau}$$

Examination of this equation shows that the independence on the initial condition $y(x_o)$ will decay only if $\left|1 - h/\tau\right| < 1$, otherwise $y(x_o + nh)$ will oscillate with rapidly increasing amplitude. Hence the calculation will be stable only if $h/\tau < 2$. Similar results are obtained for other explicit integration methods. (The stable step size for Runge-Kutta integrations is $h/\tau < 5.6$.) Thus the stable step size for explicit integration of relaxation equations is of the order of the relaxation distance which explains the large computation times associated with explicit integration of relaxation equations in near equilibrium flow regions. As shown below, the use of implicit integration methods allows the integration of relaxation equations on a step size which is independent of the relaxation length.

Implicitly integrating Equation (3.1-1) using Euler's method, the finite difference form of Equation (3.1-1) is

$$\frac{y(x_o + h) - y(x_o)}{h} = - \frac{y(x_o + h) - y_{eo} - ah}{\tau}$$

which yields

$$y(x_o + h) = \frac{y(x_o) + (y_{eo} + ah) \frac{h}{\tau}}{1 + \frac{h}{\tau}}$$

when solved for $y(x_o + h)$. After n integration steps it is found that

$$y(x_o + nh) = \frac{y(x_o)}{\left[1 + \frac{h}{\tau}\right]^n} + \sum_{i=1}^{n} \frac{y_{eo} + iah}{\left[1 + \frac{h}{\tau}\right]^{n+1-i}} \frac{h}{\tau} \qquad (3.1\text{-}2)$$

Examination of this equation shows that the dependence on the initial condition $y(x_o)$ always decays, regardless of the step size. Hence the implicit calculation will always be stable. As an extreme example, consider one integration step, $h = x - x_o$. From Equation (3.1-2), it is seen that

$$y(x) \simeq y_{eo} + ah \quad , \quad h >> \tau$$

when the step size is large compared to the relaxation length and

$$y(x) = y(x_o) \left(1 - \frac{h}{\tau}\right) + y_{eo} \frac{h}{\tau} + \ldots , \quad h << \tau$$

when the step size is small compared to the relaxation length.

It is seen that in the equilibrium limit (τ small, h/τ large) the exact solution and the implicit integration of the relaxation equation go to the same limit which is independent of the relaxation distance and depends only on the rate of change of the equilibrium condition. In the frozen case (τ large and h/τ small) the implicit and explicit methods are essentially the same (terminated Taylor series). Thus, implicit numerical integration methods can be used to integrate relaxation equations using step sizes of the order of the physical dimensions of the system of interest in all flow situations whether near equilibrium or near frozen. For a complete discussion of the numerical integration of relaxation equations, see Reference 21.

In choosing a numerical integration method, the primary items of concern are the stability, accuracy and simplicity of the method. As shown by Tyson[21] and discussed above, implicit methods are to be preferred for numerically integrating relaxation equations due to their inherent stability. Having chosen the basic integration method for stability reasons, the order of the integration method is determined by accuracy and simplicity considerations. In general, the higher the order of the integration method, the more complex the method becomes requiring more information in the form of past value or past derivatives of the function being integrated.

Second order methods (accurate to h^2 with error of order h^3) have the advantage of simplicity and flexibility since they require only one past value of the function while retaining sufficient accuracy to allow the use of reasonably economical step sizes. For these reasons, a second order implicit numerical integration method was chosen for use in the present program. A complete derivation of this numerical integration method is given in the following section.

3.1.2 Derivation of the ODK Numerical Integration Method

Consider the coupled set of first order simultaneous differential equations.

$$\frac{dy_i}{dx} = f_i(x, y_1, \ldots, y_N) \quad , \quad i = 1, 2, \ldots, N$$

It will be assumed that the equations are not singluar and that a solution exists which may be developed as a Taylor series about the forward point

$$k_{i,n+1} = \left.\frac{dy_i}{dx}\right|_{x_n+h} h - \left.\frac{d^2y_i}{dx^2}\right|_{x_n+h} \frac{h^2}{2} + \left.\frac{d^3y_i}{dx^3}\right|_{x_n+h} \frac{h^3}{6} - \left.\frac{d^4y_i}{dx^4}\right|_{x_n+h} \frac{h^4}{24} + \cdots$$

where $k_{i,n+1}$ is the increment in y_i and h is sufficiently small. For equal integration steps

$$k_{i,n+1} + k_{i,n} = 2 \left.\frac{dy_i}{dx}\right|_{x_n+h} h - 4 \left.\frac{d^2y_i}{dx^2}\right|_{x_n+h} \frac{h^2}{2} + 8 \left.\frac{d^3y_i}{dx^3}\right|_{x_n+h} \frac{h^3}{6}$$

$$- 16 \left.\frac{d^4y_i}{dx^4}\right|_{x_n+h} \frac{h^4}{24} + \cdots$$

Solving these equations for the derivative at the forward point, it is found that

$$\left.\frac{dy_i}{dx}\right|_{x_n+h} = \frac{3k_{i,n+1} - k_{i,n}}{2h} + \left.\frac{d^3y_i}{dx^3}\right|_{x_n+h} \frac{h^2}{3} - \cdots$$

Expanding the function $f_i(x, y, \ldots, y_N)$ as a Taylor's series about the back point (x_n), it is found that

$$\left.\frac{dy_i}{dx}\right|_{x_n+h} = f_{i,n} + \alpha_{i,n} h + \sum_{j=1}^{N} \beta_{i,j,n} k_{j,n+1} + \left.\frac{d^3y_i}{dx^3}\right|_{x_n} \frac{h^2}{2} + \cdots$$

where

$$f_i = f_i(x, y_1 \ldots, y_N)$$

$$\alpha_i = \frac{\partial f_i}{\partial x}$$

$$\beta_{i,j} = \frac{\partial f_i}{\partial y_j}$$

and the subscript n refers to the functions f_i, α_i and $\beta_{i,j}$ evaluated at the point x_n. Since

$$\left.\frac{d^3y}{dx^3}\right|_{x_n} = \left.\frac{d^3y}{dx^3}\right|_{x_n+h} - \left.\frac{d^4y}{dx^4}\right|_{x_n+h} h + \cdots$$

and

$$\left.\frac{d^4y}{dx^4}\right|_{x_n} = \left.\frac{d^4y}{dx^4}\right|_{x_n+h} - \cdots,$$

Thus the formula for Taylor Series expansion about the back point can be written as

$$\left.\frac{dy_i}{dx}\right|_{x_n+h} = f_{i,n} + \alpha_{i,n}h + \sum_{j=1}^{N} \beta_{i,j,n}k_{j,n+1} + \left.\frac{d^3y_i}{dx^3}\right|_{x_n+h} \frac{h^2}{2} - \cdots$$

Equating the expressions for the derivative at the forward point and back point, it is found that

$$\frac{3k_{i,n+1} - k_{i,n}}{2h} = f_{i,n} + \alpha_{i,n}h + \sum_{j=1}^{N} \beta_{i,j,n}\, k_{j,n+1} + \left.\frac{d^3y_i}{dx^3}\right|_{x_n+h} \frac{h^2}{6} + \cdots$$

or

$$k_{i,n+1} = \frac{1}{3}\left[k_{i,n} + 2\left(f_{i,n} + \alpha_{i,n}h + \sum_{j=1}^{N} \beta_{i,j,n}k_{j,n+1}\right)h\right] + \left.\frac{d^3y_i}{dx^3}\right|_{x_n+h} \frac{h^3}{9} + \cdots$$

Neglecting the third order derivative term and solving the set of N linear nonhomogeneous algebraic equations

$$\left(1 - \frac{2}{3}\beta_{i,i,n}h\right)k_{i,n+1} - \sum_{j=1}^{N}(1 - \delta_{i,j})\beta_{i,j,n}k_{j,n+1} = \frac{1}{3}\left[k_{i,n} + 2(f_{i,n} + \alpha_{i,n}h)h\right]$$

where $\delta_{i,j}$ is the Kronecker delta thus yields a second order implicit solution of the above coupled first order simultaneous differential equations.

For unequal step sizes, it can be similarly shown that solving the set of N linear nonhomogeneous algebraic equations

$$\left(1 - \frac{h_{n+1} + h_n}{2h_{n+1} + h_n}\beta_{i,i,n}h_{n+1}\right)k_{i,n+1} - \frac{h^2_{n+1}}{(2h_{n+1} + h_n)h_n}\sum_{j=1}^{N}(1 - \delta_{i,j})\beta_{i,j,n}k_{j,n+1}$$

$$= \frac{h^2_{n+1}}{(2h_{n+1} + h_n)h_n}\left[k_{i,n} + (f_{i,n} + \alpha_{i,n}h_{n+1})\frac{h_n}{h_{n+1}}(h_{n+1} + h_n)\right]$$

yields a second order implicit solution of the above set of coupled first order simultaneous differential equations.

3.2 TDK NUMERICAL INTEGRATION METHOD

The reacting gas characteristic relationships given in Section 2.5 are generally integrated using second order explicit methods. It has been shown, however,[21] that implicit integration methods are superior to explicit methods for integrating chemical relaxation equations. Thus, in the present program, the fluid dynamic equations are integrated using an explicit modified Euler method while the chemical relaxation equations are integrated using a first order implicit integratio method.

In numerically calculating flow fields using the method of characteristics, only two (previously calculated) known points are directly usable in calculating a forward point. In perfect gas flows, only two known points are required to calculate a forward point and the calculation is straightforward and unambiguous. In non-equilibrium flows, however, more than two known points are required to calculate a forward point so that a choice must be made as to which points in the flow field will be used directly and which will be interpolated. Since even small interpolation errors in species concentrations are known to cause serious stability and accuracy problems in the numerical integration of the chemical relaxation equations, the back streamline point and one characteristic point were chosen as the known points. This choice avoids interpolation for the species concentrations in that only fluid dynamic properties (velocity, pressure, etc.) and the total entropy production term due to all nonequilibrium effects need be interpolated at one of the back characteristic points. Since these quantities are all slowly varying across the characteristics mesh, they can be interpolated quite accurately. Experience has shown that this choice of numerical integration methods and known data points is optimum for reacting gas characteristics calculations. A complete derivation of the numerical integration methods used in the program are given in Sections 3.2.1 and 3.2.2 below.

3.2.1 Integration of the Fluid Dynamic Equations

Consider the flow field shown in Figure 3-1.

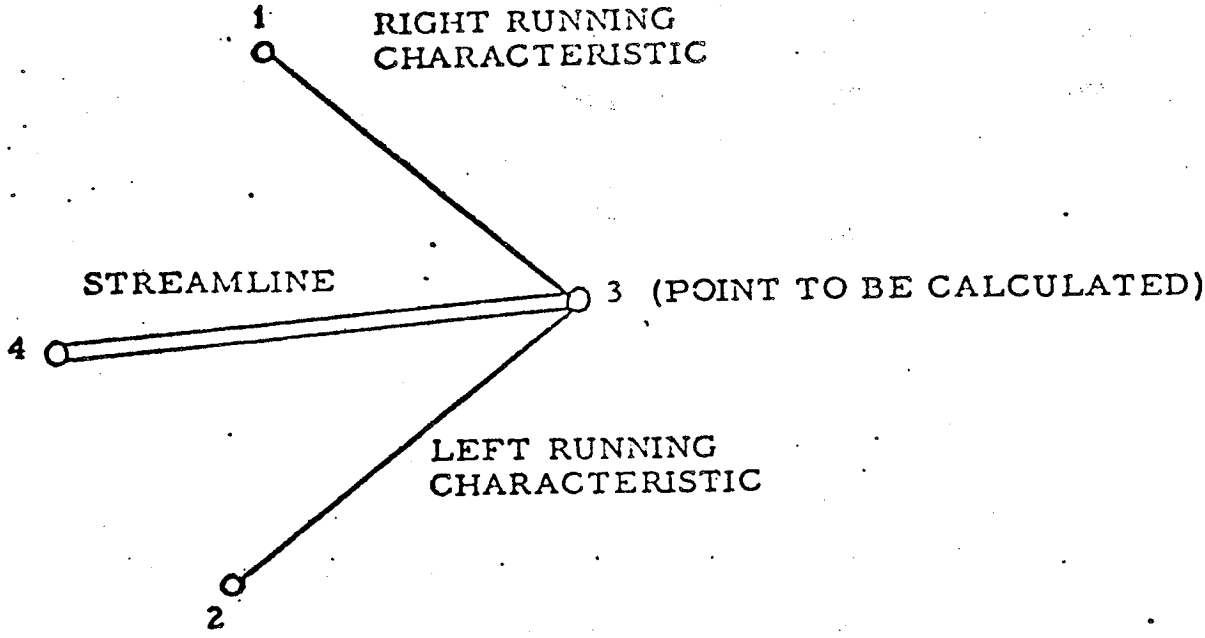


Figure 3-1. Flow Field Calculation

Between points 3 and 4 the streamline characteristics relationships are integrated as

$$r_3 = r_4 + \tan\left[\frac{1}{2}(\theta_4 + \theta_3)\right](x_3 - x_4) \qquad (3.2\text{-}1)$$

$$V_3 = \left\{V_4^2 + \frac{2N}{N-1}\frac{P_4}{\rho_4}\left[1 - \left(\frac{P_3}{P_4}\right)^{\frac{N-1}{N}}\right]\right\}^{1/2} \qquad (3.2\text{-}2)$$

$$\rho_3 = \rho_4\left(\frac{P_3}{P_4}\right)^{\frac{1}{2}\left(\frac{1}{\gamma_4}+\frac{1}{\gamma_3}\right)} \exp\left[-\frac{1}{2}\left(\frac{A_4}{\cos\theta_4} + \frac{A_3}{\cos\theta_3}\right)(x_3 - x_4)\right] \qquad (3.2\text{-}3)$$

$$T_3 = T_4\left(\frac{P_3}{P_4}\right)^{\frac{1}{2}\left(\frac{\gamma_4-1}{\gamma_4}+\frac{\gamma_3-1}{\gamma_3}\right)} \exp\left[-\frac{1}{2}\left(\frac{B_4}{\cos\theta_4} + \frac{B_3}{\cos\theta_3}\right)(x_3 - x_4)\right] \qquad (3.2\text{-}4)$$

where

$$N = \frac{\ln\left(\frac{P_3}{P_4}\right)}{\ln\left(\frac{\rho_3}{\rho_4}\right)}$$

The integration formula (3.2-1) relating the coordinates of points 3 and 4 was chosen because it is exact if the streamline is a circular arc between points 3 and 4. This is an excellent approximation over one mesh step. In integrating the momentum equation to obtain Equation (3.2.2) it was assumed that P varies as ρ^N along the streamline. In integrating the energy equation and the perfect gas relationship to obtain Equations (3.2-2) and (3.2-4), the coefficients γ^{-1}, A/cos θ, $(\gamma - 1)/\gamma$, and B/cos θ appearing in these equations were assumed to be equal to their average value between points 3 and 4. The streamline integration formulas (3.2-2), (3.2-3), and (3.2-4) are exact for nonreacting, constant gamma flows, (i.e. the special case where N equals γ and where A and B are zero). Since often much of the supersonic portion of the flow field is nonreacting (frozen) and approximately a constant gamma flow, these integration formulas are believed to be the best choice for supersonic reacting gas flow field calculations.

Between points 1 and 3 the right running characteristics relationships can be integrated as

$$r_3 = r_1 + \tan\left[\frac{1}{2}(\theta_1 + \theta_3 - \alpha_1 - \alpha_3)\right](x_3 - x_1) \qquad (3.2\text{-}5)$$

$$P_3 = P_1 \exp -\left[\frac{1}{2}(A_1G_1H_1 + A_3G_3H_3)(x_3 - x_1) - \frac{1}{2}\left(\frac{G_1H_1 \sin\theta_1}{r_1} + \frac{G_3H_3 \sin\theta_3}{r_3}\right)(x_3 - x_1) - \frac{1}{2}(G_1 + G_3)(\theta_3 - \theta_1)\right] \qquad (3.2\text{-}6)$$

The finite difference formula (3.2-5) is used for formula (2.5-3) and was chosen because it is exact if the right running characteristic is a

circular arc between points 1 and 3. In integrating the right running characteristic relationship to obtain Equation (3.2-6) the coefficients (AGH, GH sin θ/r, and G) appearing in Equation (2.5-4) were assumed to equal their average value between points 1 and 3.

If point 3 is an axis point then r_3 and θ_3 are zero and the indeterminate quantity $\sin \theta_3/r_3$ appearing in Equation (3.2-6) can be approximated by

$$\frac{\sin \theta_3}{r_3} = \frac{\tan \theta_1}{r_1 + (x_3 - x_1) \tan \theta_1} \qquad (3.2\text{-}7)$$

Equation (3.2-7) is obtained by extrapolating for the ratio $\sin \theta/r$ on the axis, assuming that the flow near the axis is a source flow.

Between points 2 and 3 the left running characteristics relationships can be integrated as

$$x_3 = x_2 + \cot\left[\frac{1}{2}(\theta_2 + \theta_3 + a_2 + a_3)\right](r_3 - r_2) \qquad (3.2\text{-}8)$$

$$P_3 = P_2 \exp\left[\frac{1}{2}(A_2G_2F_2 + A_3G_3F_3)(r_3 - r_2) - \frac{1}{2}\left(\frac{G_2F_2 \sin \theta_2}{r_2} + \frac{G_3F_3 \sin \theta_3}{r_3}\right)(r_3 - r_2) - \frac{1}{2}(G_2 + G_3)(\theta_3 - \theta_2)\right] \qquad (3.2\text{-}9)$$

The formula (3.2-8) is the finite difference expression used for formula (2.5-1) and formula (3.2-9) is the finite difference expression used for formula (2.5-2).

If point 2 is an axis point, then r_2 and θ_2 are zero and the indeterminate quantity $\sin \theta_2/r_2$ appearing in Equation (3.2-9) is that quantity previously calculated for the axis point using Equation (3.2-7).

Equations (3.2-6) and (3.2-9) can be combined to yield

$$\theta_3 = \frac{1}{G_3 + \frac{1}{2}(G_1 + G_2)} \left[\ln\left(\frac{P_2}{P_1}\right) + \frac{1}{2}(G_1 + G_3)\theta_1 + \frac{1}{2}(G_2 + G_3)\theta_2 \right.$$

$$+ \frac{1}{2}(A_2 G_2 F_2 + A_3 G_3 F_3)(r_3 - r_2)$$

$$- \frac{1}{2}\left(\frac{G_2 F_2 \sin\theta_2}{r_2} + \frac{G_3 F_3 \sin\theta_3}{r_3}\right)(r_3 - r_2)$$

$$+ \frac{1}{2}(A_1 G_1 H_1 + A_3 G_3 H_3)(x_3 - x_1)$$

$$\left. - \frac{1}{2}\left(\frac{G_1 H_1 \sin\theta_1}{r_1} + \frac{G_3 H_3 \sin\theta_3}{r_3}\right)(x_3 - x_1) \right]$$

It can be verified that use of these integration equations results in an error or order h^3 where h is the integration increment (mesh size). Since these integration equations involve the flow properties at the unknown point (3), they must be solved by iteration. The modified Euler iteration method is used by TDK to solve these equations in the various point calculations.

It should be noted that in the form of the equations given above, the chemistry is coupled by the terms A, B, Cp, and R. The TDK program has an option which allows the calculation of kinetic effects by use of tables of these variables vs. temperature that are generated automatically by the ODK subprogram. A significant advantage of this option is that it gives an order of magnitude reduction in computer time for a given case. Although exact results can be obtained in the frozen and equilibrium limits, significant error can be introduced when the expansion is in chemical nonequilibrium.

The implicit method used by TDK to integrate the chemical relaxation equations is presented below in Section 3.2.2.

3.2.2 Derivation of the TDK Numerical Integration Method

The chemical relaxation equations are a coupled set of first order simultaneous differential equations of the form

$$\frac{dc_i}{dx} = f_i(c_1, c_2, \cdots, c_N, y_1, y_2, y_3, y_4) \qquad i = 1, 2, \cdots, N$$

along the streamline where y_1, y_2, y_3, and y_4 refer to the fluid dynamic variables V, ρ, T, and θ, respectively. Assuming that the equations are not singular and that a solution exists which may be developed as a Taylor series about the forward point, one obtains

$$k_i = \left.\frac{dc_i}{dx}\right|_{x_{n+h}} h$$

where k_i is the increment in c_i and h is sufficiently small. The first coefficient of the Taylor series may be calculated as

$$\frac{dc_i}{dx} = f_i(c_1, c_2, \cdots, c_N, y_1, y_2, y_3, y_4)$$

Expanding as a Taylor series about the point x_n, it is found that

$$\left.\frac{dc_i}{dx}\right|_{x_{n+h}} = f_{i,n} + \sum_{j=1}^{N} \beta_{i,j,n} k_j + \sum_{j=1}^{4} \phi_{i,j,n} \Delta y_j + O\left[h^2\right]$$

where

$$\beta_{i,j} = \frac{\partial f_i}{\partial c_j}$$

$$\phi_{i,j} = \frac{\partial f_i}{\partial y_j}$$

and the subscript n refers to the functions f_i, $\beta_{i,j}$, and $\Phi_{i,j}$ evaluated at the point x_n.

Thus neglecting the second order error and derivative terms yields the integration formula for the increment k_i

$$k_i = \left[f_{i,n} + \sum_{j=1}^{N} \beta_{i,j,n} \; k_j + \sum_{j=1}^{4} \phi_{i,j,n} \; \Delta y_j \right] h$$

3.3 SUMMARY OF THE TDK COMPUTATIONAL PROCEDURE

The steps below summarize the computational procedure used by the TDK Computer Program (ODE-ODK-TDK input option):

Step 1. (Zone 1, inner zone O/F ratio)

1.1 ODE is used to compute:

1.1.1 P,H solution at stagnation (chamber V=0) condition

1.1.2 P,S solution at throat (ρV maximum) condition. Entropy, S, is computed in step 1.1.1 above.

1.1.3 ϵ_c,S solution at input contraction ratio.

1.2 An average expansion coefficient, N_e, is computed (Pg. 5-58). This expansion coefficient is the perfect gas expansion coefficient which would yield the throat pressure ratio computed in step 1.1.2.

1.3 A pressure table P(x) and its derivative dP(x)/dx are computed using the perfect gas relations, N_e, and the input thrust chamber geometry (pg. 5-50 to 56).

1.4 The ODK Computer Program is used to integrate the finite rate equations for one dimensional flow. The integration begins at ϵ_c. So that the flow will not be singular at the throat, P(x) and dP(x)/dx are used until the flow is supersonic ($M \leq 1.02$). For supersonic flow the area defined relations are used.

Step 2.

The sequence described in Step 1, above, is repeated for zones 2 through N $\leq$50, the outer zone.

The following throat property tables are constructed during each of the above calculations:

ρ, V, T, c_i vs. P.

These tables begin at the ODK determined throat (ρV maximum) and end when the flow attains a Mach number of 1.5.

Step 3.

An average expansion coefficient, γ_n, is computed for each zone using the tables constructed in Step 2.

$$\gamma_n = \frac{\ell n\ (P_\ell / P_1)}{\ell n\ (\rho_\ell / \rho_1)} \qquad n = 1, \ldots N \leq 50$$

The subscripts 1 and ℓ refer to the first and last table entries (at the ODK throat and at M=1.5). Thus if the flow through the throat is in equilibrium γ will attain the equilibrium value and if the flow is frozen γ will attain the frozen value.

Step 4.

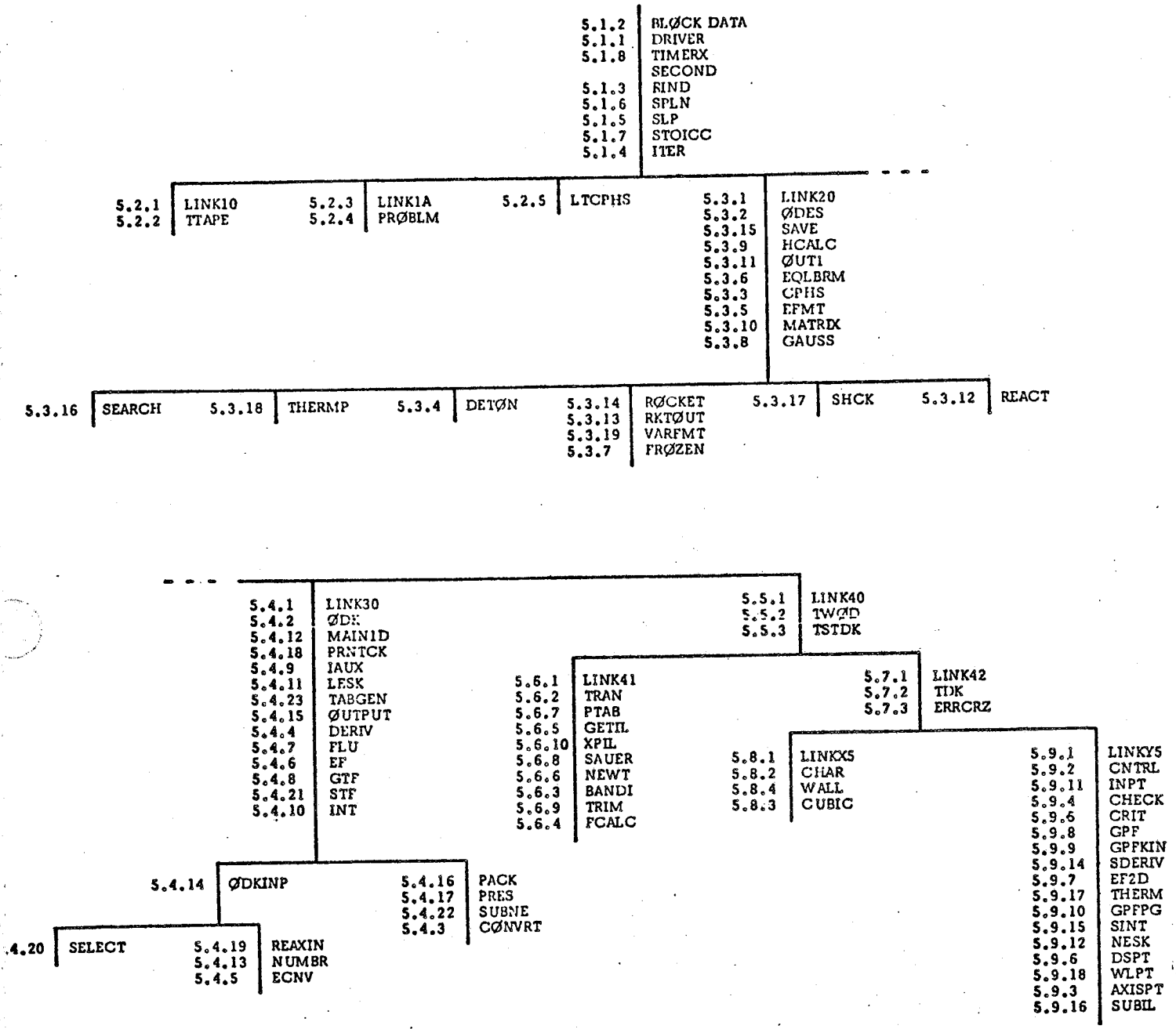
4.1 Using the above values of γ_n and the upstream radius of curvature at the nozzle throat, R_u, a two dimensional (axially symmetric) initial data line is constructed using a small perturbation method. The location of the constant pressure surface emanating from the throat minimum point is determined. The location of the slipline positions is also determined by the small perturbation method (from the continuity relation). Pressure and flow angle are matched (through a first order of approximation) at the sliplines.

4.2 Flow properties of ρ, V, T, and c_i are interpolated from the tables constructed in Step 2 using the pressure determined in Step 4.1.

Step 5.

A method of characteristics solution is computed for the nozzle. Boundary conditions are the initial data line and nozzle wall with a symmetry condition used along the nozzle axis and slip conditions (matched pressure and flow angle) used along the streamlines dividing zones of different O/F. The finite difference mesh is constructed at gas streamline and left running characteristic intersections.

4. PROGRAM OVERLAY STRUCTURE



*This overlay structure corresponds to the load map generated by the Univac 1108 computer using EXEC II CUR.

5. PROGRAM SUBROUTINES

This section contains a comprehensive description of the program subroutines. These descriptions are presented in the following order: the subroutines are grouped by overlay with the main subroutine of the overlay first followed by all other subroutines of the overlay in alphanumerical order. An index for the subroutines is presented on the following pages.

INDEX FOR SUBROUTINE DESCRIPTIONS

5.4 ØDK SUBROUTINES

5.4.1 LINK30
5.4.2 ØDK
5.4.3 CØNVRT
5.4.4 DERIV
5.4.5 ECNV
5.4.6 EF
5.4.7 FLU
5.4.8 GTF
5.4.9 IAUX
5.4.10 INT
5.4.11 LESK
5.4.12 MAIN1D
5.4.13 NUMBR
5.4.14 ØDKINP
5.4.15 ØUTPUT
5.4.16 PACK
5.4.17 PRES
5.4.18 PRNTCK
5.4.19 REAXIN
5.4.20 SELECT
5.4.21 STF
5.4.22 SUBNE
5.4.23 TABGEN

5.5 TDK CONTROL SUBROUTINES

5.5.1 LINK40
5.5.2 TWØD
5.5.3 TSTDK

5.6 TRANSONIC ANALYSIS SUBROUTINES

5.6.1 LINK41
5.6.2 TRAN
5.6.3 BANDI
5.6.4 FCALC
5.6.5 GETIL
5.6.6 NEWT
5.6.7 PTAB
5.6.8 SAUER
5.6.9 TRIM
5.6.10 XPIL

5.7 SUPERSONIC CONTROL SUBROUTINES

5.7.1 LINK42
5.7.2 TDK
5.7.3 ERRØRZ

5.8 SUPERSONIC INITIAL LINE AND WALL SUBROUTINES

5.8.1 LINKX5
5.8.2 CHAR
5.8.3 CUBIC
5.8.4 WALL

5.9 SUPERSONIC ANALYSIS SUBROUTINES

5.9.1 LINKY5
5.9.2 CNTRL
5.9.3 AXISPT
5.9.4 CHECK
5.9.5 CRIT
5.9.6 DSPT
5.9.7 EF2D
5.9.8 GPF
5.9.9 GPFKIN
5.9.10 GPFPG
5.9.11 INPT
5.9.12 NESK
5.9.13 PRINT
5.9.14 SDERIV
5.9.15 SINT
5.9.16 SUBIL
5.9.17 THERM
5.9.18 WLPT

5.1 UPPER LEVEL SUBROUTINES

5.1.1 PROGRAM DRIVER

This is the main routine for the program and as such provides overlay communication, defines the upper level labeled common blocks, and initializes certain logical control variables. DRIVER calls the thermodynamic tape generation subroutine, TTAPE, when required. Subroutine PRØBLM is called to decode the PRØBLEM card and Subprograms ØDE and/or ØDK are called to perform equilibrium/frozen and one dimensional kinetic calculations as required. Subprogram TWØD is called for Transonic and Two Dimensional Method of Characteristics as required.

5.1.2 SUBROUTINE BLØCK DATA

BLØCK DATA contains atomic data stored in ATØM(i,j) and many of the variables used with the variable format, FMT. The ATØM variables are defined in appendix B, Reference 9. The format variables are stored in the common labeled ØUPT and are described here.

A variable format was used so that one format, FMT, could be used in the final output with changes in the number of decimal places according to the sizes of the numbers. The format is used to print a label and from 1 to 13 associated numbers. The labels contain 14 alphameric characters stored in four words and printed with 3A4,A2. The numbers are all printed in a field of 9. FMT is initially set in BLØCK DATA as follows:

```
FMT  (1)   (2)   (3)   (4)   (5)   (6)   (7)   (8)   (9)   (10)  (11)
     (1H   ,3A4  ,A2,  F9.   0,    F9.   0,    F9.   0,    F9.   0,
FMT  (12)  (13)  (14)  (15)  (16)  (17)  (18)  (19)  (20)  (21)
     F9.   0,    F9.   0,    F9.   0,    F9.   0,    F9.   0,
     (22)  (23)  (24)  (25)  (26)  (27)  (28)  (29)  (30)
     F9.   0,    F9.   0,    F9.   0,    F9.   0     )
```

where the spaces are stored as blanks.

Some variables set in BLØCK DATA to modify FMT are as follows:

Variable:	F0	F1	F2	F3	F4	F5	FB	FMT13	FMT9X	FMT19
Storage:	0,	1,	2,	3,	4,	5,		13,	9X,	I9,

The following is a list of variables used as labels and printed with 3A4, A2 in FMT:

Variable	Stored label
FP	P, ATM
FT	T, DEG K
FH	H, CAL G
FS	S, CAL/(G) (K)
FM	M, MOL WT
FV	(DLV/DLP) T
FD	(DLV/DLT) P
FC	CP, CAL/(G) (K)
FG	GAMMA (S)
FL	SON VEL, M/SEC
FR1	PC/P
FC1	CF
FN	MACH NUMBER
FR	CSTAR, FT/SEC
F1	ISP, LB-SEC/LB
FA	IVAC, LB-SEC/LB
FA1, FA2	AE/AT

5.1.3 SUBROUTINE FIND

This subroutine locates the index, I, in a table such that $X(I) \leq X \leq X(I+1)$.

5.1.4 SUBROUTINE ITER (F1, X1, XNEW, NØØ)

The purpose of this subroutine is to find the root or zero of the algebraic equation

$$f(X) = 0$$

using the method of secant or false position. In particular this subroutine is designed to take advantage of the fact that the secant method will always find the root of the above equation if the root has been spanned.

Calling Sequence:

F1 is the value of the dependent variable, f, corresponding to the value of X1.

X1 is the value of the independent variable, X, which corresponds to F1.

XNEW is the predicted or new value of the independent variable

NØØ is a flag such that

NØØ = -1 the first time ITER is called.

NØØ = +1 upon subsequence calls.

Restrictions:

The user is expected to check for convergence as there are no internal checks made in ITER.

Method:

Subroutine ITER utilizes the secant method predictor formula

$$X_{i+1}=X_i-f_i \cdot (X_i-X_{i-1})/(f_i - f_{i-1})$$

where the subscript i refers to the current value of X and f except for the first iteration in which the value of X is perturbed only slightly. When the root has been spanned the subroutine saves 2 back value of f and X in order that the root may always be straddled and thus found. The linkage to the subroutine is set up so that if bounds on the root are known, then the value of XNEW may be disregarded and bounded values may be used for the first two guesses. This type of linkage necessitates that the value of X1 must be set equal to XNEW or the bounded value of X. In order to speed up convergence, if the error within the bounded domain of the dependent variable exceeds a ratio of 10, then the new value of X is set equal to one half of the range.

5.1.5 SUBROUTINE SLP (X, Y, N, MFLAG, YP, W1, W2, W3, IFLAG)

The purpose of this subroutine is to supply derivatives for a tabulated function. The end point derivatives may be specified or are calculated internally by parabolic interpolation. Interior point derivatives may be found by a cubic spline fit procedure.

Calling Sequence:

X is a table of independent variables, x_i

Y is a table of the dependent variables, y_i

N is the number of entries in each of the tables X, Y, and YP. $i = 1, \ldots N$

MFLAG this entry is a flag, m, such that

- $m > 0$ implies x is equally spaced
- $m < 0$ implies x is not equally spaced
- $|m| = 1$ y' will be continuous
- $|m| = 2$ y' and y'' will be continuous

YP is a table of the derivative, y'_i

W1 working storage of length N

W2 working storage of length N

W3 working storage of length N

IFLAG this entry is a flag, i, such that

- $i = o$ implies value for YP(1) and YP(N) will be calculated internally by parabolic differencing
- $i = 1$ implies values for YP(1) and YP(N) will be input

Method

The cubic spline fit procedure utilizes the interpolation formula given below:

$$y = A(x - x_o)^3 + B(x - x_o)^2 + C(x - x_o) + D$$

$$y' = 3A(x - x_o)^2 + 2B(x - x_o) + C$$

$$y'' = 6A(x - x_o) + 2B$$

The piecewise cubic fit to a tabular function by the above relations will yield a discontinuity in the second derivative y'', between adjacent fits of:

$$y''_{1_{01}} - y''_{1_{12}} = \frac{1}{h_{01}}\left(2y'_0 + 4y'_1 - 6\,\frac{k_{01}}{h_{01}}\right) - \frac{1}{h_{12}}\left(6\,\frac{k_{12}}{h_{12}} - 4y'_1 - 2y'_2\right)$$

where

$$h_{01} = x_1 - x_0$$

$$h_{12} = x_2 - x_1$$

$$k_{01} = y_1 - y_0$$

$$k_{12} = y_2 - y_1$$

The method consists of setting the left-hand side of the above relation equal to zero so that the second derivative is continuous across juncture points. As applied to a tabular function, the above procedure results in a set of linear simultaneous equations (tri-diagonal) to be solved for the y'_1, provided that values for y' at the end points are known.

5.1.6 SUBROUTINE SPLN

Performs either cubic or linear interpolation between two given points.

Cubic interpolation for a function and its first two derivatives is performed as described below:

Given function values y_n and y_{n+1} and first derivative values y'_n and y'_{n+1} at x_n and x_{n+1}, this subroutine evaluates y(x), y'(x), and y''(x) for $x_n \leq x < x_{n+1}$ using:

$$y = A(x - x_n)^3 + B(x - x_n)^2 + C(x - x_n) + D$$

$$y' = y'_n + \frac{x - x_n}{x_{n+1} - x_n} \cdot [y'_{n+1} - y'_n]$$

$$y'' = (y'_{n+1} - y'_n) / h$$

where:

$$A = \frac{1}{h^3} \cdot [(y'_{n+1} + y'_n)h - 2k]$$

$$B = -\frac{1}{h^2} \cdot [(y'_{n+1} + 2y'_n)h - 3k]$$

$$C = y'_n$$

$$D = y_n$$

$$h = x_{n+1} - x_n$$

$$k = y_{n+1} - y_n$$

Linear interpolation for a function and its first two derivatives is performed as described below:

$$y = y_n + \frac{x - x_n}{x_{n+1} - x_n} \cdot [y_{n+1} - y_n]$$

$$y' = \frac{y_{n+1} - y_n}{x_{n+1} - x_n}$$

$$y'' = 0.0$$

5.1.7 SUBROUTINE STOICC

For each reaction this subroutine constructs two vectors of stoichiometric coefficients, one for reactants and one for products. Up to 10 reactants and 10 products may be considered for each reaction. The total number of entries in the resultant linear reaction table is 600 , i.e. the sum of all stoichiometric coefficients can not exceed 600.

5.1.8 SUBROUTINE TIMERX

This subroutine is provided to localize printing of computer execution times during the calculations. This subroutine should be modified at each local installation to provide proper interface with local system timing routines. This subroutine calls a system subroutine named SECØND to obtain the current run execution time in seconds.

5.2 LEVEL ONE SUBROUTINES

5.2.1 SUBROUTINE LINK10

This subroutine consists only of a call to subroutine TTAPE and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.2.2 SUBROUTINE TTAPE

When a THERMØ directive card is read by the main program this subroutine is called to generate a master Thermodynamic Data tape (Logical Unit 25). The input Thermodynamic Data is in curve fit form and is identical to that required for the ØDE computer program described in NASA SP-273, Reference 9. The format for this curve fit data is described in the User's Manual, Section 6.1.

5.2.3 SUBROUTINE LINK1A

This subroutine consists only of a call to subroutine PRØBLM and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.2.4 SUBROUTINE PRØBLM

This subroutine decodes the PRØBLEM card and sets the logical flags LØDE, LØDK, LTDK, TDE, and the IDEAL GAS flag as required. The number of zones (O/F ratios) specified is also decoded.

5.2.5 SUBROUTINE LTCPHS

This subroutine processes the low temperature C_p, H, S Thermodynamic Data extension input as described in detail in Section 6.1.

5.3 ØDE SUBROUTINES

The ØDE subroutines described below form the computer program described in NASA SP-273, Reference 9. The program has been modified to run as a subroutine for up to 50 zones (defined by an Ø/F schedule) as required by the TDK program. Brief analytical descriptions for the equilibrium calculations have been obtained from Reference 9. For a complete description of ØDE see Reference 9.

5.3.1 SUBROUTINE LINK20

This subroutine consists only of a call to subroutine ØDES and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.3.2 SUBROUTINE ØDES

This is the main program for ØDE and corresponds to the Main Program described in Reference 9. Generally, the routine performs the following functions:

1. Reads code cards THERMØ, REACTANTS, ØMIT, INSERT, and NAMELISTS and directs flow of program accordingly.
2. Stores THERMØ data on tape.
3. Calls subroutine REACT to read and process REACTANTS cards.
4. Reads ØMIT and INSERT cards and stores species names.
5. Initializes variables in namelist $ØDE.
6. Reads and writes namelist $ØDE.
7. Converts assigned densities, if any, (RHO(i) in $ØDE) to specific volumes: VLM(i) = 1/RHO(i).
8. Stores the number of pressures or volumes in NP.
9. Stores values of o/f in ØXF array. If o/f values have not been inputted directly, they are calculated as follows:

Values	Code	o/f calculation in main prog
Oxidant to fuel weight ratio, o/f	ØF = .TRUE.	ØXF(i) = o/f
Fuel to air weight ratio, f/a	FA = .TRUE.	ØXF(i) = 1/(f/a)
Percent fuel, %F	FPCT = .TRUE.	ØXF(i) = (100-%F)/(%F)
Equivalence ratio, r	ERATIØ = .TRUE.	$\text{ØXF(i)} = \frac{-rV^{-(2)} - V^{+(2)}}{rV^{-(1)} + V^{+(1)}}$
Not specified		$\text{ØXF(i)} = \frac{WP(1)}{WP(2)}$

Values of WP(1) and WP(2) are defined in appendix B of Reference 9.

10. Makes necessary adjustments to consider charge balance if IØNS = .TRUE.. This is done by adding 1 to NLM and E to LLMT array.

11. Calls SEARCH to pull required THERMØ data from tape and to store the data in core.

12. Sets initial estimates for compositions. These estimates are set with each $ØDE read. They are used only for the first point in the lists of variables in namelist (e.g., the first o/f and the first T and P in a TP problem). All succeeding points use results from a previous point for estimates.

For the first point the program assigns an estimate of 0.1 for n, the total number of kilogram-moles per kilogram. The initial estimate of number of moles of each gaseous species per kilogram of mixture n_j is set equal to 0.1/m where m is the total number of gaseous species. Condensed species are assigned zero moles.

13. Sets IUSE(j) positive for condensed species listed on INSERT cards (see IUSE array).

14. Calls THERMP if TP, HP, SP, TV, UV, or SV is true.

15. Calls DETØN if DETN is true.

16. Calls SHCK if SHØCK is true.

17. Calls RØCKET is RKT is true.

5.3.3 SUBROUTINE CPHS

This subroutine evaluates the thermodynamic functions $\frac{Cp^\circ}{R}$, $\frac{H^\circ_T}{RT}$, $\frac{S^\circ_T}{R}$ from the curve fit coefficients. Two sets of coefficients are used for two adjacent temperature intervals. The functions evaluated are presented below:

$$\frac{Cp^\circ_T}{R} = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5T^4$$

$$\frac{H^\circ_T}{RT} = a_1 + \frac{a_2T}{2} + \frac{a_3T^2}{3} + \frac{a_4T^3}{4} + \frac{a_5T^4}{5} + \frac{a_6}{T}$$

$$\frac{S^\circ_T}{R} = a_1 \ln T + a_2T + \frac{a_3T^2}{2} + \frac{a_4T^3}{3} + \frac{a_5T^4}{4} + a_7$$

$$\frac{G^\circ_T}{RT} = \frac{H^\circ_T}{RT} - \frac{S^\circ_T}{R}$$

When the temperature falls below the lower limit of the curve fit coefficients, the above thermodynamic functions are obtained via linear interpolation from e input for subroutine LTCPHS.

5.3.4 SUBROUTINE DETØN

This subroutine does the calculations required to obtain Chapman-Jouget detonation properties as described in the section CHAPMAN-JOUGET DETONATIONS of Reference 9. The calculation involves a Newton-Raphson iteration to determine detonation conditions in addition to the iteration for determining equilibrium compositions.

5.3.5 SUBROUTINE EFMT

Subroutine EFMT (E-format) writes statements in a special exponent form. This form is similar to the standard FORTRAN E-format, but the letter E and some of the spaces have been removed for compactness. It is used to write density and mole fractions with the TRACE option.

5.3.6 SUBROUTINE EQLBRM

EQLBRM is the control routine for the equilibrium module which calculates equilibrium compositions and thermodynamic properties for a particular point. A free-energy minimization technique is used. The program permits calculations such as (1) chemical equilibrium for assigned thermodynamic states (T,P), (H,P), (S,P), (T,V), (U,V), or (S,V), (2) theoretical rocket performance for both equilibirum and frozen compositions during expansion, (3) incident and reflected shock properties, and (4) Chapman-Jouguet detonation properties. The program considers condensed species as well as gaseous species. A detailed description of the equations and computer program for computations involving chemical equilibria in complex systems is given in Reference 9. Figures 4(a) through 4(c) of Reference 9 gives a complete flow diagram for this subroutine.

5.3.7 SUBROUTINE FRØZEN

Subroutine FRØZEN is called from subroutine RØCKET to calculate the temperature and thermodynamic properties for the following assigned conditions:

1. Composition frozen at combustion conditions.
2. An assigned exit pressure.
3. An assigned entropy equal to the entropy at combustion conditions.

The iteration procedure used for obtaining the exit temperature is discussed in the section Procedure for Obtaining Frozen Rocket Performance (p.40, Reference9).

If a temperature is reached 50 K below the range of a condensed combustion species, calculations are stopped and control is returned to RØCKET where a message is printed and data for all preceding points are listed.

5.3.8 SUBROUTINE GAUSS

Subroutine GAUSS is used to solve the set of simultaneous linear iteration equations constructed by subroutine MATRIX. The solution is effected by performing a Gauss reduction using a modified pivot technique. In this modified pivot technique only rows are interchanged. The row to be used for the elimination of a variable is selected on the basis that the largest of its elements, after division by the leading element, must be smaller than the largest element of the other rows after division by their leading elements.

The solution vector is stored in X(k). In the event of a singularity, IMAT (which is equal to the number of rows) is set equal to IMAT - 1. IMAT is tested later in subroutine EQLBRM.

5.3.9 SUBROUTINE HCALC

The purpose of HCALC is to calculate thermodynamic properties for reactants under certain circumstances. HCALC is called from entry NEWØF of SAVE and DETØN.

HCALC is called from NEWØF when CALCH is set true. CALCH is set true in the main program when zeros have been punched in card columns 37 and 38 on one or more REACTANTS cards. The zeros are a code indicating that the enthalpy (or internal energy for UV problems) for the reactant should be calculated from the THERMØ data at the temperature punched on the card. This temperature has been stored in the RTEMP array. CPHS is called to calculate the enthalpy. The value is sorted in the ENTH array and printed in the final tables.

The properties calculated in subroutine HCALC, their FORTRAN symbols, and the conditions for which they are used are as follows:

Property	FORTRAN symbol	Equation	
$\mathcal{H}$ (k)T	HPP(k)	(192)	SHØCK problem. DETN problem with T sched HP, RKT, or DETN problem if 00 in cc 37 anc
h_o/R	HSUB0	(193)	SHØCK problem. DETN problem with T sched HP, RKT, or DETN problem if 00 in cc 37 anc
$\mathcal{U}$ (k)T	HPP(k)	(194)	UV problem if 00 in cc 37 and 38
u'_o/R	HSUB0	(195)	UV problem if 00 in cc 37 and 38
M_o	AM1	(197)	SHØCK or DETN problem
m_i	EN(j)	(205)	SHØCK problem
$\mathcal{C}_o$	CPR1	(206)	SHØCK problem
$\mathcal{A}_o$	S0	(207)	SHØCK problem

The quantity m_i was deliberately subscripted differently from EN(j) to allow for the fact that the same compound may have a different index as a reactant than as a reaction species. Thus, for example, O_2 (g) might be the third reactant read in from REACTANTS cards and also the tenth species read in by SEARCH. In this case m_3 would be stored in EN(10).

5.3.10 SUBROUTINE MATRIX

This subroutine sets up the matrices corresponding to tables I through IV of Reference 9. The assigned thermodynamic state being set up (tables I and II) is specified by the following codes:

Assigned thermodynamic state	Codes
TP	TP = .TRUE. VOL = .FALSE. CONVG = .FALSE.
HP	HP= .TRUE. VOL = .FALSE. CONVG = .FALSE.
SP	SP = .TRUE. VOL = .FALSE. CONVG = .FALSE.
TV	TP = .TRUE. VOL = .TRUE. CONVG = .FALSE.
UV	HP= .TRUE. VOL = .TRUE. CONVG = .FALSE.
SV	SP = .TRUE. VOL = .TRUE. CONVG = .FALSE.

After convergence of any of the previous six probelms, setup of the derivative matrices (tables III and IV) is specified by the following codes:

Derivative	Codes
DLVTP	CONVG = .TRUE. LOGV = .FALSE.
DLVPT	CONVG = .TRUE. LOGV = .FALSE.

5.3.11 SUBROUTINE ØUT1

This subroutine, together with entries ØUT2 and ØUT3, writes statements common to all problems. ØUT1 writes statements giving the data on REACTANTS and on o/f, percent fuel, equivalence ratio, and density.

Entry ØUT2. - This entry writes the statements for printing values of pressure, temperature, dentity, enthalpy, entropy, molecular weight, $(\partial \ln V/\partial \ln P)_T$ (if equilibrium), $(\partial \ln V/\partial \ln T)_P$ (if equilibirum), heat capacity, γ_S, and sonic velocity. These variables and corresponding labels are printed with a variable format described in BLØCK DATA.

Entry ØUT3. - Entry ØUT3 writes statements giving the equilibrium mole fractions of reaction species.

5.3.12 SUBROUTINE REACT

The purpose of subroutine REACT is to read and process the data on the REACTANTS cards. The subroutine is called from the main program after a REACTANTS code card has been read. The data on these cards are described in the REACTANTS Cards section (p. 62) of Reference 9. References to page numbers and equations given below also pertain to Reference 9.

The reactants may be divided into two groups according to card column 72 on the REACTANTS cards. The two groups are oxidants (O in cc 72) and fuels (cc 72 $\neq$ O). We generally keypunch F in card column 72 for fuels even though this is not necessary. The contents of card column 72 are read into FØX. Depending on the contents of FØX, program variables relating to oxidants or fuels are subscripted 1 for oxidants and 2 for fuels.

The FORTRAN symbols for the properties read from the REACTANTS cards and their associated properties (discussed in INPUT CALCULATIONS, p. 55 of Reference 9) are as follows:

Property	FORTRAN symbol
$a_{ij}^{(k)}$	ANLM(j,m)[a]
$W_j^{(k)}$	PECWT(j) (if no M in cc 53)
$N_j^{(k)}$	PECWT(j) (if M in cc 53)
$(H^o_{T_j})^{(k)}$	ENTH(j) (if not UV problem and 00 not in cc 37 and 38)
$(U^o_{T_j})^{(k)}$	ENTH(j) (if UV problem and 00 not in cc 37 and 38)
$o_j^{(k)}$	DENS(j)

[a]Each of the j REACTANTS cards contains from 1 to 5 stoichiometric coefficients read (indicated by subscript m) into ANUM(j,m) and their corresponding chemical symbols read into NAME(j,m). In relating an ANUM(j,m) with $a_{ij}^{(k)}$, the index i associated with a particular chemical element is determined from the chemical symbol in NAME(j,m).

If there are several oxidants their properties are combined by subroutine REACT into properties of a total oxidant using the relative proportion of each oxidant given on the REACTANTS cards. Similarly, if there are several fuels, their properties are combined into properties of a total fuel. The total oxidant and total fuel properties discussed in INPUT CALCULATIONS[9] and their associated FORTRAN symbols are as follows:

Property	FORTRAN symbol	Equation
$b_i^{(k)}$	BOP(i,k)	(187)
$M_j^{(k)}$	RMW(j)	(190)
$\mathcal{H}^{(k)}_T$	HPP(k) (if not UV problem and 00 not in cc 37 and 38)	(192)
$\mathcal{U}^{(k)}_T$	HPP(k) (if UV problem and 00 not in cc 37 and 38)	(194)
$M^{(k)}$	AM(k)	(196)
$o^{(k)}$	RH(k)	(198)
$V^{+(k)}$	VPLS(k)	(200)
$V^{-(k)}$	VMIN(k)	(201)
$W_j^{(k)} \Big/ \sum_{j=1}^{NREAC} W_j^{(k)}$	PECWT(j)	

If any of the $n_j^{(k)}$ are zero then RH(1) = RH(2) = 0.

These total oxidant and total fuel properties are subsequently combined into total reactant properties by using the values of oxidant-fuel mixture ratios obtained from the main program. This is done in NEWØF, an entry in SAVE.

Other common variables set by REACT are LLMT, NAME, ANUM, ENTH, FAZ, RTEMP, FOX, DENS, RMW, MØLES, NLM, NEWR, and NREAC.

A provision is made for eliminating a second tape search when two consecutive sets of REACTANTS cards contain the same elements. This is done by saving the element symobls (LLMT(ℓ)) in LLMTS(ℓ), the kilogram-atoms per kilogram (BOP(ℓ,k)) in SBOP(ℓ,k), and the number of elements (NLM) in NLS.

Atomic weights M_i used in equation (190)[9] are stored in ATØM(2,i). The corresponding chemical symbols are stored in ATØM(1,i). The oxidation states of the chemical elements V_i^+ or V_i^- used in equations (200) and (201)[9] are stored in ATØM(3,i). The ATØM array is stored by BLØCK DATA.

5.3.13 SUBROUTINE RKTØUT

This subroutine calculates various rocket performance parameters from previously calculated thermodynamic properties.

It is also the control program for writing rocket performance output. It contains the WRITE statements that apply specifically to rocket parameters and it calls subroutine ØUT1 and entries ØUT2 and ØUT3 for the WRITE statements common to all problems. The rocket parameters are printed with the variable format, FMT, described in BLØCK DATA.

Subroutine RKTØUT is called from subroutine RØCKET.

5.3.14 SUBROUTINE RØCKET

This subroutine is the control program for the RKT problem (rocket performance calculations discussed in section RØCKET PERFORMANCE).[9] A flow diagram for this subroutine is given in Figure 5 of Reference 9. Subroutine RØCKET obtains the required thermodynamic properties for equilibrium performance

by calling subroutine EQLBRM. For frozen performance, subroutine RØCKET calls subroutine FRØZEN to obtain the required thermodynamic properties. Rocket performance parameters are then obtained by calling subroutine RKTØUT. In addition to calling RKTØUT and FRØZEN, and in addition to using controls common to all problems (discussed in section MODULAR FORM OF THE PROGRAM, p. 75, Reference 9) subroutine RØCKET also does the following:

1. It reads and processes the input data in RKTINP namelist.
2. It calculates estimates for throat pressure ratios.
3. It calculates estimates for pressure ratios corresponding to assigned area ratios (if any).

5.3.15 SUBROUTINE SAVE

This subroutine has several functions, all of which are concerned with saving some information from a completed calculation for subsequent use in later calculations. The primary purpose is to save computer time by having good initial estimates for compositions.

These estimates for the next point, NPT, come from either the point just completed, ISV, or some other previous point. The flow of the routine is directed by ISV as follows:

1. ISV positive. Transfer compositions for point just completed for use as initial estimates for next point (transfer EN(j,ISV) to EN(j,NPT)).

2. ISV negative. Save values of ENLN(j) for gases and EN(j) for condensed in SLN(j), ENN in ENSAVE, ENNL in ENLSAV, IQ1 in IQSAVE, JSØL in JSØLS, JLIQ in JLIQS, and NLM in LL1. (These values are saved because they are to be used as initial estimates for some future point and they may be overwritten in the meantime.) Make ISV positive and transfer EN(j,ISV) to EN(j,NPT).

3. ISV zero. Use the data previously saved (as discussed in 2. as initial estimates for current point. Restore IUSE codes and inclusion or exclusion of "E" as an element for IØNS option.

Entry NEWØF. - NEWØF combines the properties of total oxidant and total fuel calculated in subroutine REACT with an o/f value to give properties for the total reactant. NEWOF is called for each mixture assigned in the MIX array in $ØDE namelist. It is called from either THERMP, RØCKET, SHCK, or DETON. The

calculated properties and corresponding FORTRAN symbols are as follows:

Property	FORTRAN symbol	Equation
b_i^o	B0(i)	(191)
h_o/R	HSUB0 (if not UV problem)	(193)
u'_o/R	HSUB0 (if UV problem)	(195)
ρ_o	RHØP	(199)
r	EQRAT	(204)

Subroutine HCALC is called by Entry NEWØF to calculate the enthalpies for each reactant that has zeros keypunched in card columns 37 and 38 in its REACTANTS card.

Values of HPP(2), HPP(1), HSUB0, B0P(i,2), B0P(i,1), and B0(i) are printed out.

5.3.16 SUBROUTINE SEARCH

This subroutine selects the Thermodynamic Data to be used in the probelm. A scan is made of the master Thermodynamic Data tape and those species that are consistent with the chemical system under consideration are selected. As the thermodynamic data are being selected, the subroutine also complies a set of formula numbers, a_{ij}, from the formulas of the reaction products. A short Thermodynamic Data file is also generated for use in subsequent calculations (multizone).

A check is made near the beginning of the routine to prevent THERMØ data from exceeding their storage allotments. These variables are all in labeled common SPECIES and are currently dimensioned for 150 species. However, this dimension may be reduced to save storage.

SEARCH is called from the main program when the logical variable NEWR is true. NEWR is set true in REACT to indicate a new chemical system. REACT also stores chemical element symbols for the current chemical system in the LLMT array. SEARCH stores THERMØ data in core for each species whose elements are included in the LLMT array (unless the species name was listed on an ØMIT card).

The THERMØ data are stored in common variables TLØW, TMID, THIGH, SUB, A, CØEF, and TEMP. SEARCH writes out the names and dates of species whose data are stored in core.

SEARCH initializes the IUSE array. IUSE(j) for gaseous species are set equal to zero. IUSE(j) for condensed species are set equal to negative integers. For the chemical system under consideration, the first possible condensed species is set equal to -1, the second to -2, and so on, with one exception. In the event there are two or more condensed pahses of the same species, each phase is given the same negative integer. Thus, if IUSE(j) for $B_2O_3(\ell)$ is set equal to -4, for example, IUSE(j) for $B_2O_3(s)$ will also be set equal to -4. A description of the IUSE array is given below.

The various condensed phases of a species are expected to be adjacent in the THERMØ data as they are read from tape. These phases must be either in increasing or decreasing order according to their temperature intervals.

NS contains the total number of species stored in core. NC contains the total number of condensed species (counting each condensed phase of a species as a separate species).

IUSE array. - Each value in the IUSE array is associated with a species. These values of IUSE serve two purposes:

1. They indicate which species are to be included in the current iteration (IUSE(j) < 0 for excluded species and IUSE(j) ≥ 0 for included species).

2. They indicate multiple phases of the same species if absolute values of IUSE(j) are equal.

The IUSE(j) are initialized in subroutine SEARCH and the main program as follows:

1. IUSE(j) = 0 for all gaseous species.

2. IUSE(j) = n for all condensed species whose names have been listed on INSERT cards. The number n indicates the species was the n^{th} condensed species whose THERMØ data were read from tape.

3. IUSE(j) = -n for all condensed species not listed on INSERT cards where n is defined in 2.

These initial values of IUSE(j) may be adjusted later in subroutine

EQLBRM. For condensed species, the sign is adjusted as species are included or excluded in the current iteration.

For the IØNS option, IUSE(j) values for ionic species are set to -10000 when the mole fractions of all ionic species are less than 10^{-8}.

5.3.17 SUBROUTINE SHCK

Subroutine SHCK is the application module for the SHØCK problems. It calculates the shock parameters discussed in the section "INCIDENT AND REFLECTED SHOCKS". It reads and processes the input data in SHKINP namelist. Depending on which options are specified, it calculates incident shock conditions based on compositions frozen at initial conditions and/or based on equilibrium compositions after shock. It also calculates, based on specified options, frozen and/or equilibrium reflected shock conditions relative to equilibrium and/or frozen incident shock conditions.

5.3.18 SUBROUTINE THERMP

This subroutine is the application module for TP, HP, SP , TV, UV, and SV problems. Common variables which must be set according to the assigned thermodynamic states are given in the section Application Modules (p. 76) or Reference 9. For these problems, the variables TP, HP, SP, S0, and VØL are set or read in subroutine ØDES. HSUB0 is set either in SAVE (entry NEWØF) or HCALC. The general flow of the routine is given in figure 3 of Reference 9.

Indices run from 1 to NP both for assigned pressures P and assigned volumes (V in ØDE and VL in THERMP). Indices run from 1to NT for assigned temperature T. NP and NT are set in the subroutine ØDES.

5.3.19 SUBROUTINE VARFMT

Subroutine VARFMT (variable format) adjusts the number of decimal places printed in F-format in the variable format, FMT, according to the size of the number. It is used for P_c/P_e, P, and A_e/A_t. Variable format is described in BLØCK DATA.

5.4 ØDK SUBROUTINES

5.4.1 SUBROUTINE LINK30

This subroutine consists only of a call to subroutine ØDK and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.4.2 SUBROUTINE ØDK

This subroutine acts as the driver for the one dimensional kinetic expansion calculation (ØDK).

5.4.3 SUBROUTINE CØNVRT

This subroutine converts input data from the externally input units to internally used computation units. In order to conserve computation time during the kinetic expansion, parameters such as molecular weights, are included in these conversions. Primed numbers are input quantities.

a) Reaction rate ratio input for reactions requiring third body terms
units: unitless
internal units: $(\text{lbs-mass/lb-mole})^{-1}$
formula: $XMM_{j,i} = XMM_{j,i}/Mw_i$

b) Pre-exponential reaction rate parameter
input units: cm, °K, g-mole, sec
internal units: ft^3, °R, lb-mole, sec

$$a_j = \frac{a_j' \cdot (.0160183)^{\lambda} \cdot 1.8^{n_j}}{\prod_{i=1}^{n} Mw_i^{\nu_{ij}'}}$$

Where λ depends on the order of the reaction.

and $.0160183 = \frac{3.531 \cdot 10^{-5}\ ft^3}{1\ cm^3} \cdot \frac{1\ \text{g-mass}}{2.2 \cdot 10^{-3}\ \text{lbs-mass}}$

c) Exponential Term:

input units: kcal/mole

internal units: °R

formula: $b_j = b'_j \cdot 905.770$

where $905.770 = \frac{1000 \text{ cal}}{1 \text{ kcal}} \cdot \frac{1}{1.98726 \text{ cal/mole-°K}} \cdot \frac{1.8°R}{1.0°K}$

d) Equilibrium Constant Multiplicative Factor:

Input units: not input

internal units: (lbs-mass) - °R/ft^3

formula:

$$DATEF(J) = \frac{\prod_{i=1}^{n} Mw_i^{\nu_{ij}}}{\prod^{n} Mw_i^{\nu_{ij}} \cdot 0.73034}$$

where $.73034 = 49,721.011 \cdot \frac{\text{ft-poundals}}{\text{(lbs-mole) °R}} \cdot \frac{1 \text{ atmos}}{68,059.59 \text{ poundals/ft}^2}$

e) Pressure:

input units: PSIA

internal units: poundals/ft^2

formula: $P = P' \cdot 4633.056$

where

$$4633.056 = \frac{144 \text{ in}^2}{1 \text{ ft}^2} \cdot 32.174 \frac{\text{ft}}{\text{sec}^2}$$

f) The initial reference enthalpy is computed using

$$H_{Ref} = \sum_{i=1}^{N} c_i h_i + \frac{V^2}{2}$$

5.4.4 SUBROUTINE DERIV

This subroutine computes the total derivatives f_i and the partial derivatives β_{ij} described in the analysis presented in Section 3 of this report.

The implicit integration method used to integrate the differential equations governing the chemical system, i.e.

$$y_i' = f_i(x, y_1, \ldots y_{NSP+3}) \qquad i=1, \ldots, NSP+3$$

where the variables

$$y_i \qquad i=1, \ldots, NSP+3$$

are $V, \rho, T, C_i \qquad i=1, \ldots, NSP$

respectively, requires evaluation of the Jacobian of the system, i. e.

$$\beta_{ij} = \frac{\partial f_i}{\partial y_j} \qquad \begin{matrix} i=1, \ldots, NSP+3 \\ j=1, \ldots, NSP+3 \end{matrix}$$

Subroutine DERIV computes only certain of the β_{ij} (those taken with respect to C_i) and the others are computed in subroutine FLU.

Also calculated by DERIV are the reaction rates, k_j, and the net production rates, X_j.

The generalized chemical reaction which is handled by this subroutine is defined by:

$$\sum_{i=1}^{NSP} \nu_{ij} \bar{M}_i \rightleftarrows \sum_{i=1}^{NSP} \nu'_{ij} \bar{M}_i$$

where $\bar{M}_i$ represents the i^{th} chemical species.

The reverse reaction rate constant is defined by the equation:

$$k_j \quad SK(J) \quad = a_j \cdot T^{-n_j} \cdot \exp(-b_j/T)$$

The net production rate for a reaction is given by:

$$X_j \quad X(J) \quad = \left[K_j \cdot \prod_{i=1}^{NSP} C_i^{\nu_{ij}} - \rho^{\lambda} \cdot \prod_{i=1}^{NSP} C_i^{\nu'_{ij}} \right] \cdot k_j \cdot M_j$$

where: λ depends on the order of the reaction*

with $M_j = \sum_{i=1}^{NSP} XMM_{j,i} \cdot C_i$ for reactions requiring a third body

and $M_j = 1$ for all other reactions

The net individual species production rate is given by the equation:

$$\frac{dC_i}{dx} \quad FN(I) \quad = \overline{K}_i \cdot \sum_{j=1}^{\ell} \psi_{ij} \cdot X_j$$

where:

$$\overline{K}_i = (Mw_i \cdot \rho \cdot r^*)/V$$

$$\psi_{ij} \equiv \nu'_{ij} - \nu_{ij}$$

The partial derivatives of the net species production rate with respect to: the chemical species; the gas velocity; the gas density; and the gas temperature are:

$$\beta(C_k, C_i) \quad BT(I,K) \quad = \quad \overline{K}_i \cdot \sum_{j=1}^{\ell} \frac{\partial X_j}{\partial C_i} \qquad i = 1, \ldots, NSP; \; k = 1, \ldots, NSP$$

$$\beta(C_i, V) \quad PHI(I,1) \quad = \quad -\frac{1}{V} \frac{dC_i}{dx} \qquad i = 1, \ldots, NSP$$

$$\beta(C_i, \rho) \quad PHI(I,2) \quad = \quad \frac{1}{\rho} \cdot \frac{dC_i}{dx} + \overline{K}_i \sum_{j=1}^{m} \frac{\partial X_j}{\partial \rho} \qquad i = 1, \ldots, NSP$$

$$\beta(C_i, T) \quad PHI(I,3) \quad = \quad \overline{K}_i \sum_{j=1}^{\ell} \frac{\partial X_j}{\partial T} \qquad i = 1, \ldots, NSP$$

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* $\lambda = \sum_{i=1}^{NSP} (\nu'_{ij} - \nu_{ij})$ so that $\lambda = 0$ for binary exchange, $\lambda = 1$ for most dissociation recombination reactions.

The subscript notation used above is:

i	=	Species subscript
j	=	Reaction subscript
ℓ	=	Total number of chemical reactions
m	=	Number of reactions requiring third body terms
NSP	=	Total number of gaseous species

5.4.5 SUBROUTINE ECNV

This subroutine translates a BCD string of characters, into one floating point numeric value. E,I, and F formats are permitted with the result always a floating point number. It is called by subroutine REAXIN to decode numeric fields in the species and reactions cards. The subroutine is coded entirely in FORTRAN. A BCD string of blanks will result in a floating point zero returned value.

5.4.6 SUBROUTINE EF

This subroutine computes equilibrium constants, K_j,

$$K_j \quad EK(J) = \frac{DATEF(J)}{T^{\lambda}} \cdot \exp\left[-\sum_{i=1}^{n} Ft_i \cdot \nu_{ij} + \sum_{i=1}^{n} Ft_i \cdot \nu'_{ij}\right]$$

also computed are

$$\frac{dK_j}{dT} \quad DKT(J) = \left[\frac{-\sum_{i=1}^{n} \frac{Ht_i}{R_i} \cdot \nu_{ij} + \sum_{i=1}^{n} \frac{Ht_i}{R_i} \cdot \nu'_{ij}}{T} - \lambda\right] \cdot \frac{K_j}{T}$$

where: Ft_i = species free energy at the current temperature

Ht_i = species enthalpy at the current temperature

DATEF(J) = is defined in section 5.4.3

5.4.7 SUBROUTINE FLU

This subroutine computes the total derivatives f_i and the partial derivatives α_i and ϑ_{ij} for the fluid dynamic equations. While the flow is subsonic, pressure defined fluid dynamic equations are used. When the flow becomes supersonic, area defined fluid dynamic equations are used. The summation terms, energy exchange term B, the diabatic heat addition term A, the Mach number, and all the partial derivatives of these terms are computed. For a subsonic integration the pressure and its derivatives are obtained from the subsonic pressure table. For a supersonic integration the area ratio and its derivatives are computed from the input geometric constraints.

The calculations logically fall into three types: a) Those done for all integrations; b) Those done only for subsonic integration; c) Those done only for supersonic integration. The following will adhere as closely as possible to a sequential description of the computations.

The operators $\Phi(i,l)$, $l = 1,2,3$ are defined as

$$\Phi(i,1) = \beta(C_i, V)$$

$$\Phi(i,2) = \beta(C_i, \rho)$$

$$\Phi(i,3) = \beta(C_i, T)$$

The total derivatives, $f_i = \frac{dC_i}{dx}$, for $i = 1, \ldots, n$ are computed as

$$f_i = \frac{\omega_i r^*}{\rho V}$$

where n is the total number of species, NSP.

For an ODTDK problem, tables of Cp, R, AA, BB, as functions of temperature are written on logical unit JANAF.

Computation of the Summation Terms and their derivatives:

First Summation

$$S1 \qquad S1 \qquad = \frac{1}{R} \cdot \sum_{i=1}^{n} \frac{dC_i}{dx} \cdot R_i$$

$$\frac{\partial S1}{\partial V} \qquad DS1V \qquad = \frac{1}{R} \cdot \sum_{i=1}^{n} \Phi_{(i,1)} \cdot R_i$$

$$\frac{\partial S1}{\partial \rho} \qquad DS1R\emptyset \qquad = \frac{1}{R} \cdot \sum_{i=1}^{n} \Phi_{(i,2)} \cdot R_i$$

$$\frac{\partial S1}{\partial T} \qquad DS1T \qquad = \frac{1}{R} \cdot \sum_{i=1}^{n} \Phi_{(i,3)} \cdot R_i$$

$$\frac{\partial S1}{\partial C_i} \qquad DS1C(I) \qquad = \frac{1}{R} \cdot \left[\sum_{j=1}^{n} \beta_{(C_j, C_i)} \cdot R_j - S1 \cdot R_i \right] \quad i = 1, \ldots, n$$

Second Summation

$$S2 \qquad S2 \qquad = \frac{1}{R \cdot T} \cdot \sum_{i=1}^{n} \frac{dC_i}{dx} \cdot h_i$$

$$\frac{\partial S2}{\partial V} \qquad DS2V \qquad = \frac{1}{R \cdot T} \cdot \sum_{i=1}^{n} \Phi_{(i,1)} \cdot h_i$$

$$\frac{\partial S2}{\partial \rho} \qquad DS2R\emptyset \qquad = \frac{1}{R \cdot T} \cdot \sum_{i=1}^{n} \Phi_{(i,2)} \cdot h_i$$

$$\frac{\partial S2}{\partial T} \qquad DS2T \qquad = \frac{1}{R \cdot T} \sum_{i=1}^{n} \left[\Phi_{(i,3)} \cdot h_i + \frac{dC_i}{dx} \cdot Cp_i \right] - \frac{S2}{T}$$

$$\frac{\partial S2}{\partial C_i} \qquad DS2C(I) \qquad = \frac{1}{R} \cdot \left[\sum_{j=1}^{n} \frac{\beta_{(C_j, C_i)} \cdot h_i}{T} - S2 \cdot R_i \right] \quad i = 1, \ldots, n$$

* R_i is the gas constant/molecular wt. of species i

Computation of the Energy Exchange Term B and its Derivatives:

$$B \qquad BB \qquad = \frac{\gamma-1}{\gamma} \cdot S2$$

$$\frac{\partial B}{\partial V} \qquad DBBV \qquad = \frac{\gamma-1}{\gamma} \cdot \frac{\partial S2}{\partial V}$$

$$\frac{\partial B}{\partial \rho} \qquad DBBR\emptyset \qquad = \frac{\gamma-1}{\gamma} \cdot \frac{\partial S2}{\partial \rho}$$

$$\frac{\partial B}{\partial T} \qquad DBBT \qquad = \frac{\gamma-1}{\gamma} \cdot \frac{\partial S2}{\partial T} + \frac{S2}{\gamma^2} \cdot \frac{\partial \gamma}{\partial T}$$

$$\frac{\partial B}{\partial C_i} \qquad DBBC(I) \qquad = \frac{\gamma-1}{\gamma} \cdot \frac{\partial S2}{\partial C_i} + \frac{S2}{\gamma^2} \cdot \frac{\partial \gamma}{\partial C_i} \qquad i = 1, \ldots, n$$

Computation of the Diabatic Heat Addition Term A and its Derivatives:

$$A \qquad AA \qquad = S1-B$$

$$\frac{\partial A}{\partial V} \qquad DAAV \qquad = \frac{\partial S1}{\partial V} - \frac{\partial B}{\partial V}$$

$$\frac{\partial A}{\partial \rho} \qquad DAAR\emptyset \qquad = \frac{\partial S1}{\partial \rho} - \frac{\partial B}{\partial \rho}$$

$$\frac{\partial A}{\partial T} \qquad DAAT \qquad = \frac{\partial S1}{\partial T} - \frac{\partial B}{\partial T}$$

$$\frac{\partial A}{\partial C_i} \qquad DAAC(I) \qquad = \frac{\partial S1}{\partial C_i} - \frac{\partial B}{\partial C_i} \qquad i = 1, \ldots, n$$

Computation of the Mach number and its derivatives:

$$M^2 \qquad XM2 \qquad = \frac{V^2}{\gamma \cdot R \cdot T}$$

$$\frac{\partial M^2}{\partial V} \qquad DM2V \qquad = \frac{2 \cdot M^2}{V}$$

$$\frac{\partial M^2}{\partial T} \qquad DM2T \qquad = -\frac{M^2}{T} - \frac{M^2}{\gamma} \cdot \frac{\partial \gamma}{\partial T}$$

$$\frac{\partial M^2}{\partial C_i} \qquad DM2C(I) \qquad = -M^2 \cdot \left[\frac{\partial \gamma}{\partial C_i} \cdot \frac{1}{\gamma} + \frac{R_i}{R} \right] \qquad i = 1, \ldots, n$$

For the subsonic portion of the nozzle, pressure defined fluid dynamic equations are used. The pressure, and its first and second derivatives are computed via interpolation in the pressure table generated by subroutine PRES. The Subsonic Gas Velocity derivatives are computed:

$$\frac{dV}{dx} \qquad FNX(1) \qquad = -\frac{1}{\rho \cdot V} \cdot \frac{dP}{dx}$$

$$\frac{\partial [FNX(1)]}{\partial x} \qquad AL(1) \qquad = -\frac{1}{\rho \cdot V} \cdot \frac{d^2P}{dx^2}$$

$$\beta(V,V) \qquad BETA(1,1) \qquad = -\frac{1}{V} \cdot \frac{dV}{dx}$$

$$\beta(V,\rho) \qquad BETA(1,2) \qquad = -\frac{1}{\rho} \cdot \frac{dV}{dx}$$

The Subsonic Gas Density derivatives are computed:

$$\frac{d\rho}{dx} \qquad FNX(2) \qquad = \rho \cdot \left[\frac{dP}{dx} \cdot \frac{1}{\gamma \cdot P} - A \right]$$

$$\frac{\partial [FNX(2)]}{\partial x} \qquad AL(2) \qquad = \frac{\rho}{\gamma \cdot P} \cdot \left[\frac{d^2P}{dx^2} - \left(\frac{dP}{dx} \right)^2 \cdot \frac{1}{P} \right]$$

$\beta(\rho,V)$ BETA(2,1) $= -\ \rho \cdot \frac{\partial A}{\partial V}$

$\beta(\rho,\rho)$ BETA(2,2) $= -\ \frac{1}{\rho} \cdot \frac{d\rho}{dx} - \rho \cdot \frac{\partial A}{\partial \rho}$

$\beta(\rho,T)$ BETA(2,3) $= -\ \rho \cdot \frac{\partial A}{\partial T} - \frac{\rho}{P \cdot \gamma^2} \cdot \frac{\partial \gamma}{\partial T} \cdot \frac{dP}{dx}$

$\beta(\rho,C_i)$ BETA(2,i+3) $= -\ \frac{\rho}{\gamma^2 P} \cdot \frac{\partial \gamma}{\partial C_i} \cdot \frac{dP}{dx} - \rho \cdot \frac{\partial A}{\partial C_i}$ $\quad i = 1,\ldots,n$

The Subsonic Gas Temperature derivatives are computed:

$\frac{dT}{dx}$ FNX(3) $= T \cdot \left[\frac{\gamma-1}{\gamma} \cdot \frac{1}{P} \cdot \frac{dP}{dx} - B\right]$

$\frac{\partial[FNX(3)]}{\partial x}$ AL(3) $= \frac{\gamma-1}{\gamma} \cdot \frac{T}{P} \cdot \left[\frac{d^2P}{dx^2} - \left(\frac{dP}{dx}\right)^2 \cdot \frac{1}{P}\right]$

$\beta(T,V)$ BETA(3,1) $= -\ T \cdot \frac{\partial B}{\partial V}$

$\beta(T,\rho)$ BETA(3,2) $= -\ T \cdot \frac{\partial B}{\partial \rho}$

$\beta(T,T)$ BETA(3,3) $= \frac{1}{T} \cdot \frac{dT}{dx} + T \frac{1}{\gamma^2 \cdot P} \frac{dP}{dx} \frac{\partial \gamma}{\partial T} - T \frac{\partial B}{\partial T}$

$\beta(T,C_i)$ BETA(3,i+3) $= T \cdot \left[\frac{1}{\gamma^2 \cdot P} \cdot \frac{dP}{dx} \cdot \frac{\partial \gamma}{\partial C_i} - \frac{\partial B}{\partial C_i}\right]$ $\quad i = 1,\ldots n$

For the supersonic portion of the nozzle, area defined fluid dynamic equations are used. The area ratio, and its derivatives are computed according to the input geometric constraints.

Area ratio and its derivatives:

1) On the circular arc of radius R_d (input item RWTD) defining the downstream throat region, $X \leq X_{tangent}$

$$a = \left[1 + R_d - \left(R_d^2 - x^2\right)^{1/2}\right]^2$$

$$\frac{da}{dx} = \frac{2x}{\left(R_d^2 - x^2\right)^{1/2}} \cdot \left[1 + R_d - \left(R_d^2 - x^2\right)^{1/2}\right]$$

$$\frac{d^2a}{dx^2} = \left[\frac{2}{\left(R_d^2 - x^2\right)^{1/2}} + \frac{2x^2}{\left(R_d - x^2\right)^{3/2}}\right] \cdot \left[1 + R_d - \left(R_d - x^2\right)^{1/2}\right] + \frac{2x^2}{R_d^2 - x^2}$$

2) For a conical nozzle and $X > X_{tangent}$

$$a = \left[r_t + \left(x - x_t\right) \tan \Theta_t\right]^2$$

$$\frac{da}{dx} = 2\left[r_t + \left(x - x_t\right) \tan \Theta_t\right] \cdot \tan \Theta_t$$

$$\frac{d^2a}{dx^2} = 2 \tan^2 \Theta_t$$

3) For a contoured nozzle and $X > X_{tangent}$

$$a = Y^2$$

$$\frac{da}{dx} = 2 \cdot Y \cdot \frac{dY}{dx}$$

$$\frac{d^2a}{dx^2} = 2 \cdot \left[Y \frac{d^2Y}{dx^2} + \left(\frac{dY}{dx} \right)^2 \right]$$

where Y, dY/dx, d^2Y/dx^2 are computed via interpolation in the table of derivatives of the input wall table generated in Subroutine SLP.

The Supersonic Gas Velocity derivatives are computed:

$$\frac{dV}{dx} \qquad FNX(1) = \frac{V}{M^2-1} \cdot \left[\frac{1}{a} \frac{da}{dx} - A \right]$$

$$\frac{\partial[FNX(1)]}{\partial x} \quad AL(1) = \frac{V}{M^2-1} \cdot \frac{1}{a} \cdot \left[\frac{d^2a}{dx^2} - \frac{1}{a} \cdot \left(\frac{da}{dx} \right)^2 \right]$$

$$\beta(V,V) \quad BETA(1,1) = \frac{1}{V} \cdot \frac{dV}{dx} - \frac{1}{M^2-1} \cdot \frac{dV}{dx} \cdot \frac{\partial M^2}{\partial V} - \frac{V}{M^2-1} \cdot \frac{\partial A}{\partial V}$$

$$\beta(V,\rho) \quad BETA(1,2) = - \frac{V}{M^2-1} \cdot \frac{\partial A}{\partial \rho}$$

$$\beta(V,T) \quad BETA(1,3) = - \frac{1}{M^2-1} \cdot \frac{dV}{dx} \cdot \frac{\partial M^2}{\partial T} - \frac{V}{M^2-1} \cdot \frac{\partial A}{\partial T}$$

$$\beta(V,C_i) \quad BETA(1,i+3) = - \frac{1}{M^2-1} \cdot \frac{dV}{dx} \cdot \frac{\partial M^2}{\partial C_i} - \frac{V}{M^2-1} \cdot \frac{\partial A}{\partial C_i} \quad i=1,\ldots,n$$

The Supersonic Gas Density derivatives are computed:

$$\frac{d\rho}{dx} \quad FNX(2) \quad = -\rho\cdot\left[\frac{M^2}{M^2-1}\cdot\left(\frac{1}{a}\cdot\frac{da}{dx} - A\right) + A\right]$$

$$\frac{\partial[FNX(2)]}{\partial x} \quad AL(2) \quad = -\rho\cdot\frac{M^2}{M^2-1}\cdot\frac{1}{a}\cdot\left[\frac{d^2a}{dx^2} - \frac{1}{a}\left(\frac{da}{dx}\right)^2\right]$$

$$\beta(\rho,V) \quad BETA(2,1) \quad = \quad \rho\cdot\left[\frac{1}{(M^2-1)^2}\cdot\left(\frac{1}{a}\frac{da}{dx} - A\right)\cdot\frac{\partial M^2}{\partial V} + \frac{1}{M^2-1}\cdot\frac{\partial A}{\partial V}\right]$$

$$\beta(\rho,\rho) \quad BETA(2,2) \quad = \quad \frac{1}{\rho}\cdot\frac{d\rho}{dx} + \frac{\rho}{M^2-1}\cdot\frac{\partial A}{\partial \rho}$$

$$\beta(\rho,T) \quad BETA(2,3) \quad = \quad \rho\cdot\left[\frac{1}{(M^2-1)^2}\cdot\left(\frac{1}{a}\frac{da}{dx} - A\right)\cdot\frac{\partial M^2}{\partial T} + \frac{1}{M^2-1}\cdot\frac{\partial A}{\partial T}\right]$$

$$\beta(\rho,C_i) \quad BETA(2,i+3) = \quad \rho\cdot\left[\frac{1}{(M^2-1)^2}\cdot\left(\frac{1}{a}\frac{da}{dx} - A\right)\frac{\partial M^2}{\partial C_i} + \frac{1}{M^2-1}\cdot\frac{\partial A}{\partial C_i}\right]$$

$$i = 1, \ldots, n$$

The Supersonic Gas Temperature derivatives are computed:

$$\frac{dT}{dx} \quad FNX(3) \quad = -T\cdot\left[(\gamma-1)\cdot\frac{M^2}{M^2-1}\cdot\left(\frac{1}{a}\frac{da}{dx} - A\right) + B\right]$$

$$\frac{\partial[FNX(3)]}{\partial x} \quad AL(3) \quad = -T\cdot\frac{M^2}{M^2-1}\cdot\frac{\gamma-1}{a}\cdot\left[\frac{d^2a}{dx^2} - \frac{1}{a}\cdot\left(\frac{da}{dx}\right)^2\right]$$

$$\beta(T,V) \quad BETA(3,1) \quad = \quad T\cdot\left[\frac{\gamma-1}{(M^2-1)^2}\left(\frac{1}{a}\frac{da}{dx} - A\right)\cdot\frac{\partial M^2}{\partial V} + \gamma-1\cdot\frac{M^2}{M^2-1}\cdot\frac{\partial A}{\partial V} - \frac{\partial B}{\partial V}\right]$$

$$\beta(T,\rho) \quad BETA(3,2) \quad = \quad T\cdot\left[\gamma-1\cdot\frac{M^2}{M^2-1}\cdot\frac{\partial A}{\partial \rho} - \frac{\partial B}{\partial \rho}\right]$$

$\beta(T,T)$ BETA(3,3) $=$

$$\frac{1}{T}\cdot\frac{dT}{dx}+T\cdot\left[\frac{\gamma-1}{(M^2-1)^2}\left(\frac{1}{a}\frac{da}{dx}-A\right)\frac{\partial M^2}{\partial T}\right.$$

$$+\gamma-1\cdot\frac{M^2}{M^2-1}\cdot\frac{\partial A}{\partial T}-\frac{\partial B}{\partial T}$$

$$\left.-\frac{M^2}{(M^2-1)}\cdot\left(\frac{1}{a}\frac{da}{dx}-A\right)\frac{\partial\gamma}{\partial T}\right]$$

$\beta(T,C_l)$ BETA(3,l+3)$=$

$$T\cdot\left[\frac{\gamma-1}{(M^2-1)^2}\cdot\left(\frac{1}{a}\frac{da}{dx}-A\right)\frac{\partial M^2}{\partial C_l}+\gamma-1\cdot\frac{M^2}{M^2-1}\cdot\frac{\partial A}{\partial C_l}\right.$$

$$\left.-\frac{\partial B}{\partial C_l}-\frac{M^2}{M^2-1}\cdot\left(\frac{1}{a}\frac{da}{dx}-A\right)\frac{\partial\gamma}{\partial C_l}\right]$$

$l=1,\ldots,n$

5.4.8 SUBROUTINE GTF

This subroutine computes the effective gas constant, gaseous heat capacity, γ, $\partial\gamma/\partial T$, $\partial\gamma/\partial C_i$ from the following formulae:

$$R = \sum_{i=1}^{NSP} C_i \cdot R_i$$

$$Cp = \sum_{i=1}^{NSP} C_i \cdot Cp_i$$

$$\gamma = \frac{Cp}{Cp-R}$$

$$\frac{\partial\gamma}{\partial T} = -\frac{\gamma\cdot(\gamma-1)}{Cp} \cdot \sum_{i=1}^{NSP} C_i \cdot \frac{\partial Cp_i}{\partial T}$$

$$\frac{\partial\gamma}{\partial C_i} = \gamma\cdot(\gamma-1)\cdot\left[-\frac{R_i}{R} - \frac{Cp_i}{Cp}\right] \qquad i = 1, \ldots, n$$

5.4.9 SUBROUTINE IAUX (HL, H, QK, RK, JX)

This subroutine performs implicit integration according to the method discussed in Section 3. The increments for the chemical species concentrations and the fluid dynamic variables at the forward point are calculated by solving the appropriate implicit finite difference formulas. Subroutine IAUX also performs explicit integration, using a modified Euler method, when the gas temperature falls below an input value.

The calling sequence parameters are:

HL - last integration step size

H - current integration step size

QK - last increments for variables

RK - computed increments for variables

JK - 1 initial 3 steps
2 general step
3 special step
4 restart step

The total derivatives, $f_{i,n}$, and partial derivatives, $\beta_{i,j,n}$ at the back point are calculated in subroutines DERIV and FLU.

The special step calculation is used at print stations, in halving the step size if required, or for integrating to specific calculation stations. If the special step calculation is used to determine the properties at a print station, the calculation is resumed using the general step calculation and the previous step size.

After each integration step, subroutine IAUX obtains the derivatives at the then current axial position.

For implicit integration the equations used are:

Initial Step and Restart

$$k_{i,1} = \left[f_{i,o} + \alpha_{i,o} h + \sum_{j=1}^{N} \beta_{i,j,o} k_{j,1} \right] \cdot h$$

General Step

$$k_{i,n+1} = \frac{1}{3} \left[k_{i,n} + 2 \cdot \left(f_{i,n} + \alpha_{i,n} h + \sum_{j=1}^{N} \beta_{i,j,n} k_{j,n+1} \right) \cdot h \right]$$

Special Step

$$k_{i,n+1} = \frac{h_{n+1}^2}{(2h_{n+1}+h_n) \cdot h_n} \left[k_{i,n} + \left[f_{i,n} + \alpha_{i,n} h_{n+1} + \sum_{j=1}^{N} \beta_{i,j,n} k_{j,n+1} \right] \cdot \frac{h_n}{h_{n+1}} (h_{n+1}+h_n) \right]$$

For explicit integration the above equations are used deleting the partial derivative terms α and β.

If the TDK problem directive was selected, gas tables for the Transonic Analysis Subprogram are written on logical unit ITSTAB.

If the option to generate input tables for the Turbulent Boundary Layer Nozzle Analysis Computer Program was selected, tables of M, P/P_c, T/T_c, C_p, V, ρ are tabulated using subroutine TABGEN.

5.4.10 SUBROUTINE INT

Provides control for the implicit integration procedure, determines the proper set of nonhomogeneous equations to solve, and, after each integration step, computes the next integration step size according to the following relations:

$$h_{n+2} = 2h_{n+1}, \qquad \left| \frac{k_{i,n+1} - 2k_{i,n} + k_{i,n-1}}{3k_{i,n+1} - k_{i,n}} \right|_{MAX} < \frac{\delta}{10}$$

$$h_{n+2} = \frac{1}{2} h_{n+1}, \qquad \left| \frac{k_{i,n+1} - 2k_{i,n} + k_{i,n-1}}{3k_{i,n+1} - k_{i,n}} \right|_{MAX} > \delta$$

$$h_{n+2} = h_{n+1}, \qquad \frac{\delta}{10} \leq \left| \frac{k_{i,n+1} - 2k_{i,n} + k_{i,n-1}}{3k_{i,n+1} - k_{i,n}} \right|_{MAX} \leq \delta$$

On option, (JF=1) only the fluid dynamic variables are used in determining the next integration step size.

If the step size is halved for the fourth step, the integration is restarted using one-half the original step size.

The correspondence between equation number and physical property is:

Equation Number	Property
1	Velocity of Gas
2	Density of Gas
3	Temperature of Gas
4 → NSP+3	Gaseous species mass fraction
	(1 → NSP) corresponds to (4 → NSP + 3)

When the flow is supersonic, continuity is used to control the integration step size to insure that:

$$\left| \frac{(\rho VA)_{N+1} - (\rho VA)_N}{(\rho VA)_{N+1}} \right| < CØNDEL$$

where CØNDEL is an input relative criterion.

5.4.11 SUBROUTINE LESK (Y)

This subroutine is a single precision linear equation solver which is used to perform the matrix inversions required by subroutine IAUX. Gaussian elimination is used with row interchange taking place to position maximum pivot elements after the rows are initially scaled.

5.4.12 SUBROUTINE MAIN1D

This subroutine provides the overall logic control for the one-dimensional kinetic expansion. The following functions are controlled:

1) Variable initialization
2) Option to start the kinetic expansion from equilibrium throat conditions
3) Controls of the integration to hit specific area ratios, the nozzle throat point, the nozzle tangent point, and the requested end point
4) Controls of the switch from the subsonic pressure defined equations to the supersonic area defined equations when ($M^2 \geq 1.02$)
5) Controls the switch from implicit to explicit integration.

For the normal mode of operation of the program, this subroutine locates the throat in the following manner:

The gaseous mass flow per unit area (ρv) is calculated and stored as a function of nozzle axial location for the present and past integration step. When

$$(\rho v)_{n+1} < (\rho v)_n$$

where n refers to the n^{th} integration step, the throat location is calculated from:

$$X^* = X_n + \frac{(X_n - X_{n-1})^2 \cdot \left[(\rho v)_{n+1} - (\rho v)_n\right] + (X_{n+1} - X_n)^2 \cdot \left[(\rho v)_n - (\rho v)_{n-1}\right]}{2 \cdot \left[(X_{n+1} - X_n) \cdot \left[(\rho v)_n - (\rho v)_{n-1}\right] - (X_n - X_{n-1}) \cdot \left[(\rho v)_{n+1} - (\rho v)_n\right]\right]}$$

and the $n+1^{th}$ integration step is repeated using a step size of $X^* - X_n$ to determine the throat conditions.

To prevent the location of a false throat due to roughness of an input pressure table, ten integration steps are required before the throat will be sought.

Through the downstream throat radius of curvature the step size is controlled so as to be less than or equal to RWTD*SIN(THETA)/25.0.

5.4.13 SUBROUTINE NUMBR

This subroutine converts a one character BCD number to a FORTRAN integer number. It is called by subroutine ECNV to decode free field numeric data. The subroutine is coded entirely in FØRTRAN.

5.4.14 SUBROUTINE ØDKINP

This subroutine provides the input processing for the kinetic expansion calculation. It performs the following functions:

1) Variable initialization to nominal values

2) Calls subroutine REAXIN to input the reactions cards and species cards if necessary

3) For an ØDE-ØDK problem, calls subroutine SELECT to select those species to be considered for the kinetic expansion calculation

4) Reads $ØDK namelist input data

5) Converts nozzle geometric parameters from input units: inches, degrees; to internal computational units: feet, radians

6) Computes nozzle tangent coordinates using:

$$r_t = 1 + R_d (1 - \cos \theta)$$

$$x_t = R_d \sin \theta$$

7) For conical nozzles, computes the axial coordinate for the exit station from the following relation:

$$x_{exit} = \frac{\sqrt{\epsilon} - r_t + x_t \cdot \tan \theta}{\tan \theta} \qquad x_{exit} \geq x_t$$

$$x_{exit} = \left\{ R_d^2 - (1 + R_d - \sqrt{EP})^2 \right\}^{\frac{1}{2}} \qquad x_{exit} < x_t$$

8) For conical nozzles, the internal axial print stations are computed using:

$$X_j = \frac{\sqrt{ARPRNT(J)} - r_t + x_t \cdot \tan\theta}{\tan\theta} \quad X_j \geq X_t$$

$$X_j = \left\{ R_d^2 - \left[1 + R_d - (ARPRNT(J))^{\frac{1}{2}}\right]^2 \right\}^{\frac{1}{2}} \quad X_j < X_t$$

9) The sum of input or selected species concentrations is checked for unity ($\pm$ XMFTST, where XMFTST is an input number), and then normalized.

10) If the input parameter RZNØRM is input, the input contoured nozzle table is normalized by RZNØRM.

5.4.15 SUBROUTINE OUTPUT

This subroutine provides conversion from internal computational units to output engineering units and the calculation of performance parameters. The following output parameters are computed by this subroutine:

The pressure (in PSIA) is computed from:

$$P_{(PSIA)} = P/4633.056$$

The gaseous species mole fractions are computed from:

$$C_{i,m} = \frac{R_i}{R} \cdot C_i$$

The gas molecular weight is computed from:

$$Mw = 49721.011/R$$

The percentage mass fraction change is computed from:

$$\% \Delta (\text{Mass Fraction}) = 100.0 \cdot (1.0 - \sum_{i=1}^{n} C_i)$$

The gas heat capacity is computed from:

$$Cp_g(BTU/LB-^{O}R) = 3.9969 \cdot 10^{-5} \cdot Cp_g$$

The gas enthalpy is computed from:

$$H_g(BTU/LB) = 3.9969 \cdot 10^{-5} \cdot \sum_{i=1}^{n} C_i \cdot h_i$$

At the throat, the characteristic exhaust velocity (ft/sec) is computed from:

$$C^* = \frac{P_c}{\rho^* \cdot V^*}$$

The vacuum specific impulse is computed from:

$$ISP_{VAC} = \frac{V + \overline{\rho \cdot V}^{P}}{g} \quad , \; g = 32.174$$

The vacuum thrust coefficient is computed from:

$$C_{F_{VAC}} = \frac{V + \overline{\rho \cdot V}^{P}}{C^*} \; .$$

The percentage enthalpy change is computed from:

$$\% \Delta H_T = \frac{100 \cdot (HREF_c - HREF)}{V^2/2}$$

where

$$HREF = \sum_{i=1}^{NSP} C_i \cdot h_i + V^2/2$$

$HREF_c$ is HREF evaluated at the initial condition for the ØDK integration (i.e. at the initial contraction ratio, ECRAT).

5.4.16 SUBROUTINE PACK

On the basis of those species currently being considered, this subroutine packs species and reaction information from the master tables into those control sections utilized by the one-dimensional kinetic expansion subprogram.

The following is a sequential description of the packing procedures:

1) Thermodynamic data for the species being considered is read into core storage.

2) The chemical species'molecular weights are computed

3) The symbolic reactions are checked for mass balance.

4) For a contoured nozzle the slope at each input wall point is computed using subroutine SLP. The wall coordinates, and each computed slope are printed for each input wall point and the print stations are set to the input axial coordinates.

5.4.17 SUBROUTINE PRES

This subroutine is used (when JPFLAG = 1) to compute the derivatives of an input pressure table.

This subroutine is also used (when JPFLAG = 0) to generate a pressure table through use of an average expansion coefficient, Ne. The generated table extends from the initial contraction ratio through the nozzle attachment point plus one normalized throat radius.

Input Pressure Table Derivative Computation (JPFLAG = 1)

If a pressure table of NTB entries is input, the table of first derivatives is computed using:

$$\left.\frac{dP}{dx}\right|_{x_1} = 0$$

$$\left.\frac{dP}{dx}\right|_{x_n} = \frac{P_{(x_{n+1})} - P_{(x_{n-1})}}{x_{(n+1)} - x_{(n-1)}} \quad , \; 1 < n < NTB$$

$$\left.\frac{dP}{dx}\right|_{x_{NTB}} = \frac{P_{(x_n)} - P_{(x_{n-1})}}{x_{(n)} - x_{(n-1)}} \quad , \; n = NTB$$

The pressure at the initial axial position is obtained by interpolation using subroutine SPLN.

Internally Computed Pressure Table Computation (JPFLAG = 0)

An average equilibrium pressure expansion coefficient from the chamber to the throat, N_e, is computed by iteration using subroutine SUBNE. The initial value for $N_e^{(1)}$ is 1.2.

The approximate equilibrium contraction ratio at the initial axial position is computed from:

$$a_c = \left[\frac{N_e - 1}{2} \cdot \frac{\left[\frac{2}{N_e+1}\right]^{\frac{N_e+1}{N_e-1}}}{\left(\frac{P_i}{P_c}\right)^{\frac{2}{N_e}} \cdot \left[1 - \left(\frac{P_i}{P_c}\right)^{\frac{N_e-1}{N_e}}\right]} \right]^{\frac{1}{2}}$$

where P_i = pressure at the initial axial position

P_c = equilibrium chamber pressure

A check is then made to determine the compatibility between the nozzle geometry and the requested contraction ratio.

If

$$\sqrt{a_c} < 1 + \left[R_u + R_i\right] \cdot \left[1 - \cos\ \theta_i\right],$$

the circular arcs R_u and R_i overlap and the following error message is printed:

INLET GEOMETRY INCOMPATIBLE WITH INITIAL CONDITIONS

The program will proceed to the next case.

Tables for pressure and its derivatives are constructed as functions of area ratio, a, and expansion coefficient, Ne. Formula used for the j + 1 iteration for pressure is:

$$\frac{p^{(j+1)}}{P_c} = \frac{p^{(j)}}{P_c} + 2\left\{\frac{N_e-1}{N_e}\cdot\left[1-\left(\frac{p^{(j)}}{P_c}\right)^{\frac{N_e-1}{N_e}}\right]^{-1}\left(\frac{p^{(j)}}{P_c}\right)^{-\frac{1}{N_e}} - \frac{2}{N_e}\cdot\left(\frac{p^{(j)}}{P_c}\right)^{-1}\right\}^{-1}$$

$$\cdot\left\{\left[\frac{N_e-1}{2}\cdot\frac{[2/(N_e+1)]^{(N_e+1)/(N_e-1)}}{\left(\frac{p^{(j)}}{P_c}\right)^{2/N_e}\cdot\left[1-\left(\frac{p^{(j)}}{P_c}\right)^{(N_e-1)/N_e}\right]}\right]^{-1/2}\cdot a - 1\right\}$$

for j = 1

$$\left.\frac{p^{(1)}}{P_c}\right|_{x_{n+1}} = \left.\frac{p}{P_c}\right|_{x_n} + \left.\frac{d(P/P_c)}{dx}\right|_{x_n}(x_{n+1} - x_n)$$

where n refers to the n^{th} table entry.

The pressure derivative formula used is:

$$\frac{d(P/P_c)}{dx} = \left[\frac{N_e-1}{N_e}\left(\frac{P}{P_c}\right)^{-\frac{1}{N_e}}\left[1-\left(\frac{P}{P_c}\right)^{\frac{N_e-1}{N_e}}\right]^{-1} - \frac{2}{N_e}\left(\frac{P}{P_c}\right)^{-1}\right]^{-1}\cdot\frac{2}{a}\cdot\frac{da}{dx}$$

Next, tables for pressure and its derivatives are constructed by the program. Table entries are at increments of

$-x_i/75$	for	$x_i < x < 0$
$(R_d \sin\theta)/25$	for	$0 < x < R_d \sin\theta$

and

$1/25$	for	$R_d \sin\theta < x < R_d \sin\theta + 1$

where the initial nozzle axial position, x_i, is computed from:

$$x_i = -\left[(R_u + R_i) \cdot \sin\theta_i + \frac{\sqrt{a_c} - 1 - (R_u + R_i) \cdot (1 - \cos\theta_i)}{\tan\theta_i}\right]$$

See Figure 5.4-1 below:

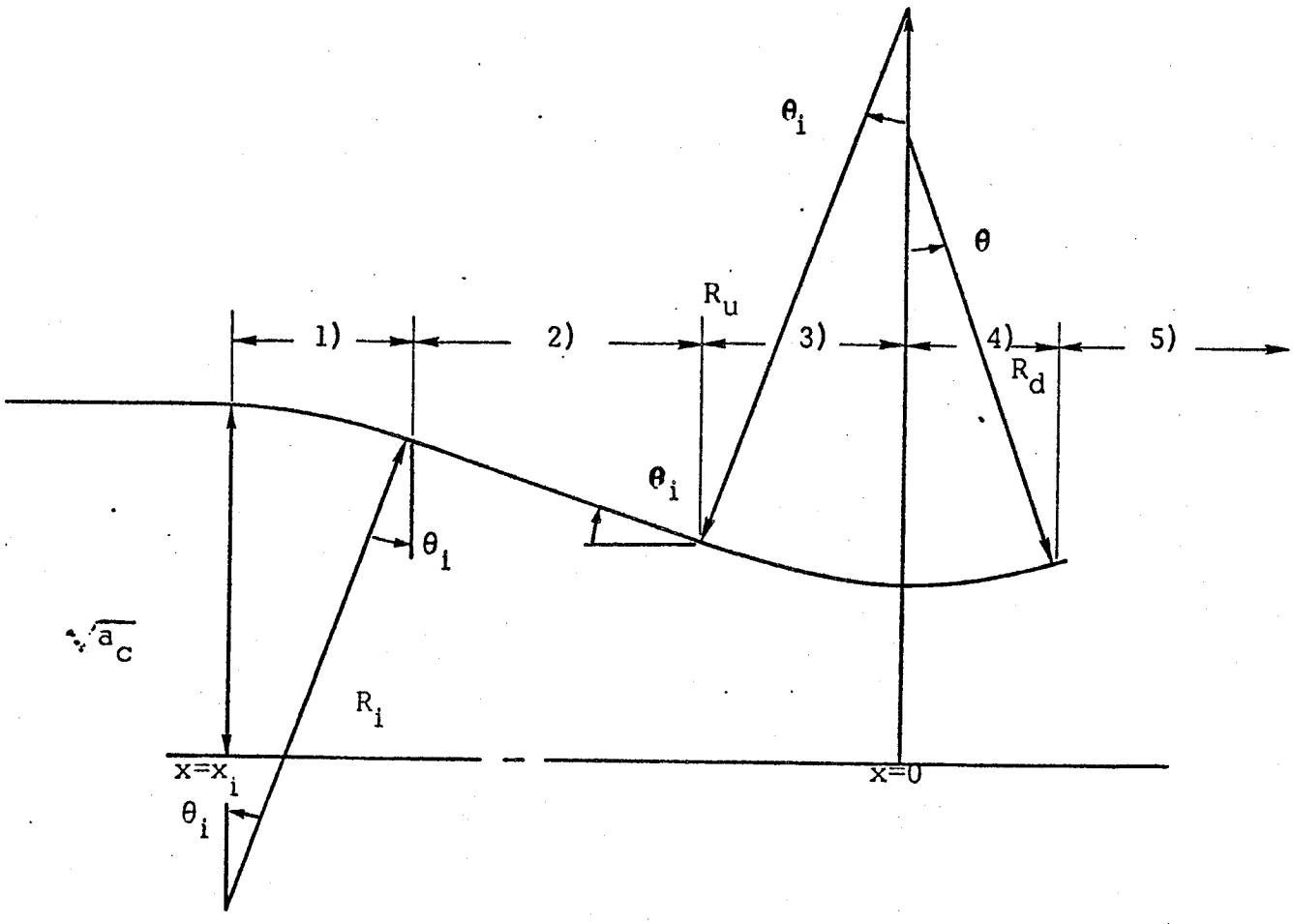


Figure 5.4-1. NOZZLE GEOMETRY

Area ratio and its derivative and (a and $\frac{da}{dx}$) are found by the five formulae below:

1) $x < x_i + R_i \sin\theta_i$

$$a = \left[\sqrt{a_c} - R_i\left(1 - \sqrt{1 - \frac{(x-x_i)^2}{R_i^2}}\right)\right]^2$$

$$\frac{da}{dx} = \frac{-2(x-x_i)}{\left[R_i^2 - (x-x_i)^2\right]^{1/2}} \cdot \sqrt{a}$$

2) $x_i + R_i \sin\theta_i < x < -R_u \sin\theta_i$

$$a = \left[\sqrt{a_c} - R_i(1 - \cos\theta_i) - (x - x_i - R_i \sin\theta_i)\tan\theta_i\right]^2$$

$$\frac{da}{dx} = -2 \cdot \sqrt{a} \cdot \tan\theta_i$$

3) $-R_u \cdot \sin\theta_i < x < 0$

$$a = \left[1 + R_u\left(1 - \sqrt{1 - \frac{x^2}{R_u^2}}\right)\right]^2$$

$$\frac{da}{dx} = \frac{2x}{\left[R_u^2 - x^2\right]^{1/2}} \cdot \sqrt{a}$$

4) $0 < x < R_d \cdot \sin\theta$

$$a = \left[1 + R_d\left(1 - \sqrt{1 - \frac{x^2}{R_d^2}}\right)\right]^2$$

$$\frac{da}{dx} = \frac{2x}{\left[R_d^2 - x^2\right]^{1/2}} \cdot \sqrt{a}$$

5) $R_d \cdot \sin\theta < x \leq R_d \cdot \sin\theta + 1$

for cone

$$a = \left[r_t + (x - x_t) \cdot \tan\theta \right]^2$$

$$\frac{da}{dx} = 2 \cdot a \cdot \tan\theta$$

for contour

$$a = Y^2$$

$$\frac{da}{dx} = 2 \cdot Y \cdot \frac{dY}{dx}$$

Three special points are included in the pressure table. These are a point at $x = x_i$ such that

$$\frac{P}{P_c} = \frac{P_i}{P_c}$$

$$\frac{d(P/P_c)}{dx} = 0$$

and two points at $x = 0$ such that

$$\frac{P}{P_c} = \left(\frac{P^*}{P_c} \right)_{\text{equilibrium}} \qquad \frac{3N_e - 1}{2(N_e - 1)}$$

$$\frac{d(P/P_c)}{dx} = - \frac{N_e}{\sqrt{R^*}} \cdot \left[\frac{2}{N_e + 1} \right]$$

with $R^* = R_u$ and $R^* = R_d$, respectively.

The following items are input directly to the computer program as described in Section 6 and shown in Figure 6-1, left to right.

R_i	RI
R_u	RWTU
θ_i	THETAI
θ	THETA
R_d	RWTD

5.4.18 SUBROUTINE PRNTCK

For the option to print starting at step ND1, printing every ND3rd step up to step ND2, this subroutine checks whether or not the current step should be printed. If it is to be printed this subroutine calls subroutine ØUTPUT.

5.4.19 SUBROUTINE REAXIN

This subroutine processes SPECIES, REACTIØNS, and THIRD BØDY REAX RATE RATIØS input cards. Reference may be made to Section 6, the Program Users Manual, for a complete description of input requirements. A table of all species appearing in the input reaction set is generated for further processing by subroutine SELECT if required.

5.4.20 SUBROUTINE SELECT

This subroutine provides the interface logic required to select the minimum species list required for the kinetic expansion calculations. The subroutine is only used for the ØDE-ØDK interface. The list of all species appearing in the input reaction set is matched against the list of species considered for the equilibrium calculation. All species which appear in both a reaction and the equilibrium calculation list are selected for the kinetic expansion calculation. If a species appears in the reaction set but has not been considered for the equilibrium calculation, the program prints an error message and terminates the current case.

If the INERTS directive was specified only those species specified under that directive will be selected for the kinetic expansion calculation.

If the INERTS directive was not specified, all those species, considered for the equilibrium calculation, whose mole fractions are greater than or equal to an input selection criterion will also be selected for the kinetic expansion calculation. Species selected in this way will be listed as inert species on the program output since they do not enter into chemical reaction.

5.4.21 SUBROUTINE STF

This subroutine evaluates the thermodynamic functions $C_{p_T}^{o}/R$, H_T^o/RT, S_T^o/R, from curve fit coefficients. The subroutine uses the same procedure as subroutine CPHS. The additional functions $dC_{p_T}^{o}/dT$ and free energy, G_T^o/RT, are also computed. The calculated functions are then converted to the internal computational units for use by the kinetic expansion calculations.

5.4.22 SUBROUTINE SUBNE

Calculates the average equilibrium pressure expansion coefficient from the chamber to the throat by iteration from the following formula (Newton's method):

$$N_e^{(n+1)} = N_e^{(n)} + \frac{\left(\frac{2}{N_e^{(n)}+1}\right)^{\frac{N_e^{(n)}}{N_e^{(n)}-1}} - \frac{P_e^*}{P_c}}{\left(\frac{2}{N_e^{(n)}+1}\right)^{\frac{N_e^{(n)}}{N_e^{(n)}-1}} \left(\frac{1}{N_e^{(n)}-1}\right)\left[\frac{1}{N_e^{(n)}-1} \ln\left(\frac{2}{N_e^{(n)}+1}\right) + \frac{N_e^{(n)}}{N_e^{(n)}+1}\right]}$$

where $N_e^{(1)} = 1.2$.

P_e^* is the equilibrium throat pressure

P_c is the equilibrium chamber pressure

This subroutine is used by subroutine PRES.

5.4.23 SUBROUTINE TABGEN (IFLAG, LTABLE,XTAB,YTAB,LUSED, X, Y, IERRØR, NY)

This subroutine records a tabular function (X,Y(NY)) in tables of fixed length. The first and last event will always be tabulated and the table will either contain all of the values specified or will be at least half full. Once the number of events exceed the table length, the table will be repacked by the deletion of every other table entry and tabulation will proceed choosing every 2^{N}th event(N=0, 1, 2. . . etc., where N is the number of times the table must be repacked). The table spacing will be a power of two except for the last event which will always be tabulated.

The calling sequence parameters are:

IFLAG	-	denotes type of entry to subroutine
		= - 1 first entry
		= 0 normal entry
		= + 1 last entry
LTABLE	-	length of tables available for tabulation
XTAB	-	table for tabulation of the variable X
YTAB	-	table for tabulation of the variable
LUSED	-	number of table entries currently used (output)
X	-	the variable X
Y	-	the variable Y
IERRØR	-	error flag
NY	-	number of Y variables to be tabulated

Note: One Dimensional Mach Number Tabulation Procedure

At the initial axial position, X and Mach number are recorded. TABGEN is then used with LTABLE=50 (assuring 25 saved values). The last recorded values are the end values for the transonic tables.

5.5 TDK CONTROL SUBROUTINES

5.5.1 SUBROUTINE LINK40

This subroutine consists only of a call to subroutine TWØD and is used only to facilitate conversion of the program overlay for use on the CDC 6000 series computer.

5.5.2 SUBROUTINE TWØD

This subroutine provides overlay linkage between the Transonic Analysis Subprogram and the Supersonic Method of Characteristics Subprogram.

5.5.3 SUBROUTINE TSTDK

This subroutine provides overlay linkage between the Transonic Analysis Subprogram and the Ideal Gas option of the Supersonic Method of Characteristics Subprogram.

5.6 TRANSONIC ANALYSIS SUBROUTINES

5.6.1 SUBROUTINE LINK41

This subroutine consists only of a call to subroutine TRAN and is used to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.6.2 SUBROUTINE TRAN

This subroutine is the controlling program for the transonic calculations, and is used to construct an initial data line for the method of characteristics calculations. Subroutine TRAN reads the Namelist $TRANS input as described in section 6. The calculations given below are performed by this subroutine. The method of analysis used is described in detail in reference 7.

Transonic Calculations

From data supplied by the ODK subprogram expansion coefficients, γ_n, are computed for each of N zones as

$$\overline{\gamma}_n = \frac{\ln(P_\ell/P_1)_n}{\ln(\rho_\ell/\rho_1)_n} \qquad n = 1, \ldots, N$$

The nomenclature for numbering zones and the slipline locations dividing the zones is given in Figure 5.6-1.

Slipline locations, Y_n, are calculated (using subroutine TRIM) as

$$\begin{bmatrix} (1+A_1K_1) & -1 & & & \\ -A_2K_2 & (1+A_2K_2) & -1 & & \\ & \ddots & \ddots & \ddots & \\ & & & -A_{N-1}K_{N-1} & (1+A_{N-1}K_{N-1}) \end{bmatrix} \begin{bmatrix} Y_1^2 \\ Y_2^2 \\ \vdots \\ Y_{N-1}^2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{bmatrix}$$

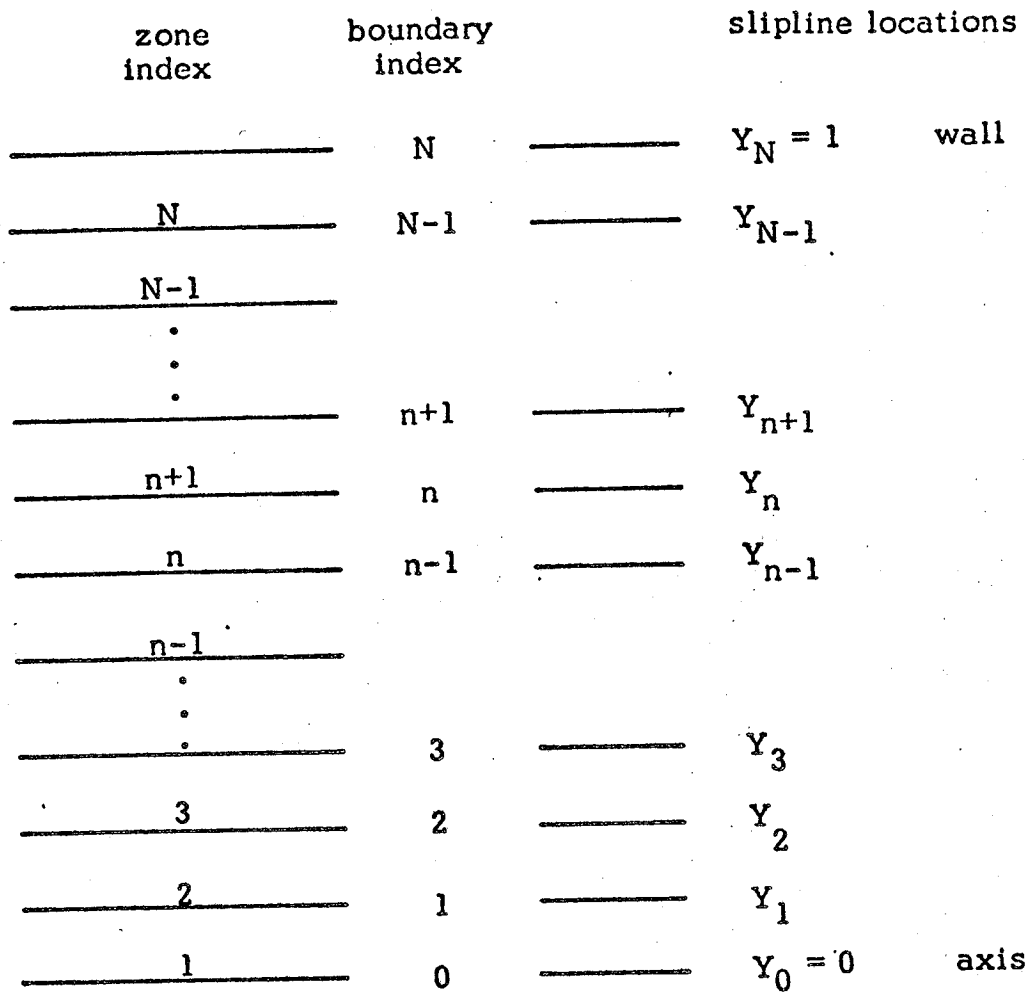


Figure 5.6-1. Nomenclature for the Numbering of Zones

where

$$A_n = \frac{\rho_n^* \; a_n^*}{\rho_{n+1}^* \; a_{n+1}^*}$$

$$K_n = \frac{\dot{m}_{n+1}}{\dot{m}_n} \qquad n = 1, 2, \ldots N-1$$

The sonic conditions ρ_n^* and a_n^* are provided by the ODK subprogram and the partial mass flow rates, $\dot{m}_n$, are input.

Newton's method (subroutines NEWT and BANDI) is used to calculate the transonic coefficients B_{0_n}, B_{1_n}, C_{1_n}, and C_{2_n}. Subroutine FCALC evaluates the boundary conditions which must be satisfied.

Distribution of Initial Line Points

Subroutine TRAN next calculates the location of points on the initial data line used to start the method of characteristics calculations. First the radial position coordinates, r_i, are computed. Two options are used for this purpose depending on the downstream throat radius of curvature, RWTD.

If

$$\text{RWTD} \leq \text{PMCRIT}$$

then the r_i are computed as follows:

$$\delta = \frac{\text{RWTD} \cdot \Delta\theta}{q + (M^2 - 1)^{1/2}}$$

where

$$q = 1 / \left((2 \cdot \text{RWTU} + \gamma / 2) / (\gamma + 1) \right)^{1/2}$$

M = Mach number

$\Delta\theta$ = Input Quantity PMDEG

points will be placed at

$$r_1 = 1$$

$$r_2 = 1 - \delta$$

$$\vdots$$

where $r_n = 1 - (n-1)\,\delta$

n = integer part of θ_j

This spacing will assure that the first left running characteristic will intersect the nozzle wall at a wall angle of approximately $\Delta\theta°$. (Nominally $\Delta\theta° = 1°$). The $r_i = Y_i$ positions are inserted using subroutine XPIL. The spacing, δ, will be successively increased after the n^{th} point until a maximum spacing is reached.

If

RWTD > PMCRIT

points are placed on the initial data line on an equal area basis, by zone.

A total of M initial line points can be distributed proportional to area among the N zones as follows:

Since the total throat area is equal to the sum of the zone areas:

$$\pi = \sum_{n=1}^{N} \pi (Y_n^2 - Y_{n-1}^2)$$

the number of points, m_n, allowed the n^{th} zone is

$$M\,(Y_n^2 - Y_{n-1}^2)$$

Since m_n must be an integer, a good choice is

$$m_n = \left[M\,(Y_n^2 - Y_{n-1}^2) + \frac{1}{2}\right]$$

where $[x]$ is the integer part of x

Example:

if $N = 2,\ Y_1 = .707,\ M = 50$

then $m_1 = \left[50\,(.707^2 - 0^2) + \frac{1}{2}\right]$

$m_1 = 25$

$m_2 = \left[50\,(1-.707^2) + \frac{1}{2}\right]$

$m_2 = 25$

Location of Initial Line Points Within the n^{th} Zone

If the circular ring bounded by r_n and r_{n-1} is subdivided into m rings each of equal area, a, then:

$$ma = \pi\,(r_n^2 - r_{n-1}^2)\,.$$

Since $a = \pi r_1^2 - \pi r_{n-1}^2$, etc., the edges of these rings are at:

$$r_1^2 = r_{n-1}^2 + \delta$$

$$r_2^2 = r_1^2 + \delta$$

$$\vdots$$

$$r_{m-1}^2 = r_{m-2}^2 + \delta$$

where

$$\delta = (r_n^2 - r_{n-1}^2) \; / \; m$$

Once the position coordinates, r_i, have been computed, the corresponding x_i coordinates and gas streamline angles θ_i are determined as follows:

$$x_1 = 0 \quad , \quad \theta_1 = 0.$$

Next the pressure, $P(1,0) \; / \; P^*$, is determined using the transonic analysis (subroutine SAUER).

$$P(1,0) = \frac{P(1,0)}{P^*} \qquad P_N^*$$

where P_N^* is the outer zone sonic pressure as provided by the ODK subprogram .

All other x_i including those corresponding to the slipline positions, Y_i, are then determined such that the above pressure value will result. The secant method subroutine ITER is used for this purpose. The θ_i are computed at the same time.

Using the above pressure, subroutine GETIL is used to interpolate for other initial line entries required by the Supersonic Method of Characteristics Subprogram.

5.6.3 SUBROUTINE BANDI (A, NBW, NEQ, NMAX, B, X, INEW, KERR)

Purpose

BANDI solves a set of linear equations Ax = b where A is a nonsymmetric band matrix.

Restrictions

The matrix A is destroyed.

Usage

Calling sequence:

CALL BANDI (A, NBW, NEQ, NMAX, B, X, INEW, KERR)

where

A is a matrix of at least NEQ rows and NBW columns (see below) which initially contains the elements of the band matrix, stored as follows:

To solve a system of the form

$$
\begin{aligned}
a_{11}x_1 + a_{12}x_2 &= b_1 \\
a_{21}x_1 + a_{22}x_2 + a_{23}x_3 &= b_2 \\
a_{32}x_2 + a_{33}x_3 + a_{34}x_4 &= b_3 \\
a_{43}x_3 + a_{44}x_4 + a_{45}x_5 &= b_4 \\
a_{54}x_4 + a_{55}x_5 &= b_5
\end{aligned}
$$

To transform an original (N by M) MATRIX A(I, J) into a packed (N by NBW) BANDED MATRIX AB (I, J), the following transformation applies.

$$AB(I, JB) = A(I, J)$$

where $JB = \left(\frac{NBW}{2} + 1\right) - (I - J)$

and NBW = BAND WIDTH

	$A_{i,1}$	$A_{i,2}$	$A_{i,3}$
$A_{1,j}$	0.0	a_{11}	a_{12}
$A_{2,j}$	a_{21}	a_{22}	a_{23}
$A_{3,j}$	a_{32}	a_{33}	a_{34}
$A_{4,j}$	a_{43}	a_{44}	a_{45}
$A_{5,j}$	a_{54}	a_{55}	0.0

NBW — is the width of the band (odd).

NEQ — is the number of equations in the system.

NMAX — is the maximum number of rows for which A has been dimensioned.

B — is the right-hand vector for the system.

X — is the solution vector returned by BANDI.

INEW — is a flag, set = 0 unless the coefficient matrix A is unchanged from a previous call to BANDI, in which case set INEW = 1.

KERR — is an error flag returned by BANDI:

= 0 if no error;

= 1 if any diagonal element becomes zero during triangularization of A.

Method

BANDI finds the solution vector X by single-pass Gaussian elimination. If INEW = 0, the coefficient matrix A is upper-triangularized by forward substitution. Backward substitution then yields the solution X. If INEW = 1, BANDI assumes that the coefficient matrix A has already been reduced on a previous entry and that only the right-hand vector B has changed. Therefore, the forward substitution is bypassed.

rogramming Information

Note that the matrix A is upper-triangularized by BANDI, destroying the original band matrix coefficients. For very large or ill-conditioned systems, one may increase the accuracy of the solution as follows:

1) Save the original band matrix coefficients from A in a similar matrix AP.

2) Call BANDI with INEW = 0 to obtain a solution x_0 of $Ax = b$.

3) Calculate $b_n = Ax_n$ using the coefficients saved in AP. (A subroutine BMMULT exists to do this.)

4) Calculate a new right-hand vector $e_n = b - b_n$.

5) Call BANDI with INEW = 1 to solve the system $A\delta x_n = e_n$.

6) Set $x_{n+1} = x_n + \delta_n$.

7) Repeat steps 3-6 until the desired convergence is attained.

Error Return

If, during triangularization of the matrix, any diagonal element becomes zero, an appropriate message is printed and KERR is set to unity before returning to the calling program.

5.6.4 SUBROUTINE FCALC

The purpose of this subroutine is the evaluation of boundary condition functions required to be zero by the transonic analysis. Subroutine FCALC is called by subroutine NEWT in which Newton's Method is used to find the zeros.

Input:

Y_n	slipline heights $n = 1, \ldots N-1$
γ_n	specific heat ratio for each zone $n = 1, \ldots N$
$B_{0_n}, B_{1_n}, C_{1_n}, C_{2_n}$	estimates for the constant coefficients sought by NEWT to satisfy the boundary conditions $n=1, \ldots N$
N	total number of zones

Output:

The values of the following functions are computed and output. If the boundary conditions are correctly satisfied, each of these ($F_{1_n}, F_{2_n}, F_{3_n}, F_{4_n}$) are zero.

At the sliplines, $n = 1, \ldots N-1$

linear term $v_n = v_{n+1}$ (i.e. match on streamline angle, 1st order);

$$F_{1_n} = \left[\frac{1}{2}(\gamma_n+1) B_{1_n}^2 Y_n + C_{1_n} Y_n^{-1}\right] - \left[\frac{1}{2}(\gamma_{n+1}+1) B_{1_{n+1}}^2 Y_n + C_{1_{n+1}} Y_n^{-1}\right]$$

constant term $v_n = v_{n+1}$;

$$F_{2_n} = \left[\frac{1}{16}(\gamma_n+1)^2 B_{1_n}^3 Y_n^3 + \frac{1}{2}(\gamma_n+1) B_{1_n} C_{1_n} Y_n (\ln Y_n - \frac{1}{2}) + \frac{1}{2}(\gamma_n+1) B_{1_n} B_{0_n} Y_n + C_{2_n} Y_n^{-1}\right]$$

$$- \left[\frac{1}{16}(\gamma_{n+1}+1)^2 B_{1_{n+1}}^3 Y_n^3 + \frac{1}{2}(\gamma_{n+1}+1) B_{1_{n+1}} C_{1_{n+1}} Y_n (\ln Y_n - \frac{1}{2}) + \frac{1}{2}(\gamma_{n+1}+1) B_{1_{n+1}} B_{0_{n+1}} Y_n + C_{2_{n+1}} Y_n^{-1}\right]$$

linear term $P_n = P_{n+1}$;

$$F_{3_n} = \gamma_n B_1 P^*_n - \gamma_{n+1} B_{1_{n+1}} P^*_{n+1}$$

constant term $P_n = P_{n+1}$;

$$F_{4_n} = \left\{\gamma_n \left[\frac{1}{4}(\gamma_n + 1) B^2_{1_n} Y^2_n + C_{1_n} \ln Y_n + B_{0_n}\right] - 1\right\} P^*_n$$

$$- \left\{\gamma_{n+1}\left[\frac{1}{4}(\gamma_{n+1} + 1) B^2_{1_{n+1}} Y^2_n + C_{1_{n+1}} \ln Y_n + B_{0_{n+1}}\right] - 1\right\} P^*_{n+1}$$

At the wall , n = N

linear term $v_N(1,z) = z$;

$$F_{1_N} = \frac{1}{R'} - \left[\frac{1}{2}(\gamma_N + 1) B^2_{1_N} + C_{1_N}\right]$$

constant term $v_N(1,z) = z$;

$$F_{2_N} = \left[\frac{1}{16}(\gamma_N + 1)^2 B^3_{1_N} - \frac{1}{4}(\gamma_N + 1) B_{1_N} C_{1_N} + \frac{1}{2}(\gamma_N + 1) B_{1_N} B_{0_N} + C_{2_N}\right]$$

Since at the axis $v_1(0,z) = 0$ it is required that $C_{1_1} = C_{2_1} = 0$.

5.6.5 SUBROUTINE GETIL (IZ, IP, PPS1)

This subroutine is used to generate the initial line entries for the Supersonic Method of Characteristics Subprogram. The values are obtained via interpolation in the gas tables generated by the One Dimensional Kinetic Analysis Subprogram.

5.6.6 SUBROUTINE

NEWT(M, F, MF, N, VAR, NVAR, FCALC, WF, PERTV, EPS1, MAXIT, NUMIT, BIN, AB, NBW, KERR)

Given a set of n functions in n unknown variables where each function is coupled as below:

$$f_i(X_j) \qquad i = 1, \ldots, n$$

$$j = i-k, \ldots, i+k$$

$$\text{and } 1 \le j \le n$$

this routine will attempt by Newton's method to find values

$$X_1, X_2, \ldots X_n$$

such that

$$\sum_{i=1}^{n} f_i^2 (X_j) = 0.$$

Method

Newton's method is used to iterate for a solution vector. The matrix of partial derivatives, J, required by the method is generated automatically by the subroutine. This matrix will be banded of width 2k+1. The matrix inversion is performed by subroutine BANDI. In the event Newton's method yields a vector which is farther from a solution in a least squares sense than the previous estimate, the increment vector is halved. Newton's algorithm for the $(k+1)^{th}$ iterant is:

$$X^{(k+1)} = X^{(k)} - J^{(k)^{-1}} f^{(k)}.$$

Restrictions

The user must supply initial values for the solution vector and also a subroutine to evaluate the functions. The subroutine must communicate with NEWT through CØMMØN statements. Subroutine BANDI is required.

Usage

Call NEWT(M, F, MF, N, VAR, NVAR, FCALC, WF, PERTV, EPS1, MAXIT, NUMIT, NUMIT, BIN, AB, NBW, KERR)

Index to Calling Sequence:

Input:	M, MF, N, VAR, NVAR, WF, PERTV, EPS1, MAXIT, NBW
Output:	VAR, F, NUMIT, KERR
Working:	BIN, AB

Explanation of Calling Sequence:

1) M is the length of the array containing the n functions.

2) F is the array containing the n function values evaluated by FCALC.

3) MF is an array of M control words:

   if MF(I)=0, include F(I)
   if MF(I)=1, exclude F(I)

4) N is the length of the array containing the n variables.

5) VAR is the array containing the n variables, x_i $i = 1, \ldots n$

6) NVAR is an array of N control words:

   if NVAR(J)=0, include VAR(J)
   if NVAR(J)=1, exclude VAR(J)

7) FCALC is a name for the subroutine which calculates the functions, F(I). A program which calls NEWT must have an EXTERNAL statement containing this name.

8) WF is an array of n weighting factors. These are used in conjunction with EPS1 to determine whether a solution has been reached.

   ω_i = WF(I)

9) PERTV is a perturbation factor used in calculating the partial derivatives required by Newton's method. If PERTV = ϵ, then:

$$\frac{\partial F}{\partial x} = \frac{F(x + \delta) - F(x)}{\delta}, \text{ where } \delta = \max\left(|\epsilon x|, \epsilon * 10^{-3}\right)$$

10) EPS1 is an error bound used to determine whether a solution has been reached. If ϵ_1 = EPS1, then a solution is claimed when

$$\sum_{i=1}^{n} (\omega_i F_i)^2 \leq \epsilon_1$$

11) MAXIT is the maximum number of iterations allowed.

12) NUMIT is the number of iterations required for solution.

13) BIN is an array required by LESK and must be at least of dimension N + 1.

14) AB is a two-dimensional array containing the augmented matrix of subroutine LESK and must be at least of dimension AB(M, N+1).

15) NBW band width = 2k+1, see subroutine BANDI.

16) KERR error indicator, see subroutine BANDI.

5.6.7 SUBROUTINE PTAB (PØNED)

If the option to punch boundary layer edge tables for input to a boundary layer program (i.e. BLIMP, MABL, or TBL) has been selected (IPTAB = 1, in $ØDE), this subroutine will punch the table up to the position where the method of characteristics calculations begin.

The following procedure is followed to make the one-dimensional throat coincident with the axisymmetric throat.

1) The pressure, P_{1D}, at the axisymmetric throat (r=1, x=0) must be given (PØNED in the calling sequence, above).

2) The axial position, x*, in the one-dimensional gas tables corresponding to the above pressure is obtained by interpolation. The points downstream of this axial position are deleted.

3) The table of axial positions (saved in the one-dimensional calculations - TABGEN) is recoordinated to fit smoothly with the axisymmetric geometry using:

$$x' = x_i + (x - x_i) \cdot \left(\frac{-x_i}{x^* - x_i} \right)$$

where x' = recoordinated axial position

x = tabulated axial position

x_i = initial axial position

x^* = axial position from 2) above

4) The radial coordinate, corresponding to each recoordinated axial coordinate, is computed using the input geometric constraints. Reference may be made to Figure 6-1 for a description of the inlet and throat geometry.

5) The axial and radial coordinates and the fluid properties are punched. The punched cards may be input directly to the boundary layer computer program.

5.6.8 SUBROUTINE SAUER (R, X, Y, G, N, I, PPS, THETA)

The purpose of this subroutine is to compute fluid dynamic properties in the transonic region of a rocket nozzle. The method used is based on the analysis of Sauer and is applicable to the situation where the flow is assumed divided into N zones (i.e. striated), each of which is characterized by a constant expansion coefficient, γ_n. The analysis has been further modified so as to extend its range of applicability to nozzles with small ($R/r^* \geq .5$) radius of curvature in the throat section.

Given position coordinates (r,x), this subroutine returns the fluid dynamic properties (P/P^*, θ).

Calling Sequence

Input;

R	radial position coordinate, r
X	axial position coordinate, x
Y	vector Y_n; n = 1 . . N containing the zone boundary coordinates
G	vector γ_n; n = 1, . . . N containing the zone expansion coefficients
N	total number of zones

Output

I	zone number, n, corresponding to r
PPS	P/P^* at (r,x)
THETA	θ at (r,x), the gas streamline angle in radian

Method

$$R' = R + \frac{\gamma}{4}$$

$$X = \left(\frac{R}{R'}\right)^{1/2} x$$

If only one zone is specified (N = 1), then

$$u' = \frac{1}{4} (\gamma + 1) B_1^2 r^2 + B_0 + B_1 X$$

$$v' = \frac{1}{16} (\gamma + 1)^2 B_1^3 r^3 + \frac{1}{2} (\gamma + 1) B_1 B_0 r + \frac{1}{2} (\gamma + 1) B_1^2 r x$$

where

$$B_1^2 = \frac{2}{(\gamma + 1)} \quad \frac{1}{R'}$$

$$B_0 = -\frac{1}{4} \quad \frac{1}{R'}$$

If more than one zone is specified ($N \geq 2$), then

$$u' = \frac{1}{4}(\gamma + 1)\, B_1^2\, r^2 + C_1 \ln r + B_0 + B_1 X$$

$$v' = \frac{1}{16}(\gamma + 1)^2\, B_1^3\, r^3 + \frac{1}{2}(\gamma + 1)\, B_1\, C_1\, r\, (\ln r - \frac{1}{2})$$

$$+ \frac{1}{2}(\gamma + 1)\, B_1\, B_0\, r + C_2\, r + \left[\frac{1}{2}(\gamma + 1)\, B_1^2\, r + C_1/r\right] x$$

where the coefficients B_0, B_1, C_1, C_2 are input through COMMON/NAMBC/ and the n^{th} value is selected, corresponding to the n^{th} zone. The zone, n, is determined such that

$$Y_{n+1} \geq r \geq Y_n$$

For all N

$$u = 1 + u'$$

$$v = v'$$

$$P/P^* = 1 - \gamma_n\, u'$$

$$\theta = \arctan (v/u)$$

6.9 SUBROUTINE TRIM (A, X, B, N, NN)

This subroutine solves the system

$$\bar{\bar{A}}\bar{X} = \bar{b}$$

for $\bar{X}$ where $\bar{\bar{A}}$ is tridiagonal, i. e.;

$$\text{all } a_{ij} = 0 \quad \text{if} \quad i > j+1 \text{ or } i < j-1.$$

The method used is Gaussian elimination.

Calling Sequence

A Is the input coefficient matrix and must be dimensioned at least A(N, 3). The elements a_{ij} must be input as

$$\begin{bmatrix} — & A(1,2) & A(1,3) \\ A(2,1) & A(2,2) & A(2,3) \\ A(3,1) & A(3,2) & A(3,3) \\ & \vdots & \\ A(N,1) & A(N,2) & — \end{bmatrix} = \begin{bmatrix} — & a_{11} & a_{12} \\ a_{21} & a_{22} & a_{23} \\ a_{32} & a_{33} & a_{34} \\ & \vdots & \\ a_{n,n-1} & a_{nn} & — \end{bmatrix}$$

The contents of A will be destroyed by TRIM.

X Is the output solution vector $\bar{X}$ and must be dimensioned at least X(N).

B Is the input vector $\bar{b}$ and must be dimensioned at least B(N). The contents of B will be destroyed by TRIM.

N Is the order of the system. N ≥ 2 is required.

NN Is the dimension of A (NN, 3), X(NN), and B(NN) in the calling program.

5.6.10 SUBROUTINE XPIL (RI,Y,NIT,NRMAX,NYMAX,NRR,NZZ)

This subroutine inserts the table of position coordinates, Y_i, into the table R_i such that the resultant table of R_i is monotonic decreasing. Each Y will be converted to a double point and the closest R_i value will be deleted.

5.7 SUPERSONIC CONTROL

5.7.1 SUBROUTINE LINK42

This subroutine consists only of a call to subroutine TDK and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.7.2 SUBROUTINE TDK

The purpose of this subroutine is to call and overlay the two portions of the Supersonic Method of Characteristics Subprogram (subroutines CHAR and CNTRL) and to call the error subroutine, ERRØRS, if required.

5.7.3 SUBROUTINE ERRØRZ(IERR)

The purpose of this subroutine is to print an error message and return control to the calling program. The program will print the message

ERRØR(i)....

where

$i = IERR, \ -100 < i < 100.$

The subroutine will search its error statement number list to determine if an additional statement exists for the given value of IERR. If an error statement is found it will also be printed.

5.8 SUPERSONIC INITIAL LINE AND WALL SUBROUTINES

5.8.1 SUBROUTINE LINKX5

This subroutine consists only of a call to subroutine CHAR and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.8.2 SUBROUTINE CHAR

This subroutine reads input for the Supersonic Method of Characteristics Subprogram and performs all calculations that are preliminary to the method of characteristics construction.

Subroutine CHAR calls subroutine WALL in order to generate coordinates for the wall table. Conditions along the initial data line, as provided by the transonic subprogram, are printed.

The initial line conditions are integrated to determine mass flow, thrust, and characteristic velocity. The expressions below are used with the integrals being evaluated by trapezoidal rule:

$\dot{m} = 2\pi r^{*2} I_1$ lb/sec mass flow

$F = 2\pi r^{*2} I_2$ lb force thrust

$C^* = P_{chamb}/2\, I_1$ ft/sec characteristic velocity, $P_c A^*/\dot{m}$

where

$$I_1 = \int_0^1 \rho V \frac{\sin(\phi - \theta)}{\sin \varphi} \, r \, dr$$

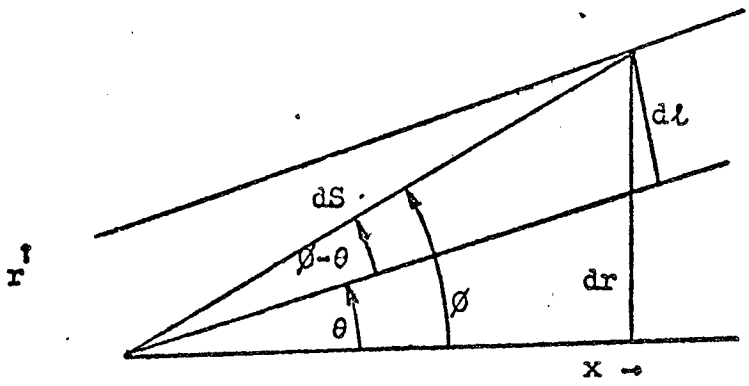
$$I_2 = \int_0^1 \left[P + \rho V^2 \frac{\sin(\phi - \theta) \cos \theta}{\sin \phi} \right] r \, dr$$

$$\phi = \arctan\left(\frac{dr}{dx}\right)$$

Mass flow and characteristic velocity are printed.

Note on Mass Flow and Thrust Calculations.

Consider an element, $d\ell$, of flow at angle θ across a surface, dS, inclined at angle Φ :



The mass flow across the element is:

$$\rho V 2\pi r \, d\ell$$

where

$$d\ell = \sin(\Phi - \theta) ds$$

$$dS = \frac{dr}{\sin \Phi}$$

so that

$$\text{mass flow} = \frac{\rho V \sin(\Phi - \theta)}{\sin \Phi} 2\pi r \, dr$$

The momentum flux in the x direction is :

$$\text{momentum flux}_x = u \cdot \text{mass flow} = V \cos \theta \cdot \text{mass flow}$$

or

$$\text{momentum flux}_x = \frac{\rho V^2 \sin(\Phi - \theta) \cos \theta}{\sin \Phi} 2\pi r \, dr.$$

Thrust between points A and B may be obtained by integrating the pressure differential and momentum flux in the x direction:

$$F = \int_A^B (P - P_a) + \rho V^2 \frac{\sin(\Phi - \theta) \cos \theta}{\sin \Phi} 2\pi r \, dr.$$

where P_a is the ambient Pressure ($P_a = 0$ in TDK)

Throughout the method of characteristics computations the variables used are equivalenced to entries in dimensioned arrays. This equivalency of variables is always in the same order as prescribed in the table given below. This equivalencing occurs for the I subscript in the following arrays: P(I,J), PP(I,J), PS(I), PSS(I), Q(I,J), Q3A(I), and Q4A(I).

TABLE 5.8-1 EQUIVALENCE TABLE FOR COMPUTED VARIABLES

I	Variable	Units
P(1,J) =	P, pressure	$lb\,f/ft^2$
2	ρ, density	$lb\,m/ft^3$
3	θ, streamline angle	radians
4	V, velocity	ft/sec
5	r, radial coordinate	
6	x, axial	
7	T, temperature	°R
8	A, term computed in subroutine	GPF
9	B, "	
10	R, real gas constant	
11	(not used)	
12	E, term computed in subroutine	GPF
13	F, "	
14	G, "	
15	H, "	
16	α, "	
17	γ, "	
18	dividing streamline flag	
19	zone number	
20	(not used currently)	
21	c_i, species mass fraction (i = I-20 ≤ 40)	
.	.	
.	.	
.	.	
60	"	

5.8.3 SUBROUTINE CUBIC (X,Y,YP,N,ARG,YARG)

The purpose of this subroutine is to perform cubic interpolation for a tabulated function whose derivatives are known.

Calling Sequence:

X	is a table of the independent variable, x_i, such that $x_{i+1} \geq x_i$
Y	is a table of the dependent variable, $y_i = y(x_i)$
YP	is a table of the derivatives of the dependent variable $y_i' = y'(x_i)$
N	is the number of entries in each of the above tables; $i = 1, \ldots N$
ARG	is the argument, x, for which interpolation is requested
YARG	is the result, $y = y(x)$

Restrictions:

The calling program must define arrays for the dummy variables X, Y, and YP. These arrays must be at least of lengths N + 1, N, and N respectively. The subroutine will save its last used table position number in X(N + 1).

If $x < x_1$ the program returns $y = y_1$

If $x > x_N$ the program returns $y = y_N$

Method:

Given : $x_0 \leq x < x_1$

so that y_0, y_0' y_1, and y_1' are known. The cubic interpolation formula given below is used to determine y

$$y = A(x - x_0)^3 + B(x - x_0)^2 + C(x - x_0) + D$$

where

$$A = \frac{1}{h^3}\left[\left(y_1' + y_0'\right) h - 2k\right]$$

$$B = \frac{-1}{h^2}\left[\left(y_1' + 2y_0'\right) h - 3k\right]$$

$$C = y_0'$$

$$D = y_0$$

and

$$h = x_1 - x_0$$

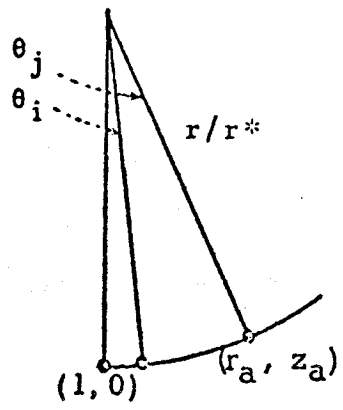
$$k = y_1 - y_0$$

5.8.4 SUBROUTINE WALL

This subroutine makes available four options for the specification of nozzle wall contours. Either a cone, parabola, arc, or a spline fit curve may be attached tangentially to a circular arc. The circular arc is specified as follows:

Symbol	Definition
θ_i	Angle defining the downstream end of the arc
θ_j	Angle defining the upstream end of the arc
r/r^*	Normalized arc radius

where



One hundred points are generated along the arc for equally incremented values of angle, θ:

$$r = 1 + r/r^* (1 - \cos \theta), \qquad \theta_i = \theta \leq \theta_j$$

$$x = r/r^* \sin \theta$$

Five options are specified below for attaching wall contours tangentially to this circular arc. The cone option requires the nozzle expansion ratio as input. The parabola and arc options require the exit point coordinates, r_e and x_e, as input. The spline fit option requires a smooth table of wall coordinates, r_i and x_i, and the exit angle at the nozzle lip, θ_e, as input.

Option 1, Cone

$$r_e = \sqrt{\epsilon}$$

$$x_e = (r_e - r_a)\text{ctn}\ \theta + x_a$$

Option 2, Parabola

Two hundred points are generated at equally incremented values of x such that:

$$r = a + \sqrt{b(x - c)}$$

where

$$a = \frac{r_e^2 - r_a^2 - 2r_a(x_e - x_a)\tan\theta_j}{2\left[r_e - r_a - (x_e - x_a)\tan\theta_j\right]}$$

$$b = 2(r_a - a)\tan\theta_j$$

$$c = x_e - \frac{(r_e - a)^2}{b}$$

Option 3, Arc

Two hundred points are generated at equally incremented values of angle such that:

$$r = r_a + \bar{R}(\cos\theta - \cos\theta_j)$$

$$x = x_a + \bar{R}(\sin\theta_j - \sin\theta)$$

where

$$\bar{R} = \frac{(x_e - x_a)^2 + (x_e - r_a)^2}{2\left[(x_e - x_a)\sin\theta_j - (r_e - r_a)\cos\theta_j\right]}$$

and the increment on angle is

$$\Delta\theta = \frac{\theta_e - \theta_j}{200}$$

where

$$\theta_e = \sin^{-1}\left[\sin\theta_j - \frac{1}{R}(x_e - x_a)\right]$$

Option 4, Spline Fit

Two hundred points will be placed along a curve input in tabular form by a cubic spline fit method (see subroutines CUBIC and SLP). Derivativies are calculated from the input values for θ_j and the exit nozzle lip angle, θ_e. This curve must connect tangentially to the circular arc described above.

Option 5, Cone (r_e, x_e input)

$$\theta_j^{(0)} = 0$$

then for i = 1, . . . 5

$$r_a^{(i)} = 1 + \frac{i}{r^*}(1-\cos\theta_j^{(i-1)})$$

$$x_a^{(i)} = \frac{r}{r^*}\sin\theta_j^{(i-1)}$$

$$\theta_j^{(i)} = \arctan\left(\frac{r_e - r_a^{(i)}}{x_e - x_a^{(i)}}\right)$$

5.9 SUPERSONIC ANALYSIS SUBROUTINES

5.9.1 SUBROUTINE LINKY5

This subroutine consists only of a call to subroutine CNTRL and is used only to facilitate conversion of the program overlay for the CDC 6000 series computer.

5.9.2 SUBROUTINE CNTRL

The purpose of this subroutine is to control the construction of the finite difference mesh for the method of characteristics solution of the supersonic nozzle flow. Left running characteristics and fluid streamlines are constructed starting at the nozzle throat point ($r = 1$, $x = 0$). These left running characteristics extend from the initial data line or nozzle axis to the wall. The mesh points are calculated by subroutines INPT, AXISPT, WLPT and DSPT under control of this subroutine.

Additional points are inserted in the mesh by subroutine CNTRL by property averaging. For example if an axis point is calculated such that $X_3 - X_4 > DS$, a point will be inserted between points 1 and 4 and the axis point calculation of point 3 is repeated. The other circumstances which cause point insertion are listed below. In each case a point is inserted along the initial data line or the previous streamline and the calculation of point 3 is repeated:

1) If subroutine INPT or DSPT find point 1 to fall beyond the nozzle wall.
2) If subroutine INPT finds point 1 to fall above a dividing streamline point.
3) If subroutine INPT or DSPT find
$$\left|\theta_1 - \theta_4\right| > \Delta\theta_{t\omega} \text{ , input item DTWI}$$
4) If a wall point is calculated such that
$$\left|\theta_3 - \theta_4\right| > \Delta\theta_{\omega} \text{ , input item DWWI}$$
5) When iterating to locate the end of the nozzle wall. (input tolerance of EPW)

At the end of each completed characteristic surface the mesh points are examined and points discarded as described below. Only interior points (ID=2) are to be discarded.

For n = 2 to n = IPPW-1, (i.e. from the initial line or axis to the wall) discard point n if

$$\left|\theta_{n-1} - \theta_n\right| + \left|\theta_{n+1} - \theta_n\right| \quad < \epsilon_\theta$$

and

$$(r_{n-1} - r_n)^2 + (z_{n-1} - z_n)^2 < \epsilon_s^2$$

where ϵ_ρ and ϵ_s are the input quantities ETHI and ES.

Whenever a mesh point calculation or insertion is completed successfully, the output routine, PRINT, is called so that the point may be printed.

Subroutine CNTRL also integrates the wall pressure by trapezoidal rule to determine the axial component of force existing between adjacent wall points,

$$\Delta F = 2\pi r^{*2} \int_{r_4}^{r_3} Pr\, dr = \frac{\pi}{2}\left(P_3 - P_4\right)\left(r_3^2 - r_4^2\right) r^{*2}.$$

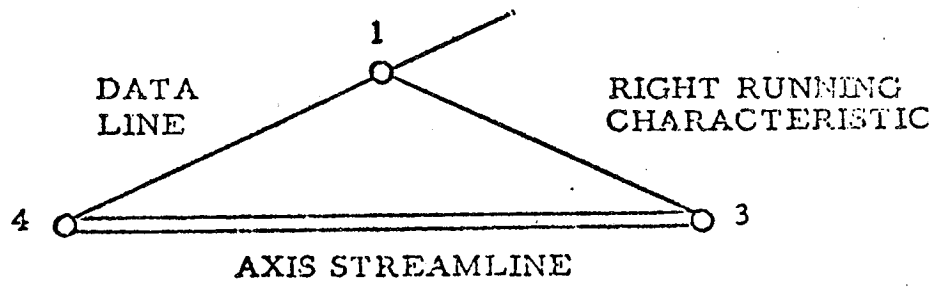
Total thrust is item found by

$$F_t = F + 2\pi r^{*2} \int_1^{r_2} Pr\, dr$$

where F is the thrust across the initial line as calculated by subroutine CHAR.

5.9.3 SUBROUTINE AXISPT

This subroutine uses two known points to calculate a new axis point.



Points 1 and 4 are known points and point 3 is the unknown point to be computed. At point 3, r_3 and θ_3 are zero.

The first estimate of the axial location of point 3 is calculated from

$$x_3^{(1)} = x_1 - \frac{r_1}{\tan 1/2(\theta_1 + \alpha_1 - \alpha_4)}$$

The first estimates of the flow properties at point 3 are calculated from

$$P_3^{(1)} = P_1 \exp \left\{ -A_1 G_1 H_1 \left[x_3^{(1)} - x_1 \right] + \frac{G_1 H_1 \sin \theta_1}{r_1} \left[x_3^{(1)} - x_1 \right] - G_1 \theta_1 \right\}$$

$$\rho_3^{(1)} = \rho_4 \left[\frac{P_3^{(1)}}{P_4} \right]^{1/\gamma_4} \exp \left\{ - A_4 \left[x_3^{(1)} - x_4 \right] \right\}$$

$$T_3^{(1)} = T_4 \left[\frac{P_3^{(1)}}{P_4} \right]^{\frac{\gamma_4 - 1}{\gamma_4}} \exp \left\{ - B_4 \left[x_3^{(1)} - x_4 \right] \right\}$$

$$N^{(1)} = \frac{\ln \left[P_3^{(1)} / P_4 \right]}{\ln \left[\rho_3^{(1)} / \rho_4 \right]}$$

$$V_3^{(1)} = \left(V_4^2 + \frac{2N^{(1)}}{N^{(1)} - 1} \frac{P_4}{\rho_4} \left\{ 1 - \left[\frac{P_3^{(1)}}{P_4} \right]^{\frac{N^{(1)} - 1}{N^{(1)}}} \right\} \right)^{1/2}$$

The first estimates of the species concentrations at point 3, $\left[c_{i_3}^{(1)}\right]$, are calculated using the Species Integration Subroutine, and the first estimates of the gas properties at point 3, $\left[A_3^{(1)}, B_3^{(1)}, F_3^{(1)}, G_3^{(1)}, H_3^{(1)}, \alpha_3^{(1)} \text{ and } \gamma_3^{(1)}\right]$, are calculated using the Gas Properties Subroutine.

The axial location of point 3 is calculated from

$$x_3^{(i+1)} = x_1 - \frac{r_1}{\tan 1/2 \left[\theta_1 - \alpha_1 - \alpha_3^{(i)}\right]}$$

The flow properties at point 3 are calculated from

$$P_3^{(i+1)} = P_1 \exp \left\{ - \frac{1}{2} \left[A_1 G_1 H_1 + A_3^{(i)} G_3^{(i)} H_3^{(i)}\right] \left[x_3^{(i+1)} - x_1\right] \right.$$

$$+ \frac{1}{2} \left[\frac{G_1 H_1 \sin \theta_1}{r_1} + \frac{G_3^{(i)} H_3^{(i)} \tan \theta_1}{r_1 + \left(x_3^{(i)} - x_1\right) \tan \theta_1} \right] \left[x_3^{(i+1)} - x_1\right]$$

$$\left. - \frac{1}{2} \left[G_1 + G_3^{(i)}\right] \theta_1 \right\}$$

$$\rho_3^{(i+1)} = \rho_4 \left[\frac{P_3^{(i+1)}}{P_4} \right]^{\frac{1}{2} \left[\frac{1}{\gamma_4} + \frac{1}{\gamma_3^{(i)}} \right]} \exp \left\{ - \frac{1}{2} \left[A_4 + A_3^{(i)}\right] \left[x_3^{(i+1)} - x_4\right] \right\}$$

$$T_3^{(i+1)} = T_4 \left[\frac{P_3^{(i+1)}}{P_4} \right]^{\frac{1}{2} \left[\frac{\gamma_4 - 1}{\gamma_4} + \frac{\gamma_3^{(i)} - 1}{\gamma_3^{(i)}} \right]} \exp \left\{ - \frac{1}{2} \left[B_4 + B_3^{(i)}\right] \left[x_3^{(i+1)} - x_4\right] \right\}$$

$$N^{(i+1)} = \frac{\ln\left[P_3^{(i+1)}/P_4\right]}{\ln\left[\rho_3^{(i+1)}/\rho_4\right]}$$

$$V_3^{(i+1)} = \left(V_4^2 + \frac{2N^{(i+1)}}{N^{(i+1)} - 1} \frac{P_4}{\rho_4} \left\{ 1 - \left[\frac{P_3^{(i+1)}}{P_4} \right]^{\frac{N^{(i+1)} - 1}{N^{(i+1)}}} \right\} \right)^{1/2}$$

The species concentrations at point 3, $\left[c_{i_3}^{(i+1)}\right]$, are calculated using the Species Integration Subroutine, and the gas properties at point 3, $\left[A_3^{(i+1)}, B_3^{(i+1)}, F_3^{(i+1)}, G_3^{(i+1)}, H_3^{(i+1)}, \alpha_3^{(i+1)}, \text{ and } \gamma_3^{(i+1)}\right]$, are calculated using the Gas Properties Subroutine.

5.9.4 SUBROUTINE CHECK (NØ)

This subroutine compares current and previous valves of the flow variables P_3, ρ_3, 0_3, V_3, r_3, x_3, and T_3 for relative convergence by calling subroutine CRIT. As soon as a variable is encountered failing the test, the variables are updated one iteration and the program returns with the convergence flag set as failed (NØ = 1). If convergence is achieved the variables are updated one iteration and the subroutine returns with the convergence flag set as passed (NØ = 0).

5.9.5 SUBROUTINE CRIT (XN, XM, NØ)

The purpose of this subroutine is to compare two valves for absolute or relative convergence and return an indicator stating if convergence has been achieved.

Calling Sequence:

XN x_n , input

XM x_m , input

NØ indicator, output

NØ = 0 implies convergence

NØ = 1 implies no convergence

where:

if $|x_m - x_n| < \epsilon_1$ then NØ = 0 , return

if $|x_n| = 0$ then NØ = 1 , return

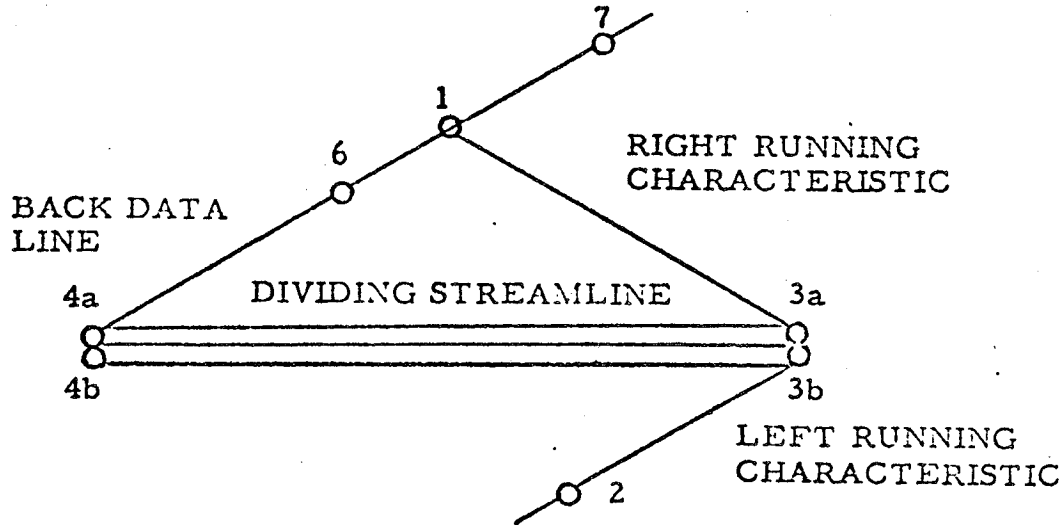
if $|x_m - x_n| / |x_n| < \epsilon_2$ then NØ = 0 , return

otherwise NØ = 1 , return

$$\epsilon_1 = \epsilon_2 = 5 \cdot 10^{-5}$$

5.9.6 SUBROUTINE DSPT

This subroutine uses five known points to calculate interior points above and below the streamline dividing two fluid mixtures.



Points 2, 4a, 4b, 6, and 7 are known points and points 3a and 3b are the unknown points to be computed. Properties at points 4a and 3a are above the streamline while properties at points 4b and 3b are below the streamline. Since the position x, r, the flow angle θ, and the pressure P are the same on both sides of the streamline at a point, they are denoted without subscript a or b. Values at point 1 are determined by interpolation between points 6 and 7. Point 6 is initially assumed to be point 4a and point 7 is the next point on the back data line.

The first estimate of the position of point 3 is calculated from

$$r_3^{(1)} = \frac{r_4 + (x_2 - x_4)\tan\theta_4 - r_2 \dfrac{\tan\theta_4}{\tan\frac{1}{2}(\theta_2 + \theta_4 + \alpha_2 + \alpha_4)}}{1 - \dfrac{\tan\theta_4}{\tan\frac{1}{2}(\theta_2 + \theta_4 + \alpha_2 + \alpha_4)}}$$

$$x_3^{(1)} = x_2 + \frac{r_3^{(1)} - r_2}{\tan\frac{1}{2}(\theta_2 + \theta_4 + \alpha_2 + \alpha_4)}$$

The first estimate of the radial location of point 1 is calculated from

$$r_1^{(1)} = \frac{r_3^{(1)} - \left[\frac{x_7 - x_6}{r_7 - r_6} r_6 + x_3^{(1)} - x_6\right] \tan \frac{1}{2}(\theta_6 + \theta_7 - \alpha_6 - \alpha_7)}{1 - \frac{x_7 - x_6}{r_7 - r_6} \tan \frac{1}{2}(\theta_6 + \theta_7 - \alpha_6 - \alpha_7)}$$

If $r_1^{(1)} > r_7$, point 7 becomes point 6 and the next point on the back data line is point 7. The above calculation is repeated until $r_6 < r_1^{(1)} \leq r_7$. (If point 6 becomes a wall point, a new point 2 is inserted by interpolation on the previous streamline and the calculation is restarted.)

The first estimate of the axial location of point 1 is calculated from

$$x_1^{(1)} = x_6 + \frac{x_7 - x_6}{r_7 - r_6}\left[r_1^{(1)} - r_6\right]$$

The first estimate of the flow properties at point 1, $\left[A_1^{(1)}, G_1^{(1)}, H_1^{(1)}, P_1^{(1)}, \alpha_1^{(1)}, \text{ and } \theta_1^{(1)}\right]$, are determined by interpolation on $r_1^{(1)}$. The first estimates of the flow properties at point 3 are calculated from

$$\theta_3^{(1)} = \frac{1}{G_1^{(1)} + G_2}\left\{\ln \frac{P_2}{P_1^{(1)}} + G_1^{(1)}\theta_1^{(1)} + G_2\theta_2 + A_2G_2F_2\left[r_3^{(1)} - r_2\right]\right.$$

$$- \frac{G_2F_2 \sin \theta_2}{r_2}\left[r_3^{(1)} - r_2\right] + A_1^{(1)}G_1^{(1)}H_1^{(1)}\left[x_3^{(1)} - x_1^{(1)}\right]$$

$$\left. - \frac{G_1H_1 \sin \theta_1^{(1)}}{r_1^{(1)}}\left[x_3^{(1)} - x_1^{(1)}\right]\right\}$$

$$P_3^{(1)} = P_2 \exp\left\{A_2 G_2 F_2 \left[r_3^{(1)} - r_2\right] - \frac{G_2 F_2 \sin \theta_2}{r_2}\left[r_3^{(1)} - r_2\right] - G_2\left[\theta_3^{(1)} - \theta_2\right]\right\}$$

$$\rho_{3a}^{(1)} = \rho_{4a}\left[\frac{P_3^{(1)}}{P_4}\right]^{\frac{1}{\gamma_{4a}}} \exp\left\{-\frac{A_{4a}}{\cos \theta_4}\left[x_3^{(1)} - x_4\right]\right\}$$

$$\rho_{3b}^{(1)} = \rho_{4b}\left[\frac{P_3^{(1)}}{P_4}\right]^{\frac{1}{\gamma_{4b}}} \exp\left\{-\frac{A_{4b}}{\cos \theta_4}\left[x_3^{(1)} - x_4\right]\right\}$$

$$T_{3a}^{(1)} = T_{4a}\left[\frac{P_3^{(1)}}{P_4}\right]^{\frac{\gamma_{4a}-1}{\gamma_{4a}}} \exp\left\{-\frac{B_{4a}}{\cos \theta_4}\left[x_3^{(1)} - x_4\right]\right\}$$

$$T_{3b}^{(1)} = T_{4b}\left[\frac{P_3^{(1)}}{P_4}\right]^{\frac{\gamma_{4b}-1}{\gamma_{4b}}} \exp\left\{-\frac{B_{4b}}{\cos \theta_4}\left[x_3^{(1)} - x_4\right]\right\}$$

$$N_a^{(1)} = \frac{\ln \left[P_3^{(1)} / P_4 \right]}{\ln \left[\rho_{3a}^{(1)} / \rho_{4a} \right]}$$

$$N_b^{(1)} = \frac{\ln \left[P_3^{(1)} / P_4 \right]}{\ln \left[\rho_{3b}^{(1)} / \rho_{4b} \right]}$$

$$V_{3a}^{(1)} = \left(V_{4a}^2 + \frac{2N_a^{(1)}}{N_a^{(1)}-1} \frac{P_4}{\rho_{4a}} \left\{ 1 - \left[\frac{P_3^{(1)}}{P_4} \right]^{\frac{N_a^{(1)}-1}{N_a^{(1)}}} \right\} \right)^{1/2}$$

$$V_{3b}^{(1)} = \left(V_{4b}^2 + \frac{2N_b^{(1)}}{N_b^{(1)}-1} \frac{P_4}{\rho_{4b}} \left\{ 1 - \left[\frac{P_3^{(1)}}{P_4} \right]^{\frac{N_b^{(1)}-1}{N_b^{(1)}}} \right\} \right)^{1/2}$$

The first estimates of the species concentrations at point 3, $\left[c_{i_{3a}}^{(1)} \text{ and } c_{i_{3b}}^{(1)} \right]$, are calculated using the Species Integration Subroutine, and the first estimates of the gas properties at point 3, $\left[A_{3a}^{(1)}, A_{3b}^{(1)}, B_{3a}^{(1)}, B_{3b}^{(1)}, F_{3a}^{(1)}, F_{3b}^{(1)}, G_{3a}^{(1)}, G_{3b}^{(1)}, H_{3a}^{(1)}, H_{3b}^{(1)}, \alpha_{3a}^{(1)}, \alpha_{3b}^{(1)}, \gamma_{3a}^{(1)}, \text{ and } \gamma_{3b}^{(1)} \right]$, are calculated using the Gas Properties Subroutine.

Point 6 is again assumed to be point 4a and point 7 is the next point on the back data line. The position of point 3 is calculated from

$$r_3^{(i+1)} = \frac{r_4 + (x_2 - x_4)\tan\frac{1}{2}\left[\theta_3^{(i)} + \theta_4\right] - r_2\dfrac{\tan\frac{1}{2}\left[\theta_3^{(i)} + \theta_4\right]}{\tan\frac{1}{2}\left[\theta_2 + \theta_3^{(i)} + \alpha_2 + \alpha_{3b}^{(i)}\right]}}{1 - \dfrac{\tan\frac{1}{2}\left[\theta_3^{(i)} + \theta_4\right]}{\tan\frac{1}{2}\left[\theta_2 + \theta_3^{(i)} + \alpha_2 + \alpha_{3b}^{(i)}\right]}}$$

$$x_3^{(i+1)} = x_2 + \frac{r_3^{(i+1)} - r_2}{\tan\frac{1}{2}\left[\theta_2 + \theta_3^{(i)} + \alpha_2 + \alpha_{3b}^{(i)}\right]}$$

The radial location of point 1 is calculated from

$$r_1^{(i+1)} = \frac{r_3^{(i+1)} - \left[\dfrac{x_7 - x_6}{r_7 - r_6}\, r_6 + x_3^{(i+1)} - x_6\right]\tan\frac{1}{2}\left[\theta_1^{(i)} + \theta_3^{(i)} - \alpha_1^{(i)} - \alpha_{3a}^{(i)}\right]}{1 - \dfrac{x_7 - x_6}{r_7 - r_6}\tan\frac{1}{2}\left[\theta_1^{(i)} + \theta_3^{(i)} - \alpha_1^{(i)} - \alpha_{3a}^{(i)}\right]}$$

If $r_1^{(i+1)} > r_7$, point 7 becomes point 6 and the next point on the back data line is point 7. The above calculation is repeated until $r_6 < r_1^{(i+1)} \leq r_7$. (If point 6 becomes a wall point, a new point 2 is inserted by interpolation on the previous streamline and the calculation is restarted.)

The axial location of point 1 is calculated from

$$x_1^{(i+1)} = x_6 + \frac{x_7 - x_6}{r_7 - r_6}\left[r_1^{(i+1)} - r_6\right]$$

The flow properties at point 1, $\left[A_1^{(i+1)}, G_1^{(i+1)}, H_1^{(i+1)}, P_1^{(i+1)}, \alpha_1^{(i+1)}, \text{and } \theta_1^{(i+1)}\right]$, are calculated by interpolation on $r_1^{(i+1)}$. The flow properties at point 3 are calculated from

$$\theta_3^{(i+1)} = \frac{1}{\frac{1}{2}\left[G_{3b}^{(i)} + G_{3b}^{(i)} + G_2 + G_1^{(i+1)}\right]}\left\{\ln\left[\frac{P_2}{P_1^{(i+1)}}\right] + \frac{1}{2}\left[G_{3a}^{(i)} + G_1^{(i+1)}\right]\theta_1^{(i+1)}\right.$$

$$+ \frac{1}{2}\left[G_2 + G_{3b}^{(i)}\right]\theta_2 + \frac{1}{2}\left[A_2G_2F_2 + A_{3b}^{(i)}\,G_{3b}^{(i)}\,F_{3b}^{(i)}\right]\left[r_3^{(i+1)} - r_2\right]$$

$$- \frac{1}{2}\left[\frac{G_2F_2\sin\theta_2}{r_2} + \frac{G_{3b}^{(i)}\,F_{3b}^{(i)}\sin\theta_{3b}^{(i)}}{r_3^{(i)}}\right]\left[r_3^{(i+1)} - r_2\right]$$

$$+ \frac{1}{2}\left[A_1^{(i+1)}G_1^{(i+1)}H_1^{(i+1)} + A_{3a}^{(i)}G_{3a}^{(i)}H_{3a}^{(i)}\right]\left[x_3^{(i+1)} - x_1^{(i+1)}\right]$$

$$\left. - \frac{1}{2}\left[\frac{G_1^{(i+1)}H_1^{(i+1)}\sin\theta_1^{(i+1)}}{r_1^{(i+1)}} + \frac{G_3^{(i)}H_{3a}^{(i)}\sin\theta_3^{(i)}}{r_3^{(i)}}\right]\left[x_3^{(i+1)} - x_1^{(i+1)}\right]\right\}$$

$$P_3^{(i+1)} = P_2\exp\left\{\frac{1}{2}\left[A_2G_2F_2 + A_{3b}^{(i)}G_{3b}^{(i)}F_{3b}^{(i)}\right]\left[r_3^{(i+1)} - r_2\right]\right.$$

$$- \frac{1}{2}\left[\frac{G_2F_2\sin\theta_2}{r_2} + \frac{G_{3b}^{(i)}F_{3b}^{(i)}\sin\theta_3^{(i)}}{r_3^{(i)}}\right]\left[r_3^{(i+1)} - r_2\right]$$

$$\left. - \frac{1}{2}\left[G_2 + G_{3b}^{(i)}\right]\left[\theta_3^{(i+1)} - \theta_2\right]\right\}$$

$$\rho_{3a}^{(i+1)} = \rho_{4a}\left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{1}{2}\left[\frac{1}{\gamma_{4a}} + \frac{1}{\gamma_{3a}^{(i)}}\right]}\exp\left\{-\frac{1}{2}\left[\frac{A_{4a}}{\cos\theta_4} + \frac{A_{3a}^{(i)}}{\cos\theta_3^{(i)}}\right]\left[x_3^{(i+1)} - x_4\right]\right\}$$

$$\rho_{3b}^{(i+1)} = \rho_{4b}\left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{1}{2}\left[\frac{1}{\gamma_{4b}} + \frac{1}{\gamma_{3b}^{(i)}}\right]} \exp\left\{-\frac{1}{2}\left[\frac{A_{4b}}{\cos\theta_4} + \frac{A_{3b}^{(i)}}{\cos\theta_3^{(i)}}\right]\left[x_3^{(i+1)} - x_4\right]\right\}$$

$$T_{3a}^{(i+1)} = T_{4a}\left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{1}{2}\left[\frac{\gamma_{4a}-1}{\gamma_{4a}} + \frac{\gamma_{3a}^{(i)}-1}{\gamma_{3a}^{(i)}}\right]} \exp\left\{-\frac{1}{2}\left[\frac{B_{4a}}{\cos\theta_4} + \frac{B_{3a}^{(i)}}{\cos\theta_3^{(i)}}\right]\left[x_3^{(i+1)} - x_4\right]\right\}$$

$$T_{3b}^{(i+1)} = T_{4b}\left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{1}{2}\left[\frac{\gamma_{4b}-1}{\gamma_{4b}} + \frac{\gamma_{3b}^{(i)}-1}{\gamma_{3b}^{(i)}}\right]} \exp\left\{-\frac{1}{2}\left[\frac{B_{4b}}{\cos\theta_4} + \frac{B_{3b}^{(i)}}{\cos\theta_3^{(i)}}\right]\left[x_3^{(i+1)} - x_4\right]\right\}$$

$$N_a^{(i+1)} = \frac{\ln\left[P_3^{(i+1)}/P_4\right]}{\ln\left[\rho_{3a}^{(i+1)}/\rho_{4a}\right]}$$

$$N_b^{(i+1)} = \frac{\ln\left[P_3^{(i+1)}/P_4\right]}{\ln\left[\rho_{3b}^{(i+1)}/\rho_{4b}\right]}$$

$$V_{3a}^{(i+1)} = \left(V_{4a}^2 + \frac{2N_a^{(i+1)}}{N_a^{(i+1)} - 1}\,\frac{P_4}{\rho_{4a}}\left\{1 - \left[\frac{P_3^{(i+1)}}{P_4}\right]\frac{N_a^{(i+1)} - 1}{N_a^{(i+1)}}\right\}\right)^{\frac{1}{2}}$$

$$V_{3b}^{(i+1)} = \left(V_{4b}^2 + \frac{2N_b^{(i+1)}}{N_b^{(i+1)} - 1}\,\frac{P_4}{\rho_{4b}}\left\{1 - \left[\frac{P_3^{(i+1)}}{P_4}\right]\frac{N_b^{(i+1)} - 1}{N_b^{(i+1)}}\right\}\right)^{\frac{1}{2}}$$

The species concentrations at point 3

$$c_{i_{3a}}^{(i+1)} \text{ and } c_{i_{3b}}^{(i+1)}$$

are calculated using the Species Integration Subroutine and the gas properties at point 3

$$A_{3a}^{(i+1)},\ A_{3b}^{(i+1)},\ B_{3a}^{(i+1)},\ B_{3b}^{(i+1)},\ F_{3a}^{(i+1)},\ F_{3b}^{(i+1)},\ G_{3a}^{(i+1)},\ G_{3b}^{(i+1)},\ H_{3a}^{(i+1)},$$

$$H_{3b}^{(i+1)},\ \alpha_{3a}^{(i+1)},\ \alpha_{3b}^{(i+1)},\ \gamma_{3a}^{(i+1)} \text{ and } \gamma_{3b}^{(i+1)}$$

are calculated using the Gas Properties Subroutine.

The above integration equations are iterated until r_3, x_3, θ_3, P_3, ρ_{3a}, ρ_{3b}, T_{3a}, T_{3b}, V_{3a}, and V_{3b} converge to the required accuracy.

5.9.7 SUBROUTINE EF2D

This subroutine computes the dissociation recombination reaction equilibrium constants and their temperature derivatives from the following formulae:

$$K_j \qquad EK(J) = \frac{DATEF(J)}{T} \cdot \exp\left[\frac{-\Delta H_j}{T} - \sum_{i=1}^{n} Ft_i \cdot \nu_{ij} + \sum_{i=1}^{n} Ft_i \cdot \nu'_{ij}\right]$$

$$\frac{dK_j}{dT} \qquad DKT(J) = \left[\frac{-\sum_{i=1}^{n}\left(\frac{Ht_i}{R_i}\right)\cdot\nu_{ij} + \sum_{i=1}^{n}\left(\frac{Ht_i}{R_i}\right)\cdot\nu'_{ij}}{T} - 1\right] \cdot \frac{K_j}{T}$$

where: Ft_i = species free energy at the current temperature

Ht_i = species enthalpy at the current temperature

ΔH_j = heat of reaction for the J^{th} reaction

DATEF(J) = is defined in section 5.4.2

5.9.8 SUBROUTINE GPF

This subroutine is called by the method of characteristics point subroutines to obtain the gas property functions R, C_p, γ, M, α, F, G, H, B, and A. For the TDE and IDEAL GAS options the GPFPG subroutine is called perform the required computations. For the TDK option the GPFKIN subroutine is called to perform the required computations.

5.9.9 SUBROUTINE GPFKIN

Given the flow properties at a point, this subroutine calculates the gas properties required in the characteristic calculations from the following relationships:

$$R = \sum_{i=1}^{N} c_i R_i$$

$$C_p = \sum_{i=1}^{N} c_i C_{pi}$$

$$\gamma = \frac{C_p}{C_p - R}$$

$$M = \frac{V}{(\gamma R T)^{1/2}}$$

$$\alpha = \sin^{-1}\left(\frac{1}{M}\right)$$

$$F = \cos\theta - \frac{\sin\theta}{\tan(\theta + \alpha)}$$

$$G = \frac{\gamma}{\sin\alpha \cos\alpha}$$

$$H = \cos\theta \tan(\theta - \alpha) - \sin\theta$$

$$B = \frac{(\gamma - 1)\cos\theta}{\gamma R T} \sum_{i=1}^{N} f_i h_i$$

$$A = \frac{\cos\theta}{R}\left(\sum_{i=1}^{N} f_i R_i - \frac{\gamma - 1}{\gamma}\,\frac{1}{T}\sum_{i=1}^{N} f_i h_i\right)$$

5.9.10 SUBROUTINE GPFPG

Given the flow properties at a point, this subroutine calculates the gas properties required in the characteristic calculations from the following relationships:

If an IDEAL GAS problem has been specified;

$$R = \sum_{i=1}^{N} c_i R_i$$

$$C_p = \sum_{i=1}^{N} c_i C_{pi}$$

$$\gamma = \frac{C_p}{C_p - R}$$

$$M = \frac{V}{(\gamma RT)^{1/2}}$$

$$\alpha = \sin^{-1}\left(\frac{1}{M}\right)$$

$$F = \cos\theta - \frac{\sin\theta}{\tan(\theta+\alpha)}$$

$$G = \frac{\gamma}{\sin\alpha\cos\alpha}$$

$$H = \cos\theta\tan(\theta-\alpha) - \sin\theta$$

$$A = B = 0$$

If a TDE (Two-Dimensional Equilibrium) problem has been specified spline interpolation is used to obtain:

γ	vs	P	ratio of specific heats
M_w	vs	P	molecular weight
T	vs	log (P)	temperature
M	vs	log (P)	Mach number
h	vs	log (P)	enthalpy

and then the following variables are computed;

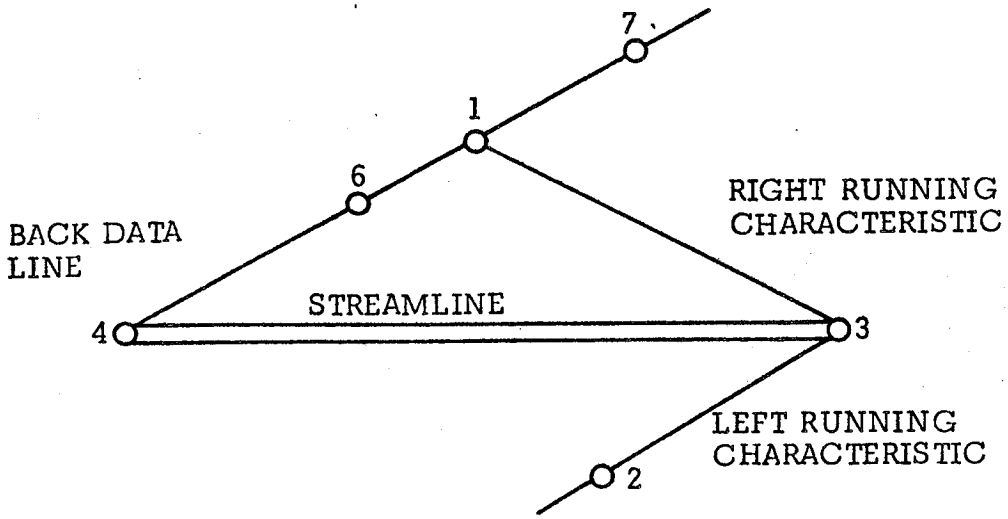
$$V = (2h_0 - 2h)^{1/2}$$

$$\rho = \frac{PM_w}{49680T}$$

and α, F, G, H, A, and B are computed as in the ideal gas problem described above.

5.9.11 SUBROUTINE INPT

This subroutine uses four known points to calculate interior points along left running characteristics.



Points 2, 4, 6, and 7 are known points and point 3 is the unknown point to be computed. Initial values (i=0) at point 3 for A, B, α, γ, and θ are taken as the values at point 4.

The position of point 3 is calculated from

$$r_3^{(i+1)} = \frac{r_4+(x_2-x_4)\tan\frac{1}{2}\left[\theta_3^{(i)}+\theta_4\right] - r_2\dfrac{\tan\frac{1}{2}\left[\theta_3^{(i)}+\theta_4\right]}{\tan\frac{1}{2}\left[\theta_2+\theta_3^{(i)}+\alpha_2+\alpha_3^{(i)}\right]}}{1-\dfrac{\tan\frac{1}{2}\left[\theta_3^{(i)}+\theta_4\right]}{\tan\frac{1}{2}\left[\theta_2+\theta_3^{(i)}+\alpha_2+\alpha_3^{(i)}\right]}}$$

$$x_3^{(i+1)} = x_2 + \frac{r_3^{(i+1)} - r_2}{\tan\frac{1}{2}\left[\theta_2+\theta_3^{(i)}+\alpha_2+\alpha_3^{(i)}\right]}$$

Values at point 1 are determined by interpolation between points 6 and 7. Point 6 is initially assumed to be point 4 and point 7 is the next point on the back data line.

The radial location of point 1 is calculated from

$$r_1^{(i+1)} = \frac{r_3^{(i+1)} - \left[\frac{x_7 - x_6}{r_7 - r_6} r_6 + x_3^{(i+1)} - x_6\right] \tan \frac{1}{2}\left[\theta_1^{(i)} + \theta_3^{(i)} - \alpha_1^{(i)} - \alpha_3^{(i)}\right]}{1 - \frac{x_7 - x_6}{r_7 - r_6} \tan \frac{1}{2}\left[\theta_1^{(i)} + \theta_3^{(i)} - \alpha_1^{(i)} - \alpha_3^{(i)}\right]}$$

If $r_1^{(i+1)} > r_7$, point 7 becomes point 6 and the next point on the back data line is point 7. The above calculation is repeated until $r_6 < r_1^{(i+1)} \leq r_7$. (If point 6 becomes a wall point, a new point 2 is inserted by interpolation on the previous streamline and the calculation is restarted.)

The axial location of point 1 is calculated from

$$x_1^{(i+1)} = x_6 + \frac{x_7 - x_6}{r_7 - r_6}\left[r_1^{(i+1)} - r_6\right]$$

The flow properties $A_1^{(i+1)}$, $G_1^{(i+1)}$, $H_1^{(i+1)}$, $\alpha_1^{(i+1)}$, and $\theta_1^{(i+1)}$ are calculated by linear interpolation on $r_1^{(i+1)}$. The pressure at point 1, $P_1^{(i+1)}$, is found by intergrating along the left running characteristic between point 6 and 7 as follows (modified Euler method)

$$P_1^{(i+1)} = \frac{1}{2}\left[P_7 (1-C_{17}) + P_6 (1+C_{16})\right]$$

where

$$C_{17} = G_7\left[(A_7 - \frac{\sin \theta_7}{r_7}) F_7 (r_7 - r_1) - (\theta_7 - \theta_1)\right]$$

$$C_{16} = G_6\left[(A_6 - \frac{\sin \theta_6}{r_6}) F_6 (r_1 - r_6) - (\theta_1 - \theta_6)\right]$$

The flow properties at point 3 are calculated from (modified Euler method)

$$P_3^{(i+1)} = P_{21} + \frac{P_{32}^{(i)}}{2}\left\{\left[(AGF)_{32}^{(i)} - (GF)_{32}^{(i)} \frac{\sin \theta_{32}^{(i)}}{r_{32}^{(i)}}\right](r_3^{(i+1)} - r_2) - G_{32}^{(i)} (\theta_3^{(i)} - \theta_2)\right\} +$$

$$\frac{P_{13}^{(i)}}{2}\left\{\left[-(AGH)_{13}^{(i)} - (GH)_{13}^{(i)} \frac{\sin \theta_{13}^{(i)}}{r_{13}^{(i)}}\right](x_3^{(i+1)} - x_1) + G_{31}^{(i)} (\theta_3^{(i)} - \theta_1)\right.$$

$$\theta_3^{(i+1)} = \frac{1}{G_{23}^{(i)} + G_{13}^{(i)}} \left\{ \frac{P_3^{(i+1)} - P_1}{P_{13}^{(i+1)}} - \frac{P_3^{(i+1)} - P_2}{P_{32}^{(i+1)}} + \left[(AGF)_{32}^{(i)} - (GF)_{32}^{(i)} \frac{\sin \theta_{32}^{(i)}}{r_{32}^{(i+1)}} \right] \right.$$

$$(r_3^{(i+1)} - r_2) - \left[-(AGH)_{13}^{(i)} + (GH)_{13}^{(i)} \frac{\sin \theta_{13}^{(i)}}{r_{13}^{(i+1)}} \right] (x_3^{(i+1)} - x_1) +$$

$$\left. G_{23}^{(i)} \theta_2 + G_{13}^{(i)} \theta_1 \right\}$$

$$\rho_3^{(i+1)} = \rho_4 \left[\frac{P_3^{(I+1)}}{P_4} \right]^{\left(\frac{1}{\gamma}\right)_{34}^{(i)}} \exp \left\{ - \left(\frac{A}{\cos \theta}\right)_{34}^{(i)} \left[x_3^{(i+1)} - x_4 \right] \right\}$$

$$T_3^{(i+1)} = T_4 \left[\frac{P_3^{(i+1)}}{P_4} \right]^{\left(\frac{\gamma - 1}{\gamma}\right)_{43}^{(i)}} \exp \left\{ - \left(\frac{B}{\cos \theta}\right)_{34}^{(i)} \left[x_3^{(i+1)} - x_4 \right] \right\}$$

The double subscripts imply averaged values, e.g.

$$P_{21} = \frac{P_2 + P_1}{2}$$

and

$$(AGF)_{32}^{(i)} = \frac{(AGF)_3^{(i)} + (AGF)_2}{2}$$

Next the gas velocity is calculated as

$$N^{(i+1)} = \frac{\ln \left[P_3^{(i+1)} / P_4 \right]}{\ln \left[\rho_3^{(i+1)} / P_4 \right]}$$

$$V_3^{(i+1)} = \left(V_4^2 + \frac{2N^{(i+1)}}{N^{(i+1)} - 1} \frac{P_4}{\rho_4} \left\{ 1 - \left[\frac{P_3^{(i+1)}}{P_4} \right]^{\frac{N^{(i+1)}-1}{N^{(i+1)}}} \right\} \right)^{1/2}$$

The species concentrations at point 3, $\left[c_{i_3}^{(i+1)}\right]$, are calculated using the Species Integration Subroutine and the gas properties at point 3, $\left[A_3^{(i+1)}, B_3^{(i+1)}, F_3^{(i+1)}, G_3^{(i+1)}, H_3^{(i+1)}, \alpha_3^{(i+1)}, \gamma_3^{(i+1)}\right]$, are calculated using the GPF subroutine.

The above integration equations are iterated (i=1,...) until r_3, x_3, θ_3, P_3, ρ_3, T_3, and V_3 converge to the required accuracy.

5.9.12 SUBROUTINE NESK (Y)

A single precision linear equation solver which is used to perform the matrix inversions required by subroutine SINT. Gaussian elimination is used with row interchange taking place to position maximum pivot elements after the rows are initially scaled. The solution vector is returned in array Y. Identical to subroutine LESK.

5.9.13 SUBROUTINE PRINT (ID)

The purpose of this subroutine is to print output for the supersonic flow calculation as requested by the program input. Printout may occur after the completion of each mesh point calculation. Points for print are selected as follows:

1) The following points are always printed:
   - axis points
   - dividing streamline points
   - initial line points
   - wall points
2) Interior points are selected for print only along every n_1th left running characteristic and only at every n_2th position along these characteristics.
3) Inserted points are printed if and only if all points are to be printed ($n_1=n_2=1$).

The items printed are listed in the table below in the order they appear, left to right, on the output sheet. A header is printed for identification purposes above each characteristic.

Item	Header	Meaning	Units	SI Units
LRC number	LRC	left running characteristic number	none	none
Identification number	ID	type of point (see below)	none	none
r	R	r position coordinate	none	none
x	X	x position coordinate	none	none
M	MACH	Mach number	none	none
θ	THETA	streamline angle	degrees	degrees
T	T(DEG.R)	temperature	$^\circ$R	$^\circ$K
P	P(PSI)	pressure	PSI	N/M^2
ρ	DENSITY	density	lb/ft^3	KG/M^3
V	VELOCITY	velocity	ft/sec	M/sec
C_f	CF	thrust coefficient	none	none
I_{sp}	ISP	specific impulse	sec	sec
Iteration number	IT	number of iterations required	none	none

If the input term NC is set non-zero, the species concentrations (partial densities) are printed seven items per line in successive rows immediately below the above items. A header giving the species names is also printed immediately below the above header.

Of the quantities above, the following are calculated within subroutine PRINT:

$$\dot{M} = V/\sqrt{\gamma P/\rho}$$

$$I_{sp} = F_t/\dot{m}g \qquad g = 32.174$$

$$C_F = g\, I_{sp}/C^*$$

The table below relates the printed identification number to the type of point calculated:

ID	Type of Point Calculated
1	initial line point, or inserted point 1 off axis
2	interior point
3	axis point
4	dividing streamline point
5	wall point
6	inserted point

If the option to punch a Mach number table has been selected, the axial and radial coordinates and the Mach number for the last wall point for each characteristic will be punched. The punch unit is referenced directly in this subroutine. A test is made in this subroutine to (on option) abort the run if the maximum number of iterations has been exceeded in calculating a mesh point to be printed.

For an ideal gas calculation the divergence efficiency, η_{DIV}, is calculated and printed at each wall point. The divergence efficiency is defined as follows:

$$\eta_{DIV} = ISP / ISP_{(1D)} \quad \text{at } \gamma = \text{constant}$$

where:

I_{sp} = as above

$I_{sp_{(1D)}} = \sum \dot{m}_i I_{sp_i}$

$I_{sp_i} = \dfrac{C_i^* C_{f_i}}{g}$

$C_i^* = \left[R_i T_{c_i} / \gamma_i \right]^{1/2} / \left[\left(\dfrac{2}{\gamma_i + 1} \right) \dfrac{\gamma_{i+1}}{\gamma_i - 1} \right]^{1/2}$

C_{f_i} = the one dimensional value for C_f at the area ratio printed.

5.9.14 SUBROUTINE SDERIV

The total derivatives f_i and the partial derivatives $\beta_{i,j}$ of the chemical relaxation equations are calculated using the relations specified in subroutine DERIV of the one-dimensional chemical kinetic and equilibrium subprogram. The additional vector $\Phi_{i,4}$ is calculated by the relation

$$\Phi_{i,4} = - f_i^* \tan \theta \qquad i = 1, \ldots, NSP$$

The calculation for $\overline{K}_i$ is replaced with

$$K_i = (MW_i \cdot \rho \cdot r^*) / (V * COS\ \theta)$$

5.9.15 SUBROUTINE SINT

This subroutine integrates the chemical relaxation equations using an implicit integration method to enhance numerical stability.

$$k_i^{(i)} = f_{i,n}\, h^{(i)} + \sum_{j=1}^{N} \beta_{ij,n}\, h^{(i)} k_j^{(i)} + h^{(i)} \sum_{j=1}^{4} \phi_{ij,n}\, \Delta y_j^{(i)}$$

where $k_i^{(i)}$ is obtained by solving $\overline{A}\,\overline{K} = \overline{\Omega}$, where

$$\overline{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{12} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & & \vdots \\ a_{N1} & a_{N2} & & a_{NN} \end{bmatrix}, \quad \overline{K} = \begin{bmatrix} k_1 \\ k_2 \\ \vdots \\ k_N \end{bmatrix}, \quad \overline{\Omega} = \begin{bmatrix} \Omega_1 \\ \Omega_2 \\ \vdots \\ \Omega_N \end{bmatrix}$$

and

$$a_{ij} = \delta_{ij} - h^{(i)} \beta_{ij,n}$$

$$\begin{cases} \delta_{ij} = 0 \text{ for } i \neq j \\ \delta_{ij} = 1 \text{ for } i = j \end{cases}$$

$$k_i = k_i^{(i)}$$

$$\Omega_i = h^{(i)} \left[f_{i,n} + \sum_{i=1}^{4} \phi_{ij,n}\, \Delta y_j^{(i)} \right]$$

If the temperature at the back point, i.e. point 4, is below the temperature criterion for explicit integration to occur (GØEXPL, nominal = 0 °R, the species concentrations are integrated using:

$$k_i^{(i)} = f_{i,n} \cdot h^{(i)}$$

5.9.16 SUBROUTINE SUBIL (MS)

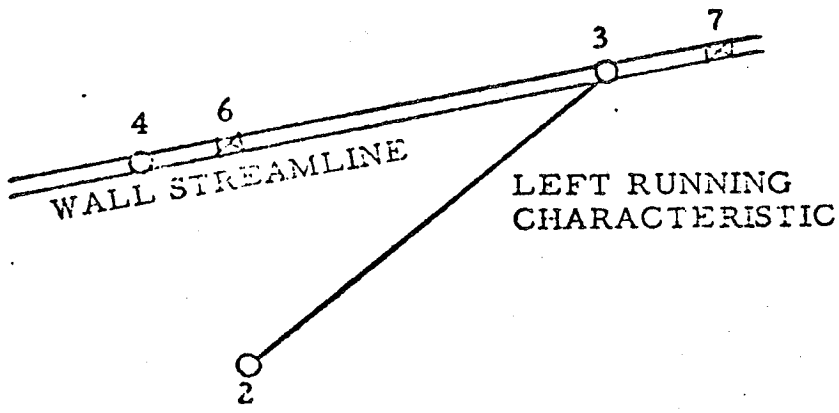
The purpose of this subroutine is to acquire values of the variables P, ρ, θ, V, x, r, T, and C_i from the initial line array, PSS, for point number MS and use subroutine GPF to calculate corresponding values for A, B, F, G, H, α, and γ. All values are then placed in the working array, PS, for use by subroutine CNTRL.

5.9.17 SUBROUTINE THERM

This subroutine reads converted and blocked JANNAF data from the tape written by subroutine STFSET of the One Dimensional Kinetic Analysis Subprogram. Subroutine SPLN is then used to interpolate on temperature for the variables F_i, H_i, and C_{P_i}.

5.9.18 SUBROUTINE WLPT

This subroutine uses two known points to calculate a wall point



Points 2 and 4 are known points and point 3 is the unknown point to be calculated. Points 6 and 7 are points in the wall table adjacent to point 3. Points 6 and 7 are initially assumed to straddle point 4.

The first estimate of the axial location of point 3 is calculated from

$$x_3^{(1)} = \frac{x_2 + \left(r_6 - r_2 - \frac{r_7 - r_6}{x_7 - x_6} x_6\right) \cot \frac{1}{2}(\theta_2 + \theta_4 + \alpha_2 + \alpha_4)}{1 - \frac{r_7 - r_6}{x_7 - x_6} \cot \frac{1}{2}(\theta_2 + \theta_4 + \alpha_2 + \alpha_4)}$$

If $x_3^{(1)} > x_7$, point 7 becomes point 6 and the next point in the wall table is point 7. The above calculation is repeated until $x_6 < x_3^{(1)} \leq x_7$.

The first estimate of the radial position of point 3 is calculated from

$$r_3^{(1)} = r_6 + \frac{r_7 - r_6}{x_7 - x_6}\left[x_3^{(1)} - x_6\right]$$

The first estimates of the flow properties at point 3 are calculated from

$$\theta_3^{(1)} = \tan^{-1}\left(\frac{r_7 - r_6}{x_7 - x_6}\right)$$

$$P_3^{(1)} = P_2 \exp\left\{A_2 G_2 F_2 \left[r_3^{(1)} - r_2\right] - \frac{G_2 F_2 \sin\theta_2}{r_2}\left[r_3^{(1)} - r_2\right] - G_2\left[\theta_3^{(1)} - \theta_2\right]\right\}$$

$$\rho_3^{(1)} = \rho_4\left[\frac{P_3^{(1)}}{P_4}\right]^{1/\gamma_4} \exp\left\{-\frac{A_4}{\cos\theta_4}\left[x_3^{(1)} - x_4\right]\right\}$$

$$T_3^{(1)} = T_4\left[\frac{P_3^{(1)}}{P_4}\right]^{\frac{\gamma_4 - 1}{\gamma_4}} \exp\left\{-\frac{B_4}{\cos\theta_4}\left[x_3^{(1)} - x_4\right]\right\}$$

$$N^{(1)} = \frac{\ln\left[P_3^{(1)}/P_4\right]}{\ln\left[\rho_3^{(1)}/\rho_4\right]}$$

$$V_3^{(1)} = \left(V_4^2 + \frac{2N^{(1)}}{N^{(1)} - 1}\frac{P_4}{\rho_4}\left\{1 - \left[\frac{P_3^{(1)}}{P_4}\right]^{\frac{N^{(1)} - 1}{N^{(1)}}}\right\}\right)^{1/2}$$

The first estimates of the species concentrations at point 3, $\left[c_{i3}^{(1)}\right]$, are calculated using the Species Integration Subroutine, and the first estimates of the gas properties at point 3, $\left[A_3^{(1)}, B_3^{(1)}, F_3^{(1)}, G_3^{(1)}, H_3^{(1)}, \alpha_3^{(1)}, \text{and } \gamma_3^{(1)}\right]$, are calculated using the Gas Properties Subroutine.

Points 6 and 7 are again assumed to straddle point 4 and the axial location of point 3 is calculated from

$$x_3^{(i+1)} = \frac{x_2 + \left(r_6 - r_2 - \frac{r_7 - r_6}{x_7 - x_6}\, x_6\right) \cot\frac{1}{2}\left[\theta_2 + \theta_3^{(i)} + \alpha_2 + \alpha_3^{(i)}\right]}{1 - \frac{r_7 - r_6}{x_7 - x_6} \cot\frac{1}{2}\left[\theta_2 + \theta_3^{(i)} + \alpha_2 + \alpha_3^{(i)}\right]}$$

If $x_3^{(i+1)} > x_7$, point 7 becomes point 6 and the next point in the wall table is point 7. The above calculation is repeated until $x_6 < x_3^{(i+1)} \leq x_7$.

The radial location of point 3 is calculated from

$$r_3^{(i+1)} = r_6 + \frac{r_7 - r_6}{x_7 - x_6}\left[x_3^{(i+1)} - x_6\right]$$

The flow properties at point 3 are calculated from

$$\theta_3^{(i+1)} = \tan^{-1}\left(\frac{r_7 - r_6}{x_7 - x_6}\right)$$

$$P_3^{(i+1)} = P_2 \exp\left\{\frac{1}{2}\left[A_3^{(i)}G_3^{(i)}F_3^{(i)} + A_2G_2F_2\right]\left[r_3^{(i+1)} - r_2\right]\right.$$

$$- \frac{1}{2}\left[\frac{G_3^{(i)}F_3^{(i)} \sin\theta_3^{(i)}}{r_3^{(i+1)}} + \frac{G_2F_2 \sin\theta_2}{r_2}\right]\left[r_3^{(i+1)} - r_2\right]$$

$$\left. - \frac{1}{2}\left[G_3^{(i)} + G_2\right]\left[\theta_3^{(i+1)} - \theta_2\right]\right\}$$

$$\rho_3^{(i+1)} = \rho_4\left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{1}{2}\left[\frac{1}{\gamma_4} + \frac{1}{\gamma_3^{(i)}}\right]} \exp\left\{-\frac{1}{2}\left[\frac{A_4}{\cos\theta_4} + \frac{A_3^{(i)}}{\cos\theta_3^{(i)}}\right]\right.$$

$$\left.\left[x_3^{(i+1)} - x_4\right]\right\}$$

$$T_3^{(i+1)} = T_4 \left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{1}{2}\left[\frac{\gamma_4 - 1}{\gamma_4} + \frac{\gamma_3^{(i)} - 1}{\gamma_3^{(i)}}\right]} \exp\left\{-\frac{1}{2}\left[\frac{B_4}{\cos \theta_4} + \frac{B_3^{(i)}}{\cos \theta_3^{(i)}}\right]\left[x_3^{(i+1)} - x_4\right]\right\}$$

$$N^{(i+1)} = \frac{\ln\left[P_3^{(i+1)}/P_4\right]}{\ln\left[\rho_3^{(i+1)}/\rho_4\right]}$$

$$V_3^{(i+1)} = \left(V_4^2 + \frac{2N^{(i+1)}}{N^{(i+1)} - 1} \frac{P_4}{\rho_4}\left\{1 - \left[\frac{P_3^{(i+1)}}{P_4}\right]^{\frac{N^{(i+1)} - 1}{N^{(i+1)}}}\right\}\right)^{1/2}$$

The species concentrations at point 3, $\left[c_{i3}^{(i+1)}\right]$, are calculated using the Species Integration Subroutine and the gas properties at point 3, $\left[A_3^{(i+1)}, B_3^{(i+1)}, F_3^{(i+1)}, G_3^{(i+1)}, H_3^{(i+1)}, \alpha_3^{(i+1)}, \text{ and } \gamma_3^{(i+1)}\right]$, are calculated using the Gas Properties Subroutine.

The above integration equations are iterated until x_3, r_3, θ_3, P_3, ρ_3, T_3, and V_3, converge to the required accuracy.

6.0 PROGRAM USER'S MANUAL

Discription of the Computer Program

This computer program was developed on the Univac 1108 computer using the FORTRAN V language. The program uses overlay and runs in 65K core. Program overlay extends four levels. (See Section 4, Program Overlay Structure)

The program input is read from logical unit 10 and program output is written on logical unit 6. Options of the programs that punch cards use PUNCH statements.

Six additional logical units are required by the program as described below:

Logical Unit	Usage	FORTRAN Name
25	Thermodynamic data tape	JANAF
26	Scratch file	KREAX
27	Scratch file	KSTF
28	Scratch file	IRREAD
29	Scratch file	ITSTAB
5	Program input storage	

These units are written and/or read by their FORTRAN names. The logical units are assigned to the FORTRAN names by DATA statements in the main program and thus may be easily redefined.

The computer program consists of four subprograms, ODE, ODK, TRANS, and TDK. All of these subprograms are required to perform a complete two dimensional non-equilibrium nozzle performance calculation. Various options exist in the program, however, which exercise the above subprograms alone, in part, or in combination.

Input to the computer program has been divided into data sets. The computer program recognizes each input data set by the first card in the set. These data sets are listed in Table 6-1.

The program input is described in detail below in the order given in Table 6-1. Data required to run a particular case must be input to the computer program in the order presented in this user's manual.

TABLE 6-1. INPUT DATA SET DESCRIPTIONS

Data Set	First Card col. no. 1 2 3 4 5 6 7 8 9 10		Last Card (if required) col. no. 1 2 3 4 5 6 7 8 9 10		Section Explaining The Data Set
Thermodynamic Data	THERMØ		END		6.1
Thermodynamic Data Below 300°K	LØW T CP HS		END L	ØW T CP HS	6.1.1
Title Cards	TITLE	(etc.)*		(none required)	6.2
Problem Card	PRØBLEM	(etc.)		(none required)	6.3
Reactant Cards	REACTANTS			(blank card required)	6.4.1
Omit and Insert Cards	OMIT INSERT	(etc.) (etc.)		(none required) (none required)	6.4.2.1 6.4.2.2
ØDE Namelist	NAMELISTS $ODE		$END	(none required)	6.4.3 6.4.3
ØDK option for Input of Initial Species Concentrations	SPECIES	(etc.)		(none required)	6.5.1.1
Reactions	REACTIØNS		LAST	REAX	6.5.2.1
Inert Species Option	INERTS	(etc.)		(none required)	6.5.2.7
Third Body Reaction Rate Ratios	THIRD BØDY	(etc.)	LAST	CARD	6.5.2.8
ODK Namelist	$ØDK		$END		6.5.3
TRANS Namelist	$TRANS		$END		6.6
TDK Namelist	$TDK		$END		6.7

* The comment (etc.) implies other information is to be punched on the card.

Certain special options to the computer program are described separately in Section 6.8.

An input data card listing for a sample case is presented in Section 7, followed by the corresponding computer output. In preparing input to the computer program it is useful to review this input card listing.

Successive cases can be run using the computer program but complete data should be input for each case.

6.1 THERMODYNAMIC DATA

This data set is identical to the THERMO DATA described in Appendix D of NASA SP-273 (i.e. Reference 9).

Using this data set, thermodynamic data curve fit coefficients may be read from cards. The curve fit coefficients are generated by the PAC computer program described in NASA TN D-4097 (i.e. Reference 22)

The thermodynamic data (i.e. $C^\circ_{p_T}$, etc.) are expressed as functions of temperature using 5 least squares curve fit coefficients (a_{1-5}) and two integration constants (a_{6-7}) as follows:

$$\frac{C^\circ_{p_T}}{R} = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5T^4 \qquad (6\text{-}1)$$

$$\frac{H^\circ_T}{RT} = a_1 + \frac{a_2T}{2} + \frac{a_3T^2}{3} + \frac{a_4T^3}{4} + \frac{a_5T^4}{5} + \frac{a_6}{T} \qquad (6\text{-}2)$$

$$\frac{S^\circ_T}{R} = a_1 \ln T + a_2T + \frac{a_3T^2}{2} + \frac{a_4T^3}{3} + \frac{a_5T^4}{4} + a_7 \qquad (6\text{-}3)$$

For each species, two sets of coefficients (a_{1-7} and a'_{1-7}) are specified for two adjacent temperature intervals, lower and upper respectively. For the data available in Reference 9 the lower temperature interval is 300° to 1000°K and the upper temperature interval is 1000°K to 5000°K.

The input format required for this thermodynamic data is defined in Table 6-2. Data cards for the species H, HO2, H2, H2O(L), H2O, H2O2, O, OH, and O2 are listed in Table 6-3 as examples. Thermodynamic data coefficients for 421 species are available in Reference 9 and are supplied with the computer program. A list of these 421 species names is presented in Figure 6-4.

Data Tape Generation and Usage:

A computer run using thermodynamic data card input will generate a data tape on logical unit JANAF. This tape may then be saved and used at a later time The program writes the THERMO data card images on unit JANAF as read but with two minor exceptions. The THERMO code card and the card numbers in card column 80 are omitted.

If thermodynamic data cards are not input, the program assumes the thermodynamic data is on logical unit JANAF. Logical unit JANAF is currently assigned a value of 25.

TABLE 6-2 FORMAT FOR THERMODYNAMIC DATA CARDS

Card order	Contents	Format	Card column
1	THERMO	3A4	1 to 6
2	Temperature ranges for 2 sets of coefficients: lowest T, common T, and highest T	3F10.3	1 to 30
3	Species name	3A4	1 to 12
	Date	2A3	19 to 24
	Atomic symbols and formula	4(A2,F3.0)	25 to 44
	Phase of species (S,L, or G for solid, liquid, or gas, respectively	A1	45
	Temperature range	2F10.3	46 to 65
	Integer 1	I15	80
4	Coefficients a_i' (i = 1 to 5) in equations (6-1) to (6-3)	5(E15.8)	1 to 75
	(for upper temperature interval)		
	Integer 2	I5	80
5	Coefficients in equations (6-1) to 6-3) (a_6', a_7' for upper temperature interval and a_1, a_2, and a_3 for lower)	5(E15.8)	1 to 75
	Integer 3	I5	80
6	Coefficients in equations (6-1) to (6-3) (a_4,a_5,a_6,a_7 for lower temperature interval)	4(E15.8)	1 to 60
	Integer 4	I20	80
(a)	Repeat cards numbered 1 to 4 in cc 80 for each species		
(Final card)	END (Indicates end of thermodynamic data)	3A4	1 to 3

[a]Gaseous species and condensed species with only one condensed phase can be in any order. However, the sets for two or more condensed phases of the same species must be adjacent. If there are more than two condensed phases of a species their sets must be either in increasing or decreasing order according to their temperature intervals.

TABLE 6-3. THERMO DATA CARDS FOR AN O_2/H_2 PROPELLANT

(Species AR, H, H_2, H_2O, N_2, O, OH, and O_2)

```
HERMO
  300.000  1000.000  5000.000
R                 L 5/66AR  100  000  000  0G   300.000  5000.000
0.25000000E 01 0.                0.                0.               0.
0.74537502E 03 0.43660006E 01 0.25000000E 01 0.                0.
0.                0.               -0.74537498E 03 0.43660006E 01
                  J 9/65H   100  000  000  0G   300.000  5000.000
0.25000000E 01 0.                0.                0.               0.
0.25471627E 05-0.46011763E 00 0.25000000E 01 0.                0.
0.                0.                0.25471627E 05-0.46011762E 00
2                 J 3/61H   20   00   00   0G   300.000  5000.000
0.31001901E 01 0.51119464E-03 0.52644210E-07-0.34909973E-10 0.36945345E-14
0.87738042E 03-0.19629421E 01 0.30574451E 01 0.26765200E-02-0.58099162E-05
0.55210391E-08-0.18122739E-11-0.98890474E 03-0.22997056E 01
20                J 3/61H   20   100  000  0G   300.000  5000.000
0.27167633E 01 0.29451374E-02-0.80224374E-06 0.10226682E-09-0.48472145E-14
0.29905826E 05 0.66305671E 01 0.40701275E 01-0.11084499E-02 0.41521180E-05
0.29637404E-08 0.80702103E-12-0.30279722E 05-0.32270046E 00
2                 J 9/65N   20   00   00   0G   300.000  5000.000
0.28963194E 01 0.15154866E-02-0.57235277E-06 0.99807393E-10-0.65223555E-14
0.90586184E 03 0.61615148E 01 0.36748261E 01-0.12081500E-02 0.23240102E-05
0.63217559E-09-0.22577253E-12-0.10611588E 04 0.23580424E 01
                  J 6/62O   100  000  000  0G   300.000  5000.000
0.25420596E 01-0.27550619E-04-0.31028033E-08 0.45510674E-11-0.43680515E-15
0.29230803E 05 0.49203080E 01 0.29464287E 01-0.16381665E-02 0.24210316E-05
0.16028432E-08 0.38906964E-12 0.29147644E 05 0.29639949E 01
H                 J 3/66O   1H   100  000  0G   300.000  5000.000
0.29106427E 01 0.95931650E-03-0.19441702E-06 0.13756646E-10 0.14224542E-15
0.39353815E 04 0.54423445E 01 0.38375943E 01-0.10778858E-02 0.96830378E-06
0.18713972E-09-0.22571094E-12 0.36412823E 04 0.49370009E 00
2                 J 9/65O   20   00   00   0G   300.000  5000.000
0.36219535E 01 0.73618264E-03-0.19652228E-06 0.36201558E-10-0.28945627E-14
0.12019825E 04 0.36150960E 01 0.36255985E 01-0.18782184E-02 0.70554544E-05
0.67635137E-08 0.21555993E-11-0.10475226E 04 0.43052778E 01
ND
```

Table 6-4. SPECIES WITH THERMODYNAMIC DATA PROVIDED

L(S)
AL(L)
AL
AL+
ALBO2
ALCL
ALCL+
ALCLF
ALCLF2
ALCL2
ALCL2+
ALCL2-
ALCL2F
ALCL3(S)
ALCL3(L)
ALCL3
ALF
ALF+
ALF2
ALF2+
ALF2-
ALF3(S)
ALF3(S)
ALF3
ALH
ALN(S)
ALN
ALO
ALO+
ALOCL
ALOF
ALOH
ALOH+
ALOH-
ALO2
ALO2-
ALO2H
AL2CL6
AL2F6
AL2O
AL2O+
AL2O2
AL2O2+
AL2O3(S)
AL2O3(L)
AR
AR+
B(S)
B(L)
B
B+

BCL
BCL+
BCLF
BCL2
BCL2+
BCL2-
BCL3
BF
BF2
BF2+
BF2-
BF3
BH
BHF2
BH2
BH3
BN(S)
BN
BO
BOCL
BOF
BOF2
BO2
BO2-
BS
B2
B2O
B2O2
B2O3(L)
B2O3
B3O3CL3
B3O3F3
BE(S)
BE(L)
BE
BE+
BEBO2
BECL
BECL+
BECLF
BECL2(S)
BECL2(L)
BECL2
BEF
BEF2(S)
BEF2(S)
BEF2(L)
BEF2
BEH
BEH+
BEN

BEO(S)
BEO(L)
BEO
BEOH
BEOH+
BEO2H2
BE2O
BE2OF2
BE2O2
BE3O3
BE4O4
BR
BR2(L)
BR2
C(S)
C
C+
C-
CCL
CCL2
CCL3
CCL4
CF
CF2
CF3
CF4
CH
CH2
CH2O
CH3
CH4
CN
CN+
CN-
CN2
CO
CCCL
CCCL2
CCF
COF2
COS
CO2
CO2-
CP
CS
CS2
C2
C2-
C2CL2
C2F2
C2F4

C2H
C2HF
C2H2
C2H4
C2N
C2N2
C2O
C3
C3O2
C4
C5
CL
CL+
CL-
CLCN
CLF
CLF3
CLO
CLO2
CL2
CL2O
CS(S)
CS(L)
CS
CS+
CSCL(S)
CSCL(S)
CSCL(L)
CSCL
CSF(S)
CSF(L)
CSF
CSO
CS2
CS2CL2
CS2F2
CS2C
E
F
F-
FCN
FO
FO2
F2
F2O
FE(S)
FE(S)
FE(S)
FE(L)
FE
FECL

FECL2(S)
FECL2(L)
FECL2
FECL3(S)
FECL3(L)
FECL3
FEO(S)
FEO(L)
FEO
FEO2H2(S)
FEO2H2
FEO3H3(S)
FE2O3(S)
FE3O4(S)
H
H+
H-
HALO
HBO
HBO+
HBO2
HCL
HCN
HCO
HCO+
HCP
HF
HNO
HO2
H2
H2O(S)
H2O(L)
H2O
H2O2
H2S
H3B3O6
HE
HE+
K(S)
K(L)
K
K+
KCL(S)
KCL(L)
KCL
KF(S)
KF(L)
KF
KF2-
K2F2
KO

KOH
KOH(S)
KOH(L)
K2
K2O(S)
LI(S)
LI(L)
LI
LI+
LICL(S)
LICL(L)
LICL
LIF(S)
LIF(L)
LIF
LIF2-
LIFO
LIH(S)
LIH(L)
LIH
LIN
LIO
LIO-
LIOH(S)
LIOH(L)
LIOH
LION
LI2
LI2CL2
LI2F2
LI2O(S)
LI2O(L)
LI2O
LI2O2
LI2O2H2
LI3CL3
LI3F3
MG(S)
MG(L)
MG
MG+
MGCL
MGCL+
MGCLF
MGCL2(S)
MGCL2(L)
MGCL2
MGF
MGF2(S)
MGF2(L)
MGF2

Table 6-4. (cont'd)

MGH	O	SIN
MGN	O+	SIO
MGO(S)	O-	SIO2(S)
MGO(L)	OH	SIO2(S)
MGO	OH+	SIO2(S)
MGOH	OH-	SIO2(L)
MGOH+	O2	SIO2
MGO2H2	O2-	SIS
N	P	SI2
NF	P(S)	SI2C
NF2	P+	SI2N
NF3	PCL3	SI3
NH	PF3	XE
NH2	PF5	
NH3	PH	
NO	PH3	
NO+	PN	
NOCL	PO	
NOF	PS	
NOF3	P2	
NO2	P4	
NO2-	S(S)	
NO2CL	S(L)	
NO2F	S	
N2	S+	
N2C	SF4	
N2H4	SF6	
N2O	SH	
N2O4	SN	
NA(S)	SO	
NA(L)	SOF2	
NA	SO2	
NA+	SO2F2	
NACL(S)	SO3	
NACL(L)	S2	
NACL	SI(S)	
NAF(S)	SI(L)	
NAF(L)	SI	
NAF	SI+	
NAF2-	SIC	
NAH	SIC2	
NAO	SICL	
NAO-	SICL2	
NAOH(S)	SICL3	
NAOH(L)	SICL4	
NAOH	SIF	
NA2	SIF2	
NA2CL2	SIF3	
NA2F2	SIF4	
NE	SIH	
NE+	SIH4	

6.1.1 THERMODYNAMIC DATA BELOW 300°K

For low temperature calculations it may be necessary to extend the curve fit data in the Thermodynamic Data file (see Section 6.1). The lower temperature limit, T_ℓ, in the Thermodynamic Data supplied with the program is

$$T_\ell = 300^\circ \text{ K}$$

Thermodynamic Data below the temperature, T_ℓ, may be input by data cards as described below.

	col 1↓	
card 1	LØW T CPHS	Directive for start of low temperature CPHS tables (col 1 through 10).
card 2	. . . . . n	12 character species name, left justified followed by the integer, n, punched in column 21. The integer n must be such that $1 \leq n \leq 3$ and represent the number of Thermodynamic Data points to be input for this species.
card 3	T°_1K $C^\circ_{P_T}$ H°_T S°_T 1	First Thermodynamic Data point for the above species, input 4F 10.0, I5.
	⋮	
card n+2	T°_nK $C^\circ_{P_T}$ H°_T S°_T 2 nth ($1 \leq n \leq 3$)	nth Thermodynamic Data point for the above species, input 4F 10.0, I5.
. . .	Repeat cards 2 through n + 2 above for each species to be input. Temperature must be $T_1 < T_2 < T_3 < T_\ell$.	
(final card)	END LØW T CPHS	end directive (col 1 through 14)

An example of this input is given in Table 6-5 which shows a card listing extending the Thermodynamic Data for an O_2/H_2 propellant to 100°K. Data in Table 6-5 is taken directly from the JANAF tables (Reference 9), except for Argon which is taken from NASA SP-3001.

The quantity H°_T is defined as

$$H^\circ_T = (H^\circ - H^\circ_{298}) - \Delta H^\circ_{f_{298}} \quad , \text{ cal/mole}$$

$C^\circ_{P_T}$, cal/mole - deg K

S°_T , cal/mole - deg K

TABLE 6-5. LOW TEMPERATURE $C^{\circ}_{P_T}$, H°_T, S°_T DATA FOR AN O_2/H_2 PROPELLANT

```
LOW T CPHS
AR                                  2
100.0          4.9681     -984.5          31.556          1
200.0          4.9681     -487.7          34.999          2
H                                   2
100.0          4.968        51118.        21.965          1
200.0          4.968        51614.        25.408          2
H2                                  2
100.0          5.393       -1265.         24.387          1
200.0          6.518       -662.0         28.520          2
H2O                                 2
100.0          7.961     -59378.9         36.396          1
200.0          7.969     -58581.9         41.916          2
N2                                  2
100.0          7.074      -1387.0         38.113          1
200.0          6.989       -684.          42.986          2
O                                   2
100.0          5.666        58479.        32.466          1
200.0          5.434        59036.        36.340          2
OH                                  2
100.0          7.567         7879.        35.852          1
200.0          7.309         8623.        41.021          2
O2                                  2
100.0          6.958       -1381.         41.395          1
200.0          6.961        -685.         46.218          2
END LOW T CPHS
```

6.2 TITLE CARDS

This input permits labeling of runs with alphanumeric information. As many title cards as desired may be input in sequence. Card format is as follows:

col 1-5	col 6-77
TITLE	any alphanumeric information

6.3 PROBLEM CARD

This card must always be input. It defines the type of problem to be solved and the number of O/F ratios (zones) to be used. The problem card format is as follows:

col 1 ↓

PROBLEM problem type, output units, number of zones, comment

The problem types are:

Problem Type	Description of Problem Type
ØDE	Equilibrium type calculations as described in NASA-SP273.
ØDK	Kinetic one dimensional nozzle expansion from input initial composition.
ØDE-ØDK	Equilibrium, Frozen, and Kinetic one dimensional nozzle expansion from computed initial composition.
ØDE-ØDK-TDK	Two Dimensional Kinetic nozzle expansion from computed initial composition.
TDE	Two Dimensional Equilibrium nozzle expansion using tables generated by ØDE. For this option the logical unit JANAF is used for temporary storage. Therefore, Thermodynamic Data must be generated for each case and JANAF should not be permanent thermodynamic data file.
IDEAL GAS	An ideal gas two dimensional calculation, (see special options section 6.8.1).
TDK(LFINL)	A TDK calculation from an input initial line, (see special options section 6.8.2).

The unit system used for the computer print out is specified as follows:

SI = 0, gives English units

and

SI = 1, gives Standard International (SI) units.

If this field is not input, English units are assumed.

The number of zones must be input as follows:

NZØNES = n,

where

$1 \leq n \leq 50$

This field must end with a comma.

If NZØNES is not input then n = 1 is assumed.

The last field on the problem card can be used for comment.

Example Problem Cards:

```
PRØBLEM ØDE-ØDK-TDK, NZØNES = 5, TEST CASE DEMØ
PRØBLEM ØDE, NZØNES = 10, TEN EQ/FR CALCS
PRØBLEM ØDK, KIN EXPN FRØM INPUT START CØND
PRØBLEM TDE, SI = 1, NZØNES = 3, TEST CASE
```

6.4 ØDE INPUT DATA (ALL PROBLEMS SPECIFYING ØDE)

The ØDE Input data described here is exactly as defined in NASA SP-273, Reference 9, except namelists input $INPT2 and $RKINP have been combined into a single list named $ØDE. Any type of equilibrium calculation available with the computer program described in Reference 9 can thus be computed using the $ØDE input data*. In this document, however, only the RKT option of namelist is described. The RKT option differs from that of Reference 9 for problem types other then single zone ØDE.

The ØDE input data consists of the following input groups:

1.	REACTANTS	directive card, followed by up to 15 data cards, followed by a blank card, specifying reactants.
2.	ØMIT and INSERT	directives to omit or insert species for equilibrium/frozen calculations.
3.	NAMELISTS	directive card followed by input namelist $ØDE specifying input case data.

6.4.1 REACTANTS CARDS

This set of cards is required for all ØDE problems. The first card in the set contains the word REACTANTS punched in card columns 1 to 9. The last card in the set is blank. In between the first and last cards may be any number of cards up to a maximum of 15, one for each reactant species being considered. The cards for each reactant must give the chemical formula and the relative amount of the reactant. For some problems, enthalpy values are required. The format and contents of the cards are summarized in Table 6-6. A list of some REACTANTS cards is given in Table 6-7.

Relative amounts of reactants. - The relative amounts of reactants may be specified in several ways. They may be specified in terms of moles, mole fraction, or mole percent (by keypunching M in card column 53) or in terms of weight, weight fraction, or weight percent (blank in column 53).

Relative amounts of total fuel to total oxidants can also be input. For this situation, each reactant must be specified as a fuel or an oxidizer by keypunching an F or O, respectively, in column 72 of the REACTANTS card. The amounts

*These options include TP, HP, SP, TV, UV, or SV problems, Chapman-Jouguet detonation problems, and incident or reflected shock problems.

TABLE 6-6. REACTANTS CARDS

Order	Contents	Format	Card columns
First	REACTANTS	3A4	1 to 9
Any	One card for each reactant species (maximum 15). Each card contains:		
	(1) Atomic symbols and formula numbers (maximum 5 sets)[a]	5(A2, F7.5)	1 to 45
	(2) Relative weight[b] or number of moles	F7.5	46 to 52
	(3) Blank if (2) is relative weight or M if (2) is number of moles	A1	53
	(4) Enthalpy or internal energy[a], cal mole	F9.5	54 to 62
	(5) State: S, L, or G for solid, liquid or gas, respectively	A1	63
	(6) Temperature associated with enthalpy in (4)	F8.5	64 to 71
	(7) F if fuel or O if oxidant	A1	72
	(8) Density in g cm^3 (optional)	F8.5	73 to 80
Last	Blank		

[a]Program will calculate the enthalpy or internal energy (4) for species in the THERMO data at the temperature (6) if zeros are punched in card columns 37 and 38. (See section Reactant enthalpy for additional information.)

[b]Relative weight of fuel in total fuels or oxidant in total oxidants. All reactants must be given either all in relative weights or all in number of moles.

TABLE 6-7 LISTING OF SAMPLE REACTANTS CARDS

```
REACTANTS
H 2.                                                    100.     0.          G298.15  F
N .7808810 .209795AR.004662                             100.     -7.202164G298.15  0


REACTANTS
N 1.      H 4.      CL1.      O 4.                      72.06    -70730.     S298.15  F
C 1.      H 1.869550 .031256S .008415                   18.58    -2999.082L298.15  F
AL1.                                                     9.00     +0.0        S298.15  F
MG1.      O 1.                                            .20     -143700.    S298.15  F
H 2.      O 1.                                            .16     -68317.4    L298.15  F


REACTANTS
H 2.                                        00          100.     0.          G298.15  F
O 2.                                        00          100.0    0.0         G298.15  O


REACTANTS
N 2.      H 8.      C 2.                                50.0     12734.8     L298.15  F  .78
N 2.      H 4.                                          50.0     12050.      L298.15  F 1.00
F 2.                                                    100.     -3030.892L  85.24    O 1.54


REACTANTS
LI1.                                                    100.     0.          S298.15  F
F 2.                                                    100.     -3030.892L  85.24    O 1.54


REACTANTS
N 2.      H 4.                                           80.     12100.      L298.15  F 1.00
BE1.                                                     20.     0.0         S298.15  F 1.85
H 2.      O 2.                                          100.     -44880.     L298.15  O 1.40
```

*Listed above are six examples. Each example must end with a blank card.

given on the REACTANTS cards are relative to total fuel or total oxidant rather than total reactant.

There are four options in the $ØDE namelist for indicating relative amounts of total fuel to total oxidant as follows:

1. Oxidant to fuel weight ratio (ØF is true)
2. Equivalence ratio (ERATIØ is true)
3. Fuel percent by weight (FPCT is true)
4. Fuel to air or fuel to oxidant weight ratio (FA is true)

For each option, except ØDE with NZØNES=1, the values are given in the ØFSKED array of $ØDE (described in Section 6.4.3). For ØDE with NZØNES=1, the MIX array is used as described in Reference 9.

Reactant enthalpy. Assigned values for the total reactant are calculated automatically by the program from the enthalpies of the individual reactants. Values for the individual reactants are either keypunched on the REACTANTS cards or calculated from the THERMØ data as follows:

Enthalpies are taken from the REACTANTS cards unless zeros are punched in card columns 37 and 38. For each REACTANTS card with the "00" code, an enthalpy will be calculated for the species from the THERMØ data for the temperature given in card columns 64 to 71.

When the program is calculating the individual reactant enthalpy for values from the THERMØ data, the following two conditions are required:

1. The reactant must also be one of the species in the set of THERMØ data. For example, $NH_3(g)$ is in the set of THERMØ data but $NH_3(\ell)$ is not. Therefore, if $NH_3(g)$ is used as a reactant its enthalpy could be calculated automatically, but that of $NH_3(\ell)$ could not be.
2. The temperature T must be in the range $T_{low}/1.2 \leq T \leq T_{high} \times 1.2$ where T_{low} to T_{high} is the temperature range of the THERMØ data.

For cases with NZØNES > 1 (see Problem card, Section 6.3) it may be desirable to modify the enthalpy of each zone. This can be done by using the DELH input array. For the i^{th} zone the i^{th} DELH entry will be added to the system

enthalpy as computed by ØDE from the reactants cards (see above). For example, overall system enthalpy of the propellants in the tank can be input through the reactants cards and the work added or extracted per zone can be input by the DELH entries. An alternate method would be to input zero enthalpy on the Reactants cards and input enthalpy per zone by the DELH entries.

6.4.2 ØMIT and INSERT Cards

ØMIT and INSERT cards are optional. They contain the names of particular species in the library of Thermodynamic Data for the specific purposes discussed below. Each card contains the word ØMIT (in card columns 1-4) or INSERT (in card columns 1-6) and the names of from 1 to 4 species starting in columns 16, 31, 46, and 61. The names must be exactly the same as they appear in the THERMØ data.

6.4.2.1 ØMIT Cards

These cards list species to be omitted from the THERMØ data. If ØMIT cards are not used, the program will consider as possible species all those species in the THERMØ data which are consistent with the chemical system being considered. Occasionally it may be desired to specifically omit one or more species from considerations as possible species. This may be accomplished by means of ØMIT cards.

6.4.2.2 INSERT Cards

These cards contain the names of condensed species only. They have been included as options for two reasons.

The first and more important reason for including the INSERT card option is that, in rare instances, it is impossible to obtain convergence for assigned enthalpy problems (HP or RKT) without the use of an INSERT card. This occurs when, by considering gases only, the temperature becomes extremely low. In these cases, the use of an INSERT card containing the name of the required condensed species can eliminate this kind of convergence difficulty. When this difficulty occurs, the following message is printed by the program: "LOW TEMPERATURE IMPLIES CONDENSED SPECIES SHOULD HAVE BEEN INCLUDED ON AN INSERT CARD".

The second and less important reason is that if one knows that one or several particular condensed species will be present among the final equilibrium compositions for the first assigned point, then a small amount of computer time can be saved by using an INSERT card. Those condensed species whose chemical formulas are included on an INSERT card will be considered by the program during the initial iterations for the first assigned point. If the INSERT card were not used, only gaseous species would be considered during the initial iterations. However, after convergence, the program would automatically insert the appropriate condensed species and reconverge. Therefore, it usually is immaterial whether or not INSERT cards are used. For all other assigned points the inclusion of condensed species is handled automatically by the program.

6.4.3 $ØDE NAMELIST INPUT

The ØDE subprogram contains namelist input sections $ØDE and $SHKINP. The Namelist $ØDE must be preceded by a card with NAMELISTS punched in card columns 1-9.

The $ØDE Namelist is required for the following problem types:

ØDE
ØDE-ØDK
ØDE-ØDK-TDK
TDE

For the ØDE problem type any of nine (9) different equilibrium problems can be solved. These are TP,HP,SP,TV,UV,SV,RKT,DETN, and SHØCK. For the ØDE-ØDK, ØDE-ØDK-TDK, or TDE problem type, only the RKT problem can be solved. In this section only the RKT input option is discussed. Reference 9 is to be used to prepare input for the other equilibrium problems.

The variables input by the $ØDE namelist are listed in Table 6-8. Additional information about some of these variables follows:

Pressure units. - The program assumes the pressure in the P schedule to be in units of atmospheres unless either PSIA = true, or SI = true.

Relative amounts of fuel(s) and oxidizer(s). - These quantities may be specified by assigning 1 to 15 values for either o/f, %F, f/a, or r. If no value is assigned for any of these, the program assumes the relative amounts of fuel(s) and oxidizer(s) to be those specified on the REACTANTS cards. (See discussion in REACTANTS Cards, Section 6.4.1)

RKT problem. - Only one value for chamber pressure, P, is to be input for cases with NZØNES > 1 (see problem card, Section 6.3). The stagnation pressure used for the i^{th} zone will be the value input for P multiplied by the i^{th} value input in the schedule XP. If not input, all XP entries are assumed equal to one. For TDK type

problems, zone one is taken about the nozzle axis of symmetry and the last zone is bounded by the nozzle wall. Similarly, the i^{th} zone will have a mixture ratio equal to the i^{th} entry in the ØFSKED schedule.

Print out will be given for the chamber pressure condition (i.e. stagnation) and the throat condition. Print out may be requested at other conditions by use of the PCP schedule and the SUBAR and SUPAR schedules.

The program will calculate both equilibrium and frozen performance unless FRØZ = F or EQL = F are input. If FRØZ = F, only equilibrium performance will be calculated. If EQL = F, only frozen performance will be calculated.

TABLE 6-8 VARIABLES IN $ØDE NAMELIST

Variable	No. of entries	Type	Value before read	Definition and comments
RKT	1	L	False	Rocket problem[a]
P	26	R	0	Assigned pressures: stagnation pressures for rocket problems: values in atm unless PSIA, or SI = .T., (see below)
SI	1	L	False	[a]Values in P array are in N/m^2
PSIA	1	L	False	[a]Values in P array are in psia units
XP	50	R	1.	Multipliers for the i^{th} zone stagnation pressure (zone 1 = inner zone)
ØF	1	L	False	Oxidant to fuel weight ratios are to be input[a]
ERATIØ	1	L	False	Equivalence ratios are to be input[a]
FPCT	1	L	False	Percent fuel by weight are to be input[a]
FA	1	L	False	Fuel to air weight ratios are to be input[a]
ØFSKED	50	R	0	For a Rocket problem, and NZØNES > 1, ØFSKED will be used rather than MIX (see Reference 9). Relative amounts of total oxidant to total fuel are input as defined by ØF, ERATIØ, FPCT, or FA. For ØDE-ØDK-TDK and TDE problem types these values define the oxidant to fuel ratios for each zone (zone 1 = inner zone)
DELH	50	R	0	Corresponding to each zone this value will be added to the system enthalpy input thru the reactants cards. Units are BTU/# if PSIA=.T., joule/kilogram if SI=.T., otherwise cal/gram.
IØNS	1	L	False	Consider ionic species[a]
WFLØW	1	R	0	Input nozzle mass flow option for ØDE-ØDK-TDK or TDE problems. If a value for WFLØW is input an expansion with this mass flow will be computed. The values input for P and XP are used as estimates for computing stagnation pressure for each zone. The program will adjust these stagnation pressures to obtain the desired nozzle mass flow within a tolerance of RELERR. Units are lbs/sec if PSI=.T. otherwise kilograms/sec.

[a]If variable is set to be true.

[b]Set variable false if these calculations are not desired.

Table 6-8 (cont'd)

Variable	No. of entries	Type	Value before read	Definition and comments
RELERR	1	R	.0005	Relative difference between requested and computed mass flow rate. The program stops if this error is exceeded.
PCP	50	R	0	Compute and print solutions at these values of chamber pressure to pressure ratio (entries must be < 1.)
SUBAR	50	R	0	Compute and print solutions at these values of subsonic area ratios (entries must $\neq$ 1.)
SUPAR	50	R	0	Compute and print solutions at these values of supersonic area ratio (entries must $\neq$ 1)
ECRAT	1	R	0	Subsonic area ratio to start ØDK calculations with computed equilibrium conditions. The SUBAR input table must include an entry equal to ECRAT.
EQTHST	1	T	False	To start ØDK calculations with computed equilibrium conditions at the nozzle throat.[a]
EQL	1	L	True	Calculate rocket performance assuming equilibrium composition during expansion[b].
FRØZ	1	L	True	Calculate rocket performance assuming frozen composition during expansion[b].
LISTSP	1	L	False	List names and dates of all species residing on thermodynamic data used[a].
KASE	1	I	0	Optional assigned number associated with case.

[a]If variable is set to be true.

[b]Set variable false if these calculations are not desired.

6.4.3.1 OPTION TO PUNCH TABLES FOR BOUNDARY LAYER PROGRAM INPUT

Conditions computed along the nozzle wall can be output as punched cards for input to the BLIMP, TBL, or MABL boundary layer analysis computer programs. These conditions are taken by the boundary layer computer program as being the inviscid flow condition at the edge of the boundary layer. Tables to be punched are: x, y, and P/P_c (i.e. the nozzle wall coordinates and the ratio of pressure to chamber pressure along the wall). The tables are punched in NAMELIST format readable by BLIMP (see the punched card listing given at the end of the sample output, Section 7).

A maximum of 50 entries upstream of the throat are saved and punched. The wall point at the end of every characteristic is punched up to a maximum of 500 total table entries. The user may specify a number by which the punched table will be offset. Thus, the first point may be output with identification 5 by input of IØFF=4. The use of IØFF enables the user to extend the table by adding points upstream.

If punched cards for input to a boundary layer program are required, the following items must be input as part of the $ØDE Namelist input:

Item Name		Description
IPTAB	=	If IPTAB=1, one title card will be punched (this will be the last title card input as described in 6.2) followed by tables of X, Y, and P/P_c along the nozzle wall. These cards are for input to the BLIMP or MABL computer programs. The first point punched will correspond to beginning of the converging section of the nozzle (i.e. at ECRAT; see Figure 6-1, also table 6-8).
IØFF	=	The first point to be punched will be numbered as IØFF+1.
IPTBL	=	If IPTBL and IPTAB=1, tables of M, T/T_c, C_p, V, and ρ, will also be punched. These additional cards are required for input to the TBL computer program (i.e. the December 21, 1973 version).

If a TDE problem is specified, the following items must also be input when IPTAB=1:

Item Name		Input Quantity	Units	SI Units
RSTAR	=	throat radius, r*	inches	meters
RWTU	=	upstream normalized wall throat radius of curvature, R_u	none	none
RWTD	=	downstream normalized wall throat radius of curvature, R_d	none	none
THETAI	=	inlet angle, θ_i	degrees	degrees
RI	=	normalized inlet wall radius of curvature, R_i	none	none

These items define the nozzle geometry from the combustion chamber through the throat as shown in Figure 6-1. For a TDE option it is necessary that IPTBL=0.

6.5 ØDK INPUT DATA

Certain ØDK input data is required for all of the problem types specified in Section 6.3 except ØDE and TDE. The ØDK input data consists of three data groups as follows:

TABLE 6-9. PROBLEMS REQUIRING ØDK DATA

Data group	Problem types requiring the data group	Section describing the data group
SPECIES	ØDK, TDK(LFINL)	6.5.1
REACTIØNS	ØDK ØDE-ØDK ØDE-ØDK-TDK TDK(LFINL)	6.5.2
$ØDK	ØDK ØDE-ØDK ØDE-ØDK-TDK IDEAL GAS TDK(LFINL)	6.5.3

6.5.1 SPECIES

Species used by the computer program are determined in several possible ways, depending upon the problem type. Methods used to determine chemical species for each probelm type are discussed below.

ØDK

For ØDK problems species names and concentrations must be input, see Section 6.5.1.1.

ØDE-ØDK

For ØDE-ØDK problems the initial start conditions for the kinetic expansion are obtained from an equilibrium calculation. The species list generated by

the equilibrium calculation generally contains many more species than the 40 species for which the ØDK subprogram is dimensioned. Therefore a selection processes is required to interface the ØDE calculated equilibrium start conditions with the ØDK kinetic expansion calculations. This selection is performed using the following rules:

Rule 1 If a species appears in a reaction, it is selected for the kinetic calculation.

Rule 2 If a species is specified using INERTS directive it is selected for the kinetic calculations.

Rule 3 If any species has a mole fraction greater than an input criterion, it is selected for the kinetic calculation.

Species which are selected but which do not appear in a reaction are treated as Inert and listed as such on the output list of selected species.

ØDE-ØDK-TDK

For ØDE-ØDK-TDK problems species are selected by the above rules for ØDE-ØDK problems. However, for multizone TDK cases it is necessary that each zone have the same species list. Thus the INERTS input (see Section 6.5.2.7) must be used to assure the same species are selected for each zone.

IDEAL GAS

No species required.

TDK(LFINL)

Species names and concentrations must be input as described in Section 6.8.2.

6.5.1.1 ØDK OPTION FOR INPUT OF INITIAL SPECIES CONCENTRATIONS (APPLIES ONLY TO THE ØDK PROBLEM TYPE)

This input begins with a single card with SPECIES in columns 1 through 7 and with either MASS FRACTIØNS or MØLE FRACTIØNS in columns 9 through 22. If the identifier for mass or mole fractions is omitted, mass fractions are assumed. Up to 40 species cards may be input. Only those species specified by input species cards will be considered for an ØDK problem. The order of the input

species cards is independent of the order in which the species appear on the master Thermodynamic Data file.

A chemical species is identified symbolically by 12 alphanumeric characters and must correspond identically with the species name as it appears on the Thermodynamic Data file. A complete list of the current species names are listed in Table 6-4 (condensed species, however, may not be specified in the species list.) The species symbol may not contain the characters * or =.

Col	Function
1-10	Not used
11-22	Species symbol (left justified)
23-30	Not used
31-60	Value of initial species concentration (if zero must be input as 0.0) free field F or E format
61-80	User Identification if desired

6.5.2 REACTIØNS

Chemical reactions must be input for problem types ØDK, ØDE-ØDK, ØDE-ØDK-TDK, and TDK(LFINL).

Up to 50 reactions with an implied third body and a total 150 reactions may by input to the program. Only one card per reaction, and only one reaction per card is permitted. Cards specifying third body reactions must precede cards specifying all other reactions. Species names appearing in the symbolic reaction set must correspond identically with the species names as they appear in the master Thermodynamic Data (see Table 6-4). A card listing for a sample reaction set is presented in Table 6-10.

The symbolic reaction set contains directive cards and reaction/data cards in groups as outlined below:

REACTIØNS	Directive for start of symbolic reaction input
.	
.	Reactions with implied third body speices
END TBR REAX	Directive for end of third body reactions
.	
.	All other reactions
.	

LAST REAX	Directive for end of reactions
INERTS	Specified Inert Species
THIRD BØDY REAX RATE RATIØS	Directive for start of third body reaction rate ratios
.	Third body reaction rate ratios
.	
.	
LAST CARD	Directive for end of REACTIØNS input

The content and format of each type of card is defined as follows:

6.5.2.1 The symbolic reaction set begins with a card containing the word REACTIØNS in columns 1 through 9. Other columns on this card can be used for comments.

6.5.2.2 Each card defining a reaction is divided into five fields, separated by commas. Each field contains:

field 1	a reaction	
field 2	A = followed by a value of A	rate parameters for the reactions
field 3	N = followed by the value of N	
field 4	B = followed by the baluc of B, the activation energy (Kcal/mole)	
field 5	available for comments	

The general form of a reaction is:

$$N_1 \text{*Symbol}_1 + N_2 \text{*Symbol}_2 + \ldots = N_a \text{*Symbol}_a + N_b \text{*Symbol}_b + \ldots$$

where the left hand side represents reactants and the right hand side represents products. The reaction can be either endothermic or exothermic.

The multipliers, N, must be integers and represent stoichiometric coefficients. If no stoichiometric coefficient is given, the value 1 is assumed. The dimensioning currently in the program requires that:

$$N_1 + N_2 + \ldots . \leq 10$$

and

$$N_a + N_b + \ldots . \leq 10$$

The chemical species (denoted by the word "symbol" in the above general form) can contain up to 12 characters each of which must match a species name contained in the thermodynamic data (see Table 6-2, card 3).

examples:

Reaction	Interpretation
NA++CL-=NACL	$Na^{+} + Cl^{-} = NaCl$
B+2+Ø-2=BØ	$B^{++} + Ø^{--} = BØ$
BE+2+2*ØH-=BEØHØH	$Be^{++} + 2ØH^{-} = Be(ØH)_2$

The value assigned to A, N, B define the forward (i.e. left to right) reaction rate, k, as

$$k = A \cdot T^{-N} \cdot e^{-(1000B/\Re T)}$$

in units of cc, °K, mole, sec.

All three reaction rate parameters must be input. The numeric value of each parameter may be specified in either I, F, or E format. If E format is used the E must appear before the exponent.

6.5.2.3 The reactions with an implied third body must precede other types of reactions, and must be followed by the directive (columns 1 through 12):

Col 1 ↓

END TBR REAX

all reactions prior to the above directive will have a third body term added to each side of the reaction. E.g.

H2 = H + H, . . .

END TBR REAX

defines the chemical reaction

$$H_2 + M = H + H + M$$

where M is a generalized third body. Specific third body effects may be included by inputing specific third body reaction rate ratios as outlined in 6.5.2.8. Cards encountered after the END TBR REAX directive card do not have a third body term added.

6.5.2.4 All other reactions are input next, exactly as described under 6.5.2.2.

6.5.2.5 After the last reaction has been defined, a card with LAST REAX in columns 1 through 9 is input.

TABLE 6-10 REACTIONS AND RATE DATA FOR C,CL,F,H,N, AND O SYSTEMS (FROM REFERENCE 16)

```
FACTIONS CCLFHNO    MAY 3-4 1972  JANNAF PSWG     K=AT**-N EXP(-1000B/RT)
  H + OH   = H2O      , A=7.5E23 , N=2.6 , B=0.,                    (AR) NO.  1
  O + H    = OH       , A=4.0E18 , N=1.  , B=0.,                    (AR) NO.  2
  O + O    = O2       , A=1.2E17 , N=1.  , B=0.,                    (AR) NO.  3
  F + F    = F2       , A=5.7E15 , N=1.  , B=0.,                    (AR) NO.  4
  H + F    = HF       , A=2.5E18 , N=1.  , B=0.,                    (AR) NO.  5
  H + H    = H2       , A=6.4E17 , N=1.  , B=0.,                    (AR) NO.  6
     CO2   = O + CO    , A=2.7E32 , N=4.5 , B=127.555,               (N2) NO.  7
  C + O    = CO       , A=3.0E16 , N=.5  , B=0.,                    (M)  NO.  8
  N + N    = N2       , A=1.0E18 , N=1.  , B=0.,                    (M)  NO.  9
  N + O    = NO       , A=6.4E16 , N=.5  , B=0.,          BAULCH    (N2) NO. 10
 CL + F    = CLF      , A=3.0E16 , N=.5  , B=0.,                    (M)  NO. 11
  H + CL   = HCL      , A=3.0E16 , N=.5  , B=0.,                    (M)  NO. 12
 CL + CL   = CL2      , A=1.1E19 , N=1.  , B=0.,                    (M)  NO. 13
NO TBR REAX
 H2 + OH   = H + H2O  , A=2.19E13, N=0.  , B=5.15,        BAULCH    NO. 21
 OH + OH   = O + H2O  , A=5.75E12, N=0.  , B=.780,        BAULCH    NO. 22
  H + OH   = O + H2   , A=7.33E12, N=0.  , B=7.300,       BAULCH    NO. 23
  O + OH   = H + O2   , A=1.3E13 , N=0.  , B=0.,          BAULCH    NO. 25
 OH + CO   = H + CO2  , A=5.6E11 , N=0.  , B=1.080,       BAULCH    NO. 41
 O2 + CO   = O + CO2  , A=8.85E9 , N=-.656,B=45.920,      BAULCH    NO. 42
  N + NO   = O + N2   , A=3.1E13 , N=0.  , B=.334,        BAULCH    NO. 48
  N + O2   = O + NO   , A=6.43E9 , N=-1. , B=6.250,       BAULCH    NO. 51
  H + OH   = H2+ O2   , A=1.41E13, N=.015, B=49.264,                NO. 24
  H + F2   = HF+ F    , A=5.3E12 , N=-.5 , B=4.000,                 NO. 26
 H2 + F    = HF+ H    , A=5.0E12 , N=0.  , B=5.700,                 NO. 27
 H2 + F2   = HF+ HF   , A=1.75E10, N=-.5 , B=39.739,                NO. 28
  H + CL2  = HCL+CL   , A=3.0E14 , N=0.  , B=3.000,                 NO. 29
 H2 + CL2  = HCL+HCL  , A=1.75E10, N=-.5 , B=45.375                 NO. 30
 HCL+ H    = H2+CL    , A=6.2E11 , N=-.5 , B=3.100,                 NO. 31
 HCL+ F    = HF+CL    , A=1.9E12 , N=-.68, B=.600,                  NO. 32
 CL2+ F    = CL+CLF   , A=6.2E12 , N=-.68, B=.500,                  NO. 33
 CL + F2   = F +CLF   , A=7.6E12 , N=-.68, B=.300,                  NO. 34
 CLF+ H    = HF+CL    , A=1.8E12 , N=-.68, B=3.200,                 NO. 35
 CLF+ H    = HCL+F    , A=5.6E12 , N=-.68, B=1.900,                 NO. 36
 CLF+ H2   = HCL+HF   , A=1.8E10 , N=-.5 , B=46.337,                NO. 37
 F2 + HCL  = HF+CLF   , A=1.8E10 , N=-.5 , B=39.427,                NO. 38
 CLF+ HCL  = HF+CL2   , A=1.8E10 , N=-.5 , B=46.025,                NO. 39
 F2 + CL2  = CLF+CLF  , A=1.8E10 , N=-.5 , B=26.758,                NO. 40
 CO2+ C    = CO+CO    , A=1.1E11 , N=-.5 , B=6.995,                 NO. 43
  C + OH   = CO+ H    , A=5.3E11 , N=-.5 , B=5.628,                 NO. 44
  C + NO   = CO+ N    , A=5.3E11 , N=-.5 , B=8.303,                 NO. 45
 CO2+ N    = CO+NO    , A=1.1E11 , N=-.5 , B=59.618,                NO. 46
  C + O2   = CO+ O    , A=5.3E11 , N=-.5 , B=6.552,                 NO. 47
 NO + NO   = N2+O2    , A=1.0E13 , N=0.  , B=79.490,                NO. 49
  N + OH   = NO+ H    , A=5.3E11 , N=-.5 , B=5.628,                 NO. 50
 OH + F    = HF+ O    , A=2.9E12 , N=-.68, B=.200,                  NO. 52
 H2O+ F    = HF+OH    , A=1.4E10 , N=-.68, B=.600,                  NO. 53
 CL + OH   = H2O+CL   , A=1.0E11 , N=-.5 , B=6.0,
 OH + CL   = HCL+O    , A=5.0E11 , N=-.5 , B=6.0,
LAST REAX
```

6.5.2.6 Reaction rate data for 13 dissociation-recombination (implied third body) reactions and 35 binary exchange reactions are listed in Table 6-10 for propulsion systems containing elements C, Cl, F, N and O. These rates are taken from Reference 16 (two additional reactions from Reference 15 are included). Cards can be abstracted from Table 6-10 for input to the computer program. For the implied third body reactions, the third body for which the rate applies is indicated in parenthesis in the comment field (M represents a "generalized" third body, see Section 2.2 for further details).

6.5.2.7 INERT SPECIES OPTION

Inert species (i.e. species not appearing in reactions) can be included in the input by input of a card with INERTS in columns 1 through 6 followed by a list of inert species names. The species names must each be followed by a comma and each name must written exactly as in the master Thermodynamic Data. The last comma must be followed by the word END. See Table 6-11 for an example. The species list can continue on to the next card, but a species name can not overlap onto the next card.

6.5.2.8 THIRD BODY REACTION RATE RATIOS

As described above in Section 6.5.2.2 for the j^{th} reaction only one reaction rate, k_j, where

$$k_j = AT^{-N_j} e^{-B_j/\Re T}$$

can be input. For three body recombination reactions such as

$$H + \emptyset H + M_i = H_2\emptyset + M_i$$

the rate of reaction is in general different for each species, M_i, depending upon the efficiency of the species, M_i, as a third body collision partner. As discussed in Section 2.2 the temperature dependance of a recombination rate is approximately independant of the third body, i.e. for the i^{th} third body and j^{th} reaction:

$$k_{ij} \doteq A_{ij} T^{-N_j} e^{-B_j/\Re T}$$

The third body efficiency of the i^{th} species for the j^{th} reaction is then defined as

$$m_{ij} \equiv A_{ij}/A_j$$

Thus m_{ij} is the ratio of the reaction rate with species M_i as the third body to the reaction rate input on the reaction card described in Section 6.5.2.2.

If reaction rate ratios, m_{ij}, are to be input for the dissociation-recombination reactions, a card with THIRD BØDY REAX RATE RATIØS in columns 1 through 27 must be input next. If this card is deleted from the input, the program assumes all $m_{ij} = 1$. If this card is included in the input, it must be followed either by a card with ALL EQUAL 1.0 in columns 1 through 13 (which sets all $m_{ij}=1$) or by SPECIES cards as described below:

The m_{ij}, can be input using a card with the word SPECIES in columns 1 through 7. This word is followed by the name of the i^{th} species followed by a comma, followed by the values m_{ij} in F format, each followed by a comma. These m_{ij} values can be continued onto succeeding cards. Note that the m_{ij} values depend on the order of input of the reaction cards, i.e. the j^{th} reaction is defined by the j^{th} card input after the REACTIØNS card.

Table 6-11 gives a sample input for a Hydrogen/Oxygen system using third body reaction rate ratios. In this example the three body recombination rates are input with Argon as the third body. The rate with H_2 as a third body is a factor of 5 larger then with Ar as a third body for the first three reactions and a factor of 4 larger for the fourth (Hydrogen recombination) reaction.

6.5.2.9 At this point in the data input deck a card with LAST CARD in columns 1 through 9 must be input.

TABLE 6-11 LISTING OF SAMPLE REACTIONS CARDS FOR AN O_2/H_2 PROPELLAN.

```
REACTIONS   O-H      MAY 3-4 1972  JANNAF PSWG
   H + OH  = H2O      , A=7.5E23 , N=2.6 , B=0.,        (AR) NO.
   O + H   = OH       , A=4.0E18 , N=1.  , B=0.,        (AR) NO.
   O + O   = O2       , A=1.2E17 , N=1.  , B=0.,        (AR) NO.
   H + H   = H2       , A=6.4E17 , N=1.  , B=0.,        (AR) NO.
END TBR REAX
  H2 + OH  = H + H2O  , A=2.19E13, N=0.  , B=5.15,      BAULCH NO.
  OH + OH  = O + H2O  , A=5.75E12, N=0.  , B=1.780,     BAULCH NO.
   H + OH  = O + H2   , A=7.33E12, N=0.  , B=7.300,     BAULCH NO.
   O + OH  = H + O2   , A=1.3E13 , N=0.  , B=0.,        BAULCH NO.
LAST REAX
INERTS N2,AR,END
THIRD BODY REAX RATE RATIOS
SPECIES AR,1.,1.,1.,1.,
SPECIES H2,5.,5.,5.,4.,
SPECIES H2O,20.,5.,5.,20.,
SPECIES O2,5.,5.,4.5,1.5,
SPECIES N2,4.,4.,4.,1.5,
SPECIES H,12.5,12.5,12.5,25.,
SPECIES O,12.5,12.5,12.5,25.,
SPECIES OH,12.5,12.5,12.5,25.,
LAST CARD
```

6.5.3 $ØDK NAMELIST INPUT

$ØDK Namelist input specifies the conditions for the kinetic expansion calculation. The input is read in subroutine ØDKINP and consists of the following groups of data as outlined below:

- 6.5.3.1 Inlet, Throat and Expansion Nozzle Geometry
- 6.5.3.2 Integration Control
- 6.5.3.3 Print Control
- 6.5.3.4 Species Selection and Mass/Mole Fraction Check
- 6.5.3.5 ODK Problem Input

6.5.3.1 INLET, THROAT, AND EXPANSION NOZZLE GEOMETRY

The nozzle geometry is defined in Figure 6-1. At the tangent point where the nozzle is attached to the throat section either a cone or a contoured nozzle defined by a wall table may be input. Two radii of curvature for the throat wall (upstream and downstream) must be specified.

Item Name		Input Quantity	Units	SI Units
RSTAR	=	throat radius	inches	meters
RWTU	=	upstream normalized wall throat radius of curvature*	none	none
RWTD	=	downstream normalized wall throat radius of curvature**	none	none
THETAI	=	inlet angle	degrees	degrees
RI	=	normalized inlet wall radius of curvature	none	none

*The transonic analysis requires that a value of RWTU ≥ .5 be input.

** If a corner expansion (i.e. Prandtl-Meyer fan) is desired, a value of RWTD = .05 is recommended. Experience has shown that values smaller than this give the same result but are computationally less efficient.

For a Conical Nozzle Option**

Item Name		Input Quantity	Units
IWALL	= 1	requests cone option	none
THETA	=	cone angle	degrees
EP	=	nozzle expansion ratio (≤ 400). If EP is input each ØDK expansion will be through EP. If EP is not input only the Throat and Transonic Table generation will be done.	none
EPS	=	nozzle expansion ratio for the TDK wall table. If EP is not input and EPS is input, the ØDK expansions will end after Transonic Table generation, and the TDK expansion will be through EPS.	none

For a Contoured Nozzle Option**

Item Name		Input Quantity	Units
IWALL	= 4	requests contour option	none
THETA	=	wall angle at tangent point	degrees
THE	=	wall angle at exit	degrees
NRZS	=	number of points in table, ≤ 20	none
PWRS(2)	=	normalized radial wall coordinate table*	none
PWZS(2)	=	normalized axial wall coordinate table *	none

*PWRS(1) and PWZS(1) are internally computed at the coordinates of the contour attachment point.

**The nozzle option selected in $ØDK input will be used for TDK unless overidden in $TDK input.

RZNØRM	=	optional normalization factor for input wall coordinate tables.	none
EP	=	for TDK option if ØDK print is desired (JPRINT= -1) set EP=1.	none

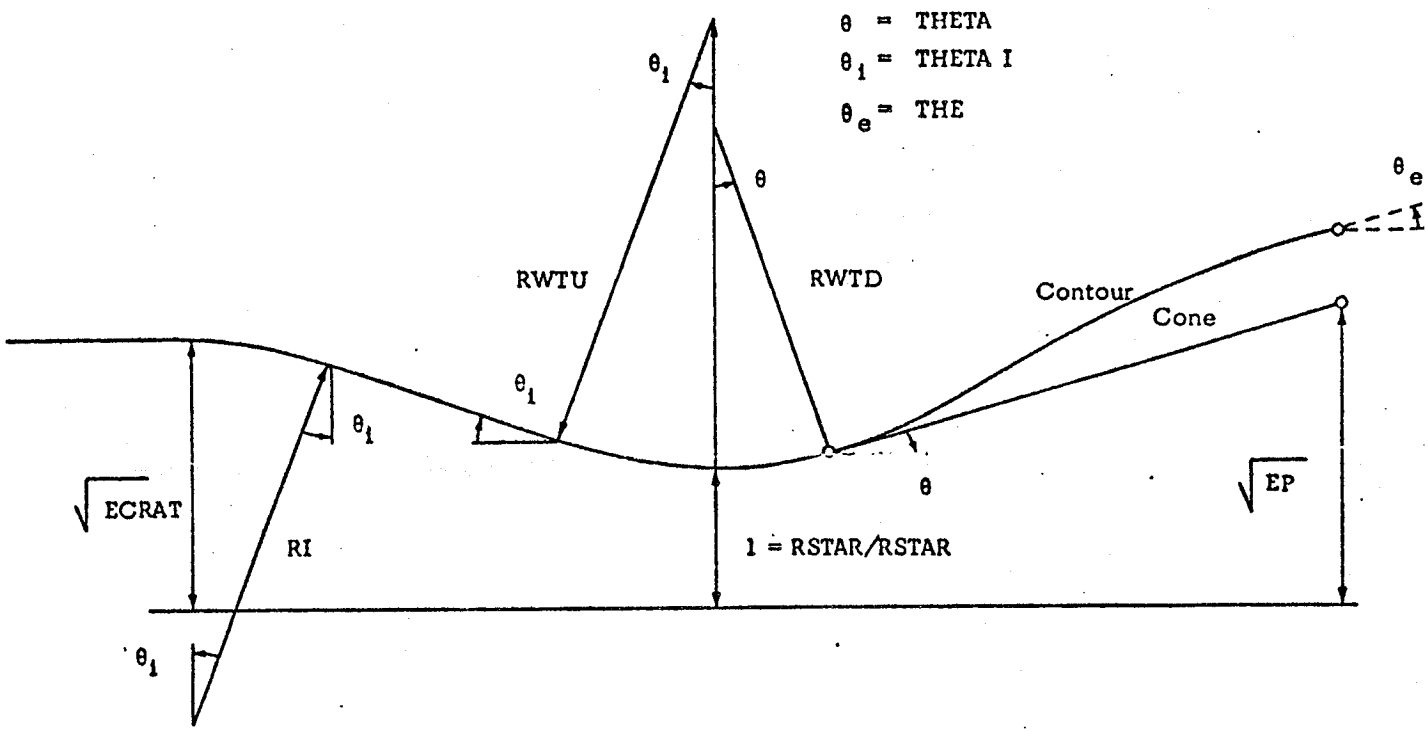


Figure 6-1. NOZZLE GEOMETRY

6.5.3.2 INTEGRATION CONTROL

The program begins its calculations using an implicit integration method to integrate the fluid dynamic and chemical relaxation equations. For near equilibrium flow an implicit method is used since it is inherently stable. However, once the flow has become sufficiently frozen, explicit methods become numerically stable and can be used more efficiently. The program uses temperature as a freeze criterion in order to switch from an implicit to an explicit method. This criterion is T < TEXPLI where TEXPLI is assumed 0°R but may be input. The program always prints the axial position at which the switch occurs. For high area ratio nozzles this procedure can be especially useful.

The integration routine controls the step size such that the relative error in the dependent variable increments be less than a prescribed fraction, DEL. Only doubling or halving of the step size is permitted, and on option, either all the variables may be considered (JF=0), or only the fluid dynamic variables (JF = 1) may be considered.

When the flow becomes supersonic and the area defined fluid dynamic equations are used, an additional check on continuity is applied in the form

$$\left| \frac{(\rho VA)_{N+1} - (\rho VA)_N}{(\rho VA)_{N+1}} \right| < \text{CØNDEL}$$

where CØNDEL is an input relative criterion.

The step size is held between the two input bounds HMIN and HMAX. Fixed step cases may be run by setting input values for HI, HMAX, HMIN, all equal.

Item Name		Input Quantity	Units
HI	=	initial step size	none
HMAX	=	upper bound on step size	none
HMIN	=	lower bound on step size	none
DEL	=	fractional incremental error	none
TEXPLI	=	temperature below which explicit integration will start	°R, °K if SI units
CØNDEL	=	relative error criterion for continuity check for supersonic flow	none
JF	= 0	all variables considered for step size control	none
	= 1	only fluid dynamic variables considered for step size control	none

6.5.3.3 PRINT CONTROL

Output from the Kinetic Expansion Calculation consists of complete output for each print station selected. The end point of the nozzle is always printed. Print stations are selected from one of the following options:

Item Name		Function
JPRNT	= -2	print throat and input area ratios (conical nozzle only)
	= -1	print at internally set area ratios for conical nozzle.* Print at input wall contour points for contoured nozzles
	= 0	print at every integration step
	= +1	print every ND3rd step up to the throat and then nominal area ratios
	= +2	print every ND3rd step over entire nozzle.

---

* For JPRNT = -1 and a conical nozzle (i.e. IWALL = 1), the internally set area ratios are:

ARPRNT(1) = 2,3,4,...,39,40,42,...,58,60,64,...,116,120,128,...,200,210,220,.

If JPRNT is +1 or +2 the following must be input:

Item Name		Function
ND1	=	first integration step to be selected for print
ND2	=	last integration step to be selected for print
ND3	=	print every ND3rd step between ND1 and ND2.

If JPRNT = -2 the following must be input:

Item Name		Function
ARPRNT (1)	=	requested area ratios for print, must be monotonic increasing and greater than 1.0 (usually entries are the same as those used in SUPAR of $ Ø DE)
NJPRNT	=	number of area ratios requested for print ≤ 100.

An extended print option may be selected as follows:

Item Name		Value	Function
IDYSCI	=	0	no extended print requested
	=	1	extended print option selected

6.5.3.4 SPECIES SELECTION AND MOLE/MASS FRACTION CHECK

In order to interface ØDE equilibrium calculated start conditions with the kinetic expansion calculations, special consideration must be made for inert species (those not appearing in the reaction set). Inerts may be selected explicitly by use of the INERTS directive or by use of a relative selection criterion.

If A MULTIZONE TDK PROBLEM IS SPECIFIED INERTS MUST BE SPECIFIED VIA THE INERTS DIRECTIVE. This is required so that the chemistry selected for multizone cases will be compatible.

The INERTS directive is described in Section (6.5.2.6).

The relative selection criterion (ØDK or 1 Zone TDK problems,) is described below:

Item Name	Function
EPSEL =	all species which do not appear explicitly in the reaction set but whose mole fractions are greater then the input value for EPSEL, will be retained for the kinetic expansion. Species selected under this criterion are treated as inert. The program assumes EPSEL = 1.0E-5, unless input.

In some instances it may be desirable to use input species concentrations which do not sum to unity. Species concentrations, either input or from equilibrium start conditions, are summed and the sum checked as described below.

Item Name		Function
XMFTST	=	Input species concentrations are summed and checke versus unity using this input criterion. If $\left\| 1 - \sum \text{species concentrations} \right\| < \text{XMFTST}$ then the test is passed. The species concentrations will then be normalized such that $\sum \text{species concentrations} = 1$.

The program assumes XMFTST = 1.0E-3, unless input.

If the test is not passed, an error message will be given and the run terminated.

6.5.3.5 ODK PROBLEM INPUT

This input is required when PROBLEM ØDK is specified on the problem card. A kinetic expansion from input arbitrary start conditions is to be computed. In addition to the input items described in section 6.5.3, an ØDK problem requires input of those items described in sections 6.5.1 and 2.

Item Name		Input Quantity	Units	SI Units
PC	=	chamber pressure	PSIA	N/M^2
T	=	initial temperature	°R	°K
V	=	initial gas velocity	ft/sec	m/sec
JPFLAG	= 0	pressure table calculated internally	none	none
	= 1	pressure table input		
ECRAT	=	initial contraction ratio	none	none

For JPFLAG = 0 option the following must be input:

Item Name		Input Quantity	Units	SI Units
PI	=	initial pressure	PSIA	N/M^2
PESTAR	=	throat pressure	PSIA	N/M^2

For JPFLAG = 1 option the following must be input:

Item Name		Input Quantity	Units
PTB(1)	=	normalized pressure table entries*	none
ZTB(1)	=	normalized pressure table coordinates**	none
NTB	=	number of pressure table entries, ≤ 127	none
Z	=	initial axial position	none

---

* normalized to input chamber pressure, PC
** normalized to input throat radius, RSTAR

6.5.3.6 MASS AVERAGED ØDK ISP

A mass averaged ØDK ISP summary page may be obtained at the end of the ØDK calculations as described below:

Item Name		Description
MAVISP	=1	Specifies mass averaged ISP option
XM(1)	=	Ratio of mass flow rate of each zone (zone 1 = inner zone) to the total mass flow rate.

6.6 $TRANS NAMELIST INPUT

6.6.1 When a TDK subproblem has been specified, the input data set $TRANS is required for the transonic calculation. The input variables are read in subroutine TRAN and are described below.

Item Name	Input Quantity
XM(1) =	Ratio of mass flow rate of each zone (zone 1 = inner zone) to the total mass flow rate. (need not be input if MAVISP=1 option specified and XM input in $ØDK).
ALI =	Number of degrees initial line will be displaced downstream. The program assumes ALI is zero. If ALI is not zero, a symmetric throat is required (RWTD = RWTU)
IBUG =	If input is nonzero, intermediate transonic output will be printed.

The following input may be used to control the construction of the initial line:

Item Name	Input Quantity
MP =	Number of points to be placed on the initial line. MP is nominally 50. For RWTD ≤ PMCRIT, the number of points placed on the initial line will be incremented by the largest integer of theta, the downstream tangent angle.
PMCRIT =	For RWTD > PMCRIT an equal area, by zone, distribution is requested. See Section 5.6.1. For RWTD ≤ PMCRIT an initial line distribution to assure the first left running characteristic will intersect the wall at a wall angle of PMDEG degrees. PMCRIT is nominally 1.0.
PMDEG =	Intersection angle, in degrees, for the first left running characteristic if RWTD < PMCRIT. PMDEG is nominally 1.0 degrees.
THJ =	For a TDE subproblem, THJ must be input in this namelist.

6.7 $TDK NAMELIST INPUT

This data set is read by subroutine CHAR and contains the input items for the Supersonic Method of Characteristics Subprogram. These items are divided into to three types:

1) Nozzle Geometry; 2) Print Control; 3) Characteristics Mesh Control.

6.7.1 Nozzle Geometry (see Figure 6-1, also Section 5.8.5)*

Item Name		Input Quantity	Units
IWALL	=	wall option flag. The value assigned this item determines the type of wall to be specified. 0 => arbitrary contour 1 => cone; θ, ϵ 2 => parabolic contour 3 => circular arc contour 4 => spline fit contour 5 => cone; r_n, x_n	none
If IWALL = 0		(arbitrary contour)	
PW(1)	=	The wall coordinate points r_1, x_1, are to be input sequentially: PW(1) = r_1, x_1, r_2, x_2, ... r_n, x_n, 0., 0., a pair of zero coordinates marks the end of the table. A value of $n \leq 300$ is required. This table is normalized to the throat radius and the origin is at the throat so that necessarily $r_1 = 1$, $x_1 = 0$.	none
If IWALL = 1		(cone; θ, ϵ)	
RWTD	=	radius of curvature of the throat, downstream.	none
THJ	=	exit cone half angle (will be THETA from $ØDK unless input)	degrees
EPS	=	expansion ratio	none

*For options 1 or 4, the input defined by Section 6.2.3.1 is not required since the input wall parameters from $ØDK will be used unless overridden by the above.

Item Name		Input Quantity	Units
If IWALL = 2 or 3		(parabolic contour or circular arc contour)	
RWTD	=	as above	none
THJ	=	wall inflection angle (will be THETA from $ØDK unless input)	degrees
RWMAX	=	nozzle end point radial coordinate, r_n	none
ZWMAX	=	nozzle end point axial coordinate, x_n	none
If IWALL = 4		(spline fit contour)	

As in IWALL options 1, 2, and 3 the program assumes the throat to begin with a circular arc downstream of the minimum point. The final point on this circular arc is located at an inclination of THJ degrees. The contour exit angle, THE degrees, must also be input. The contour to be spline fit between THJ and THE must be input in tabular form. The first point on the spline fit is automatically located by the program on the circular arc at the point of inclination THJ.

Item Name		Input Quantity	Units
RWTD	=	radius of curvature of the throat, downstream	none
THJ	=	RWTD and the angle THJ define the end point of the circular arc and the beginning of the spline fit (will be THETA from $ØDK unless input)	degrees
NRZS	=	n, the number of points to be spline fit. $n \leq 20$ is required.	none
PWRS(2)	=	radial wall coordinated to be spline fit. PWRS(2) = $r_2, r_3, \ldots, r_n$	none
PWZS(2)	=	axial wall coordinates to be spline fit. PWZS(2) = $x_2, x_3, \ldots, x_n$	none
THE	=	nozzle exit angle	degrees
If IWALL = 5		(cone; r_n, x_n)	
RWTD	=	As above	none
RWMAX	=	As above	none
ZWMAX	=	As above	none

6.7.2 Print Control

Item Name		Input Quantity	Units
N1	=	flow parameters will be printed for every N1th interior point along characteristics selected for print	none
N2	=	every N2th characteristic will be selected for print	none
NC	=	for NC $\neq$ 0 species concentrations (partial densities) will be printed with the flow parameters. If NC=1 the quantities A, B, γ, heat capacity (BTU/Lb-$^{\circ}$R), and enthalpy (ft^2/sec^2) will be appended to the species concentration print.	none
MASSFL	=	at the completion of each left running characteristic (LRC) the massflow is integrated. If MASSFL = 0 then no mass flow printed MASSFL = 1 then total mass flow and the number of points on the LRC are printed for each LRC MASSFL = 2 then mass flow for each point along LRC is printed MASSFL = 3 Same as MASSFL = 2 with the addition of execution time at the end of each LRC see Section 5.8.1, CHAR	none
NDS	=	for NDS = 1 Dividing Streamline Points will be printed. (Nominal) for NDS = 0 Dividing Streamline Points will be suppressed.	none

6.7.3 Characteristics Mesh Control

Item Name		Input Quantity	Units
DS	=	insertions will be made such that successive points along streamlines will not be separated by more than DS.	none
DWWI	=	insertion control parameter $\Delta\theta_\omega$ described in Section 5.9.2.	degrees
EPW	=	the program will insert such that the wall end point is located within a tolerance EPW.	none
IMAX	=	the maximum number of interations to be allowed while attempting to achieve a relative convergence for the flow variables of $5*10^{-5}$.	none
IMAXF = 1		the program will terminate the case if a printed point requires maximum iterations for convergence.	none
or			
IMAXF = 0		program will continue the case after IMAX iterations per point have occurred	none
TEXPLI	=	input temperature below which explicit integration for the species concentrations will be used.	°R, °K if SI Units
ETHI	=	ϵ_θ for point editing as described in Section 5.9.2, CNTRL.	degrees
ES	=	ϵ_s for point editing as described in Section 5.9.2, CNTRL.	none
DTWI	=	$\Delta\theta_{t\omega}$ criterion for insertion in subroutines INPT, DSPT as described in Section 5.9.2, CNTRL.	degrees

6.7.4 Inputs from DER, Reference 10.

Item Name		Input Quantity	Units
ØFBAR	=	Overall mixture ratio including condensed phases. For print out only.	none
ETABAR	=	Overall evaporation efficiency, i.e. the ratio of gas flow to total propellant flow at the throat. I_{sp}, total = $I_{sp,gas}$ *ETABAR	none
DRPISP	=	Ratio of total condensed phase momentum to the mass flow at the throat. Not used, reserved for future use.	lbf sec/lbm (if SI Units then N sec/kg)

6.7.5 Exit Plane Option

On option, the TDK method of characteristics calculation will continue the mesh construction through the exit plane of the nozzle and print a summary of the exit plane properties.

Item Name		Input Quantity	Function
EXITPL	=	.TRUE.	Exit plane calculation requested.

6.7.6 Punch Initial Line

During any calculation generating an initial line, the initial line may be punched in a form suitable for running an input initial line option. The following input is required.

Input Quantity	Function
ILPCH = .TRUE.	Requests Punching of Initial Line
IPUNIT =	The Fortran unit number assigned to the PUNCH. (e.g. on Univac 1108 IPUNIT = -3, on the other machines it may be 7, 8, etc.)

IMPORTANT NOTE

IF IPTAB = 1 option is selected, i. e. the boundary layer edge conditions punched for TBL input, the initial line punched cards will be interspersed with the TBL edge conditions punched cards.

6.8 SPECIAL OPTIONS

6.8.1 IDEAL GAS OPTION

The TDK program contains a useful option by which the real gas chemistry can be replaced by ideal gas chemistry. This option requires much less computing time for a given case and is useful for preliminary check-out of cases to be run later with real gas nonequilibrium chemistry. It also calculates the nozzle divergence efficiency, N_{DIV} (See Section 5, subroutine PRINT).

The ideal gas option is invoked using the PROBLEM card as outlined below

PROBLEM IDEAL GAS, NZONES = n, comment

where $1 \leq n \leq 50$

Only the $TRAN and $TDK data sets are to be input. These data sets are input as described in Sections 6.6 and 6.7, respectively, with the following required additions:

Additions to the $TRANS NAMELIST INPUT

Item Name		Input Quantity
G(1)	=	Value of specific heat ratio, γ, for each zone, inner to outer, the number of zones is specified on the PROBLEM card.
RWTU	=	Upstream normalized wall throat radius of curvature
RWTD	=	Downstream normalized wall throat radius of curvature
THJ	=	End point of circular arc RWTD (same as THETA, Section 6.5.3.1 see Figure 6-1).
PSA	=	Chamber pressure in lbs/in^2. (N/m^2 if SI units)
XP(1)	=	(From Table 6-8) All assumed = 1, if not input.
TC(1)	=	Chamber temperature, °R, for each zone, inner to outer. (°K if SI Units)
RGC(1)	=	Real gas constant, ft^2/sec^2 °R, (i.e. 49721/M_w=g*154 for each zone, inner to outer. (m^2/sec^2 °K if SI Units)
XMW(1)	=	Gas Molecular Weight, If input then RGC (I) need not be input.

Additions to the $TDK NAMELIST INPUT

Item Name		Input Quantity
RSTAR	=	Nozzle throat radius in inches. (meters if SI Units)

Table 6-12 lists a sample input data deck for an ideal gas problem.

6.8.2 INPUT INITIAL LINE OPTION

A T D K calculation starting from an input initial line may be specified via TDK(LFINL) on the PRØBLEM card (see Section 6.3). This option requires the input of the following:

a) PRØBLEM TDK(LFINL), NZONES = n, comment
where $1 \leq n \leq 50$.

b) SPECIES cards as defined in Section 6.5.1. The species concentrations field, col. 31-60, should be left blank.

c) REACTIØNS cards as described in Section 6.5.2.

d) $ØDK namelist input. All input is as previously described with the addition of the chamber pressure which must be input as:

Item Name		Input Quantity	Units	SI Units
PC	=	Chamber Pressure (used only for C*)	PSIA	N/m^2

e) $TDK namelist input. All input is as previously described, with the addition of the number of points to be input on the initial line which must be input as:

Item Name		Input Quantity
INLINE	=	Number of points to be input on the input initial line, ≤ 151.

f) $LINE namelist input. One $LINE namelist input must be specified for each input point (i.e. INLINE $LINE data sets). The input is as described below:

Input Item		Input Quantity	Units	SI Units
N	=	Optional sequence number	none	none
RC	=	Normalized Radial Coordinate	none	none
XC	=	Normalized Axial Coordinate	none	none
THETA	=	Flow Angle	degrees	degrees
PRES	=	Pressure	PSIA	N/m^2
DENS	=	Density	lbm/ft^3	Kg/m^3
VEL	=	Velocity	ft/sec	m/sec
TEMP	=	Temperature	^oR	^oK
ZONE	=	Zone number,(inner zone is zone 1)	none	none
SPMASS(1)	=	Species mass fractions in the order input in the SPECIES CARDS	none	none
DSFLAG	=	Dividing Streamline Flag. Of the two points of a dividing streamline, the point closest to the axis must have input DSFLAG = 1.0.	none	none

Due to the namelist type input, only those input parameters which change need be input. For example, RC, XC, THETA would normally change for each point, whereas PRES is constant on the initial line.

The dividing streamline points which form the boundaries between zones must conform to the following requirements:

1) RC, XC, PRES, and THETA must be the same for the two points comprising a dividing streamline.

2) Of the two points comprising a dividing streamline, the point closest to the axis must have its dividing streamline flag set to 1.0.

Table 6-13 lists a sample data deck for a problem with an input initial line.

TABLE 6-12. CARD LISTING FOR IDEAL GAS PROBLEM

```
TITLE SAMPLE CASE ONC
PROBLEM IDEAL GAS,NZONES=1,
 $TRANS
 G(1)=1.23,
 RWTU=2.,      RWTD=.5,
 THJ=35.6738,
 PSA=100.,
 TC(1)=5500.,
 XMW(1)=20.,
 XM(1)=1,
 ALI=0.,
 $END
 $TDK
 RSTAR=2.,
 IWALL=4,
 NRZS=11,
 PWRS(2)=1.16843,1.26475,1.47910,1.73375,
 2.04940,2.45930,3.68226,4.84772,5.79198,6.32481,
 PWZS(2)=.39575,.53008,.82905,1.19473,
 1.66923,2.32795,4.68717,7.68599,10.9601,13.3114,
 THE=11.5813,
 $END
```

TABLE 6-13. CARD LISTING FOR TDK INPUT INITIAL LINE PROBLEM

```
PRORLEM TDK(LFINL), NZONFS=2, TEST OF INPUT INITIAL LINE
SPECIES MASS FRACTIONS
          C
          CO
          CO2
          H
          HO2
          H2
          H2O
          H2O2
          N
          NO
          N2
          O
          OH
          O2
                                        TEST CASE IN ODK FORWARD RATES
REACTIONS
CO + O = CO2          ,A=0.1E17,B=0.35E01,N=0.0,                          FORWARD   1
OH + H = H2O          ,A=0.1F20,B=0.0,N=0.1E01,                           FORWARD   2
C + O = CO            ,A=0.3E17,B=0.0,N=0.5E00,                           FORWARD   3
 2*H = H2             ,A=0.75E19,B=0.0,N=0.1E01,                          FORWARD   4
 N + N = N2           ,A=0.1F19,B=0.0,N=0.1E01,                           FORWARD   5
N + O = NO            ,A=0.6E17,B=0.0,N=0.5E00,                           FORWARD   6
 O + H = OH           ,A=0.2E19,B=0.0,N=0.1E01,                           FORWARD   7
 O + O = O2           ,A=0.19E17,B=0.0,N=0.5E00,                          FORWARD   8
END TBR REAX
 OH + CO = CO2 + H    ,A=0.31E12,B=0.6E00,N=0.0,                          FORWARD   9
 O2 + CO = CO2 + O    ,A=0.35E13,B=0.51E02,N=0.0,                         FORWARD  10
 H2 + OH = H2O + H    ,A=0.6E12,B=0.5E01,N=-0.5E00,                       FORWARD  11
 2 * OH = H2O + O     ,A=0.106666E14,B=0.96671E00,N=0.134E-01,            FORWARD  12
CO2 + C = CO + CO     ,A=0.105E12,B=0.69949E01,N=-0.5E00,                 FORWARD  13
 OH + C = CO + H      ,A=0.53E12,B=0.5627RE01,N=-0.5E00,                  FORWARD  14
 NO + C = CO + N      ,A=0.53E12,B=0.83025E01,N=-0.5E00,                  FORWARD  15
 CO2 + N = NO + CO    ,A=0.105E14,B=0.59616E02,N=-0.5E00,                 FORWARD  16
 O2 + C = CO + O      ,A=0.53E12,B=0.6551RE01,N=-0.5E00,                  FORWARD  17
 OH + H = H2 + O      ,A=0.14E13,B=0.519E01,N=0.0,                        FORWARD  18
   2*OH = H2 + O2     ,A=0.14127E14,B=0.492644E02,N=0.15E-01,             FORWARD  19
 NO + N = N2 + O      ,A=0.15E14,B=0.0,N=0.0,                             FORWARD  20
   2 * NO = N2 + O2   ,A=0.1E14,B=0.79488E02,N=0.0,                       FORWARD  21
 OH + N = NO + H      ,A=0.53E12,B=0.5627RE01,N=-0.5E00,                  FORWARD  22
 O2 + N = NO + O      ,A=0.18E09,B=0.6001E01,N=-0.15E01,                  FORWARD  23
 OH + O = O2 + H      ,A=0.32E12,B=0.1E00,N=-0.47E00,                     FORWARD  24
LAST REAX
THIRD BODY REAX RATE RATIOS
ALL EQUAL 1.0
LAST CARD
 $ODK RSTAR=4.16, THETA=34.827, THETAI=30.0, RWTU=2.0, RWTD=2.0, RI=2.0,
 IWALL=4, THE=11.573, NRZS=10, PC=100.0,
 PWRS(2)=1.4002, 1.4533, 1.5670, 1.6934, 1.8302,
         1.9824, 2.6826, 3.2580, 3.8141,
 PWZS(2)=1.2029, 1.2803, 1.4475, 1.6343, 1.8433,                          $
         2.0800, 3.2604, 4.3617, 5.5599,                                  $
 $TDK INLINF=53, MASSFL=2, NC=1,
 $LINE  N=0 ,   RC= 1.00000,  XC= .00000,  THETA= 0.000,
 PRES= 47.835, DENS= 0.021216, VEL=4088.61, TEMP=3330.5, ZONE=2,
 SPMASS(1)=.1453928E-15, .2358961F-00, .2804647F-1, .4515528E-4, ZONE=2,
 SPMASS(5)=.5594654E-10, .5272499F-01, .1733660E-0, .3559407E-9, ZONE=2,
 SPMASS(9) = .1036159E-8, 0.4053095F-5, 0.5098968, 0.2459435E-7, ZONE=2,
 SPMASS(13)= .2060921E-4, .1081624F-7,                            ZONE=2$
 $LINE  N=1 ,   RC=  .99045,  XC= .00759,  THETA=  .094,                  $
 $LINE  N=2 ,   RC=  .98081,  XC= .01519,  THETA=  .187,                  $
 $LINE  N=3 ,   RC=  .97107,  XC= .02281,  THETA=  .279,                  $
 $LINE  N=4 ,   RC=  .96123,  XC= .03044,  THETA=  .371,                  $
 $LINE  N=5 ,   RC=  .95129,  XC= .03809,  THETA=  .463,                  $
```

TABLE 6-13. (Continued)

```
$LINE  N=6 ,   RC=  .94124,  XC= .04576,  THETA=  .553,                $
$LINE  N=7 ,   RC=  .93109,  XC= .05345,  THETA=  .644,                $
$LINE  N=8 ,   RC=  .92082,  XC= .06115,  THETA=  .733,                $
$LINE  N=9 ,   RC=  .91044,  XC= .06888,  THETA=  .822,                $
$LINE  N=10,   RC=  .89994,  XC= .07663,  THETA=  .911,                $
$LINE  N=11,   RC=  .89994,  XC= .07663,  THETA=  .911   , DSFLAG=1,0,
PRES= 47.835, DENS= 0.018990, VEL=4246.37, TEMP=5211.42, ZONE=1,
SPMASS(1) = .1414904E-11, .8868762E-01, .1059997    , .8602222E-03, ZONE=1,
SPMASS(5) = .1919915E-04, .6655514E-02, .3170608    , .3989318E-05, ZONE=1,
SPMASS(9) = .1935402E-05, .1222397E-01, .4251789    , .3626382E-02, ZONE=1,
SPMASS(13)= .2391190E-01, .1576951E-01,                          ZONE=1$
$LINE N=11, RC=  .88862,   XC =  .08356,  THETA =  0.954   $
$LINE  N=12,   RC=  .87716,  XC= .09103,  THETA= 1.010                 $
$LINE  N=13,   RC=  .86554,  XC= .09850,  THETA= 1.065                 $
$LINE  N=14,   RC=  .85376,  XC= .10597,  THETA= 1.118                 $
$LINE  N=15,   RC=  .84182,  XC= .11344,  THETA= 1.169                 $
$LINE  N=16,   RC=  .82971,  XC= .12091,  THETA= 1.218                 $
$LINE  N=17,   RC=  .81741,  XC= .12838,  THETA= 1.264                 $
$LINE  N=18,   RC=  .80493,  XC= .13585,  THETA= 1.308                 $
$LINE  N=19,   RC=  .79226,  XC= .14332,  THETA= 1.350                 $
$LINE  N=20,   RC=  .77937,  XC= .15080,  THETA= 1.390                 $
$LINE  N=21,   RC=  .76627,  XC= .15827,  THETA= 1.427                 $
$LINE  N=22,   RC=  .75295,  XC= .16547,  THETA= 1.461                 $
$LINE  N=23,   RC=  .73938,  XC= .17321,  THETA= 1.493                 $
$LINE  N=24,   RC=  .72556,  XC= .18068,  THETA= 1.523                 $
$LINE  N=25,   RC=  .71147,  XC= .18815,  THETA= 1.549                 $
$LINE  N=26,   RC=  .69709,  XC= .19562,  THETA= 1.573                 $
$LINE  N=27,   RC=  .68242,  XC= .20309,  THETA= 1.594                 $
$LINE  N=28,   RC=  .66742,  XC= .21056,  THETA= 1.611                 $
$LINE  N=29,   RC=  .65207,  XC= .21803,  THETA= 1.626                 $
$LINE  N=30,   RC=  .63636,  XC= .22550,  THETA= 1.637                 $
$LINE  N=31,   RC=  .62024,  XC= .23297,  THETA= 1.644                 $
$LINE  N=32,   RC=  .60370,  XC= .24044,  THETA= 1.648                 $
$LINE  N=33,   RC=  .58669,  XC= .24791,  THETA= 1.648                 $
$LINE  N=34,   RC=  .56917,  XC= .25538,  THETA= 1.643                 $
$LINE  N=35,   RC=  .55110,  XC= .26286,  THETA= 1.635                 $
$LINE  N=36,   RC=  .53241,  XC= .27033,  THETA= 1.621                 $
$LINE  N=37,   RC=  .51305,  XC= .27780,  THETA= 1.603                 $
$LINE  N=38,   RC=  .49292,  XC= .28527,  THETA= 1.579                 $
$LINE  N=39,   RC=  .47193,  XC= .29274,  THETA= 1.549                 $
$LINE  N=40,   RC=  .44997,  XC= .30021,  THETA= 1.512                 $
$LINE  N=41,   RC=  .42688,  XC= .30768,  THETA= 1.468                 $
$LINE  N=42,   RC=  .40247,  XC= .31515,  THETA= 1.416                 $
$LINE  N=43,   RC=  .37647,  XC= .32262,  THETA= 1.354                 $
$LINE  N=44,   RC=  .34855,  XC= .33009,  THETA= 1.282                 $
$LINE  N=45,   RC=  .31818,  XC= .33765,  THETA= 1.195                 $
$LINE  N=46,   RC=  .28459,  XC= .34503,  THETA= 1.091                 $
$LINE  N=47,   RC=  .24646,  XC= .35250,  THETA=  .965                 $
$LINE  N=48,   RC=  .20123,  XC= .35997,  THETA=  .803                 $
$LINE  N=49,   RC=  .14229,  XC= .36744,  THETA=  .579                 $
$LINE  N=50,   RC=  .07115,  XC= .37305,  THETA=  .294                 $
$LINE  N=51,   RC=  .00000,  XC= .37492,  THETA=  .000                 $
```

6.9 INITIAL VALUES FOR THE $ØDK, $TRANS, AND $TDK INPUTS

The following defines nominal values to which variables will be set if not input. If a variable is not listed, no nominal value is set. Variables are set in the subroutine containing the Namelist read..

$ØDE, set in subroutine ØDE

DELH(I)	=	0.
ECRAT	=	0.
EQL	=	.TRUE.
EQTHST	=	.FALSE.
ERATIØ	=	.FALSE.
FA	=	.FALSE.
FPCT	=	.FALSE.
FRØZ	=	.TRUE.
IØNS	=	.FALSE.
KASE	=	0
LISTSP	=	.FALSE.
ØF	=	.FALSE.
ØFSKED(I)	=	0.
P(I)	=	0.
PCP(I)	=	0.
PSIA	=	.FALSE.
RELERR	=	.0005
RKT	=	.FALSE.
SI	=	.FALSE.
SUBAR(I)	=	0.
SUPAR(I)	=	0.
WFLØW	=	0.
XP(I)	=	1.

$ØDK, set in subroutine ØDKINP

CØNDEL	=	1.0E-6
DEL	=	.001
EPS	=	0.
EPSEL	=	1.0E-5
HI	=	.01
HMAX	=	.10001
HMIN	=	.005
IDYSCI	=	0
IWALL	=	1
JF	=	0
JPFLAG	=	0
JPRNT	=	-1
RZNØRM	=	1.
TEXPLI	=	0.
XM(I)	=	0.
XMFTST	=	1.0E-3

$TRANS, set in subroutine TRAN

ALI	=	0.
IBUG	=	0
MP	=	50
PMCRIT	=	1.
PMDEG	=	1.
XM(I)	=	0.

$TDK, set in subroutine CHAR

DRPISP	=	0.
DS	=	.15
DTWI	=	2.
DWWI	=	3.
EPW	=	.01
ES	=	.005

$TDK (cont'd)

ETABAR	=	1.
ETHI	=	.25
IMAX	=	10
IMAXF	=	0
MASSFL	=	1
NC	=	0
NDS	=	1
N1	=	1000
N2	=	1000
ØFBAR	=	0.
TEXPLI	=	0.

7. INPUT AND OUTPUT FOR A SAMPLE CASE

On the following pages input and output for a sample ØDE-ØDK-TDK problem are presented. The calculation is performed for a liquid oxygen/gaseous hydrogen propellant systems. The injector is assumed to produce a stratified nozzle flow with a mixture ratio of 6.5 near the axis, 8.0 in the central zone, and 5.0 near the wall. Equal mass flow is assumed for each of these zones. Each zone is assumed to have a different stagnation pressure. The pressures are 300, 285, and 270 psia from axis to wall. The calculation was performed using an Univac 1108 computer. Execution time for the case was 4.772 minutes.

A brief description of the computer output is presented followed by a complete listing of the computer program print out. The last page of this section contains a listing of punched cards of boundary layer inviscid edge conditions (IPTAB=1) obtained from the sample case.

7.1 DESCRIPTION OF PROGRAM OUTPUT

Output for an N Zone ØDE-ØDK-TDK problem is outlined below:

1. All input data cards are listed
2. ØDE subprogram output
   a. Fuel/Oxidizer/Mixture description and list of species considered
   b. Equilibrium calculation output; Frozen calculation output
   c. Summary of Equilibrium Contraction Ratio conditions
3. ØDK subprogram output
   a. Listing of Reactions, etc. cards as they are read
   b. Species list from Reactions
   c. Reaction table
   d. Selected species list for kinetic expansion
   e. Dissociation/Recombination reaction rate ratios
   f. Initial and Throat conditions for one dimension ØDK expansion
4. 2 and 3 above are repeated for each zone with redundant print omitted.
5. Inputs to the transonic calculations and the calculated results are printed. These include γ, mass flow for each zone and, the slipline locations, Y_n.
6. Number of points on the initial line, characteristics mesh control parameters and table of x vs. r wall coordinates are printed. The wall table is used by TDK to define the nozzle wall downstream of the throat plane (see Subroutine WALL, Section 5.8.4).
7. A table of P, ρ, θ, V, r, x, and mass flow rate is printed corresponding to the initial data line for starting the method of characteristics calculations. The method used to calculate the mass flow rate, $\dot{m}$, and the characteristic velocity, C*, (also printed) is described in Section 5.8.2.
8. Results of the method of characteristics calculations are then printed. The calculations begin at the initial data line (until the axis is reached) and follow each left running characteristic to the wall.

```
THERMO
   300.000  1000.000  5000.000
AR                L 5/66AR  100  000  000  0G   300.000  5000.000             1
 0.25000000E 01 0.              0.              0.              0.             2
-0.74537502E 03 0.43660006E 01 0.25000000E 01 0.              0.             3
 0.             0.             -0.74537498E 03 0.43660006E 01                 4
H                 J 9/65H   100  000  000  0G   300.000  5000.000             1
 0.25000000E 01 0.              0.              0.              0.             2
 0.25471627E 05-0.46011763E 00 0.25000000E 01 0.              0.             3
 0.             0.              0.25471627E 05-0.46011762E 00                 4
H2                J 3/61H   20   00   00   0G   300.000  5000.000             1
 0.31001901E 01 0.51119464E-03 0.52644210E-07-0.34909973E-10 0.36945345E-14    2
-0.87738042E 03-0.19629421E 01 0.30574451E 01 0.26765200E-02-0.98099162E-05    3
 0.55210391E-08-0.18122739E-11-0.98890474E 03-0.22997056E 01                   4
H20               J 3/61H   20   100  000  0G   300.000  5000.000             1
 0.27167633E 01 0.29451374E-02-0.80224374E-06 0.10226682E-09-0.48472145E-14    2
-0.29905826E 05 0.66305671E 01 0.40701275E 01-0.11084499E-02 0.41521180E-05    3
-0.29637404E-08 0.80702103E-12-0.30279722E 05-0.32270046E 00                   4
N2                J 9/65N   20   00   00   0G   300.000  5000.000             1
 0.28963194E 01 0.15154866E-02-0.57235277E-06 0.99807393E-10-0.65223555E-14    2
-0.90586184E 03 0.61615148E 01 0.36748261E 01-0.12081500E-02 0.23240102E-05    3
-0.63217559E-09-0.22577253E-12-0.10611588E 04 0.23580424E 01                   4
O                 J 6/620   100  000  000  0G   300.000  5000.000             1
 0.25420596E 01-0.27550619E-04-0.31028033E-08 0.45510674E-11-0.43680515E-15    2
 0.29230803E 05 0.49203080E 01 0.29464287E 01-0.16381665E-02 0.24210316E-05    3
-0.16028432E-08 0.38906964E-12 0.29147644E 05 0.29639949E 01                   4
OH                J 3/660   1H   100  000  0G   300.000  5000.000             1
 0.29106427E 01 0.95931650E-03-0.19441702E-06 0.13756646E-10 0.14224542E-15    2
 0.39353815E 04 0.54423445E 01 0.38375943E 01-0.10778858E-02 0.96830378E-06    3
 0.18713972E-09-0.22571094E-12 0.36412823E 04 0.49370009E 00                   4
O2                J 9/650   20   00   00   0G   300.000  5000.000             1
 0.36219535E 01 0.73618264E-03-0.19652228E-06 0.36201558E-10-0.28945627E-14    2
-0.12019825E 04 0.36150960E 01 0.36255985E 01-0.18782184E-02 0.70554544E-05    3
-0.67635137E-08 0.21555993E-11-0.10475226E 04 0.43052778E 01                   4
END
TITLE  3 ZONE TDK TEST CASE,LOX/GH2
PROBLEM ODE-ODK-TDK, NZONES=3,          **** T E S T  C A S E ****
REACTANTS
H 2.                                          100.      -2154.L   20.27F .0709
O 2.                                        99.398      -3102.L   90.180 1.149
N 2.                                          .053      -2939.L   77.350 .808
AR1.                                          .549      -2607.L   90.  0

NAMELISTS
 $ODE
 IPTAB=1,
 RKT=.T.,
 P(1)=300.,PSIA$.T,,
 XP(1)=1.,.95,.9,
 OFSKED=6.5,8.,5.,
 ECRAT=3,,SUBAR(1)=3.,
 SUPAR(1)=2.,4.,10.,15.,20.,25.,
 $END
```

```
REACTIONS   O-H      MAY 3-4 1972  JANNAF PSWG
   H + OH  = H2O       , A=7.5E23 , N=2.6 , B=0.,        (AR) NO.  1
   O + H   = OH        , A=4.0E18 , N=1.  , B=0.,        (AR) NO.  2
   O + O   = O2        , A=1.2E17 , N=1.  , B=0.,        (AR) NO.  3
   H + H   = H2        , A=6.4E17 , N=1.  , B=0.,        (AR) NO.  6
END TBR REAX
  H2 + OH  = H + H2O   , A=2.19E13, N=0.  , B=5.15,      BAULCH  NO. 21
  OH + OH  = O + H2O   , A=5.75E12, N=0.  , B=.780,      BAULCH  NO. 22
   H + OH  = O + H2    , A=7.33E12, N=0.  , B=7.300,     BAULCH  NO. 23
   O + OH  = H + O2    , A=1.3E13 , N=0.  , B=0.,        BAULCH  NO. 25
LAST REAX
INERTS N2,AR,END
THIRD BODY REAX RATE RATIOS
SPECIES AR,1.,1.,1.,1.,
SPECIES H2,5.,5.,5.,4.,
SPECIES H2O,20.,5.,5.,20.,
SPECIES O2,5.,5.,4.5,1.5,
SPECIES N2,4.,4.,4.,1.5,
SPECIES H,12.5,12.5,12.5,25.,
SPECIES O,12.5,12.5,12.5,25.,
SPECIES OH,12.5,12.5,12.5,25.,
LAST CARD
 $ODK
 RSTAR=2.,RWTU=1.,RWTD=1.,THETAI=30.,RI=2.,
 IWALL=1, THETA=15.,
 EPS=2.,
 $END
 $TRANS
 MP=30,
 XM(1)=.33334,.33333,.33333,
 $END
 $TDK
 NC=1,
 $END

THERMO

TITLE  3 ZONE TDK TEST CASE,LOX/GH2

PROBLEM ODE-ODK-TDK, NZONES=3,          **** T E S T  C A S E ****
```

ZONE= 1

REACTANTS

H	2.0000	-.0000	-.0000	-.0000	-.0000	100.000000	-2154.00	L	20.270	F	.07090
O	2.0000	-.0000	-.0000	-.0000	-.0000	99.398000	-3102.00	L	90.180	O	1.14900
N	2.0000	-.0000	-.0000	-.0000	-.0000	.053000	-2939.00	L	77.350	O	.80800
AR	1.0000	-.0000	-.0000	-.0000	-.0000	.549000	-2607.00	L	90.000	O	-.00000

NAMELISTS

SPECIES BEING CONSIDERED IN THIS SYSTEM

L 5/66 AR	J 9/65 H	J 3/61 H2	J 3/61 H2O	J 9/65 N2
J 6/62 O	J 3/66 OH	J 9/65 O2		

OF = 6.500000

	EFFECTIVE FUEL HPP(2)	EFFECTIVE OXIDANT HPP(1)	MIXTURE HSUBO
ENTHALPY (KG-MOL)(DEG K)/KG	-.53769264+03	-.48698226+02	-.11389748+03

KG-ATOMS/KG	BOP(I,2)	BOP(I,1)	BO(I)
H	.99209302-00	.00000000	.13227907-00
O	.00000000	.62126080-01	.53842602-01
N	.00000000	.37839034-04	.32793829-04
AR	.00000000	.13742866-03	.11910483-03

PT	H	O	N	AR	
1	-9.911	-16.150	-17.100	-25.793	10.000
2	-10.110	-16.431	-17.274	-26.216	3.000
PC/PT= 1.728141 T = 3233.46					
2	-10.110	-16.431	-17.274	-26.216	2.000
PC/PT= 1.726860 T = 3233.67					
3	-9.918	-16.160	-17.106	-25.808	4.000
3	-9.920	-16.162	-17.107	-25.811	2.000
3	-9.920	-16.162	-17.107	-25.811	2.000
3	-9.920	-16.162	-17.107	-25.811	1.000
4	-10.671	-17.414	-17.770	-27.415	5.000
4	-10.643	-17.354	-17.745	-27.354	3.000
4	-10.643	-17.354	-17.745	-27.354	2.000
5	-10.995	-18.279	-18.064	-28.142	4.000
5	-10.975	-18.215	-18.046	-28.097	3.000
5	-10.975	-18.214	-18.046	-28.097	1.000
6	-11.337	-19.904	-18.385	-28.985	4.000
6	-11.330	-19.860	-18.379	-28.968	2.000
7	-11.458	-20.823	-18.500	-29.308	4.000
7	-11.464	-20.875	-18.505	-29.325	2.000
8	-11.560	-21.778	-18.595	-29.586	3.000
8	-11.554	-21.718	-18.590	-29.570	2.000
9	-11.616	-22.380	-18.648	-29.741	3.000
9	-11.622	-22.445	-18.653	-29.757	2.000

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

PC = 300.0 PSIA

CHEMICAL FORMULA			WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H	2.00000	1.00000	-2194.000	L	20.27	.0709
OXIDANT	O	2.00000	.99398	-3102.000	L	90.18	1.1490
OXIDANT	N	2.00000	.00053	-2939.000	L	77.35	.8080
OXIDANT	AR	1.00000	.00549	-2607.000	L	90.00	-.0000

O/F= .6500+01 PERCENT FUEL= .0000 EQUIVALENCE RATIO= .1228+01 STOIC MIXTURE RATIO= .0000 DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7269	1.0236	7.5248	20.056	67.800	115.48	168.41	225.59
P, PSIA	300.0	173.7	293.1	39.87	14.96	4.425	2.598	1.781	1.330
T, DEG R	6110	5821	6097	5092	4610	3955	3647	3428	3261
H, BTU/LB	-407.4	-867.9	-427.6	-1976.4	-2617.8	-3311.9	-3579.2	-3755.1	-3884.0
S, BTU/(LB)(R)	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738
DEN (LBM/FT3)	.639-01	.394-01	.626-01	.107-01	.449-02	.157-02	.100-02	.730-03	.573-03
M, MOL WT	13.965	14.155	13.973	14.617	14.858	15.034	15.067	15.078	15.083
(DLV/DLP)T	-1.04072	-1.03437	-1.04044	-1.01772	-1.00845	-1.00186	-1.00074	-1.00035	-1.00018
(DLV/DLT)P	1.7429	1.6585	1.7395	1.3881	1.2035	1.0510	1.0217	1.0107	1.0059
CP, BTU/(LB)(R)	2.7890	2.6244	2.7828	1.9855	1.4659	.9638	.8455	.7925	.7636
GAMMA (S)	1.1290	1.1271	1.1289	1.1289	1.1412	1.1760	1.1935	1.2041	1.2112
SON VEL, FT/SEC	4955.7	4800.4	4948.8	4422.1	4195.8	3921.6	3789.9	3689.5	3608.5
MACH NUMBER	.0000	1.0000	.2033	2.0038	2.5065	3.0742	3.3242	3.5080	3.6552
AE/AT		1.0000	3.0003	2.0000	4.0000	10.0000	15.000	20.000	25.000
CSTAR, FT/SEC		7355	7355	7355	7355	7355	7355	7355	7355
CF		.653	.137	1.205	1.430	1.639	1.713	1.760	1.793
IVAC, LBF-SEC/L		261.6	701.3	336.2	372.5	408.4	421.3	429.4	435.3
I, LBF-SEC/LBM		149.2	31.3	275.4	326.9	374.7	391.6	402.3	409.9

MOLE FRACTIONS

AR	.001663	.001686	.001664	.001741	.001770	.001791	.001795	.001796	.001796
H	.046555	.040206	.046281	.023874	.013883	.004310	.001973	.001011	.000563
H2	.210192	.204302	.209937	.190612	.185234	.184239	.184773	.185100	.185280
H2O	.657923	.684872	.659092	.750492	.783969	.806666	.810286	.811475	.811945
N2	.000229	.000232	.000229	.000240	.000244	.000247	.000247	.000247	.000247
O	.008445	.006357	.008350	.002159	.000643	.000043	.000007	.000002	.000000
OH	.064455	.053801	.063994	.027411	.013128	.002625	.000906	.000367	.000167
O2	.010537	.008545	.010453	.003471	.001130	.000080	.000013	.000003	.000001

NOTE, WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

PC = 300.0 PSIA

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	1.00000	-2154.000	L	20.27	.0709
OXIDANT	O 2.00000	.99398	-3102.000	L	90.18	1.1490
OXIDANT	N 2.00000	.00053	-2939.000	L	77.35	.8080
OXIDANT	AR 1.00000	.00549	-2607.000	L	90.00	-.0000

O/F= .6580+01 PERCENT FUEL= .0000 EQUIVALENCE RATIO= .1228+01 STOIC MIXTURE RATIO= .0000 DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7756	1.0248	8.4242	23.848	86.045	149.87	221.70	300.20
P, PSIA	300.0	169.0	292.8	35.61	12.58	3.487	2.002	1.353	.9993
T, DEG R	6110	5543	6085	4220	3486	2717	2427	2236	2096
H, BTU/LB	-407.4	-883.1	-428.6	-1959.1	-2528.3	-3092.4	-3295.4	-3425.3	-3518.7
S, BTU/(LB)(R)	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738	4.2738
DEN (LBM/FT3)	.639-01	.397-01	.626-01	.110-01	.469-02	.167-02	.107-02	.787-03	.620-03
M, MOL WT	13.965	13.965	13.965	13.965	13.965	13.965	13.965	13.965	13.965
CP,BTU/(LB)(R)	.8445	.8324	.8440	.7912	.7571	.7096	.6880	.6725	.6605
GAMMA (S)	1.2026	1.2062	1.2028	1.2193	1.2315	1.2508	1.2608	1.2684	1.2746
SON VEL,FT/SEC	5114.7	4878.7	5104.5	4280.1	3909.2	3478.7	3300.6	3177.7	3084.1
MACH NUMBER	.0000	1.0000	.2018	2.0588	2.6353	3.3321	3.6421	3.8671	4.0457
AE/AT		1.0000	3.0001	2.0000	4.0000	10.000	15.000	20.000	25.000
CSTAR, FT/SEC		7182	7182	7182	7182	7182	7182	7182	7182
CF		.679	.143	1.227	1.434	1.614	1.674	1.711	1.737
IVAC,LBF-SEC/L		277.4	685.5	326.9	357.6	386.2	396.0	402.1	406.4
I, LBF-SEC/LBM		151.6	32.0	273.9	320.2	360.3	373.6	381.9	387.8

MOLE FRACTIONS

AR	.00166	H	.04656	H2	.21019	H2O	.65792
N2	.00023	O	.00844	OH	.06446	O2	.01054
AR	.001663	H	.046555	H2	.210192	H2O	.657923
N2	.000229	O	.008445	OH	.064455	O2	.010537

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .0000005 FOR ALL ASSIGNED CONDITIONS

EQUILIBRIUM CONTRACTION CONDITIONS ZONE 1

TEMPERATURE	(DEGR)	.60970928+04
PRESSURE	(PSIA)	.29308783+03
VELOCITY	(FT/S)	.10067241+04

SPECIES MOLE FRACTIONS

1	AR	.16642494-02
2	H	.46281222-01
3	H2	.20993705-00
4	H2O	.65909152-00
5	N2	.22911374-03
6	O	.83500642-02
7	OH	.63993879-01
8	O2	.10452930-01

ZONE = 1

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE = .042 (MIN) $$$$$$$$$$

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REACTIONS   O-H      MAY 3-4 1972  JANNAF PSWG
   H + OH  = H2O      , A=7.5E23 , N=2.6 , B=0.,        (AR) NO.  1
   O + H   = OH       , A=4.0E18 , N=1.  , B=0.,        (AR) NO.  2
   O + O   = O2       , A=1.2E17 , N=1.  , B=0.,        (AR) NO.  3
   H + H   = H2       , A=6.4E17 , N=1.  , B=0.,        (AR) NO.  6
END TBR REAX
  H2 + OH  = H + H2O  , A=2.19E13, N=0.  , B=5.15,   BAULCH  NO. 21
  OH + OH  = O + H2O  , A=5.75E12, N=0.  , B=.780,   BAULCH  NO. 22
   H + OH  = O + H2   , A=7.33E12, N=0.  , B=7.300,  BAULCH  NO. 23
   O + OH  = H + O2   , A=1.3E13 , N=0.  , B=0.,     BAULCH  NO. 25
LAST REAX
INERTS N2,AR,END
THIRD BODY REAX RATE RATIOS
SPECIES AR,1.,1.,1.,1.,
SPECIES H2,5.,5.,5.,4.,
SPECIES H2O,20.,5.,5.,20.,
SPECIES O2,5.,5.,4.5,1.5,
SPECIES N2,4.,4.,4.,1.5,
SPECIES H,12.5,12.5,12.5,25.,
SPECIES O,12.5,12.5,12.5,25.,
SPECIES OH,12.5,12.5,12.5,25.,
LAST CARD
```

SPECIES TABLE

ZONE = 1

(OBTAINED FROM REACTIONS)

1	H
2	OH
3	H2O
4	O
5	O2
6	H2

REACTION TABLE

ZONE = 1

```
THIRD BODY REACTION   1   A=   .7500000+24   B=   .0000000   N=   .2600000+01
                    REACTANTS  H          + OH
                    PRODUCTS   H2O

THIRD BODY REACTION   2   A=   .4000000+19   B=   .0000000   N=   .1000000+01
                    REACTANTS  O          + H
                    PRODUCTS   OH

THIRD BODY REACTION   3   A=   .1200000+18   B=   .0000000   N=   .1000000+01
                    REACTANTS  O          + O
                    PRODUCTS   O2

THIRD BODY REACTION   4   A=   .6400000+18   B=   .0000000   N=   .1000000+01
                    REACTANTS  H          + H
                    PRODUCTS   H2

          REACTION    5   A=   .2190000+14   B=   .5150000+01   N=   .0000000
                    REACTANTS  H2         + OH
                    PRODUCTS   H          + H2O

          REACTION    6   A=   .5730000+13   B=   .7800000-00   N=   .0000000
                    REACTANTS  OH         + OH
                    PRODUCTS   O          + H2O

          REACTION    7   A=   .7330000+13   B=   .7300000+01   N=   .0000000
                    REACTANTS  H          + OH
                    PRODUCTS   O          + H2

          REACTION    8   A=   .1300000+14   B=   .0000000   N=   .0000000
```

SELECTED SPECIES FOR KINETIC EXPANSION

ZONE = 1

1	AR	.16642494-02	INERT SPECIES
2	H	.46201222-01	
3	H2	.20993705-00	
4	H2O	.65909152-00	
5	N2	.22911374-03	INERT SPECIES
6	O	.83500642-02	
7	OH	.63993879-01	
8	O2	.10452930-01	

DISSOCIATION RECOMBINATION REACTION RATE RATIOS

ZONE = 1

1	.10000+01	.12500+02	.50000+01	.20000+02	.40000+01	.12500+02
	.12500+02	.50000+01				
2	.10000+01	.12500+02	.50000+01	.50000+01	.40000+01	.12500+02
	.12500+02	.50000+01				
3	.10000+01	.12500+02	.50000+01	.50000+01	.40000+01	.12500+02
	.12500+02	.45000+01				
4	.10000+01	.25000+02	.40000+01	.20000+02	.15000+01	.25000+02
	.25000+02	.15000+01				

SSSSSSSSSS CURRENT EXECUTION TIME THIS CASE = .080 (MIN) SSSSSSSSSS

INITIAL CONDITIONS KINETIC EXPANSION

ZONE = 1 O/F = 6.5000

FLOW PROPERTIES

MACH NUMBER	.19709122-00
VELOCITY (FT/SEC)	.10067241+04
PRESSURE (PSIA)	.29300782+03
DENSITY (LB/FT3)	.62588051-01
TEMPERATURE (DEG-R)	.60970928+04
ENTHALPY (BTU/LB)	-.42766342+03
GAS MOLECULAR WEIGHT	.13972974+02
HEAT CAPACITY (BTU/LB-DEG-R)	.84430440-00
GAMMA	.12025759+01

NOZZLE GEOMETRY

THROAT RADIUS (FT)	.16666667-00
THROAT WALL RADIUS DNSTREAM	.10000000+01
CONE ANGLE (DEG)	.15000000+02
EXPANSION RATIO	.00000000
CONTRACTION RATIO	.30002809+01
INLET ANGLE (DEG)	.30000000+02
INLET WALL RADIUS	.20000000+01
THROAT WALL RADIUS UPSTREAM	.10000000+01

CHEMICAL COMPOSITION

NO.	SPECIES	MASS FRACTION	MOLE FRACTION	NO.	SPECIES	MASS FRACTION	MOLE FRACTION
1	AR	.47580019-02	.16642494-02	2	H	.33385936-02	.46281221-01
3	H2	.30288504-01	.20993705-00	4	H20	.84976596-00	.65909152-00
5	N2	.45933346-03	.22911374-03	6	O	.95610294-02	.83500642-02
7	OH	.77890900-01	.63993877-01	8	O2	.23937725-01	.10452930-01

THROAT CONDITIONS KINETIC EXPANSION

ZONE = 1 O/F = 6.5000

FLOW PROPERTIES

MACH NUMBER	.96932986-00
PRESSURE (PSIA)	.17362727+03
VELOCITY (FT/SEC)	.48028602+04
DENSITY (LB/FT3)	.39359432-01
TEMPERATURE (DEG-R)	.58174641+04
ENTHALPY (BTU/LB)	-.86835729+03
GAS MOLECULAR WEIGHT	.14152528+02
HEAT CAPACITY(BTU/LB-DEG)	.83831627-00
GAMMA	.12012048+01

PERFORMANCE PARAMETERS

VACUUM THRUST COEFFICIENT	.12319782+01
VACUUM SPECIFIC IMPULSE (SEC)	.28153864+03
CHARACTERISTIC VELOCITY (FT/SEC)	.73525846+04

INTEGRATION PARAMETERS

STEP SIZE	.49999999-02
AXIAL POSITION	.00000000
PERCENT ENTHALPY CHANGE	.10736396-01
PERCENT MASS FRACTION CHANGE	.11622906-03

CHEMICAL COMPOSITION

NO.	SPECIES	MASS FRACTION	MOLE FRACTION	NO.	SPECIES	MASS FRACTION	MOLE FRACTION
1	AR	.47580019-02	.16856351-02	2	H	.28709494-02	.40309919-01
3	H2	.29107463-01	.20434347-00	4	H20	.87147666-00	.68461641-00
5	N2	.45933346-03	.23205785-03	6	O	.72139474-02	.63812137-02
7	OH	.64715346-01	.53852285-01	8	O2	.19397162-01	.85790364-02

ZONE= 2

SPECIES BEING CONSIDERED IN THIS SYSTEM

L 5/66 AR	J 9/65 H	J 3/61 H2	J 3/61 H20	J 9/65 N2
J 6/62 O	J 3/66 OH	J 9/65 O2		

OF = 8.000000

ENTHALPY (KG-MOL)(DEG K)/KG	EFFECTIVE FUEL HPP(2)	EFFECTIVE OXIDANT HPP(1)	MIXTURE HSUBO
	-.53769264+03	-.48698226+02	-.10303094+03

KG-ATOMS/KG	BOP(I,2)	BOP(I,1)	BO(I)
H	.99209302-00	.00000000	.11023256+00
O	.00000000	.62126080-01	.55223182-01
N	.00000000	.37839034-04	.33634697-04
AR	.00000000	.13742866-03	.12215880-03

PT	H	O	N	AR	
1	-10.215	-15.533	-17.067	-25.714	10.000
2	-10.443	-15.736	-17.246	-26.142	3.000
PC/PT= 1.725523 T = 3271.95					
2	-10.443	-15.736	-17.246	-26.141	2.000
PC/PT= 1.723421 T = 3272.28					
3	-10.224	-15.540	-17.074	-25.730	3.000
3	-10.225	-15.541	-17.075	-25.732	2.000
3	-10.225	-15.541	-17.075	-25.733	2.000
3	-10.225	-15.541	-17.075	-25.733	1.000
4	-11.127	-16.354	-17.766	-27.367	4.000
4	-11.088	-16.319	-17.737	-27.299	3.000
4	-11.087	-16.318	-17.737	-27.299	2.000
5	-11.576	-16.764	-18.088	-28.120	4.000
5	-11.544	-16.735	-18.065	-28.068	3.000
5	-11.544	-16.735	-18.065	-28.068	2.000
6	-12.168	-17.306	-18.479	-29.035	4.000
6	-12.147	-17.286	-18.465	-29.003	3.000
7	-12.405	-17.523	-18.622	-29.372	3.000
7	-12.426	-17.542	-18.634	-29.401	2.000
8	-12.656	-17.752	-18.764	-29.709	3.000
8	-12.633	-17.731	-18.751	-29.679	3.000
9	-12.776	-17.861	-18.828	-29.862	3.000
9	-12.800	-17.883	-18.840	-29.891	3.000

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

PC = 285.0 PSIA

CHEMICAL FORMULA		WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	1.00000	-2154.000	L	20.27	.0709
OXIDANT	O 2.00000	.99398	-3102.000	L	90.18	1.1490
OXIDANT	N 2.00000	.00053	-2939.000	L	77.35	.8080
OXIDANT	AR 1.00000	.00549	-2607.000	L	90.00	-.0000

O/F= .8000+01 PERCENT FUEL= .0000 EQUIVALENCE RATIO= .7981-00 STOIC MIXTURE RATIO= .0000 DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7234	1.0235	7.4335	19.504	53.193	104.59	149.03	195.88
P, PSIA	285.0	165.4	278.4	38.34	14.61	4.510	2.725	1.912	1.455
T, DEG R	6164	5890	6152	5230	4838	4385	4194	4059	3954
H, BTU/LB	-368.5	-777.6	-386.5	-1764.9	-2338.7	-2965.2	-3211.1	-3376.3	-3499.5
S, BTU/(LB)(R)	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898
DEN (LBM/FT3)	.681-01	.420-01	.667-01	.114-01	.478-02	.167-02	.106-02	.774-03	.607-03
M, MOL WT	15.818	16.046	15.828	16.632	16.991	17.386	17.536	17.633	17.703
(DLV/DLP)T	-1.05081	-1.04559	-1.05059	-1.03205	-1.02377	-1.01480	-1.01146	-1.00932	-1.00782
(DLV/DLT)P	1.9202	1.8643	1.9179	1.6852	1.5500	1.3783	1.3063	1.2577	1.2218
CP,BTU/(LB)(R)	2.8641	2.7948	2.8616	2.4990	2.2238	1.8223	1.6365	1.5044	1.4030
GAMMA (S)	1.1247	1.1216	1.1246	1.1157	1.1143	1.1165	1.1195	1.1226	1.1256
SON VEL,FT/SEC	4667.9	4524.4	4661.6	4176.7	3971.7	3741.8	3648.6	3584.5	3535.7
MACH NUMBER	.0000	1.0000	.2034	2.0014	2.4999	3.0463	3.2688	3.4225	3.5401
AE/AT		1.0000	2.9998	2.0000	4.0000	10.000	15.000	20.000	25.000
CSTAR, FT/SEC		6952	6952	6952	6952	6952	6952	6952	6952
CF		.651	.136	1.202	1.428	1.640	1.716	1.765	1.800
IVAC,LBF-SEC/L		266.0	662.7	317.9	352.9	388.5	401.7	410.3	416.6
I, LBF-SEC/LBM		140.6	29.5	259.8	308.6	354.3	370.7	381.3	389.0

MOLE FRACTIONS

AR	.001932	.001960	.001934	.002032	.002076	.002124	.002142	.002154	.002163
H	.039456	.034237	.039228	.021567	.014481	.007555	.005257	.003904	.003013
H2	.124344	.115211	.123959	.089443	.071679	.049784	.040592	.034322	.029646
H2O	.679239	.708922	.680511	.786880	.836001	.891614	.913346	.927608	.937946
N2	.000266	.000270	.000266	.000280	.000286	.000292	.000295	.000297	.000298
O	.018171	.015337	.018045	.008879	.005582	.002648	.001758	.001259	.000943
OH	.097062	.086279	.096596	.059141	.043091	.026130	.019923	.016006	.013256
O2	.039530	.037784	.039461	.031778	.026804	.019853	.016688	.014449	.012736

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

PC = 285.0 PSIA

CHEMICAL FORMULA		
FUEL	H	2.00000
OXIDANT	O	2.00000
OXIDANT	N	2.00000
OXIDANT	AR	1.00000

WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
1.00000	-2154.000	L	20.27	.0709
.99398	-3102.000	L	90.18	1.1490
.00053	-2939.000	L	77.35	.8080
.00549	-2607.000	L	90.00	-.0000

O/F= .8000+01 PERCENT FUEL= .0000 EQUIVALENCE RATIO= .9981-00 STOIC MIXTURE RATIO= .0000 DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7741	1.0247	8.3927	23.700	85.184	148.08	218.74	295.82
P, PSIA	285.0	160.6	278.1	33.96	12.03	3.346	1.925	1.303	.9634
T, DEG R	6164	5598	6139	4277	3543	2774	2483	2292	2151
H, BTU/LB	-368.5	-791.7	-387.4	-1750.9	-2259.6	-2765.4	-2947.9	-3064.8	-3149.1
S, BTU/(LB)(R)	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898	3.8898
DEN (LBM/FT3)	.681-01	.423-01	.668-01	.117-01	.500-02	.178-02	.114-02	.838-03	.660-03
M, MOL WT	15.818	15.818	15.818	15.818	15.818	15.818	15.818	15.818	15.818
CP,BTU/(LB)(R)	.7526	.7423	.7522	.7071	.6777	.6364	.6175	.6038	.5932
GAMMA (S)	1.2004	1.2037	1.2005	1.2160	1.2276	1.2459	1.2554	1.2627	1.2687
SON VEL,FT/SEC	4822.3	4601.9	4812.7	4043.1	3697.2	3296.1	3130.3	3015.9	2928.7
MACH NUMBER	.0000	1.0000	.2019	2.0571	2.6311	3.3226	3.6293	3.8515	4.0276
AE/AT		1.0000	3.0000	2.0000	4.0000	10.000	15.000	20.000	25.000
CSTAR, FT/SEC		6782	6782	6782	6782	6782	6782	6782	6782
CF		.679	.143	1.226	1.434	1.615	1.675	1.713	1.739
IVAC,LBF-SEC/L		261.9	647.4	308.7	337.9	365.1	374.5	380.3	384.4
I, LBF-SEC/LBM		143.0	30.2	258.5	302.4	340.4	353.1	361.0	366.6

MOLE FRACTIONS

AR	.00193	H	.03946	H2	.12434	H2O	.67924
N2	.00027	O	.01817	OH	.09706	O2	.03953
AR	.001932	H	.039456	H2	.124344	H2O	.679239
N2	.000266	O	.018171	OH	.097062	O2	.039530

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .0000005 FOR ALL ASSIGNED CONDITIONS

EQUILIBRIUM CONTRACTION CONDITIONS ZONE 2

TEMPERATURE	(DEGR)	.61515340+04
PRESSURE	(PSIA)	.27844690+03
VELOCITY	(FT/S)	.94876215+03

SPECIES MOLE FRACTIONS

1	AR	.19335328-02
2	H	.39228033-01
3	H2	.12395943+00
4	H2O	.68051094-00
5	N2	.26618544-03
6	O	.18045282-01
7	OH	.96595535-01
8	O2	.39461081-01


```
ZONE =  2

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE =         .384  (MIN) $$$$$$$$$$

REACTIONS    O-H      MAY 3-4 1972  JANNAF PSWG
   H + OH   = H2O      , A=7.5E23 , N=2.6 , B=0.,          (AR) NO.  1
   O + H    = OH       , A=4.0E18 , N=1.  , B=0.,          (AR) NO.  2
   O + O    = O2       , A=1.2E17 , N=1.  , B=0.,          (AR) NO.  3
   H + H    = H2       , A=6.4E17 , N=1.  , B=0.,          (AR) NO.  6
END TBR REAX
  H2 + OH   = H + H2O  , A=2.19E13, N=0.  , B=5.15,      BAULCH  NO. 21
  OH + OH   = O + H2O  , A=5.75E12, N=0.  , B=.780,      BAULCH  NO. 22
   H + OH   = O + H2   , A=7.33E12, N=0.  , B=7.300,     BAULCH  NO. 23
   O + OH   = H + O2   , A=1.3E13 , N=0.  , B=0.,        BAULCH  NO. 25
LAST REAX
INERTS N2,AR,END
THIRD BODY REAX RATE RATIOS
SPECIES AR,1.,1.,1.,1.,
SPECIES H2,5.,5.,5.,4.,
SPECIES H2O,20.,5.,5.,20.,
SPECIES O2,5.,5.,4.5,1.5,
SPECIES N2,4.,4.,4.,1.5,
SPECIES H,12.5,12.5,12.5,25.,
SPECIES O,12.5,12.5,12.5,25.,
SPECIES OH,12.5,12.5,12.5,25.,
LAST CARD
```

SPECIES TABLE

ZONE = 2

(OBTAINED FROM REACTIONS)

1	H
2	OH
3	H2O
4	O
5	O2
6	H2

REACTION TABLE

ZONE = 2

```
THIRD BODY REACTION   1   A=   .7500000+24   B=   .0000000      N=   .2600000+01
                    REACTANTS  H            + OH
                    PRODUCTS   H2O

THIRD BODY REACTION   2   A=   .4000000+19   B=   .0000000      N=   .1000000+01
                    REACTANTS  O            + H
                    PRODUCTS   OH

THIRD BODY REACTION   3   A=   .1200000+18   B=   .0000000      N=   .1000000+01
                    REACTANTS  O            + O
                    PRODUCTS   O2

THIRD BODY REACTION   4   A=   .6400000+18   B=   .0000000      N=   .1000000+01
                    REACTANTS  H            + H
                    PRODUCTS   H2

          REACTION    5   A=   .2190000+14   B=   .5150000+01   N=   .0000000
                    REACTANTS  H2           + OH
                    PRODUCTS   H            + H2O

          REACTION    6   A=   .5750000+13   B=   .7800000-00   N=   .0000000
                    REACTANTS  OH           + OH
                    PRODUCTS   O            + H2O

          REACTION    7   A=   .7330000+13   B=   .7300000+01   N=   .0000000
                    REACTANTS  H            + OH
                    PRODUCTS   O            + H2

          REACTION    8   A=   .1300000+14   B=   .0000000      N=   .0000000
                    REACTANTS  O            + OH
```

SELECTED SPECIES FOR KINETIC EXPANSION

ZONE = 2

1	AR	.19335328-02	INERT SPECIES
2	H	.39228033-01	
3	H2	.12395943+00	
4	H2O	.68051094-00	
5	N2	.26618544-03	INERT SPECIES
6	O	.18045282-01	
7	OH	.96595535-01	
8	O2	.39461081-01	

DISSOCIATION RECOMBINATION REACTION RATE RATIOS

ZONE = 2

1	.10000+01	.12500+02	.50000+01	.20000+02	.40000+01	.12500+02
	.12500+02	.50000+01				
2	.10000+01	.12500+02	.50000+01	.50000+01	.40000+01	.12500+02
	.12500+02	.50000+01				
3	.10000+01	.12500+02	.50000+01	.50000+01	.40000+01	.12500+02
	.12500+02	.45000+01				
4	.10000+01	.25000+02	.40000+01	.20000+02	.15000+01	.25000+02
	.25000+02	.15000+01				

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE = .416 (MIN) $$$$$$$$$$

INITIAL CONDITIONS KINETIC EXPANSION

ZONE = 2 O/F = 8.0000

FLOW PROPERTIES

MACH NUMBER	.19700044-00
VELOCITY (FT/SEC)	.94876215+03
PRESSURE (PSIA)	.27844690+03
DENSITY (LB/FT3)	.66759533-01
TEMPERATURE (DEG-R)	.61515340+04
ENTHALPY (BTU/LB)	-.38653061+03
GAS MOLECULAR WEIGHT	.15828025+02
HEAT CAPACITY (BTU/LB-DEG-R)	.75244716-00
GAMMA	.12002830+01

NOZZLE GEOMETRY

THROAT RADIUS (FT)	.16666667-00
THROAT WALL RADIUS DNSTREAM	.10000000+01
CONE ANGLE (DEG)	.15000000+02
EXPANSION RATIO	.00000000
CONTRACTION RATIO	.29997544+01
INLET ANGLE (DEG)	.30000000+02
INLET WALL RADIUS	.20000000+01
THROAT WALL RADIUS UPSTREAM	.10000000+01

CHEMICAL COMPOSITION

NO.	SPECIES	MASS FRACTION	MOLE FRACTION	NO.	SPECIES	MASS FRACTION	MOLE FRACTION
1	AR	.48800002-02	.19335327-02	2	H	.24981435-02	.39228033-01
3	H2	.15788121-01	.12395943+00	4	H2O	.77455246-00	.68051094-00
5	N2	.47111114-03	.26618544-03	6	O	.18240663-01	.18045282-01
7	OH	.10379286+00	.96595534-01	8	O2	.79776673-01	.39461081-01

THROAT CONDITIONS KINETIC EXPANSION

ZONE = 2 O/F = 8.0000

FLOW PROPERTIES

MACH NUMBER	.96800096-00
PRESSURE (PSIA)	.16528711+03
VELOCITY (FT/SEC)	.45266823+04
DENSITY (LB/FT3)	.41971178-01
TEMPERATURE (DEG-R)	.58871052+04
ENTHALPY (BTU/LB)	-.77798647+03
GAS MOLECULAR WEIGHT	.16043635+02
HEAT CAPACITY(BTU/LB-DEG)	.74761777-00
GAMMA	.11985867+01

PERFORMANCE PARAMETERS

VACUUM THRUST COEFFICIENT	.12312813+01
VACUUM SPECIFIC IMPULSE (SEC)	.26597049+03
CHARACTERISTIC VELOCITY (FT/SEC)	.69499427+04

INTEGRATION PARAMETERS

STEP SIZE	.49999999-02
AXIAL POSITION	.00000000
PERCENT ENTHALPY CHANGE	.14795538-01
PERCENT MASS FRACTION CHANGE	.10728836-03

CHEMICAL COMPOSITION

NO.	SPECIES	MASS FRACTION	MOLE FRACTION	NO.	SPECIES	MASS FRACTION	MOLE FRACTION
1	AR	.48800002-02	.19598714-02	2	H	.21560136-02	.34316790-01
3	H2	.14488543-01	.11530546+00	4	H2O	.79574472-00	.70865373-00
5	N2	.47111114-03	.26981142-03	6	O	.15326034-01	.15368407-01
7	OH	.91478158-01	.86294482-01	8	O2	.75454371-01	.37831493-01

ZONE= 3

SPECIES BEING CONSIDERED IN THIS SYSTEM

L 5/66 AR	J 9/65 H	J 3/61 H2	J 3/61 H20	J 9/65 N2
J 6/62 O	J 3/66 OH	J 9/65 O2		

OF = 5.000000

	EFFECTIVE FUEL	EFFECTIVE OXIDANT	MIXTURE
	HPP(2)	HPP(1)	HSUBO
ENTHALPY (KG-MOL)(DEG K)/KG	-.53769264+03	-.48698226+02	-.13019729+03

KG-ATOMS/KG	BOP(I,2)	BOP(I,1)	BO(I)
H	.99209302-00	.00000000	.16534884-00
O	.00000000	.62126080-01	.51771732-01
N	.00000000	.37839034-04	.31532528-04
AR	.00000000	.13742866-03	.11452388-03

PT	H	O	N	AR	
1	-9.581	-17.280	-17.139	-25.969	10.000
2	-9.742	-17.755	-17.294	-26.372	4.000
PC/PT= 1.739709 T = 2989.48					
2	-9.743	-17.756	-17.295	-26.373	2.000
PC/PT= 1.742976 T = 2988.83					
3	-9.587	-17.296	-17.145	-25.984	4.000
3	-9.588	-17.299	-17.146	-25.986	2.000
3	-9.588	-17.299	-17.146	-25.986	2.000
3	-9.588	-17.299	-17.146	-25.986	1.000
4	-10.159	-19.663	-17.696	-27.466	5.000
4	-10.147	-19.584	-17.684	-27.433	3.000
4	-10.147	-19.584	-17.684	-27.432	1.000
5	-10.395	-21.645	-17.919	-28.133	4.000
5	-10.383	-21.517	-17.907	-28.097	3.000
5	-10.383	-21.516	-17.907	-28.097	1.000
6	-10.659	-25.108	-18.162	-28.898	4.000
6	-10.653	-25.006	-18.156	-28.879	2.000
7	-10.762	-26.852	-18.256	-29.194	3.000
7	-10.768	-26.960	-18.262	-29.212	1.000
8	-10.856	-28.658	-18.343	-29.463	3.000
8	-10.850	-28.531	-18.338	-29.445	1.000
9	-10.907	-29.735	-18.391	-29.608	2.000
9	-10.914	-29.870	-18.397	-29.626	1.000

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

PC = 270.0 PSIA

CHEMICAL FORMULA		
FUEL	H	2.00000
OXIDANT	O	2.00000
OXIDANT	N	2.00000
OXIDANT	AR	1.00000

WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
1.00000	-2154.000	L	20.27	.0709
.99398	-3102.000	L	90.18	1.1490
.00053	-2939.000	L	77.35	.8080
.00549	-2607.000	L	90.00	-.0000

O/F= .5000+01 PERCENT FUEL= .0000 EQUIVALENCE RATIO= .1397+01 STOIC MIXTURE RATIO= .0000 DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7430	1.0240	7.9450	22.243	80.057	139.33	205.92	278.56
P, PSIA	270.0	154.9	263.7	33.98	12.14	3.373	1.938	1.311	.9693
T, DEG R	5728	5380	5713	4414	3738	2948	2641	2439	2291
H, BTU/LB	-465.7	-987.9	-488.7	-2227.8	-2920.2	-3623.2	-3877.8	-4041.0	-4158.6
S, BTU/(LB)(R)	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515
DEN (LBM/FT3)	.513-01	.316-01	.503-01	.861-02	.365-02	.129-02	.825-03	.605-03	.476-03
M, MOL WT	11.684	11.799	11.689	12.011	12.064	12.076	12.076	12.077	12.077
(DLV/DLP)T	-1.01739	-1.01210	-1.01715	-1.00275	-1.00054	-1.00003	-1.00000	-1.00000	-1.00000
(DLV/DLT)P	1.3318	1.2442	1.3280	1.0657	1.0148	1.0009	1.0002	1.0001	1.0000
CP,BTU/(LB)(R)	2.0630	1.8041	2.0520	1.1906	.9605	.8455	.8169	.7984	.7844
GAMMA (S)	1.1479	1.1526	1.1490	1.1835	1.2137	1.2422	1.2524	1.2596	1.2655
SON VEL,FT/SEC	5289.4	5111.7	5281.7	4650.2	4324.0	3882.8	3690.3	3556.6	3454.6
MACH NUMBER	.0000	1.0000	.2031	2.0193	2.5630	3.2373	3.5408	3.7608	3.9350
AE/AT		1.0000	3.0004	2.0000	4.0000	10.000	15.000	20.000	25.000
CSTAR, FT/SEC		7730	7730	7730	7730	7730	7730	7730	7730
CF		.661	.139	1.215	1.434	1.626	1.690	1.730	1.759
IVAC,LBF-SEC/L		296.7	737.3	352.3	387.7	420.7	432.0	439.1	444.1
I, LBF-SEC/LBM		158.9	33.3	291.9	344.5	390.7	406.1	415.7	422.5

MOLE FRACTIONS

AR	.001338	.001351	.001339	.001376	.001382	.001383	.001383	.001383	.001383
H	.037123	.028045	.036729	.008062	.001797	.000102	.000020	.000005	.000002
H2	.357410	.360050	.357510	.368568	.372075	.373132	.373186	.373196	.373198
H2O	.578402	.593700	.579111	.619072	.624208	.625185	.625220	.625225	.625227
N2	.000184	.000186	.000184	.000189	.000190	.000190	.000190	.000190	.000190
O	.001451	.000741	.001414	.000039	.000001	.000000	.000000	.000000	.000000
OH	.023148	.015432	.022793	.002667	.000345	.000007	.000001	.000000	.000000
O2	.000944	.000495	.000921	.000027	.000001	.000000	.000000	.000000	.000000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

PC = 270.0 PSIA

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	1.00000	-2154.000	L	20.27	.0709
OXIDANT	O 2.00000	.99398	-3102.000	L	90.18	1.1490
OXIDANT	N 2.00000	.00053	-2939.000	L	77.35	.8080
OXIDANT	AR 1.00000	.00549	-2607.000	L	90.00	-.0000

O/F= .5000+01 PERCENT FUEL= .0000 EQUIVALENCE RATIO= .1597+01 STOIC MIXTURE RATIO= .0000 DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7814	1.0249	8.5452	24.418	89.354	156.72	233.07	316.93
P, PSIA	270.0	151.6	263.4	31.60	11.06	3.022	1.723	1.158	.8519
T, DEG R	5728	5175	5703	3887	3176	2436	2158	1977	1844
H, BTU/LB	-465.7	-1000.6	-489.6	-2202.5	-2831.5	-3447.9	-3667.2	-3806.7	-3906.5
S, BTU/(LB)(R)	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515	4.8515
DEN (LBM/FT3)	.513-01	.319-01	.503-01	.885-02	.379-02	.135-02	.869-03	.638-03	.503-03
M, MOL WT	11.684	11.684	11.684	11.684	11.684	11.684	11.684	11.684	11.684
CP,BTU/(LB)(R)	.9751	.9587	.9745	.9043	.8610	.8031	.7774	.7594	.7455
GAMMA (S)	1.2113	1.2157	1.2114	1.2316	1.2462	1.2687	1.2800	1.2886	1.2956
SON VEL,FT/SEC	5433.4	5173.8	5422.2	4513.8	4103.6	3626.3	3428.7	3292.4	3188.6
MACH NUMBER	.0000	1.0000	.2017	2.0653	2.6514	3.3687	3.6914	3.9272	4.1152
AE/AT		1.0000	3.0000	2.0000	4.0000	10.000	15.000	20.000	25.000
CSTAR, FT/SEC		7582	7582	7582	7582	7582	7582	7582	7582
CF		.682	.144	1.230	1.435	1.611	1.669	1.705	1.731
IVAC,LBF-SEC/L		293.1	723.8	344.9	376.8	406.1	416.0	422.1	426.4
I, LBF-SEC/LBM		160.8	34.0	289.8	338.2	379.7	393.4	401.9	407.8

MOLE FRACTIONS

AR	.00134	H	.03712	H2	.35741	H2O	.57840
N2	.00018	O	.00145	OH	.02315	O2	.00094
AR	.001338	H	.037123	H2	.357410	H2O	.578402
N2	.000184	O	.001451	OH	.023148	O2	.000944

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .0000005 FOR ALL ASSIGNED CONDITIONS

EQUILIBRIUM CONTRACTION CONDITIONS ZONE 3

TEMPERATURE	(DEGR)	,57127937+04
PRESSURE	(PSIA)	,26367943+03
VELOCITY	(FT/S)	,10732467+04

SPECIES MOLE FRACTIONS

1	AR	,13386696-02
2	H	,36728753-01
3	H2	,35750986-00
4	H20	,57911071-00
5	N2	,18429185-03
6	O	,14143899-02
7	OH	,22792512-01
8	O2	,92083946-03

```
ZONE = 3

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE =        .714  (MIN) $$$$$$$$$$

REACTIONS    O-H      MAY 3-4 1972  JANNAF PSWG
   H + OH  = H20      , A=7.5E23 , N=2.6 , B=0.,          (AR) NO.  1
   O + H   = OH       , A=4.0E18 , N=1.  , B=0.,          (AR) NO.  2
   O + O   = O2       , A=1.2E17 , N=1.  , B=0.,          (AR) NO.  3
   H + H   = H2       , A=6.4E17 , N=1.  , B=0.,          (AR) NO.  6
END TBR REAX
  H2 + OH  = H + H20  , A=2.19E13, N=0.  , B=5.15,     BAULCH  NO. 21
  OH + OH  = O + H20  , A=5.75E12, N=0.  , B=1.780,    BAULCH  NO. 22
   H + OH  = O + H2   , A=7.33E12, N=0.  , B=7.300,    BAULCH  NO. 23
   O + OH  = H + O2   , A=1.3E13 , N=0.  , B=0.,       BAULCH  NO. 25
LAST REAX
INERTS N2,AR,END
THIRD BODY REAX RATE RATIOS
SPECIES AR,1.,1.,1.,1.,
SPECIES H2,5.,5.,5.,4.,
SPECIES H20,20.,5.,5.,20.,
SPECIES O2,5.,5.,4.5,1.5,
SPECIES N2,4.,4.,4.,1.5,
SPECIES H,12.5,12.5,12.5,25.,
SPECIES O,12.5,12.5,12.5,25.,
SPECIES OH,12.5,12.5,12.5,25.,
LAST CARD
```

SPECIES TABLE

ZONE = 3

(OBTAINED FROM REACTIONS)

1	H
2	OH
3	H2O
4	O
5	O2
6	H2

REACTION TABLE

ZONE = 3

```
THIRD BODY REACTION   1   A=   .7500000+24   B=   .0000000   N=   .2600000+01
                    REACTANTS  H              + OH
                    PRODUCTS   H2O

THIRD BODY REACTION   2   A=   .4000000+19   B=   .0000000   N=   .1000000+01
                    REACTANTS  O              + H
                    PRODUCTS   OH

THIRD BODY REACTION   3   A=   .1200000+18   B=   .0000000   N=   .1000000+01
                    REACTANTS  O              + O
                    PRODUCTS   O2

THIRD BODY REACTION   4   A=   .6400000+18   B=   .0000000   N=   .1000000+01
                    REACTANTS  H              + H
                    PRODUCTS   H2

          REACTION    5   A=   .2190000+14   B=   .5150000+01   N=   .0000000
                    REACTANTS  H2             + OH
                    PRODUCTS   H              + H2O

          REACTION    6   A=   .5750000+13   B=   .7800000-00   N=   .0000000
                    REACTANTS  OH             + OH
                    PRODUCTS   O              + H2O

          REACTION    7   A=   .7330000+13   B=   .7300000+01   N=   .0000000
                    REACTANTS  H              + OH
                    PRODUCTS   O              + H2

          REACTION    8   A=   .1300000+14   B=   .0000000   N=   .0000000
                    REACTANTS  O              + O
```

SELECTED SPECIES FOR KINETIC EXPANSION

ZONE = 3

1	AR	.13386696-02	INERT SPECIES
2	H	.36728753-01	
3	H2	.35750986-00	
4	H2O	.57911071-00	
5	N2	.18429185-03	INERT SPECIES
6	O	.14143899-02	
7	OH	.22792512-01	
8	O2	.92083946-03	

DISSOCIATION RECOMBINATION REACTION RATE RATIOS

ZONE = 3

1	.10000+01	.12500+02	.50000+01	.20000+02	.40000+01	.12500+02
	.12500+02	.50000+01				
2	.10000+01	.12500+02	.50000+01	.50000+01	.40000+01	.12500+02
	.12500+02	.50000+01				
3	.10000+01	.12500+02	.50000+01	.50000+01	.40000+01	.12500+02
	.12500+02	.45000+01				
4	.10000+01	.25000+02	.40000+01	.20000+02	.15000+01	.25000+02
	.25000+02	.15000+01				

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE = .746 (MIN) $$$$$$$$$$

INITIAL CONDITIONS KINETIC EXPANSION

ZONE = 3 O/F = 5.0000

FLOW PROPERTIES		NOZZLE GEOMETRY	
MACH NUMBER	.19782266-00	THROAT RADIUS (FT)	.16666667-00
VELOCITY (FT/SEC)	.10732467+04	THROAT WALL RADIUS DNSTREAM	.10000000+01
PRESSURE (PSIA)	.26367943+03	CONE ANGLE (DEG)	.15000000+02
DENSITY (LB/FT3)	.50272718-01	EXPANSION RATIO	.00000000
TEMPERATURE (DEG-R)	.57127937+04	CONTRACTION RATIO	.30003832+01
ENTHALPY (BTU/LB)	-.48973585+03	INLET ANGLE (DEG)	.30000000+02
GAS MOLECULAR WEIGHT	.11686992+02	INLET WALL RADIUS	.20000000+01
HEAT CAPACITY (BTU/LB-DEG-R)	.97479801-00	THROAT WALL RADIUS UPSTREAM	.10000000+01
GAMMA	.12112551+01		

CHEMICAL COMPOSITION

NO.	SPECIES	MASS FRACTION	MOLE FRACTION	NO.	SPECIES	MASS FRACTION	MOLE FRACTION
1	AR	.45750032-02	.13386696-02	2	H	.31672091-02	.36728753-01
3	H2	.61657878-01	.35750987-00	4	H20	.89253861-00	.57911072-00
5	N2	.44166693-03	.18429185-03	6	O	.19359574-02	.14143900-02
7	OH	.33162884-01	.22792512-01	8	O2	.25208126-02	.92083947-03

THROAT CONDITIONS KINETIC EXPANSION

ZONE = 3 O/F = 5.0000

FLOW PROPERTIES

MACH NUMBER	.97663952-00
PRESSURE (PSIA)	.15470990+03
VELOCITY (FT/SEC)	.51164334+04
DENSITY (LB/FT3)	.31646448-01
TEMPERATURE (DEG-R)	.53741871+04
ENTHALPY (BTU/LB)	-.98882812+03
GAS MOLECULAR WEIGHT	.11796155+02
HEAT CAPACITY(BTU/LB-DEG)	.96469972-00
GAMMA	.12115848+01

PERFORMANCE PARAMETERS

VACUUM THRUST COEFFICIENT	.12352593+01
VACUUM SPECIFIC IMPULSE (SEC)	.29661430+03
CHARACTERISTIC VELOCITY (FT/SEC)	.77257209+04

INTEGRATION PARAMETERS

STEP SIZE	.49999999-02
AXIAL POSITION	.00000000
PERCENT ENTHALPY CHANGE	.86906098-02
PERCENT MASS FRACTION CHANGE	.13709068-03

CHEMICAL COMPOSITION

NO.	SPECIES	MASS FRACTION	MOLE FRACTION	NO.	SPECIES	MASS FRACTION	MOLE FRACTION
1	AR	.45750032-02	.13509424-02	2	H	.24229882-02	.28355947-01
3	H2	.61507557-01	.35990787-00	4	H20	.90621261-00	.59337344-00
5	N2	.44166693-03	.18598141-03	6	O	.10259770-02	.75643984-03
7	OH	.22437424-01	.15562390-01	8	O2	.13754269-02	.50704241-03

TRANSONIC ANALYSIS SUBPROGRAM (SEE SECTION 5.. OF TDK MANUAL)

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE = 1.020 (MIN) $$$$$$$$$$

3 ZONE(S) SPECIFIED

THROAT UPSTREAM RADIUS OF CURVATURE =	1.00000
THROAT DOWNSTREAM RADIUS OF CURVATURE =	1.00000
NUMBER OF POINTS ON INITIAL LINE (MP) =	60
P-M INIT LINE DISTRIB CRIT (PMCRIT) =	1.00000
P-M LRC WALL INTERSECT ANGLE (PMDEG) =	1.00000

ZONE	GAMMA	MASS FLOW THRU ZONE
1	1.12912	.33334
2	1.12226	.33333
3	1.16293	.33333

ZONE	K(I)	Y(I)
1	.99997	.56233
2	1.00000	.79425
3	.00000	1.00000

TWO DIMENSIONAL KINETIC ANALYSIS SUBPROGRAM (SEE SECTION 5.7 OF TDK MANUAL)

$$$$$$$$$$ CURRENT EXECUTION TIME THIS CASE = 1.113 (MIN) $$$$$$$$$$

NUMBER OF POINTS ON INITIAL LINE = 63

CHARACTERISTICS MESH CONTROL PARAMETERS
(SEE SECTION 5.9.3 TDK MANUAL)

INSERTION CONTROL, STREAMLINE POINT SEPARATION (DS) =	.150
INSERTION CONTROL, NOZZLE END POINT TOLERANCE (EPW) =	.010
INSERTION CONTROL, FLOW ANGLE CHANGE (DTWI) =	2.000
INSERTION CONTROL, WALL ANGLE CHANGE (DWWI) =	3.000
EDIT CONTROL, CHARACTERISTICS POINT SEPARATION (ES) =	.005
EDIT CONTROL, CHARACTERISTICS POINT ANGLE CHANGE (ETHI) =	.250

IWALL = 1 OPTION SPECIFIED

WALL COORDINATES

R/R*	X/R*	SLOPE(DEG)
1.0000000	.0000000	
1.0000034	.0026180	.07501
1.0000137	.0052360	.22502
1.0000308	.0078539	.37504
1.0000548	.0104718	.52506
1.0000857	.0130896	.67508
1.0001234	.0157073	.82478
1.0001679	.0183249	.97514
1.0002193	.0209424	1.12485
1.0002776	.0235598	1.27522
1.0003427	.0261769	1.42495
1.0004146	.0287940	1.57502
1.0004934	.0314108	1.72477
1.0005791	.0340273	1.87518
1.0006716	.0366437	2.02496
1.0007710	.0392598	2.17507
1.0008772	.0418757	2.32488
1.0009902	.0444912	2.47502
1.0011101	.0471065	2.62486
1.0012369	.0497214	2.77504
1.0013705	.0523360	2.92524
1.0015109	.0549502	3.07481
1.0016582	.0575640	3.22505
1.0018123	.0601775	3.37499
1.0019733	.0627905	3.52495
1.0021411	.0654031	3.67493
1.0023157	.0680153	3.82526
1.0024972	.0706270	3.97497
1.0026855	.0732382	4.12504
1.0028807	.0758489	4.27480
1.0030827	.0784591	4.42492
1.0032915	.0810687	4.57507
1.0035071	.0836778	4.72493
1.0037296	.0862864	4.87514
1.0039589	.0888943	5.02506
1.0041951	.0915016	5.17502
1.0044380	.0941083	5.32501
1.0046878	.0967144	5.47504
1.0049444	.0993197	5.62478
1.0052079	.1019244	5.77520
1.0054781	.1045285	5.92502
1.0057552	.1071317	6.07488
1.0060391	.1097343	6.22511
1.0063297	.1123361	6.37472
1.0066272	.1149371	6.52503
1.0069315	.1175374	6.67506
1.0072427	.1201368	6.82514
1.0075606	.1227354	6.97494
[illegible]	[illegible]	7.12510

1.0082168	.1279301	7.27500
1.0085551	.1305262	7.42494
1.0089003	.1331213	7.57494
1.0092522	.1357156	7.72498
1.0096109	.1383089	7.87508
1.0099763	.1409012	8.02490
1.0103486	.1434926	8.17511
1.0107277	.1460830	8.32505
1.0111135	.1486724	8.47471
1.0115061	.1512608	8.62509
1.0119055	.1538481	8.77520
1.0123117	.1564344	8.92472
1.0127246	.1590197	9.07526
1.0131443	.1616038	9.22491
1.0135707	.1641868	9.37495
1.0140040	.1667687	9.52503
1.0144439	.1693495	9.67487
1.0148907	.1719291	9.82509
1.0153442	.1745075	9.97505
1.0158044	.1770847	10.12509
1.0162714	.1796607	10.27487
1.0167451	.1822355	10.42504
1.0172255	.1848090	10.57496
1.0177127	.1873813	10.72494
1.0182067	.1899522	10.87500
1.0187073	.1925219	11.02514
1.0192147	.1950903	11.17502
1.0197288	.1976573	11.32499
1.0202496	.2002230	11.47502
1.0207772	.2027872	11.62483
1.0213114	.2053501	11.77501
1.0218524	.2079116	11.92496
1.0224001	.2104717	12.07499
1.0229544	.2130303	12.22511
1.0235155	.2155875	12.37497
1.0240832	.2181432	12.52493
1.0246577	.2206974	12.67498
1.0252388	.2232501	12.82509
1.0258266	.2258012	12.97498
1.0264211	.2283508	13.12496
1.0270222	.2308988	13.27502
1.0276301	.2334453	13.42486
1.0282446	.2359902	13.57509
1.0288657	.2385334	13.72510
1.0294935	.2410750	13.87489
1.0301280	.2436149	14.02508
1.0307691	.2461532	14.17505
1.0314168	.2486898	14.32479
1.0320712	.2512247	14.47495
1.0327322	.2537579	14.62520
1.0333999	.2562893	14.77491
1.0340742	.2588191	14.92488
1.4142136	1.6775165	15.00000
.0000000	.0000000	

P(PSIA)	RHO(LBM/FT3)	THETA(DEG)	VEL(FT/SEC)	R	X	MASS FLOW RATE
.13084+03	.27380-01	-.42635-04	.58043+04	.10000+01	.00000	.00000
.13084+03	.27380-01	.30711-00	.58043+04	.98813-00	.67255-02	.32768-00
.13084+03	.27380-01	.60382-00	.58043+04	.97627-00	.13534-01	.65242-00
.13084+03	.27380-01	.88999-00	.58043+04	.96440-00	.20423-01	.97418-00
.13084+03	.27380-01	.11660+01	.58043+04	.95253-00	.27391-01	.12929+01
.13084+03	.27380-01	.14321+01	.58043+04	.94067-00	.34438-01	.16086+01
.13084+03	.27380-01	.16880+01	.58043+04	.92880-00	.41560-01	.19212+01
.13084+03	.27380-01	.19343+01	.58043+04	.91694-00	.48756-01	.22306+01
.13084+03	.27380-01	.21708+01	.58043+04	.90507-00	.56024-01	.25368+01
.13084+03	.27380-01	.23976+01	.58043+04	.89320-00	.63361-01	.28398+01
.13084+03	.27380-01	.26152+01	.58043+04	.88134-00	.70767-01	.31395+01
.13084+03	.27380-01	.28234+01	.58043+04	.86947-00	.78238-01	.34359+01
.13084+03	.27380-01	.30227+01	.58043+04	.85760-00	.85773-01	.37290+01
.13084+03	.27380-01	.32128+01	.58043+04	.84574-00	.93369-01	.40186+01
.13084+03	.27380-01	.33943+01	.58043+04	.83387-00	.10102+00	.43049+01
.13084+03	.27380-01	.35670+01	.58043+04	.82201-00	.10874+00	.45876+01
.13084+03	.27380-01	.37313+01	.58043+04	.81014-00	.11650+00	.48669+01
.13084+03	.27380-01	.39383+01	.58043+04	.79425-00	.12700-00	.52353+01
.13084+03	.34088-01	.39383+01	.53768+04	.79425-00	.12700-00	.52353+01
.13084+03	.34088-01	.38093+01	.53768+04	.78641-00	.13304-00	.54434+01
.13084+03	.34088-01	.39043+01	.53768+04	.77454-00	.14222-00	.57544+01
.13084+03	.34088-01	.39923+01	.53768+04	.76267-00	.15144-00	.60611+01
.13084+03	.34088-01	.40735+01	.53768+04	.75081-00	.16068-00	.63633+01
.13084+03	.34088-01	.41480+01	.53768+04	.73894-00	.16995-00	.66612+01
.13084+03	.34088-01	.42158+01	.53768+04	.72708-00	.17925-00	.69546+01
.13084+03	.34088-01	.42771+01	.53768+04	.71521-00	.18857-00	.72435+01
.13084+03	.34088-01	.43321+01	.53768+04	.70334-00	.19791-00	.75279+01
.13084+03	.34088-01	.43807+01	.53768+04	.69148-00	.20726-00	.78077+01
.13084+03	.34088-01	.44232+01	.53768+04	.67961-00	.21664-00	.80829+01
.13084+03	.34088-01	.44597+01	.53768+04	.66774-00	.22603-00	.83536+01
.13084+03	.34088-01	.44902+01	.53768+04	.65588-00	.23543-00	.86195+01
.13084+03	.34088-01	.45191+01	.53768+04	.64164-00	.24672-00	.89326+01
.13084+03	.34088-01	.45430+01	.53768+04	.62455-00	.26029-00	.92992+01
.13084+03	.34088-01	.45566+01	.53768+04	.60405-00	.27657-00	.97263+01
.13084+03	.34088-01	.45533+01	.53768+04	.58167-00	.29434-00	.10176+02
.13084+03	.34088-01	.45357+01	.53768+04	.56233-00	.30969-00	.10551+02
.13084+03	.30637-01	.45357+01	.58693+04	.56233-00	.30969-00	.10551+02
.13084+03	.30637-01	.43533+01	.58693+04	.53693-00	.33155-00	.11017+02
.13084+03	.30637-01	.42800+01	.58693+04	.51456-00	.35074-00	.11409+02
.13084+03	.30637-01	.41930+01	.58693+04	.49219-00	.36610-00	.11779+02
.13084+03	.30637-01	.40928+01	.58693+04	.46981-00	.37659-00	.12128+02
.13084+03	.30637-01	.39801+01	.58693+04	.44744-00	.38660-00	.12459+02
.13084+03	.30637-01	.38554+01	.58693+04	.42507-00	.39612-00	.12774+02
.13084+03	.30637-01	.37194+01	.58693+04	.40270-00	.40515-00	.13071+02
.13084+03	.30637-01	.35725+01	.58693+04	.38033-00	.41369-00	.13352+02
.13084+03	.30637-01	.34154+01	.58693+04	.35795-00	.42175-00	.13617+02
.13084+03	.30637-01	.32487+01	.58693+04	.33558-00	.42931-00	.13865+02
.13084+03	.30637-01	.30730+01	.58693+04	.31321-00	.43639-00	.14096+02
.13084+03	.30637-01	.28889+01	.58693+04	.29084-00	.44298-00	.14311+02
.13084+03	.30637-01	.26969+01	.58693+04	.26847-00	.44908-00	.14510+02
.13084+03	.30637-01	.24977+01	.58693+04	.24609-00	.45470-00	.14692+02
.13084+03	.30637-01	.22919+01	.58693+04	.22372-00	.45982-00	.14859+02
.13084+03	.30637-01	.20800+01	.58693+04	.20135-00	.46446-00	.15009+02
.13084+03	.30637-01	.18626+01	.58693+04	.17898-00	.46861-00	.15143+02
.13084+03	.30637-01	.16404+01	.58693+04	.15660-00	.47227-00	.15262+02
.13084+03	.30637-01	.14139+01	.58693+04	.13423-00	.47544-00	.15364+02
.13084+03	.30637-01	.11839+01	.58693+04	.11186+00	.47813-00	.15451+02
.13084+03	.30637-01	.95073-00	.58693+04	.89488-01	.48033-00	.15521+02

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    .13084+03      .30637-01      .47780-00      .58693+04      .44744-01      .48325-00      .15616+02
    .13084+03      .30637-01      .23920-00      .58693+04      .22372-01      .48399-00      .15639+02
    .13084+03      .30637-01      .11964+00      .58693+04      .11186-01      .48417-00      .15645+02
    .13084+03      .30637-01      .00000         .58693+04      .00000         .48423-00      .15647+02

MASS FLOW RATE (LB/SEC) =   .156472+02          CSTAR (FT/SEC) =   .697656+04

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)    DENSITY      VELOCITY    CF        ISP      IT      ZONE
          AR                    H             H2                      H2O            N2            O         OH
          C2
          AA                    BB             GAMMA                  CP(BTU/LB)     SUM CI*HI     V**2/2    1-SUM C(I)
  0 15    1.00000               .00000  1.121  -.000     5265.15      130.838        .27380-01     5804.34   1.2973  281.297  0      3
          .4575003-02           .2216857-02    .6148966-01           .9097058-00    .4416669-03   .8274670-03     .1962187-01
          .1120219-02
          .4959466-01  -.6794870-01            .1211900+01           .9611790-00    -.2849886+08  .1684518+08     .1445413-05

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)    DENSITY      VELOCITY    CF        ISP      IT      ZONE
          AR                    H             H2                      H2O            N2            O         OH
          C2
          AA                    BB             GAMMA                  CP(BTU/LB)     SUM CI*HI     V**2/2    1-SUM C(I)
  1  1     .98813               .00673  1.121  .307      5265.15      130.838        .27380-01     5804.34   .0000   .000  0      3
          .4575003-02           .2216857-02    .6148966-01           .9097058-00    .4416669-03   .8274670-03     .1962187-01
          .1120219-02
          .4959466-01  -.6794869-01            .1211900+01           .9611790-00    -.2849886+08  .1684518+08     .1445413-05
  1  5     1.00008              .01284  1.137  .736      5250.88      128.167        .26900-01     5882.38   1.2973  281.314  3      3
          .4575003-02           .2195864-02    .6148684-01           .9100807-00    .4416669-03   .8076161-03     .1931566-01
          .1095179-02
          .5182319-01  -.7138747-01            .1211960+01           .9607107-00    -.2896034+08  .1730121+08     .1460314-05
MASS FLOW POINT    1  =      .32721-00   AREA RATIO =      .1000+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)    DENSITY      VELOCITY    CF        ISP      IT      ZONE
          AR                    H             H2                      H2O            N2            O         OH
          C2
          AA                    BB             GAMMA                  CP(BTU/LB)     SUM CI*HI     V**2/2    1-SUM C(I)
  2  1     .97627               .01353  1.121  .604      5265.15      130.838        .27380-01     5804.34   .0000   .000  0      3
          .4575003-02           .2216857-02    .6148966-01           .9097058-00    .4416669-03   .8274670-03     .1962187-01
          .1120219-02
          .4959466-01  -.6794869-01            .1211900+01           .9611790-00    -.2849886+08  .1684518+08     .1445413-05
  2  6     .98220               .01013  1.121  .455      5265.15      130.838        .27380-01     5804.34   .0000   .000  0      3
          .4575003-02           .2216857-02    .6148966-01           .9097058-00    .4416669-03   .8274670-03     .1962187-01
          .1120219-02
  2  5     1.00019              .01936  1.146  1.109     5243.44      126.788        .26652-01     5922.80   1.2974  281.336  3      3
          .4575003-02           .2184920-02    .6148557-01           .9102733-00    .4416669-03   .7975611-03     .1915815-01
          .1082368-02
          .5408182-01  -.7417861-01            .1211992+01           .9604655-00    -.2920040+08  .1753977+08     .1460314-05
  2  5     1.00034              .02589  1.155  1.484     5236.04      125.417        .26405-01     5963.11   1.2976  281.366  3      3
          .4575003-02           .2173673-02    .6148440-01           .9104690-00    .4416669-03   .7872861-03     .1899819-01
          .1069304-02
          .5517219-01  -.7564045-01            .1212023+01           .9602204-00    -.2944089+08  .1777933+08     .1460314-05
MASS FLOW POINT    3  =      .65144-00   AREA RATIO =      .1001+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)    DENSITY      VELOCITY    CF        ISP      IT      ZONE
          AR                    H             H2                      H2O            N2            O         OH
          C2
          AA                    BB             GAMMA                  CP(BTU/LB)     SUM CI*HI     V**2/2    1-SUM C(I)
  3  1     .96440               .02042  1.121  .890      5265.15      130.839        .27380-01     5804.34   .0000   .000  0      3
          .4575003-02           .2216857-02    .6148966-01           .9097058-00    .4416669-03   .8274670-03     .1962187-01
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        .4575003-02     .2149925-02     .6148207-01     .9108800-00     .4416669-03     .7657463-03     .1866221-01
        .1041904-02
        .5604044-01    -.7710132-01     .1212089+01     .9597039-00    -.2994585+08     .1828022+08     .1475215-05
MASS FLOW POINT    4   =      .97241-00   AREA RATIO =       .1002+01

LRC ID    R          X          MACH    THETA  T (DEG,R)   P (PSI)   DENSITY      VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2                H2O         N2             O                OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)   SUM CI*HI      V**2/2          1-SUM C(I)
   4  1    .95253     .02739   1.121    1.166     5265.15    130.839    .27380-01   5804.34    .0000      .000  0
        .4575003-02     .2216857-02     .6148966-01     .9097058-00     .4416669-03     .8274670-03     .1962187-01
        .1120219-02
        .4959466-01    -.6794869-01     .1211900+01     .9611790-00    -.2849886+08     .1684518+08     .1445413-05
   4  5   1.00139     .05268   1.191    3.020     5204.26    119.704    .25370-01   6132.17   1.2985   281.573  3
        .4575003-02     .2125229-02     .6147994-01     .9113032-00     .4416669-03     .7438207-03     .1831586-01
        .1013857-02
        .5735834-01    -.7885955-01     .1212160+01     .9591608-00    -.3047185+08     .1880175+08     .1475215-05
MASS FLOW POINT    5   =      .12906+01   AREA RATIO =       .1003+01

LRC ID    R          X          MACH    THETA  T (DEG,R)   P (PSI)   DENSITY      VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2                H2O         N2             O                OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)   SUM CI*HI      V**2/2          1-SUM C(I)
   5  1    .94067     .03444   1.121    1.432     5265.15    130.838    .27380-01   5804.34    .0000      .000  0
        .4575003-02     .2216857-02     .6148966-01     .9097058-00     .4416669-03     .8274670-03     .1962187-01
        .1120219-02
        .4959466-01    -.6794869-01     .1211900+01     .9611790-00    -.2849886+08     .1684518+08     .1445413-05
   5  5   1.00221     .06640   1.210    3.807     5187.30    116.763    .24835-01   6220.09   1.2993   281.729  3
        .4575003-02     .2099679-02     .6147795-01     .9117382-00     .4416669-03     .7215101-03     .1795933-01
        .9852482-03
        .5834172-01    -.8013842-01     .1212235+01     .9585901-00    -.3101903+08     .1934474+08     .1475215-05
MASS FLOW POINT    6   =      .16056+01   AREA RATIO =       .1004+01

LRC ID    R          X          MACH    THETA  T (DEG,R)   P (PSI)   DENSITY      VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2                H2O         N2             O                OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)   SUM CI*HI      V**2/2          1-SUM C(I)
   6  1    .92880     .04156   1.121    1.688     5265.15    130.839    .27380-01   5804.34    .0000      .000  0
        .4575003-02     .2216857-02     .6148966-01     .9097058-00     .4416669-03     .8274670-03     .1962187-01
        .1120219-02
        .4959466-01    -.6794869-01     .1211900+01     .9611790-00    -.2849886+08     .1684518+08     .1445413-05
   6  5   1.00323     .08035   1.230    4.608     5169.56    113.766    .24288-01   6310.31   1.3001   281.919  3
        .4575003-02     .2073398-02     .6147605-01     .9121837-00     .4416669-03     .6989225-03     .1759355-01
        .9562339-03
        .5909494-01    -.8107806-01     .1212317+01     .9579895-00    -.3158827+08     .1991001+08     .1475215-05
MASS FLOW POINT    7   =      .19174+01   AREA RATIO =       .1006+01

LRC ID    R          X          MACH    THETA  T (DEG,R)   P (PSI)   DENSITY      VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2                H2O         N2             O                OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)   SUM CI*HI      V**2/2          1-SUM C(I)
   7  1    .91694     .04876   1.121    1.934     5265.15    130.838    .27380-01   5804.34    .0000      .000  0
        .4575003-02     .2216857-02     .6148966-01     .9097058-00     .4416669-03     .8274670-03     .1962187-01
        .1120219-02
        .4959466-01    -.6794869-01     .1211900+01     .9611790-00    -.2849886+08     .1684518+08     .1445413-05
   7  5   1.00448     .09454   1.251    5.425     5150.99    110.727    .23730-01   6402.86   1.3012   282.145  3
        .4575003-02     .2046488-02     .6147421-01     .9126388-00     .4416669-03     .6761471-03     .1721927-01
        .9269371-03
                                        .1212486+01     .9573567-00    -.3218038+08     .2049833+08     .1490116-05
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LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA / H2O / CP(BTU/LB)	T (DEG.R) / N2 / SUM CI*HI	P (PSI) / O / V**2/2	DENSITY / OH / 1-SUM C(I)	VELOCITY / CF / ISP / IT	ZONE
8	1	.90507	.05602	1.121	2.171	5265.15	130.838	.27380-01	5804.34 .0000	3
		.4575003-02	.2216857-02	.6148966-01	.9097058-00	.4416669-03	.8274670-03	.000 0		
		.1120219-02						.1962187-01		
		.4959466-01	-.6794869-01	.1211900+01	.9611790-00	-.2849886+08	.1684518+08	.1445413-05		
8	5	1.00596	.10898	1.272	6.256	5131.53	107.618	.23161-01	6497.82 1.3024 282.405 3	3
		.4575003-02	.2019029-02	.6147242-01	.9131026-00	.4416669-03	.6532590-03	.1683705-01		
		.8974636-03								
		.5996607-01	-.8206719-01	.1212502+01	.9566888-00	-.3279652+08	.2111080+08	.1490116-05		
MASS FLOW POINT 9 = .25312+01 AREA RATIO = .1012+01										
LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA / H2O / CP(BTU/LB)	T (DEG.R) / N2 / SUM CI*HI	P (PSI) / O / V**2/2	DENSITY / OH / 1-SUM C(I)	VELOCITY / CF / ISP / IT	ZONE
9	1	.89320	.06336	1.121	2.398	5265.15	130.839	.27380-01	5804.34 .0000	3
		.4575003-02	.2216857-02	.6148966-01	.9097058-00	.4416669-03	.8274670-03	.000 0		
		.1120219-02						.1962187-01		
		.4959466-01	-.6794869-01	.1211900+01	.9611790-00	-.2849886+08	.1684518+08	.1445413-05		
9	5	1.00768	.12368	1.294	7.105	5111.10	104.470	.22580-01	6595.23 1.3037 282.700 3	3
		.4575003-02	.1991100-02	.6147065-01	.9135744-00	.4416669-03	.6303289-03	.1644749-01		
		.8679109-03								
		.6013955-01	-.8219126-01	.1212608+01	.9559830-00	-.3343777+08	.2174850+08	.1475215-05		
MASS FLOW POINT 10 = .28332+01 AREA RATIO = .1015+01										
LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA / H2O / CP(BTU/LB)	T (DEG.R) / N2 / SUM CI*HI	P (PSI) / O / V**2/2	DENSITY / OH / 1-SUM C(I)	VELOCITY / CF / ISP / IT	ZONE
10	1	.88134	.07077	1.121	2.615	5265.15	130.839	.27380-01	5804.34 .0000	3
		.4575003-02	.2216857-02	.6148966-01	.9097058-00	.4416669-03	.8274670-03	.000 0		
		.1120219-02						.1962187-01		
		.4959466-01	-.6794869-01	.1211900+01	.9611790-00	-.2849886+08	.1684518+08	.1445413-05		
10	5	1.00966	.13865	1.316	7.970	5089.66	101.277	.21990-01	6695.14 1.3053 283.030 3	3
		.4575003-02	.1962784-02	.6146883-01	.9140532-00	.4416669-03	.6074274-03	.1605124-01		
		.8303741-03								
		.6015627-01	-.8208958-01	.1212724+01	.9552367-00	-.3410513+08	.2241245+08	.1490116-05		
MASS FLOW POINT 11 = .31318+01 AREA RATIO = .1019+01										
LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA / H2O / CP(BTU/LB)	T (DEG.R) / N2 / SUM CI*HI	P (PSI) / O / V**2/2	DENSITY / OH / 1-SUM C(I)	VELOCITY / CF / ISP / IT	ZONE
11	1	.86947	.07824	1.121	2.823	5265.15	130.838	.27380-01	5804.34 .0000	3
		.4575003-02	.2216857-02	.6148966-01	.9097058-00	.4416669-03	.8274670-03	.000 0		
		.1120219-02						.1962187-01		
		.4959466-01	-.6794869-01	.1211900+01	.9611790-00	-.2849886+08	.1684518+08	.1445413-05		
11	5	1.01191	.15390	1.339	8.853	5067.12	98.039	.21389-01	6797.65 1.3069 283.395 3	3
		.4575003-02	.1934164-02	.6146706-01	.9145382-00	.4416669-03	.5846188-03	.1564884-01		
		.8089397-03								
		.6000562-01	-.8175332-01	.1212850+01	.9544462-00	-.3480002+08	.2310405+08	.1475215-05		
MASS FLOW POINT 12 = .34270+01 AREA RATIO = .1024+01										
										ZONE

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        AA               BB                GAMMA                CP(BTU/LB)        SUM CI*HI         V**2/2             1-SUM C(I)
12  1     .85760       .08577    1.121   3.023      5265.15    130.838      .27380-01    5804.34    .0000     .000  0                 3
      .4575003-02      .2216857-02       .6148966-01       .9097058-00       .4416669-03       .8274670-03       .1962187-01
      .1120219-02
      .4959466-01     -.6794869-01       .1211900+01       .9611790-00      -.2849886+08       .1684518+08       .1445413-05
12  5  1.01446        .16943    1.363    9.755      5043.42     94.761      .20777-01    6902.84   1.3088    283.794  3               3
      .4575003-02      .1905333-02       .6146518-01       .9150287-00       .4416669-03       .5619713-03       .1524096-01
      .7796986-03
      .5970067-01     -.8119388-01       .1212990+01       .9536081-00      -.3552370+08       .2382462+08       .1490116-05
MASS FLOW POINT   13    =       .37187+01    AREA RATIO =          .102[illegible]+01
                                                                                                                                  ZONE
LRC ID     R             X              MACH      THETA   T (DEG.R)    P (PSI)     DENSITY       VELOCITY    CF          ISP      IT
          AR                    H                    H2                 H2O               N2                 O                 OH
          C2
          AA               BB                GAMMA                CP(BTU/LB)        SUM CI*HI         V**2/2             1-SUM C(I)
13  1     .84574       .09337    1.121   3.213      5265.15    130.838      .27380-01    5804.34    .0000     .000  0                 3
      .4575003-02      .2216857-02       .6148966-01       .9097058-00       .4416669-03       .8274670-03       .1962187-01
      .1120219-02
      .4959466-01     -.6794869-01       .1211900+01       .9611790-00      -.2849886+08       .1684518+08       .1445413-05
13  5  1.01731        .18527    1.388   10.677      5018.47     91.443      .20157-01    7010.82   1.3108    284.228  3               3
      .4575003-02      .1876395-02       .6146319-01       .9155237-00       .4416669-03       .5395510-03       .1482825-01
      .7507390-03
      .5921423-01     -.8038326-01       .1213143+01       .9527181-00      -.3627778+08       .2457577+08       .1490116-05
MASS FLOW POINT   14    =       .40070+01    AREA RATIO =          .1035+01
                                                                                                                                  ZONE
LRC ID     R             X              MACH      THETA   T (DEG.R)    P (PSI)     DENSITY       VELOCITY    CF          ISP      IT
          AR                    H                    H2                 H2O               N2                 O                 OH
          C2
          AA               BB                GAMMA                CP(BTU/LB)        SUM CI*HI         V**2/2             1-SUM C(I)
14  1     .83387       .10102    1.121   3.394      5265.15    130.838      .27380-01    5804.34    .0000     .000  0                 3
      .4575003-02      .2216857-02       .6148966-01       .9097058-00       .4416669-03       .8274670-03       .1962187-01
      .1120219-02
      .4959466-01     -.6794869-01       .1211900+01       .9611790-00      -.2849886+08       .1684518+08       .1445413-05
14  5  1.02049        .20141    1.414   11.620      4992.18     88.089      .19526-01    7121.63   1.3129    284.695  3               3
      .4575003-02      .1847463-02       .6146103-01       .9160222-00       .4416669-03       .5174290-03       .1441153-01
      .7221550-03
      .5855155-01     -.7932412-01       .1213311+01       .9517722-00      -.3706355+08       .2535884+08       .1490116-05
MASS FLOW POINT   15    =       .42917+01    AREA RATIO =          .1041+01
                                                                                                                                  ZONE
LRC ID     R             X              MACH      THETA   T (DEG.R)    P (PSI)     DENSITY       VELOCITY    CF          ISP      IT
          AR                    H                    H2                 H2O               N2                 O                 OH
          C2
          AA               BB                GAMMA                CP(BTU/LB)        SUM CI*HI         V**2/2             1-SUM C(I)
15  1     .82201       .10874    1.121   3.567      5265.15    130.838      .27380-01    5804.34    .0000     .000  0                 3
      .4575003-02      .2216857-02       .6148966-01       .9097058-00       .4416669-03       .8274670-03       .1962187-01
      .1120219-02
      .4959466-01     -.6794869-01       .1211900+01       .9611790-00      -.2849886+08       .1684518+08       .1445413-05
15  5  1.02403        .21789    1.441   12.585      4964.46     84.704      .18887-01    7235.40   1.3152    285.196  3               3
      .4575003-02      .1818668-02       .6145866-01       .9165232-00       .4416669-03       .4956767-03       .1399164-01
      .6940413-03
      .5770935-01     -.7801186-01       .1213496+01       .9507655-00      -.3788268+08       .2617552+08       .1505017-05
MASS FLOW POINT   16    =       .45729+01    AREA RATIO =          .1049+01
                                                                                                                                  ZONE
LRC ID     R             X              MACH      THETA   T (DEG.R)    P (PSI)     DENSITY       VELOCITY    CF          ISP      IT
          AR                    H                    H2                 H2O               N2                 O                 OH
          C2
          AA               BB                GAMMA                CP(BTU/LB)        SUM CI*HI         V**2/2             1-SUM C(I)
16  1     .81014       .11650    1.121   3.731      5265.15    130.838      .27380-01    5804.34    .0000     .000  0                 3
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        .4959466-01   -.6794870-01    .1211900+01    .9611790-00   -.2849886+08    .1684518+08    .1445413-05
16  5   1.02793    .23469   1.469  13.574    4935.22     81.289    .18240-01   7352.24  1.3177  285.730  3
        .4575003-02    .1790151-02    .6145599-01    .9170255-00    .4416669-03    .4743609-03    .1356939-01
        .6664873-03
        .5667444-01   -.7643233-01    .1213700+01    .9496924-00   -.3873703+08    .2702774+08    .1519918-05
MASS FLOW POINT   17   =     .48504+01   AREA RATIO =      .1057+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT        ZONE
          AR           H                   H2                H2O          N2              O                OH
          C2
          AA           BB                  GAMMA             CP(BTU/LB)   SUM CI*HI       V**2/2           1-SUM C(I)
17  1     .79425    .12700   1.121  3.938    5265.15     130.839    .27380-01   5804.34   .0000    .000  0   3
        .4575003-02    .2216857-02    .6148966-01    .9097058-00    .4416669-03    .8274670-03    .1962187-01
        .1120219-02
        .4959466-01   -.6794869-01    .1211900+01    .9611790-00   -.2849886+08    .1684518+08    .1445413-05
17  5   1.03385    .25799   1.508  14.951    4892.63     76.605    .17346-01   7516.33  1.3213  286.505  3   3
        .4575003-02    .1752516-02    .6145130-01    .9177094-00    .4416669-03    .4461501-03    .1299223-01
        .6302469-03
        .5353787-01   -.7246808-01    .1214014+01    .9481105-00   -.3996149+08    .2824758+08    .1505017-05
MASS FLOW POINT   18   =     .52162+01   AREA RATIO =      .1069+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT        ZONE
          AR           H                   H2                H2O          N2              O                OH
          C2
          AA           BB                  GAMMA             CP(BTU/LB)   SUM CI*HI       V**2/2           1-SUM C(I)
18  1     .79425    .12700   1.165  3.938    5771.24     130.839    .34088-01   5376.81   .0000    .000  0   2
        .4880000-02    .2015317-02    .1392208-01    .8048514-00    .4711111-03    .1414330-01    .8621553-01
        .7350011-01
        .7636847-01   -.1098904+00    .1197933+01    .7453532-00   -.2367608+08    .1445505+08    .1147389-05
18  1     .78641    .13304   1.165  3.809    5771.24     130.839    .34088-01   5376.81   .0000    .000  0   2
        .4880000-02    .2015317-02    .1392208-01    .8048514-00    .4711111-03    .1414330-01    .8621553-01
        .7350011-01
        .7636847-01   -.1098904+00    .1197933+01    .7453532-00   -.2367608+08    .1445505+08    .1147389-05
18  4     .79492    .13733   1.155  3.522    5785.88     132.499    .34438-01   5334.90   .0000    .000  5   2
        .4880000-02    .2012280-02    .1392786-01    .8046860-00    .4711111-03    .1414270-01    .8648146-01
        .7339744-01
       -.1916827-01    .2550535-01    .1197859+01    .7456249-00   -.3276498+08    .1423055+08    .1147389-05
18  4     .79492    .13733   1.110  3.522    5279.31     132.499    .27657-01   5755.98   .0000    .000  5   3
        .4575003-02    .2204028-02    .6150070-01    .9097180-00    .4416669-03    .8215450-03    .1962895-01
        .1108666-02
        .1764828-01   -.2507171-01    .1211761+01    .9616228-00   -.2819235+08    .1656566+08    .1460314-05
18  5     1.03833    .27469   1.515  15.000    4888.76     75.747    .17171-01   7546.93  1.3239  287.072  3   3
        .4575003-02    .1721453-02    .6146228-01    .9180232-00    .4416669-03    .4297035-03    .1273875-01
        .6064894-03
        .4888825-01   -.6589387-01    .1213983+01    .9479483-00   -.4018528+08    .2847808+08    .1519918-05
MASS FLOW POINT   20   =     .54250+01   AREA RATIO =      .1078+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT        ZONE
          AR           H                   H2                H2O          N2              O                OH
          C2
          AA           BB                  GAMMA             CP(BTU/LB)   SUM CI*HI       V**2/2           1-SUM C(I)
19  1     .77454    .14222   1.165  3.904    5771.24     130.839    .34088-01   5376.81   .0000    .000  0   2
        .4880000-02    .2015317-02    .1392208-01    .8048514-00    .4711111-03    .1414330-01    .8621553-01
        .7350011-01
        .7636847-01   -.1098904+00    .1197933+01    .7453532-00   -.2367608+08    .1445505+08    .1147389-05
19  6     .78047    .13763   1.165  3.857    5771.24     130.839    .34088-01   5376.81   .0000    .000  0   2
        .4880000-02    .2015317-02    .1392208-01    .8048514-00    .4711111-03    .1414330-01    .8621553-01
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		.7340280-01							
		.1160020-02	-.1291256-02	.1197871+01	.7455860-00	-.3277459+08	.1425847+08	.1147389-05	
19	4	.79541	.14511 1.111	3.568 5278.85	132.291	.27617-01	5762.02 .0000	.000 3	3
		.4575003-02	.2199114-02	.6150170-01	.9097772-00	.4416669-03	.8178120-03	.1958342-01	
		.1102696-02							
		.1654146-01	-.2291607-01	.1211753+01	.9616055-00	-.2822609+08	.1660043+08	.1460314-05	
19	5	1.04129	.28575 1.516	15.000 4890.28	75.569	.17129-01	7553.28 1.3256	287.446 3	3
		.4575003-02	.1701419-02	.6147109-01	.9181965-00	.4416669-03	.4199861-03	.1260089-01	
		.5919906-03							
		.4475583-01	-.6041183-01	.1213924+01	.9479917-00	-.4022942+08	.2852602+08	.1519918-05	
19	4	.79590	.15291 1.160	3.699 5779.45	131.601	.34243-01	5357.54 .0000	.000 3	2
		.4880000-02	.2012163-02	.1391954-01	.8048335-00	.4711111-03	.1413319-01	.8634534-01	
		.7340401-01							
		.2172763-01	-.3061346-01	.1197880+01	.7455041-00	-.3287066+08	.1435164+08	.1147389-05	
19	4	.79590	.15291 1.115	3.699 5275.05	131.601	.27495-01	5782.12 .0000	.000 3	3
		.4575003-02	.2194596-02	.6150070-01	.9098644-00	.4416669-03	.8134074-03	.1951185-01	
		.1096963-02							
		.1949209-01	-.2673974-01	.1211771+01	.9614822-00	-.2834420+08	.1671647+08	.1475215-05	
19	5	1.04420	.29661 1.517	15.000 4891.67	75.411	.17091-01	7558.94 1.3273	287.814 3	3
		.4575003-02	.1683230-02	.6147912-01	.9183534-00	.4416669-03	.4112265-03	.1247599-01	
		.5789076-03							
		.4127446-01	-.5572825-01	.1213871+01	.9480318-00	-.4026899+08	.2856878+08	.1519918-05	

MASS FLOW POINT 22 = .57354+01 AREA RATIO = .1090+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / THETA / GAMMA	T (DEG.R) / H2 / CP(BTU/LB)	P (PSI) / H2O / SUM CI*HI	DENSITY / N2 / V**2/2	VELOCITY / O / 1-SUM C(I)	CF / OH	ISP / IT	ZONE
		.76267	.15144 1.165	3.992	5771.24	130.839	.34088-01	5376.81 .0000	.000 0		2
20	1	.4880000-02	.2015317-02	.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01			
		.7350011-01									
		.7636847-01	-.1098904+00	.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05			
20	6	.78149	.15328 1.157	3.707	5782.39	132.069	.34347-01	5345.74 .0000	.000 0		2
		.4880000-02	.2010943-02	.1391972-01	.8048240-00	.4711111-03	.1412834-01	.8638088-01			
		.7338386-01									
20	4	.79642	.16079 1.166	3.876	5774.53	130.667	.34032-01	5381.15 .0000	.000 3		2
		.4880000-02	.2009832-02	.1390707-01	.8050483-00	.4711111-03	.1410927-01	.8618957-01			
		.7338372-01									
		.3753693-01	-.5344502-01	.1197880+01	.7454094-00	-.3301463+08	.1447840+08	.1147389-05			
20	4	.79642	.16079 1.121	3.876	5269.71	130.667	.27329-01	5809.36 .0000	.000 3		3
		.4575003-02	.2189340-02	.6149904-01	.9099745-00	.4416669-03	.8080292-03	.1942049-01			
		.1090438-02									
		.2357230-01	-.3226512-01	.1211800+01	.9613093-00	-.2850510+08	.1687433+08	.1475215-05			
20	5	1.04709	.30738 1.518	15.000	4893.05	75.277	.17058-01	7563.78 1.3290	288.179 3		3
		.4575003-02	.1666519-02	.6148656-01	.9184968-00	.4416669-03	.4032693-03	.1236173-01			
		.5669857-03									
		.3812237-01	-.5148519-01	.1213821+01	.9480725-00	-.4030275+08	.2860539+08	.1534820-05			
20	4	.79697	.16871 1.172	4.078	5769.41	129.588	.33786-01	5408.48 .0000	.000 3		2
		.4880000-02	.2006327-02	.1389061-01	.8053234-00	.4711111-03	.1407668-01	.8600707-01			
		.7334370-01									
		.4880607-01	-.6979551-01	.1197872+01	.7453099-00	-.3318799+08	.1462585+08	.1147389-05			
20	4	.79697	.16871 1.128	4.078	5263.54	129.588	.27137-01	5840.88 .0000	.000 3		3
		.4575003-02	.2183073-02	.6149719-01	.9101038-00	.4416669-03	.8016905-03	.1931328-01			
		.1082831-02									
		.2769304-01	-.3791685-01	.1211832+01	.9611090-00	-.2869189+08	.1705793+08	.1460314-05			
20	5	1.04996	.31809 1.519	15.000	4894.19	75.141	.17026-01	7568.64 1.3307	288.543 3		3
		.4575003-02	.1651167-02	.6149334-01	.9186294-00	.4416669-03	.3960030-03	.1225579-01			
		.5560929-03									
		.3512218-01	-.4770487-01	.1213777+01	.9481050-00	-.4033700+08	.2864217+08	.1534820-05			

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R)	P (PSI) / H2O / CP(BTU/LB)	DENSITY / N2 / SUM CI*HI	VELOCITY / O / V**2/2	CF	ISP / OH / 1-SUM C(I)	IT	ZONE
21	1	.75081 .4880000-02 .7350011-01 .7636847-01	.16068 .2015317-02 -.1098904+00	1.165	4.074 .1392208-01 .1197933+01	5771.24	130.839 .8048514-00 .7453532-00	.34088-01 .4711111-03 -.2367608+08	5376.81 .1414330-01 .1445505+08	.0000	.000 0 .8621553-01 .1147389-05		2
21	6	.78254 .4880000-02 .7333816-01	.16898 .2007226-02	1.165	3.932 .1390003-01	5775.46	130.868 .8051501-00	.34078-01 .4711111-03	5376.08 .1409214-01	.0000	.000 0 .8616008-01		2
21	4	.79756 .4880000-02 .7328802-01	.17673 .2001951-02	1.179	4.295 .1387126-01	5764.27	128.422 .8056410-00	.33518-01 .4711111-03	5438.09 .1403787-01	.0000	.000 3 .8580765-01		2
21	4	.79756 .4575003-02 .1074059-02	.17673 .2175705-02	1.135	4.295 .6149542-01	5256.94	128.422 .9102492-00	.26929-01 .4416669-03	5875.00 .7944485-03	.0000	.000 3 .1919303-01		3
21	5	1.05283 .4575003-02 .5460464-03	.32881 .1636930-02	1.520	15.000 .6149958-01	4895.10	75.003 .9187535-00	.16994-01 .4416669-03	7573.61 .3892962-03	1.3324	288.907 2 .1215648-01		3
21	4	.79818 .4880000-02 .7322184-01	.18477 .1997012-02	1.187	4.521 .1385000-01	5759.11	127.203 .8059865-00	.33236-01 .4711111-03	5469.11 .1399505-01	.0000	.000 3 .8559736-01		2
21	4	.79818 .4575003-02 .1064315-02	.18477 .2167413-02	1.143	4.521 .6149378-01	5250.09	127.203 .9104069-00	.26711-01 .4416669-03	5910.73 .7865019-03	.0000	.000 3 .1906302-01		3
21	5	1.05569 .4575003-02 .5368225-03	.33948 .1623806-02	1.521	15.000 .6150525-01	4895.71	74.855 .9188694-00	.16960-01 .4416669-03	7578.93 .3831252-03	1.3340	289.270 2 .1206339-01		3
		.3052577-01	-.4122519-01		.1213702+01		.9481440-00	-.4041081+08	.2872010+08		.1534820-05		

MASS FLOW POINT 24 = .63445+01 AREA RATIO = .1114+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R)	P (PSI) / H2O / CP(BTU/LB)	DENSITY / N2 / SUM CI*HI	VELOCITY / O / V**2/2	CF	ISP / OH / 1-SUM C(I)	IT	ZONE
22	1	.73894 .4880000-02 .7350011-01 .7636847-01	.16995 .2015317-02 -.1098904+00	1.165	4.148 .1392208-01 .1197933+01	5771.24	130.839 .8048514-00 .7453532-00	.34088-01 .4711111-03 -.2367608+08	5376.81 .1414330-01 .1445505+08	.0000	.000 0 .8621553-01 .1147389-05		2
22	6	.78369 .4880000-02 .7324377-01	.18490 .1999522-02	1.177	4.309 .1386479-01	5765.28	128.777 .8057327-00	.33602-01 .4711111-03	5429.10 .1402231-01	.0000	.000 0 .8578463-01		2
22	4	.79884 .4880000-02 .7314720-01	.19294 .1991628-02	1.194	4.756 .1382725-01	5753.96	125.950 .8063535-00	.32946-01 .4711111-03	5501.09 .1394912-01	.0000	.000 3 .8537900-01		2
22	4	.79884 .4575003-02 .1053638-02	.19294 .2158208-02	1.151	4.756 .6149234-01	5243.11	125.950 .9105754-00	.26486-01 .4416669-03	5947.54 .7779034-03	.0000	.000 3 .1892441-01		3
		.3693181-01	-.5062926-01		.1211932+01		.9604399-00	-.2932816+08	.1768660+08		.1475215-05		

		.2846707-01	-.3844181-01	.1213671+01	.9481532-00	-.4044948+08	.2876058+08	.1534820-05		2
22	4	.79954	.20112 1.202	4.996	5748.75	124.675	.32650-01	5533.74 .0000	.000 3	
		.4880000-02	.1985995-02	.1380358-01	.8067341-00	.4711111-03	.1390138-01		.8515489-01	
		.7306780-01								
		.6699171-01	-.9613169-01	.1197793+01	.7448995-00	-.3400625+08	.1531114+08	.1147389-05		3
22	4	.79954	.20112 1.159	4.996	5236.03	124.675	.26256-01	5985.08 .0000	.000 3	
		.4575003-02	.2148358-02	.6149106-01	.9107514-00	.4416669-03	.7688707-03		.1877986-01	
		.1042316-02								
		.3898581-01	-.5343275-01	.1211964+01	.9602060-00	-.2955398+08	.1791062+08	.1475215-05		3
22	5	1.06141	.36084 1.524	15.000	4896.36	74.550	.16893-01	7589.93 1.3374	289.997 2	
		.4575003-02	.1600212-02	.6151528-01	.9190808-00	.4416669-03	.3720803-03		.1189307-01	
		.5203633-03								
		.2663294-01	-.3595947-01	.1213644+01	.9481535-00	-.4049080+08	.2880352+08	.1549721-05		

MASS FLOW POINT 25 = .66434+01 AREA RATIO = .1127+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA T (DEG.R) / CP(BTU/LB)	P (PSI) / H2O	DENSITY / N2 / SUM CI*HI	VELOCITY / O / V**2/2	CF / OH / 1-SUM C(I)	ISP IT	ZONE
		.72708	.17925 1.165	4.216	5771.24	130.839	.34088-01	5376.81 .0000	.000 0		2
23	1	.4880000-02	.2015317-02	.1392208-01	.8048514-00	.4711111-03	.1414330-01		.8621553-01		
		.7350011-01									
		.7636847-01	-.1098904+00	.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05			2
23	6	.78497	.20108 1.192	4.745	5755.06	126.399	.33053-01	5489.66 .0000	.000 0		
		.4880000-02	.1989467-02	.1382180-01	.8064301-00	.4711111-03	.1393564-01		.8536298-01		
		.7310776-01									2
23	4	.80029	.20944 1.210	5.242	5743.46	123.373	.32346-01	5567.17 .0000	.000 3		
		.4880000-02	.1980101-02	.1377894-01	.8071293-00	.4711111-03	.1385170-01		.8492395-01		
		.7298375-01									
		.6863694-01	-.9848163-01	.1197768+01	.7447932-00	-.3422691+08	.1549670+08	.1147389-05			3
23	4	.80029	.20944 1.167	5.242	5228.81	123.373	.26021-01	6023.51 .0000	.000 3		
		.4575003-02	.2137835-02	.6148992-01	.9109356-00	.4416669-03	.7593807-03		.1862884-01		
		.1030329-02									
		.4059420-01	-.5562883-01	.1211995+01	.9599666-00	-.2978618+08	.1814132+08	.1475215-05			3
23	5	1.06428	.37156 1.525	15.000	4896.36	74.388	.16857-01	7595.82 1.3391	290.362 2		
		.4575003-02	.1589559-02	.6151971-01	.9191781-00	.4416669-03	.3671007-03		.1181434-01		
		.5129747-03									
		.2496341-01	-.3370040-01	.1213621+01	.9481472-00	-.4053408+08	.2884825+08	.1534820-05			2
23	4	.80107	.21777 1.218	5.490	5738.10	122.061	.32040-01	5601.00 .0000	.000 3		
		.4880000-02	.1974072-02	.1375375-01	.8075328-00	.4711111-03	.1380100-01		.8468900-01		
		.7289716-01									
		.6996922-01	-.1003735+00	.1197742+01	.7446852-00	-.3445087+08	.1568558+08	.1162291-05			3
23	4	.80107	.21777 1.176	5.490	5221.50	122.061	.25783-01	6062.36 .0000	.000 3		
		.4575003-02	.2126880-02	.6148891-01	.9111245-00	.4416669-03	.7496343-03		.1847399-01		
		.1017946-02									
		.4186312-01	-.5736369-01	.1212027+01	.9597235-00	-.3002221+08	.1837608+08	.1490116-05			3
23	5	1.06714	.38223 1.526	15.000	4896.15	74.217	.16821-01	7602.00 1.3407	290.726 2		
		.4575003-02	.1579649-02	.6152375-01	.9192701-00	.4416669-03	.3624656-03		.1173976-01		
		.5061211-03									
		.2348108-01	-.3169082-01	.1213601+01	.9481332-00	-.4057975+08	.2889522+08	.1549721-05			

MASS FLOW POINT 26 = .69381+01 AREA RATIO = .1139+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA T (DEG.R) / CP(BTU/LB)	P (PSI) / H2O	DENSITY / N2 / SUM CI*HI	VELOCITY / O / V**2/2	CF / OH / 1-SUM C(I)	ISP IT	ZONE
		.71521	.18857 1.165	4.277	5771.24	130.839	.34088-01	5376.81 .0000	.000 0		2
24	1	.4880000-02	.2015317-02	.1392208-01	.8048514-00	.4711111-03	.1414330-01		.8621553-01		

24	6	.78641	.21757	1.207	5.208	5744.65	123.886	.32469-01	5554.03	.0000	.000 0	2
		.4880000-02	.1978147-02		.1377431-01	.8071936-00		.4711111-03	.1383983-01	.8491373-01		
		.7294814-01										
24	4	.80190	.22624	1.226	5.743	5732.63	120.727	.31729-01	5635.49	.0000	.000 3	2
		.4880000-02	.1967855-02		.1372778-01	.8079480-00		.4711111-03	.1374882-01	.8444798-01		
		.7280729-01										
		.7096699-01	-.1017868+00		.1197715+01	.7445747-00		-.3468013+08	.1587936+08	.1147389-05		
24	4	.80190	.22624	1.184	5.743	5214.05	120.727	.25542-01	6101.94	.0000	.000 3	3
		.4575003-02	.2115417-02		.6148802-01	.9113196-00		.4416669-03	.7395678-03	.1831418-01		
		.1005097-02										
		.4208147-01	-.5874248-01		.1212059+01	.9594748-00		-.3026406+08	.1861684+08	.1505017-05		
24	5	1.07002	.39299	1.528	15.000	4895.76	74.039	.16783-01	7608.45	1.3424	291.092 2	3
		.4575003-02	.1570291-02		.6152750-01	.9193581-00		.4416669-03	.3580866-03	.1166816-01		
		.4936688-03										
		.2213044-01	-.2986119-01		.1213585+01	.9481130-00		-.4062758+08	.2894424+08	.1549721-05		
24	4	.80277	.23473	1.235	5.998	5727.08	119.388	.31415-01	5670.26	.0000	.000 3	2
		.4880000-02	.1961550-02		.1370142-01	.8083693-00		.4711111-03	.1369597-01	.8420373-01		
		.7271576-01										
		.7189229-01	-.1030720+00		.1197687+01	.7444624-00		-.3491220+08	.1607591+08	.1162291-05		
24	4	.80277	.23473	1.193	5.998	5206.52	119.388	.25298-01	6141.82	.0000	.000 3	3
		.4575003-02	.2103664-02		.6148722-01	.9115178-00		.4416669-03	.7293609-03	.1815184-01		
		.9920215-03										
		.4371536-01	-.5985867-01		.1212091+01	.9592224-00		-.3050912+08	.1886096+08	.1505017-05		
24	5	1.07289	.40369	1.529	15.000	4895.19	73.854	.16745-01	7615.16	1.3441	291.457 2	3
		.4575003-02	.1561538-02		.6153094-01	.9194418-00		.4416669-03	.3539838-03	.1159992-01		
		.4936465-03										
		.2092712-01	-.2822966-01		.1213571+01	.9480863-00		-.4067760+08	.2899530+08	.1549721-05		

MASS FLOW POINT 27 = .72284+01 AREA RATIO = .1151+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R)	P (PSI) / H2O / CP(BTU/LB)	DENSITY / N2 / SUM CI*HI	VELOCITY / O / V**2/2	CF	ISP / OH / 1-SUM C(I)	IT	ZONE
25	1	.70334	.19791	1.165	4.332	5771.24	130.839	.34088-01	5376.81	.0000	.000 0		2
		.4880000-02	.2015317-02		.1392208-01	.8048514-00		.4711111-03	.1414330-01	.8621553-01			
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01	.7453532-00		-.2367608+08	.1445505+08	.1147389-05			
25	6	.78801	.23435	1.223	5.689	5734.02	121.294	.31865-01	5620.84	.0000	.000 0		2
		.4880000-02	.1966098-02		.1372401-01	.8079986-00		.4711111-03	.1373866-01	.8444575-01			
		.7277466-01											
25	4	.80370	.24335	1.243	6.258	5721.42	118.030	.31097-01	5705.64	.0000	.000 3		2
		.4880000-02	.1955087-02		.1367437-01	.8088012-00		.4711111-03	.1364185-01	.8395375-01			
		.7262153-01											
		.7266904-01	-.1041355+00		.1197659+01	.7443475-00		-.3514948+08	.1627715+08	.1147389-05			
25	4	.80370	.24335	1.202	6.258	5198.82	118.030	.25051-01	6182.36	.0000	.000 3		3
		.4575003-02	.2091516-02		.6148650-01	.9117208-00		.4416669-03	.7189248-03	.1798549-01			
		.9786124-03											
		.4435875-01	-.6071586-01		.1212124+01	.9589639-00		-.3075978+08	.1911081+08	.1490116-05			
25	5	1.07578	.41448	1.531	15.000	4894.45	73.662	.16705-01	7622.14	1.3458	291.825 2		3
		.4575003-02	.1553228-02		.6153413-01	.9195224-00		.4416669-03	.3500827-03	.1153400-01			
		.4879425-03											
		.1963488-01	-.2674883-01		.1213560+01	.9480539-00		-.4072982+08	.2904848+08	.1549721-05			
25	4	.80467	.25199	1.252	6.518	5715.68	116.670	.30778-01	5741.24	.0000	.000 3		2
		.4880000-02	.1948558-02		.1364699-01	.8092382-00		.4711111-03	.1358720-01	.8370074-01			
		.7252606-01											
		.7356771-01	-.1051053+00		.1197631+01	.7442307-00		-.3538953+08	.1648094+08	.1162291-05			
25		.80467	.25199	1.211	6.518	5191.04	116.670	.24803-01	6223.14	.0000	.000 3		3

25	5	1.07867	.42524	1.532	15.000	4893.54	73.463	.16664-01	7629.38	1.3475	292.192	2
		.4575003-02	.1545409-02		.6153706-01	.9195996-00	.4416669-03	.3464024-03	.1147075-01			
		.4825843-03										
		.1887206-01	-.2543931-01		.1213551+01	.9480156-00	-.4078419+08	.2910370+08	.1564622-05			

MASS FLOW POINT 28 = .75142+01 AREA RATIO = .1164+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF	ISP	IT	ZONE
26	1	.69148	.20726	1.165	4.381	5771.24	130.839	.34088-01	5376.81	.0000	.000	0	2
		.4880000-02	.2015317-02		.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01				
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05				
26	6	.78979	.25143	1.240	6.183	5723.03	118.647	.31245-01	5689.60	.0000	.000	0	2
		.4880000-02	.1953530-02		.1367149-01	.8088375-00	.4711111-03	.1363342-01	.8396004-01				
		.7259175-01											
26	4	.80569	.26076	1.261	6.783	5709.81	115.292	.30455-01	5777.44	.0000	.000	3	2
		.4880000-02	.1941885-02		.1361896-01	.8096853-00	.4711111-03	.1353136-01	.8344209-01				
		.7242817-01											
		.7397453-01	-.1059431+00		.1197602+01	.7441110-00	-.3563490+08	.1668938+08	.1162291-05				
26	4	.80569	.26076	1.220	6.783	5183.08	115.292	.24551-01	6264.56	.0000	.000	3	3
		.4575003-02	.2066509-02		.6148528-01	.9121351-00	.4416669-03	.6977534-03	.1764593-01				
		.9513221-03											
		.4528285-01	-.6192529-01		.1212192+01	.9584324-00	-.3127270+08	.1962236+08	.1505017-05				
26	5	1.08157	.43608	1.534	15.000	4892.48	73.257	.16622-01	7636.90	1.3492	292.562	2	3
		.4575003-02	.1537944-02		.6153979-01	.9196745-00	.4416669-03	.3428795-03	.1140924-01				
		.4774767-03											
		.1798313-01	-.2423650-01		.1213545+01	.9479719-00	-.4084087+08	.2916115+08	.1579523-05				
26	4	.80676	.26955	1.269	7.048	5703.86	113.913	.30130-01	5813.83	.0000	.000	3	2
		.4880000-02	.1935154-02		.1359062-01	.8101372-00	.4711111-03	.1347504-01	.8318059-01				
		.7232915-01											
		.7464941-01	-.1068461+00		.1197573+01	.7439895-00	-.3588310+08	.1690032+08	.1162291-05				
26	4	.80676	.26955	1.229	7.048	5175.02	113.913	.24299-01	6306.18	.0000	.000	3	3
		.4575003-02	.2053710-02		.6148475-01	.9123456-00	.4416669-03	.6870673-03	.1747325-01				
		.9375122-03											
		.4560250-01	-.6233390-01		.1212227+01	.9581590-00	-.3153489+08	.1988396+08	.1519918-05				
26	5	1.08447	.44690	1.536	15.000	4891.27	73.044	.16579-01	7644.69	1.3509	292.931	2	3
		.4575003-02	.1530878-02		.6154231-01	.9197466-00	.4416669-03	.3395334-03	.1134984-01				
		.4726472-03											
		.1721417-01	-.2318823-01		.1213541+01	.9479228-00	-.4089967+08	.2922063+08	.1564622-05				

MASS FLOW POINT 29 = .77954+01 AREA RATIO = .1176+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF	ISP	IT	ZONE
27	1	.67961	.21664	1.169	4.423	5771.24	130.839	.34088-01	5376.81	.0000	.000	0	2
		.4880000-02	.2015317-02		.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01				
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05				
27	6	.79175	.26883	1.256	6.687	5711.65	115.955	.30614-01	5760.03	.0000	.000	0	2
		.4880000-02	.1940530-02		.1361699-01	.8097068-00	.4711111-03	.1352472-01	.8345749-01				
		.7240116-01											
27	4	.80788	.27848	1.278	7.318	5697.78	112.520	.29802-01	5850.76	.0000	.000	3	2
		.4880000-02	.1928288-02		.1356166-01	.8105987-00	.4711111-03	.1341764-01	.8291364-01				
		.7222777-01											
		.7517106-01	-.1075559+00		.1197544+01	.7438651-00	-.3613655+08	.1711572+08	.1177192-05				
					7.318	5166.79	112.520	.24044-01	6348.38	.0000	.000	3	3

		.9235247-03										
		.4585489-01	-.6264223-01	.1212263+01	.9578789-00	-.3180245+08	.2015100+08	.1505017-05				
27	5	1.08739	.45780 1.538	15.000 4889.94	72.824	.16535-01	7652.72 1.3526	293.302 2				3
		.4575003-02	.1524093-02	.6154466-01	.9198169-00	.4416669-03	.3363111-03	.1129179-01				
		.4680164-03										
		.1650926-01	-.2223034-01	.1213539+01	.9478691-00	-.4096049+08	.2928207+08	.1579523-05				
27	4	.80905	.28743 1.287	7.588 5691.63	111.126	.29473-01	5887.89 .0000	.000 3				2
		.4880000-02	.1921371-02	.1353240-01	.8110649-00	.4711111-03	.1335979-01	.8264388-01				
		.7212538-01										
		.7572499-01	-.1083054+00	.1197514+01	.7437387-00	-.3639294+08	.1733361+08	.1162291-05				
27	4	.80905	.28743 1.248	7.588 5158.44	111.126	.23788-01	6390.78 .0000	.000 3				3
		.4575003-02	.2027481-02	.6148388-01	.9127742-00	.4416669-03	.6654672-03	.1712125-01				
		.9095432-03										
		.4606351-01	-.6288649-01	.1212301+01	.9575941-00	-.3207297+08	.2042103+08	.1519918-05				
27	5	1.09031	.46868 1.540	15.000 4888.46	72.593	.16490-01	7661.00 1.3543	293.673 2				3
		.4575003-02	.1517632-02	.6154684-01	.9198851-00	.4416669-03	.3332302-03	.1123539-01				
		.4636088-03										
		.1588524-01	-.2138180-01	.1213539+01	.9478106-00	-.4102336+08	.2934549+08	.1579523-05				

MASS FLOW POINT 30 = .80722+01 AREA RATIO = .1139+01

LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	O		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
28	1	.66774	.22603 1.165		4.460	5771.24	130.839	.34088-01	5376.81	.0000	.000	0	2
		.4880000-02	.2015317-02		.1392208-01		.8048514-00	.4711111-03		.1414330-01	.8621553-01		
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01		.7453532-00	-.2367608+08		.1445505+08	.1147389-05		
28	6	.79390	.28653 1.274		7.201	5699.89	113.229	.29973-01	5831.97	.0000	.000	0	2
		.4880000-02	.1927143-02		.1356066-01		.8106046-00	.4711111-03		.1341287-01	.8293878-01		
		.7220365-01											
28	4	.81028	.29651 1.296		7.862	5685.34	109.720	.29141-01	5925.52	.0000	.000	3	2
		.4880000-02	.1914322-02		.1350254-01		.8115404-00	.4711111-03		.1330088-01	.8236882-01		
		.7202073-01											
		.7620708-01	-.1089456+00		.1197484+01		.7436095-00	-.3665459+08		.1755591+08	.1177192-05		
28	4	.81028	.29651 1.257		7.862	5149.92	109.720	.23529-01	6433.72	.0000	.000	3	3
		.4575003-02	.2014089-02		.6148351-01		.9129919-00	.4416669-03		.6545864-03	.1694229-01		
		.8954301-03											
		.4617486-01	-.6300811-01		.1212339+01		.9573023-00	-.3234877+08		.2069639+08	.1519918-05		
28	5	1.09324	.47965 1.542		15.000	4886.88	72.365	.16443-01	7669.52	1.3561	294.047	2	3
		.4575003-02	.1511391-02		.6154888-01		.9199519-00	.4416669-03		.3302463-03	.1118002-01		
		.4593576-03											
		.1531869-01	-.2061222-01		.1213541+01		.9477480-00	-.4108812+08		.2941075+08	.1579523-05		
28	4	.81156	.30562 1.306		8.136	5678.97	108.314	.28809-01	5963.35	.0000	.000	3	2
		.4880000-02	.1907228-02		.1347238-01		.8120206-00	.4711111-03		.1324156-01	.8209090-01		
		.7191511-01											
		.7671713-01	-.1096286+00		.1197454+01		.7434781-00	-.3691932+08		.1778076+08	.1177192-05		
28	4	.81156	.30562 1.267		8.136	5141.28	108.314	.23270-01	6476.85	.0000	.000	3	3
		.4575003-02	.2000635-02		.6148319-01		.9132102-00	.4416669-03		.6437478-03	.1676273-01		
		.8813603-03											
		.4627677-01	-.6310731-01		.1212379+01		.9570056-00	-.3262763+08		.2097482+08	.1519918-05		
28	5	1.09618	.49060 1.544		15.000	4885.16	72.128	.16396-01	7678.29	1.3578	294.419	3	3
		.4575003-02	.1505413-02		.6155078-01		.9200170-00	.4416669-03		.3273747-03	.1112589-01		
		.4552852-03											
		.1462957-01	-.1994358-01		.1213544+01		.9476807-00	-.4115503+08		.2947808+08	.1579523-05		

MASS FLOW POINT 31 = .83443+01 AREA RATIO = .1202+01

LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE

		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
29	1	.65588	.23543	1.165	4.490	5771.24	130.839	.34088-01	5376.81	.0000	.000 0		2
		.4880000-02	.2015317-02		.1392208-01		.8048514-00	.4711111-03		.1414330-01	.8621553-01		
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01		.7453532-00	-.2367608+08		.1445505+08	.1147389-05		
29	6	.79626	.30454	1.292	7.724	5687.73	110.476	.29323-01	5905.30	.0000	.000 0		2
		.4880000-02	.1913398-02		.1350256-01		.8115297-00	.4711111-03		.1329809-01	.8240430-01		
		.7199964-01											
29	4	.81291	.31486	1.315	8.414	5672.48	106.897	.28473-01	6001.64	.0000	.000 3		2
		.4880000-02	.1900008-02		.1344164-01		.8125097-00	.4711111-03		.1318123-01	.8180787-01		
		.7180727-01											
		.7716293-01	-.1102064+00		.1197424+01		.7433439-00	-.3718921+08		.1800987+08	.1177192-05		
29	4	.81291	.31486	1.276	8.414	5132.46	106.897	.23009-01	6520.49	.0000	.000 3		3
		.4575003-02	.1986980-02		.6148291-01		.9134309-00	.4416669-03		.6328480-03	.1658097-01		
		.8671975-03											
		.4631128-01	-.6311716-01		.1212421+01		.9567017-00	-.3291157+08		.2125839+08	.1534820-05		
29	5	1.09914	.50164	1.546	15.000	4883.35	71.885	.16348-01	7687.24	1.3595	294.795 3		3
		.4575003-02	.1499605-02		.6155258-01		.9200811-00	.4416669-03		.3245791-03	.1107256-01		
		.4513361-03											
		.1437425-01	-.1932531-01		.1213549+01		.9476102-00	-.4122342+08		.2954686+08	.1579523-05		
29	4	.81430	.32413	1.324	8.692	5665.89	105.482	.28138-01	6040.12	.0000	.000 3		2
		.4880000-02	.1892746-02		.1341060-01		.8130033-00	.4711111-03		.1312053-01	.8152197-01		
		.7189852-01											
		.7760877-01	-.1108005+00		.1197394+01		.7432075-00	-.3746225+08		.1824155+08	.1177192-05		
29	4	.81430	.32413	1.286	8.692	5123.52	105.482	.22748-01	6564.30	.0000	.000 3		3
		.4575003-02	.1973287-02		.6148267-01		.9136519-00	.4416669-03		.6220106-03	.1639865-01		
		.8531065-03											
		.4633271-01	-.6310463-01		.1212463+01		.9563926-00	-.3319858+08		.2154503+08	.1534820-05		
29	5	1.10209	.51266	1.548	15.000	4881.43	71.635	.16298-01	7696.46	1.3612	295.170 3		3
		.4575003-02	.1494009-02		.6155425-01		.9201440-00	.4416669-03		.3218731-03	.1102015-01		
		.4475303-03											
		.1398593-01	-.1879406-01		.1213555+01		.9475351-00	-.4129399+08		.2961776+08	.1579523-05		

MASS FLOW POINT 32 = .86117+01 AREA RATIO = .1215+01

LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	0		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
30	1	.64164	.24672	1.163	4.519	5771.24	130.839	.34088-01	5376.81	.0000	.000 0		2
		.4880000-02	.2015317-02		.1392208-01		.8048514-00	.4711111-03		.1414330-01	.8621553-01		
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01		.7453532-00	-.2367608+08		.1445505+08	.1147389-05		
30	6	.79912	.32473	1.312	8.308	5673.89	107.424	.28601-01	5987.46	.0000	.000 0		2
		.4880000-02	.1897845-02		.1343655-01		.8125799-00	.4711111-03		.1316830-01	.8179776-01		
		.7176740-01											
30	4	.81606	.33543	1.336	9.031	5657.87	103.775	.27733-01	6086.78	.0000	.000 3		2
		.4880000-02	.1883862-02		.1337262-01		.8136071-00	.4711111-03		.1304636-01	.8117281-01		
		.7156498-01											
		.7797405-01	-.1112517+00		.1197357+01		.7430407-00	-.3779612+08		.1852446+08	.1192093-05		
30	4	.81606	.33543	1.298	9.031	5112.58	103.775	.22432-01	6617.38	.0000	.000 3		3
		.4575003-02	.1956624-02		.6148244-01		.9139199-00	.4416669-03		.6089393-03	.1617780-01		
		.8361076-03											
		.4611560-01	-.6281568-01		.1212516+01		.9560131-00	-.3354892+08		.2189489+08	.1549721-05		
30	5	1.10567	.52601	1.551	15.000	4879.00	71.329	.16238-01	7707.77	1.3633	295.623 3		3
		.4575003-02	.1487485-02		.6155613-01		.9202182-00	.4416669-03		.3187073-03	.1095810-01		
		.4430994-03											
		.1355057-01	-.1820551-01		.1213564+01		.9474410-00	-.4138064+08		.2970485+08	.1594424-05		
30	4	.81790	.34677	1.347	9.369	5649.71	102.074	.27328-01	6133.65	.0000	.000 3		2
								.4711111-03		.1297178-01	.8081996-01		

		.7841023-01	-.1118019+00	.1197320+01	.7428708-00	-.3813431+08	.1881083+08	.1177192-05					
30	4	.81790	.34677 1.310	9.369	5101.46	102.074	.22117-01	6670.66	.0000	.000 3			3
		.4575003-02	.1939938-02	.6148228-01	.9141876-00	.4416669-03	.5960065-03	.1595674-01					
		.8192590-03											
		.4600490-01	-.6262343-01	.1212572+01	.9556258-00	-.3390343+08	.2224883+08	.1549721-05					
30	5	1.10924	.53935 1.554	15.000	4876.44	71.017	.16176-01	7719.35	1.3654	296.075 3			3
		.4575003-02	.1481193-02	.6155789-01	.9202911-00	.4416669-03	.3156448-03	.1089713-01					
		.4368297-03											
		.1319715-01	-.1772017-01	.1213575+01	.9473420-00	-.4146960+08	.2979416+08	.1594424-05					

MASS FLOW POINT 33 = .89263+01 AREA RATIO = .1230+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF	ISP IT	ZONE
		.62455	.26029 1.165	4.543	5771.24	130.839	.34088-01	5376.81	.0000	.000 0	
31	1	.4880000-02	.2015317-02	.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01			2
		.7350011-01									
		.7636847-01	-.1098904+00	.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05			
31	6	.79556	.34481 1.326	8.714	5664.75	105.281	.28090-01	6045.81	.0000	.000 0	2
		.4880000-02	.1889239-02	.1339809-01	.8131956-00	.4711111-03	.1309424-01	.8142924-01			
		.7164131-01									
31	4	.82024	.36063 1.362	9.780	5639.72	100.023	.26839-01	6190.59	.0000	.000 3	2
		.4880000-02	.1864003-02	.1328722-01	.8149635-00	.4711111-03	.1288055-01	.8038773-01			
		.7126468-01									
		.7875705-01	-.1121996+00	.1197275+01	.7426618-00	-.3854938+08	.1916172+08	.1192093-05			
31	4	.82024	.36063 1.325	9.780	5087.79	100.023	.21735-01	6735.32	.0000	.000 3	3
		.4575003-02	.1919650-02	.6148215-01	.9145121-00	.4416669-03	.5804437-03	.1568842-01			
		.7989873-03									
		.4560107-01	-.6208961-01	.1212641+01	.9551476-00	-.3433767+08	.2268224+08	.1549721-05			
31	5	1.11358	.55555 1.557	15.000	4873.18	70.629	.16100-01	7733.74	1.3679	296.624 3	3
		.4575003-02	.1473836-02	.6155985-01	.9203778-00	.4416669-03	.3120451-03	.1082437-01			
		.4338397-03									
		.1281433-01	-.1720210-01	.1213590+01	.9472159-00	-.4158038+08	.2990537+08	.1609325-05			
31	4	.82269	.37456 1.376	10.189	5629.56	97.985	.26352-01	6247.69	.0000	.000 3	2
		.4880000-02	.1853027-02	.1323971-01	.8157174-00	.4711111-03	.1278890-01	.7995109-01			
		.7109754-01									
		.7938667-01	-.1125961+00	.1197231+01	.7424488-00	-.3896986+08	.1951682+08	.1206994-05			
31	4	.82269	.37456 1.339	10.189	5073.89	97.985	.21356-01	6800.08	.0000	.000 3	3
		.4575003-02	.1899382-02	.6148211-01	.9148353-00	.4416669-03	.5651305-03	.1542091-01			
		.7789969-03									
		.4535226-01	-.6169479-01	.1212713+01	.9546589-00	-.3477693+08	.2312056+08	.1564622-05			
31	5	1.11792	.57173 1.561	15.000	4869.72	70.232	.16022-01	7748.56	1.3705	297.171 3	3
		.4575003-02	.1466721-02	.6156166-01	.9204633-00	.4416669-03	.3085516-03	.1075252-01			
		.4290185-03									
		.1252426-01	-.1680110-01	.1213608+01	.9470827-00	-.4169482+08	.3002012+08	.1609325-05			

MASS FLOW POINT 34 = .92945+01 AREA RATIO = .1250+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF	ISP IT	ZONE
		.60405	.27657 1.165	4.557	5771.24	130.839	.34088-01	5376.81	.0000	.000 0	
32	1	.4880000-02	.2015317-02	.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01			2
		.7350011-01									
		.7636847-01	-.1098904+00	.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05			
32	2	.62681	.28799 1.176	4.777	5769.27	128.89[illegible]	.33614-01	5426.17	.0000	.000 10	2

32	6	.80044	.37502	1.356	9.562	5643.64	100.876	.27042-01	6167.20	.0000	.000 0
		.4880000-02	.1865800-02		.1329780-01	.8147885-00		.4711111-03	.1289887-01	.8050942-01	
		.7128752-01									
32	6	.80650	.37149	1.358	9.651	5641.06	100.502	.26956-01	6177.25	.0000	.000 0
		.4880000-02	.1861726-02		.1328154-01	.8150420-00		.4711111-03	.1286604-01	.8037376-01	
		.7122181-01									
32	4	.82424	.38307	1.384	10.438	5623.37	96.758	.26058-01	6282.32	.0000	.000 3
		.4880000-02	.1846333-02		.1321065-01	.8161780-00		.4711111-03	.1273310-01	.7968474-01	
		.7099485-01									
		.7910856-01	-.1126041+00		.1197204+01	.7423183-00		-.3922673+08	.1973380+08	.1206994-05	
32	4	.82424	.38307	1.348	10.438	5065.40	96.758	.21127-01	6839.33	.0000	.000 3
		.4575003-02	.1887012-02		.6148223-01	.9150304-00		.4416669-03	.5559792-03	.1525924-01	
		.7669756-03									
		.4561125-01	-.6184064-01		.1212758+01	.9543589-00		-.3504491+08	.2338824+08	.1564622-05	
32	5	1.12055	.58155	1.563	15.000	4867.70	69.999	.15976-01	7757.25	1.3720	297.503 3
		.4575003-02	.1462458-02		.6156277-01	.9205140-00		.4416669-03	.3064811-03	.1070987-01	
		.4261546-03									
		.1234970-01	-.1655813-01		.1213618+01	.9470048-00		-.4176205+08	.3008749+08	.1609325-05	
32	4	.82583	.39162	1.393	10.686	5617.12	95.537	.25765-01	6316.96	.0000	.000 3
		.4880000-02	.1839628-02		.1318147-01	.8166404-00		.4711111-03	.1267716-01	.7941709-01	
		.7089191-01									
		.7918890-01	-.1126730+00		.1197177+01	.7421866-00		-.3948500+08	.1995200+08	.1221895-05	
32	4	.82583	.39162	1.357	10.686	5056.84	95.537	.20898-01	6878.56	.0000	.000 3
		.4575003-02	.1874703-02		.6148233-01	.9152250-00		.4416669-03	.5468782-03	.1509778-01	
		.7550702-03									
		.4539876-01	-.6150658-01		.1212804+01	.9540558-00		-.3531402+08	.2365732+08	.1564622-05	
32	5	1.12318	.59138	1.569	15.000	4865.52	69.754	.15928-01	7766.42	1.3735	297.835 3
		.4575003-02	.1458284-02		.6156379-01	.9205649-00		.4416669-03	.3044307-03	.1066697-01	
		.4233371-03									
		.1221561-01	-.1636979-01		.1213631+01	.9469205-00		-.4183313+08	.3015865+08	.1609325-05	
32	6	.80943	.38830	1.375	10.126	5629.05	98.082	.26378-01	6244.95	.0000	.000 0
		.4880000-02	.1848706-02		.1322521-01	.8159358-00		.4711111-03	.1275820-01	.7985650-01	
		.7102353-01									
32	4	.82747	.40019	1.402	10.931	5610.85	94.327	.25475-01	6351.53	.0000	.000 3
		.4880000-02	.1832911-02		.1315220-01	.8171043-00		.4711111-03	.1262115-01	.7914865-01	
		.7078853-01									
		.7922762-01	-.1126793+00		.1197150+01	.7420539-00		-.3974436+08	.2017096+08	.1206994-05	
32	4	.82747	.40019	1.366	10.931	5048.23	94.327	.20672-01	6917.69	.0000	.000 3
		.4575003-02	.1862433-02		.6148245-01	.9154187-00		.4416669-03	.5378779-03	.1493706-01	
		.7432886-03									
		.4513672-01	-.6111467-01		.1212850+01	.9537500-00		-.3558392+08	.2392721+08	.1564622-05	
32	5	1.12582	.60123	1.567	15.000	4863.24	69.503	.15879-01	7775.81	1.3751	298.167 3
		.4575003-02	.1454175-02		.6156476-01	.9206157-00		.4416669-03	.3024045-03	.1062413-01	
		.4205633-03									
		.1210754-01	-.1621547-01		.1213644+01	.9468329-00		-.4190603+08	.3023163+08	.1609325-05	
32	4	.82915	.40879	1.410	11.173	5604.57	93.127	.25186-01	6385.99	.0000	.000 3
		.4880000-02	.1826187-02		.1312284-01	.8175692-00		.4711111-03	.1256510-01	.7887972-01	
		.7068469-01									
		.7918313-01	-.1125748+00		.1197124+01	.7419206-00		-.4000454+08	.2039043+08	.1221895-05	
32	4	.82915	.40879	1.375	11.173	5039.59	93.127	.20447-01	6956.67	.0000	.000 3
		.4575003-02	.1850204-02		.6148262-01	.9156111-00		.4416669-03	.5289866-03	.1477720-01	
		.7316378-03									
		.4486216-01	-.6070098-01		.1212898+01	.9534420-00		-.3585430+08	.2419762+08	.1564622-05	
32	5	1.12846	.61108	1.570	15.000	4860.88	69.247	.15829-01	7785.44	1.3766	298.498 3
		.4575003-02	.1450124-02		.6156567-01	.9206665-00		.4416669-03	.3003982-03	.1058125-01	
		.4178259-03									
		.1201017-01	-.1607937-01		.1213658+01	.9467421-00		-.4198088+08	.3030654+08	.1624227-05	

MASS FLOW POINT 35 = .97245+01 AREA RATIO = .1273+01

		AR	H	H2	H2O	N2	O	OH	
		C2							
		AA	BB	GAMMA	CP(BTU/LB)	SUM CI*HI	V**2/2	1-SUM C(I)	
33	1	.58167	.29434 1.165	4.553 5771.24	130.839	.34088-01	5376.81 .0000	.000 0	2
		.4880000-02	.2015317-02	.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01	
		.7350011-01							
		.7636847-01	-.1098904+00	.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05	
33	2	.60655	.30689 1.181	4.889 5765.65	128.124	.33439-01	5445.65 .0000	.000 10	2
		.4880000-02	.2001821-02	.1387212-01	.8056201-00	.4711111-03	.1403855-01	.8583475-01	
		.7328038-01							
		.3917367-01	-.5642593-01	.1197851+01	.7452347-00	-.2395660+08	.1482753+08	.1162291-05	
33	6	.80674	.41043 1.391	10.537 5618.47	95.867	.25844-01	6308.04 .0000	.000 0	2
		.4880000-02	.1838232-02	.1317883-01	.8166751-00	.4711111-03	.1266928-01	.7941990-01	
		.7086643-01							
33	6	.81270	.40614 1.393	10.624 5616.26	95.565	.25775-01	6316.19 .0000	.000 0	2
		.4880000-02	.1834906-02	.1316525-01	.8168860-00	.4711111-03	.1264314-01	.7930685-01	
		.7081152-01							
33	4	.83106	.41836 1.420	11.441 5597.70	91.823	.24872-01	6423.66 .0000	.000 3	2
		.4880000-02	.1818723-02	.1309034-01	.8180830-00	.4711111-03	.1250310-01	.7858369-01	
		.7056881-01							
		.7884113-01	-.1120369+00	.1197094+01	.7417746-00	-.4029106+08	.2063173+08	.1221895-05	
33	4	.83106	.41836 1.385	11.441 5030.10	91.823	.20202-01	6999.25 .0000	.000 3	3
		.4575003-02	.1836702-02	.6148290-01	.9158222-00	.4416669-03	.5192742-03	.1460185-01	
		.7188944-03							
		.4438386-01	-.6004251-01	.1212951+01	.9531024-00	-.3615137+08	.2449478+08	.1579523-05	
33	5	1.13138	.62197 1.572	15.000 4858.33	68.970	.15774-01	7795.85 1.3783	298.864 3	3
		.4575003-02	.1445686-02	.6156669-01	.9207217-00	.4416669-03	.2982124-03	.1053455-01	
		.4148455-03							
		.1187665-01	-.1590135-01	.1213673+01	.9466439-00	-.4206191+08	.3038766+08	.1624227-05	
33	4	.83303	.42796 1.429	11.704 5590.85	90.538	.24562-01	6461.06 .0000	.000 3	2
		.4880000-02	.1811285-02	.1305787-01	.8185961-00	.4711111-03	.1244137-01	.7828842-01	
		.7045268-01							
		.7843317-01	-.1114159+00	.1197064+01	.7416283-00	-.4057728+08	.2087262+08	.1221895-05	
33	4	.83303	.42796 1.395	11.704 5020.60	90.538	.19959-01	7041.49 .0000	.000 3	3
		.4575003-02	.1823272-02	.6148325-01	.9160310-00	.4416669-03	.5097247-03	.1442816-01	
		.7063393-03							
		.4397283-01	-.5944070-01	.1213004+01	.9527615-00	-.3644778+08	.2479129+08	.1579523-05	
33	5	1.13430	.63287 1.575	15.000 4855.69	68.688	.15719-01	7806.50 1.3800	299.230 3	3
		.4575003-02	.1441302-02	.6156766-01	.9207769-00	.4416669-03	.2960500-03	.1048788-01	
		.4119030-03							
		.1178631-01	-.1577379-01	.1213689+01	.9465422-00	-.4214488+08	.3047069+08	.1624227-05	
33	6	.81633	.42503 1.411	11.140 5602.76	92.960	.25151-01	6390.58 .0000	.000 0	2
		.4880000-02	.1820368-02	.1310186-01	.8178893-00	.4711111-03	.1252211-01	.7872734-01	
		.7058672-01							
33	4	.83505	.43759 1.438	11.961 5584.03	89.274	.24257-01	6498.08 .0000	.000 3	2
		.4880000-02	.1803874-02	.1302548-01	.8191074-00	.4711111-03	.1237993-01	.7799447-01	
		.7033651-01							
		.7797304-01	-.1107093+00	.1197035+01	.7414824-00	-.4086250+08	.2111251+08	.1236796-05	
33	4	.83505	.43759 1.404	11.961 5011.14	89.274	.19721-01	7083.28 .0000	.000 3	3
		.4575003-02	.1809930-02	.6148367-01	.9162375-00	.4416669-03	.5003398-03	.1425631-01	
		.6939827-03							
		.4350011-01	-.5876507-01	.1213058+01	.9524205-00	-.3674277+08	.2508642+08	.1579523-05	
33	5	1.13722	.64378 1.578	15.000 4852.95	68.399	.15662-01	7817.41 1.3817	299.595 3	3
		.4575003-02	.1436968-02	.6156859-01	.9208322-00	.4416669-03	.2939047-03	.1044109-01	
		.4089925-03							
		.1172385-01	-.1568150-01	.1213706+01	.9464368-00	-.4223013+08	.3055598+08	.1624227-05	
33	4	.83712	.44726 1.448	12.211 5577.26	88.034	.23956-01	6534.67 .0000	.000 3	2

33	4	.83712	.44726	1.414	12.211	5001.73	88.034	.19487-01	7124.55	.0000	.000	3	3
		.4575003-02	.1796683-02		.6148416-01	.9164414-00	.4416669-03	.4911252-03	.1408652-01				
		.6818317-03											
		.4300288-01	-.5805304-01		.1213112+01	.9520800-00	-.3703579+08	.2537962+08	.1594424-05				
33	5	1.14015	.65472	1.580	15.000	4850.11	68.103	.15605-01	7828.62	1.3833	299.961	3	3
		.4575003-02	.1432674-02		.6156946-01	.9208876-00	.4416669-03	.2917719-03	.1039408-01				
		.4061078-03											
		.1167545-01	-.1561011-01		.1213725+01	.9463272-00	-.4231781+08	.3064367+08	.1639128-05				

MASS FLOW POINT 36 = .10178+02 AREA RATIO = .1300+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF	ISP	IT	ZONE
34	1	.56233	.30969	1.169	4.536	5771.24	130.839	.34088-01	5376.81	.0000	.000	0	2
		.4880000-02	.2015317-02		.1392208-01	.8048514-00	.4711111-03	.1414330-01	.8621553-01				
		.7350011-01											
		.7636847-01	-.1098904+00		.1197933+01	.7453532-00	-.2367608+08	.1445505+08	.1147389-05				
34	6	.81361	.44584	1.425	11.480	5593.32	91.077	.24692-01	6445.71	.0000	.000	0	2
		.4880000-02	.1811006-02		.1306023-01	.8185515-00	.4711111-03	.1244290-01	.7833754-01				
		.7044455-01											
34	4	.84087	.46431	1.463	12.641	5565.66	85.928	.23445-01	6597.36	.0000	.000	3	2
		.4880000-02	.1783696-02		.1293729-01	.8204974-00	.4711111-03	.1221317-01	.7719856-01				
		.7001760-01											
		.7609604-01	-.1078929+00		.1196954+01	.7410871-00	-.4163654+08	.2176257+08	.1236796-05				
34	4	.84087	.46431	1.430	12.641	4985.46	85.928	.19087-01	7195.20	.0000	.000	3	3
		.4575003-02	.1773857-02		.6148511-01	.9167913-00	.4416669-03	.4753904-03	.1379496-01				
		.6611103-03											
		.4148089-01	-.5613017-01		.1213206+01	.9514890-00	-.3754119+08	.2588545+08	.1594424-05				
34	5	1.14529	.67387	1.585	15.000	4845.15	67.591	.15504-01	7848.09	1.3863	300.600	3	3
		.4575003-02	.1425225-02		.6157098-01	.9209838-00	.4416669-03	.2880821-03	.1031253-01				
		.4011300-03											
		.1152959-01	-.1542426-01		.1213757+01	.9461362-00	-.4247036+08	.3079629+08	.1654029-05				
34	4	.84478	.48146	1.479	13.047	5554.34	83.908	.22953-01	6658.24	.0000	.000	3	2
		.4880000-02	.1771107-02		.1288219-01	.8213636-00	.4711111-03	.1210958-01	.7670510-01				
		.6981608-01											
		.7446160-01	-.1055122+00		.1196903+01	.7408418-00	-.4211793+08	.2216606+08	.1251698-05				
34	4	.84478	.48146	1.446	13.047	4969.50	83.903	.18703-01	7263.72	.0000	.000	3	3
		.4575003-02	.1751371-02		.6148639-01	.9171308-00	.4416669-03	.4603023-03	.1351181-01				
		.6411053-03											
		.4042590-01	-.5464824-01		.1213300+01	.9509051-00	-.3803653+08	.2638084+08	.1594424-05				
34	5	1.15044	.69308	1.590	15.000	4839.97	67.065	.15401-01	7868.18	1.3892	301.239	3	3
		.4575003-02	.1417845-02		.6157243-01	.9210802-00	.4416669-03	.2844294-03	.1023059-01				
		.3962095-03											
		.1147464-01	-.1534241-01		.1213792+01	.9459360-00	-.4262823+08	.3095410+08	.1654029-05				

MASS FLOW POINT 37 = .10554+02 AREA RATIO = .1324+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF	ISP	IT	ZONE
35	1	.56233	.30969	1.204	4.536	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		.4758002-02	.2637667-02		.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01				
		.1738295-01											
		.7488028-01	-.1065767+00		.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05				
35	1	.53693	.33155	1.204	4.353	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		.4758002-02	.2637667-02		.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01				
		.1738295-01											
		.7488028-01	-.1065767+00		.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05				

		.4758002-02	.2605790-02	.2844013-01	.8837883-00	.4593335-03	.5979906-02	.5720332-01				
		.1676389-01										
		.5207090-01	-.7422127-01	.1200557+01	.8344803-00	-.2591028+08	.1796705+08	.1311302-05				
35	4	.56556	.34814 1.194	5.061 5756.06	126.011	.32953-01	5499.52 .0000	.000 10				2
		.4880000-02	.1993206-02	.1383451-01	.8062338-00	.4711111-03	.1396305-01	.8545603-01				
		.7316715-01										
		.5385472-01	-.7717424-01	.1197821+01	.7450452-00	-.2427095+08	.1512236+08	.1147389-05				
35	6	.80604	.47657 1.442	11.827 5580.88	88.795	.24140-01	6512.96 .0000	.000 0				2
		.4880000-02	.1796968-02	.1299945-01	.8195094-00	.4711111-03	.1232726-01	.7779134-01				
		.7022329-01										2
35	6	.82807	.48085 1.464	12.553 5563.99	85.823	.23424-01	6600.42 .0000	.000 0				
		.4880000-02	.1778468-02	.1291817-01	.8207881-00	.4711111-03	.1217475-01	.7706055-01				
		.6992770-01										2
35	4	.84781	.49440 1.490	13.329 5546.13	82.453	.22599-01	6702.38 .0000	.000 3				
		.4880000-02	.1761789-02	.1284146-01	.8220024-00	.4711111-03	.1203328-01	.7634349-01				
		.6966529-01										
		.7290086-01	-.1032915+00	.1196865+01	.7406630-00	-.4247033+08	.2246094+08	.1236796-05				3
35	4	.84781	.49440 1.458	13.329 4957.86	82.453	.18427-01	7313.36 .0000	.000 3				
		.4575003-02	.1734675-02	.6148765-01	.9173781-00	.4416669-03	.4493988-03	.1330543-01				
		.6265492-03										
		.3989118-01	-.5376493-01	.1213369+01	.9504770-00	-.3839813+08	.2674261+08	.1594424-05				3
35	5	1.15431	.70754 1.594	15.000 4835.88	66.657	.15321-01	7883.80 1.3914	301.719 3				
		.4575003-02	.1412338-02	.6157345-01	.9211532-00	.4416669-03	.2817023-03	.1016852-01				
		.3925429-03										
		.1149835-01	-.1535551-01	.1213820+01	.9457782-00	-.4275139+08	.3107717+08	.1654029-05				2
35	4	.85092	.50738 1.501	13.595 5538.16	81.065	.22258-01	6745.19 .0000	.000 3				
		.4880000-02	.1752622-02	.1280147-01	.8226288-00	.4711111-03	.1195845-01	.7599020-01				
		.6951611-01										
		.7132443-01	-.1010060+00	.1196827+01	.7404886-00	-.4281439+08	.2274877+08	.1236796-05				3
35	4	.85092	.50738 1.469	13.595 4946.53	81.065	.18160-01	7361.45 .0000	.000 3				
		.4575003-02	.1718267-02	.6148902-01	.9176190-00	.4416669-03	.4388076-03	.1310422-01				
		.6124188-03										
		.3898855-01	-.5250064-01	.1213436+01	.9500583-00	-.3875048+08	.2709550+08	.1609325-05				3
35	5	1.15820	.72205 1.598	15.000 4831.58	66.234	.15239-01	7900.03 1.3937	302.199 3				
		.4575003-02	.1406851-02	.6157440-01	.9212270-00	.4416669-03	.2789693-03	.1010558-01				
		.3888871-03										
		.1152179-01	-.1537707-01	.1213851+01	.9456122-00	-.4287951+08	.3120520+08	.1654029-05				
35	6	.83390	.50644 1.487	13.118 5547.17	82.856	.22699-01	6690.28 .0000	.000 0				2
		.4880000-02	.1760056-02	.1283720-01	.8220616-00	.4711111-03	.1202296-01	.7633292-01				
		.6963297-01										2
35	4	.85410	.52042 1.512	13.841 5530.45	79.729	.21931-01	6786.58 .0000	.000 3				
		.4880000-02	.1743627-02	.1276226-01	.8232419-00	.4711111-03	.1188526-01	.7564599-01				
		.6936865-01										
		.6960316-01	-.9852949-01	.1196789+01	.7403194-00	-.4314950+08	.2302885+08	.1236796-05				3
35	4	.85410	.52042 1.481	13.841 4935.53	79.729	.17904-01	7407.93 .0000	.000 3				
		.4575003-02	.1702141-02	.6149054-01	.9178531-00	.4416669-03	.4285710-03	.1290871-01				
		.5987234-03										
		.3803013-01	-.5117241-01	.1213502+01	.9496497-00	-.3909305+08	.2743869+08	.1609325-05				3
35	5	1.16210	.73662 1.602	15.000 4827.10	65.800	.15154-01	7916.78 1.3959	302.679 3				
		.4575003-02	.1401367-02	.6157530-01	.9213017-00	.4416669-03	.2762307-03	.1004183-01				
		.3852351-03										
		.1156119-01	-.1542103-01	.1213883+01	.9454391-00	-.4301210+08	.3133768+08	.1654029-05				2
35	4	.85736	.53350 1.522	14.068 5523.04	78.454	.21617-01	6826.44 .0000	.000 3				
		.4880000-02	.1734815-02	.1272394-01	.8238400-00	.4711111-03	.1181385-01	.7531197-01				
		.6922312-01										
		.6711121-01	-.9583189-01	.1196752+01	.7401561-00	-.4347449+08	.2330017+08	.1236796-05				3
35	4	.85736	.53350 1.491	14.068 4924.90	78.454	.17659-01	7452.64 .0000	.000 3				
						.4616669-03	.4186967-03	.1271922-01				

35	5	1.16601	.75122	1.606	15.000	4822.47	65.355	.15067-01	7933.97	1.3981	303.159	3	3
		.4575003-02	.1395873-02		.6157617-01	.9213772-00	.4416669-03	.2734864-03	.9977352-02				
		.3815837-03											
		.1161029-01	-.1547894-01		.1213917+01	.9452596-00	-.4314853+08	.3147398+08	.1668930-05				
MASS FLOW POINT 39 = .11025+02 AREA RATIO = .1360+01													
LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	O		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
36	1	.51456	.35074	1.204	4.280	5668.06	130.859	.30637-01	5869.35	.0000	.000	0	1
		.4758002-02	.2637667-02		.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01				
		.1708295-01											
		.7488028-01	-.1065767+00		.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05				
36	4	.56879	.38298	1.255	5.537	5636.78	122.142	.28810-01	6095.99	.0000	.000	6	1
		.4758002-02	.2579497-02		.2837591-01	.8849794-00	.4593335-03	.5863419-02	.5648162-01				
		.1650153-01											
		.4749298-01	-.6762085-01		.1200494+01	.8341084-00	-.2649887+08	.1858056+08	.1311302-05				
36	4	.56879	.38298	1.217	5.537	5741.38	122.142	.32048-01	5598.90	.0000	.000	6	2
		.4880000-02	.1974396-02		.1375796-01	.8074496-00	.4711111-03	.1380784-01	.8476951-01				
		.7288846-01											
		.5057518-01	-.7242074-01		.1197732+01	.7447481-00	-.2481710+08	.1567387+08	.1147389-05				
36	6	.83369	.53591	1.506	13.506	5534.00	80.472	.22113-01	6764.02	.0000	.000	0	2
		.4880000-02	.1746221-02		.1277542-01	.8230330-00	.4711111-03	.1190825-01	.7577463-01				
		.6941016-01											
36	6	.83964	.53063	1.507	13.603	5532.43	80.274	.22067-01	6769.63	.0000	.000	0	2
		.4880000-02	.1743250-02		.1276363-01	.8232139-00	.4711111-03	.1188564-01	.7568216-01				
		.6935910-01											
36	4	.86026	.54500	1.530	14.258	5517.16	77.419	.21362-01	6859.06	.0000	.000	3	2
		.4880000-02	.1727204-02		.1269140-01	.8243458-00	.4711111-03	.1175297-01	.7503440-01				
		.6909586-01											
		.6540598-01	-.9259133-01		.1196718+01	.7400254-00	-.4374319+08	.2352337+08	.1236796-05				
36	4	.86026	.54500	1.500	14.258	4916.26	77.419	.17459-01	7489.20	.0000	.000	3	3
		.4575003-02	.1672597-02		.6149404-01	.9182705-00	.4416669-03	.4103704-03	.1255999-01				
		.5742214-03											
		.3611128-01	-.4851702-01		.1213616+01	.9489293-00	-.3969708+08	.2804409+08	.1624227+05				
36	5	1.16941	.76391	1.610	15.000	4818.83	65.001	.14997-01	7947.72	1.4000	303.574	3	3
		.4575003-02	.1391031-02		.6157710-01	.9214410-00	.4416669-03	.2711333-03	.9923044-02				
		.3784294-03											
		.1155695-01	-.1541184-01		.1213943+01	.9451182-00	-.4325770+08	.3158316+08	.1668930-05				
36	4	.86321	.55654	1.538	14.433	5511.50	76.431	.21118-01	6890.41	.0000	.000	3	2
		.4880000-02	.1719812-02		.1265976-01	.8248366-00	.4711111-03	.1169401-01	.7476635-01				
		.6897116-01											
		.6327725-01	-.8955833-01		.1196684+01	.7398993-00	-.4400252+08	.2373889+08	.1236796-05				
36	4	.86321	.55654	1.508	14.433	4907.95	76.431	.17268-01	7524.32	.0000	.000	3	3
		.4575003-02	.1659161-02		.6149594-01	.9184552-00	.4416669-03	.4023275-03	.1240574-01				
		.5633318-03											
		.3513706-01	-.4718532-01		.1213665+01	.9486166-00	-.3995997+08	.2830773+08	.1609325-05				
36	5	1.17282	.77662	1.613	15.000	4815.09	64.641	.14926-01	7961.74	1.4019	303.990	3	3
		.4575003-02	.1386203-02		.6157800-01	.9215049-00	.4416669-03	.2687889-03	.9868510-02				
		.3752877-03											
		.1154845-01	-.1539330-01		.1213970+01	.9449729-00	-.4336919+08	.3169462+08	.1654029-05				
36	6	.84524	.55340	1.525	14.010	5519.79	78.074	.21526-01	6838.36	.0000	.000	0	2
		.4880000-02	.1728143-02		.1269791-01	.8242388-00	.4711111-03	.1176337-01	.7511065-01				
		.6910878-01											
36	4	.86630	.56811	1.546	14.592	5506.07	75.469	.20884-01	6920.50	.0000	.000	3	2
		.4880000-02	.1712631-02		.1262905-01	.8253122-00	.4711111-03	.1163689-01	.7450759-01				
		.6884929-01											
		[illegible]	[illegible]		[illegible]	[illegible]	-.4425251+08	.2394666+08	.1251698-05				

		,4575003-02	.1645998-02	.6149796-01	.9186339-00	.4416669-03	.3945704-03	.1225649-01					
		,5528001-03											
		,3417573-01	-.4587044-01	.1213711+01	.9483151-00	-.4021324+08	.2856176+08	.1624227-05					
36	5	1.17624	,78937 1.617	15.000	4811.25	64.275	.14854-01	7976.04 1.4038	304.405 3				3
		,4575003-02	.1381386-02	.6157888-01	.9215692-00	.4416669-03	.2664490-03	.9813616-02					
		,3721559-03											
		.1155069-01	-.1538916-01	.1213998+01	.9448232-00	-.4348326+08	.3180864+08	.1668930-05					
36	4	.86924	,57971 1.553	14.736	5500.90	74.593	.20662-01	6949.30 .0000	.000 3				2
		,4880000-02	.1705697-02	.1259929-01	.8257725-00	.4711111-03	.1158160-01	.7425835-01					
		,6873027-01											
		,5911309-01	-.8363223-01	.1196619+01	.7396620-00	-.4449284+08	.2414636+08	.1251698-05					
36	4	.86924	,57971 1.524	14.736	4892.34	74.593	.16911-01	7590.23 .0000	.000 3				3
		,4575003-02	.1633112-02	.6150007-01	.9188065-00	.4416669-03	.3870955-03	.1211228-01					
		,5426229-03											
		,3320421-01	-.4454965-01	.1213755+01	.9480256-00	-.4045653+08	.2880581+08	.1624227-05					
36	5	1.17968	,80215 1.620	15.000	4807.31	63.903	.14781-01	7990.60 1.4057	304.820 3				3
		,4575003-02	.1376575-02	.6157973-01	.9216338-00	.4416669-03	.2641133-03	.9758410-02					
		,3690334-03											
		,1155176-01	-.1538641-01	.1214027+01	.9446697-00	-.4359955+08	.3192488+08	.1683831-05					

MASS FLOW POINT 40 = .11420+02 AREA RATIO = .1392+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH	THETA / H2 / GAMMA	T (DEG.R)	P (PSI) / H2O / CP(BTU/LB)	DENSITY / N2 / SUM CI*HI	VELOCITY / O / V**2/2	CF	ISP / OH / 1-SUM C(I)	IT	ZONE
		,49219	,36610	1.204	4.193	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		,4758002-02	.2637667-02		.2851504-01		.8823969-00	.4593335-03		.6120145-02		.5802866-01	
		,1708295-01											
		,7488028-01	-.1065767+00		.1200649+01		.8348638-00	-.2741878+08		.1722461+08		.1311302-05	
37	4	.57198	,41457 1.279		6.006	5619.64	118.338	.28017-01	6196.92	.0000	.000	4	1
		,4758002-02	.2554184-02		.2831153-01		.8861704-00	.4593335-03		.5749577-02		.5574636-01	
		,1624931-01											
		,5138061-01	-.7304949-01		.1200444+01		.8336954-00	-.2711280+08		.1920088+08		.1311302-05	
37	4	.57198	,41457 1.241		6.006	5725.36	118.338	.31159-01	5697.64	.0000	.000	4	2
		,4880000-02	.1955922-02		.1368101-01		.8086787-00	.4711111-03		.1365335-01		.8405880-01	
		,7261995-01											
		,5562460-01	-.7956381-01		.1197651+01		.7444239-00	-.2538972+08		.1623157+08		.1147389-05	
37	6	.84432	,57899 1.538		14.243	5510.60	76.413	.21114-01	6891.29	.0000	.000	0	2
		,4880000-02	.1718617-02		.1265506-01		.8249117-00	.4711111-03		.1168433-01		.7472401-01	
		,6895396-01											
													2
37	4	.87476	,60053 1.566		14.970	5492.18	73.093	.20289-01	6997.98	.0000	.000	3	
		,4880000-02	.1693897-02		.1254901-01		.8265494-00	.4711111-03		.1148845-01		.7383825-01	
		,6852861-01											
		,5576563-01	-.7882363-01		.1196565+01		.7394659-00	-.4489917+08		.2448583+08		.1266599-05	
37	4	.87476	,60053 1.537		14.970	4879.41	73.093	.16619-01	7644.66	.0000	.000	3	3
		,4575003-02	.1611114-02		.6150383-01		.9190991-00	.4416669-03		.3744759-03		.1186779-01	
		,5254627-03											
		,3122906-01	-.4198563-01		.1213830+01		.9475331-00	-.4086895+08		.2922041+08		.1624227-05	
37	5	1.18578	,82499 1.627		15.000	4800.37	63.252	.14653-01	8016.22	1.4092	305.559	3	3
		,4575003-02	.1367980-02		.6158130-01		.9217484-00	.4416669-03		.2599699-03		.9660509-02	
		,3634978-03											
		,1146959-01	-.1528945-01		.1214078+01		.9443988-00	-.4380474+08		.3212993+08		.1683831-05	
37	4	.88059	,62143 1.577		15.156	5484.30	71.731	.19949-01	7042.64	.0000	.000	3	2
		,4860000-02	.1682760-02		.1250167-01		.8272785-00	.4711111-03		.1140095-01		.7344838-01	
		,6833544-01											
		,5221958-01	-.7380227-01		.1196512+01		.7392875-00	-.4527502+08		.2479942+08		.1251698-05	
37	4	.88059	,62143 1.549		15.156	4867.58	71.731	.16353-01	7694.56	.0000	.000	3	3

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37  5   1.19192     .84790   1.633   15.000    4793.22     62.590     .14523-01   8042.40  1.4126  306.297  3
      .4575003-02     .1359394-02     .6158284-01     .9218634-00     .4416669-03     .2558582-03     .9562131-02
      .3579985-03
      .1145886-01    -.1526891-01     .1214132+01     .9441188-00    -.4401513+08     .3234006+08     .1683831-05
MASS FLOW POINT   41  =      .11791+02   AREA RATIO =      .1421+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT
          AR           H                   H2                H2O         N2            O                 OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)   SUM CI*HI      V**2/2          1-SUM C(I)
38  1     .46981     .37659   1.204    4.093    5668.06    130.839     .30637-01   5869.35   .0000     .000  0
      .4758002-02     .2637667-02     .2851504-01     .8823969-00     .4593335-03     .6120145-02     .5802866-01
      .1708295-01
      .7488028-01    -.1065767+00     .1200649+01     .8348638-00    -.2741878+08     .1722461+08     .1311302-05
38  4     .57492     .44157   1.300    6.421    5603.34    114.864     .27290-01   6290.16   .0000     .000  4
      .4758002-02     .2531097-02     .2825215-01     .8872681-00     .4593335-03     .5645800-02     .5506523-01
      .1601899-01
      .5570500-01    -.7906382-01     .1200403+01     .8333010-00    -.2768520+08     .1978307+08     .1311302-05
38  4     .57492     .44157   1.263    6.421    5710.24    114.864     .30345-01   5788.80   .0000     .000  4
      .4880000-02     .1939018-02     .1360984-01     .8098159-00     .4711111-03     .1351158-01     .8339793-01
      .7237352-01
      .6046769-01    -.8642827-01     .1197579+01     .7441165-00    -.2592433+08     .1675510+08     .1162291-05
38  6     .96344     .62368   1.571   14.927    5486.88     72.460     .20135-01   7018.68   .0000     .000  0
      .4880000-02     .1686510-02     .1251783-01     .8270319-00     .4711111-03     .1143041-01     .7357811-01
      .6840294-01
38  4     .88524     .63928   1.587   15.274    5478.20     70.674     .19685-01   7077.66   .0000     .000  3
      .4880000-02     .1673724-02     .1246350-01     .8278645-00     .4711111-03     .1133047-01     .7313838-01
      .6817704-01
      .4919713-01    -.6953518-01     .1196468+01     .7391486-00    -.4557195+08     .2504665+08     .1266599-05
38  4     .88524     .63928   1.559   15.274    4858.36     70.674     .16145-01   7733.65   .0000     .000  3
      .4575003-02     .1572453-02     .6151171-01     .9195926-00     .4416669-03     .3533422-03     .1145523-01
      .4963837-03
      .2843743-01    -.3814465-01     .1213948+01     .9467242-00    -.4155000+08     .2990463+08     .1639128-05
38  5   1.19718     .86753   1.639   15.000    4786.79     62.006     .14408-01   8065.62  1.4155  306.925  2
      .4575003-02     .1352085-02     .6158408-01     .9219627-00     .4416669-03     .2523593-03     .9477100-02
      .3533273-03
      .1151953-01    -.1532952-01     .1214181+01     .9438667-00    -.4420243+08     .3252710+08     .1683831-05
38  4     .89014     .65717   1.595   15.361    5472.63     69.703     .19441-01   7110.06   .0000     .000  3
      .4880000-02     .1665158-02     .1242747-01     .8284163-00     .4711111-03     .1126403-01     .7284898-01
      .6802571-01
      .4628348-01    -.6541563-01     .1196425+01     .7390210-00    -.4584783+08     .2527650+08     .1251698-05
38  4     .89014     .65717   1.567   15.361    4849.89     69.703     .15954-01   7769.79   .0000     .000  3
      .4575003-02     .1555631-02     .6151559-01     .9198002-00     .4416669-03     .3444763-03     .1128175-01
      .4841197-03
      .2715880-01    -.3640652-01     .1213993+01     .9463959-00    -.4182870+08     .3018480+08     .1639128-05
38  5   1.20245     .88720   1.645   15.000    4780.19     61.415     .14291-01   8089.26  1.4183  307.552  2
      .4575003-02     .1344772-02     .6158530-01     .9220626-00     .4416669-03     .2488655-03     .9391486-02
      .3486732-03
      .1155207-01    -.1536307-01     .1214232+01     .9436077-00    -.4439362+08     .3271808+08     .1683831-05
MASS FLOW POINT   42  =      .12139+02   AREA RATIO =      .1446+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT
          AR           H                   H2                H2O         N2            O                 OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)   SUM CI*HI      V**2/2          1-SUM C(I)
39  1     .44744     .38660   1.204    3.980    5668.06    130.839     .30637-01   5869.35   .0000     .000  0
      .4758002-02     .2637667-02     .2851504-01     .8823969-00     .4593335-03     .6120145-02     .5802866-01
      .1708295-01
      .7488028-01    -.1065767+00     .1200649+01     .8348638-00    -.2741878+08     .1722461+08     .1311302-05
```

		.4758002-02	.2506855-02	.2819040-01	.8884111-00	.4593335-03	.5537883-02	.5435790-01				
		.1577718-01										
		.5797011-01	-.8219142-01	.1200359+01	.8328930-00	-.2827623+08	.2038996+08	.1311302-05				
39	4	.57809	.46881 1.286	6.837 5694.75	111.338	.29515-01	5882.34 .0000	.000 4				2
		.4880000-02	.1921312-02	.1353539-01	.8110020-00	.4711111-03	.1336381-01	.8271321-01				
		.7211204-01										
		.6286754-01	-.8980811-01	.1197502+01	.7437993-00	-.2647670+08	.1730095+08	.1177192-05				
39	6	.87298	.65914 1.591	15.195 5473.55	70.195	.19569-01	7093.57 .0000	.000 0				2
		.4880000-02	.1668410-02	.1244014-01	.8282295-00	.4711111-03	.1128757-01	.7293309-01				
		.6808894-01										
39	4	.89509	.67515 1.603	15.418 5467.38	68.801	.19215-01	7140.42 .0000	.000 2				2
		.4880000-02	.1657037-02	.1239329-01	.8289392-00	.4711111-03	.1120117-01	.7257555-01				
		.6788142-01										
		.4366119-01	-.6169580-01	.1196385+01	.7389006-00	-.4610714+08	.2549279+08	.1266599-05				
39	4	.89509	.67515 1.576	15.418 4841.97	68.801	.15776-01	7803.63 .0000	.000 2				3
		.4575003-02	.1539412-02	.6151952-01	.9199972-00	.4416669-03	.3360931-03	.1111701-01				
		.4724912-03										
		.2592261-01	-.3473390-01	.1214035+01	.9460878-00	-.4209080+08	.3044831+08	.1639128-05				
39	5	1.20776	.90703 1.651	15.000 4773.28	60.804	.14171-01	8113.79 1.4212	308.181 3				3
		.4575003-02	.1337426-02	.6158645-01	.9221640-00	.4416669-03	.2453549-03	.9304383-02				
		.3440073-03										
		.1160540-01	-.1542242-01	.1214287+01	.9433357-00	-.4459263+08	.3291683+08	.1698732-05				
39	4	.90006	.69315 1.610	15.450 5462.56	67.970	.19006-01	7168.60 .0000	.000 2				2
		.4880000-02	.1649349-02	.1236103-01	.8294316-00	.4711111-03	.1114193-01	.7231971-01				
		.6774402-01										
		.4113514-01	-.5811932-01	.1196346+01	.7387895-00	-.4634870+08	.2569440+08	.1266599-05				
39	4	.90006	.69315 1.583	15.450 4834.66	67.970	.15611-01	7835.02 .0000	.000 2				3
		.4575003-02	.1523824-02	.6152351-01	.9201833-00	.4416669-03	.3281980-03	.1096141-01				
		.4615061-03										
		.2474710-01	-.3314309-01	.1214073+01	.9458022-00	-.4233493+08	.3069381+08	.1639128-05				
39	5	1.21309	.92690 1.658	15.000 4766.25	60.190	.14049-01	8138.60 1.4241	308.807 3				3
		.4575003-02	.1330059-02	.6158761-01	.9222659-00	.4416669-03	.2418546-03	.9216919-02				
		.3393563-03										
		.1164089-01	-.1546198-01	.1214343+01	.9430584-00	-.4479447+08	.3311841+08	.1698732-05				

MASS FLOW POINT 43 = .12470+02 AREA RATIO = .1472+01

LRC	ID	R / AR / C2 / AA	X / H	MACH / THETA / GAMMA	T (DEG.R) / H2 / CP(BTU/LB)	P (PSI) / H2O / SUM CI*HI	DENSITY / N2 / V**2/2	VELOCITY / O / 1-SUM C(I)	CF / OH	ISP / IT	ZONE
		.42507	.39612 1.204	3.855	5668.06 130.839	.30637-01	5869.35 .0000	.000 0			
		.4758002-02	.2637667-02	.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01			
		.1708295-01									
		.7408028-01	-.1065767+00	.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05			
40	4	.58148	.49630 1.345	7.252	5569.45 107.810	.25804-01	6482.97 .0000	.000 3			1
		.4758002-02	.2481871-02	.2812703-01	.8895854-00	.4593335-03	.5427573-02	.5363170-01			
		.1552782-01									
		.5934257-01	-.8404977-01	.1200314+01	.8324715-00	-.2888367+08	.2101443+08	.1326203-05			
40	4	.58148	.49630 1.309	7.252	5678.82 107.810	.28682-01	5977.08 .0000	.000 3			2
		.4880000-02	.1903057-02	.1345840-01	.8122266-00	.4711111-03	.1321184-01	.8200822-01			
		.7183964-01									
		.6461969-01	-.9220568-01	.1197423+01	.7434709-00	-.2704546+08	.1786272+08	.1162291-05			
40	6	.88273	.69483 1.608	15.342	5462.29 68.263	.19084-01	7158.54 .0000	.000 0			2
		.4880000-02	.1651943-02	.1237009-01	.8293037-00	.4711111-03	.1115921-01	.7236481-01			
		.6779797-01									
40	4	.90505	.71121 1.617	15.458	5458.02 67.193	.18810-01	7195.10 .0000	.000 2			2
		.4880000-02	.1642070-02	.1233046-01	.8298979-00	.4711111-03	.1108592-01	.7207795-01			

		.4575003-02	.1508827-02	.6152749-01	.9203600-00	.4416669-03	.3207336-03	.1081354-01		
		.4510981-03								
		.2363299-01	-.3163797-01	.1214108+01	.9455332-00	-.4256531+08	.3092548+08	.1639128-05		
40	5	1.21844	.94689 1.664	15.000 4759.00	59.565	.13926-01	8164.02 1.4270	309.433 3		3
		.4575003-02	.1322655-02	.6158874-01	.9223687-00	.4416669-03	.2383483-03	.9128454-02		
		.3347016-03								
		.1168591-01	-.1551187-01	.1214401+01	.9427714-00	-.4500195+08	.3332562+08	.1713634-05		
40	4	.91005	.72928 1.623	15.448 5453.76	66.469	.18627-01	7219.95 .0000	.000 2		2
		.4880000-02	.1635188-02	.1230154-01	.8303385-00	.4711111-03	.1103307-01	.7185011-01		
		.6748920-01								
		.3671216-01	-.5184815-01	.1196273+01	.7385859-00	-.4679010+08	.2606387+08	.1266599-05		
40	4	.91005	.72928 1.597	15.448 4821.38	66.469	.15313-01	7892.20 .0000	.000 2		3
		.4575003-02	.1494440-02	.6153144-01	.9205275-00	.4416669-03	.3136938-03	.1067338-01		
		.4412623-03								
		.2258754-01	-.3022517-01	.1214140+01	.9452806-00	-.4278201+08	.3114342+08	.1639128-05		
40	5	1.22381	.96691 1.671	15.000 4751.64	58.933	.13801-01	8189.65 1.4299	310.057 3		3
		.4575003-02	.1315234-02	.6158988-01	.9224718-00	.4416669-03	.2348575-03	.9039791-02		
		.3300662-03								
		.1171638-01	-.1554425-01	.1214461+01	.9424798-00	-.4521177+08	.3353519+08	.1698732-05		

MASS FLOW POINT 44 = .12784+02 AREA RATIO = .1498+01

LRC	ID	R / AR / C2 / AA	X / H / BB	MACH / H2 / GAMMA	THETA T (DEG.R) / H2O / CP(BTU/LB)	P (PSI) / N2 / SUM CI*HI	DENSITY / O / V**2/2	VELOCITY / OH / 1-SUM C(I)	CF / ISP / IT	ZONE
		.40270	.40515 1.204	3.719 5668.06	130.839	.30637-01	5869.35 .0000	.000 0		1
41	1	.4758002-02	.2637667-02	.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01		
		.1708295-01								
		.7488028-01	-.1065767+00	.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05		
41	4	.58511	.52403 1.368	7.665 5551.88	104.300	.25061-01	6580.86 .0000	.000 3		1
		.4758002-02	.2456395-02	.2806250-01	.8907817-00	.4593335-03	.5315885-02	.5289157-01		
		.1527335-01								
		.6020253-01	-.8516202-01	.1200270+01	.8320371-00	-.2950270+08	.2165387+08	.1326203-05		
41	4	.58511	.52403 1.332	7.665 5662.57	104.300	.27849-01	6072.57 .0000	.000 3		2
		.4860000-02	.1884486-02	.1337968-01	.8134764-00	.4711111-03	.1305750-01	.8128996-01		
		.7155973-01								
		.6557196-01	-.9347364-01	.1197344+01	.7431339-00	-.2762531+08	.1843807+08	.1162291-05		
41	6	.89258	.73069 1.622	15.387 5452.60	66.603	.18665-01	7215.21 .0000	.000 0		2
		.4880000-02	.1637074-02	.1230712-01	.8302656-00	.4711111-03	.1104423-01	.7186198-01		
		.6753169-01								
41	4	.91505	.74741 1.630	15.421 5449.67	65.785	.18454-01	7243.59 .0000	.000 2		2
		.4880000-02	.1628663-02	.1227401-01	.8307579-00	.4711111-03	.1098293-01	.7163290-01		
		.6737123-01								
		.3481680-01	-.4916246-01	.1196240+01	.7384910-00	-.4699361+08	.2623483+08	.1281500-05		
41	4	.91505	.74741 1.604	15.421 4815.27	65.785	.15177-01	7918.50 .0000	.000 2		3
		.4575003-02	.1480606-02	.6153533-01	.9206872-00	.4416669-03	.3070204-03	.1053961-01		
		.4319287-03								
		.2160646-01	-.2890142-01	.1214171+01	.9450393-00	-.4298877+08	.3135133+08	.1654029-05		
41	5	1.22920	.98704 1.677	15.000 4744.11	58.304	.13676-01	8215.72 1.4328	310.680 3		3
		.4575003-02	.1307778-02	.6159102-01	.9225756-00	.4416669-03	.2313685-03	.8950453-02		
		.3254337-03								
		.1174886-01	-.1557716-01	.1214523+01	.9421804-00	-.4542584+08	.3374900+08	.1713634-05		
41	4	.92004	.76553 1.636	15.380 5445.74	65.138	.18291-01	7266.09 .0000	.000 2		2
		.4880000-02	.1622479-02	.1224782-01	.8311569-00	.4711111-03	.1093536-01	.7142574-01		
		.6725928-01								
		.3516879-01	-.4681248-01	.1196209+01	.7383997-00	-.4718746+08	.2639805+08	.1281500-05		
41	4	.92004	.76553 1.610	15.380 4809.43	65.138	.15048-01	7943.52 .0000	.000 2		3
		.4575003-02	.1467344-02	.6153913-01	.9208393-00	.4416669-03	.3007084-03	.1041215-01		
		.4236928-03								

41	5	1.23460	1.00720	1.684	15.000	4736.50	57.670	.13550-01	8241.94	1.4356	311.299	3	3
		.4575003-02	.1300314-02	.6159217-01	.9226793-00	.4416669-03	.2279013-03	.8861085-02					
		.3208275-03											
		.1177029-01	-.1559575-01	.1214586+01	.9418769-00	-.4564185+08	.3396478+08	.1728535-05					

MASS FLOW POINT 45 = .13080+02 AREA RATIO = .1524+01

LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	O		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
42	1	.38033	.41369	1.204	3.572	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		.4758002-02	.2637667-02	.2851504-01	.8823969-00		.4593335-03	.6120145-02			.5802866-01		
		.1708295-01											
		.7408028-01	-.1065767+00	.1200649+01	.8348638-00		-.2741878+08	.1722461+08			.1311302-05		
42	4	.58698	.55202	1.391	8.074	5533.86	100.817	.24320-01	6679.44	.0000	.000	3	1
		.4758002-02	.2430547-02	.2799700-01	.8919967-00		.4593335-03	.5203271-02			.5213884-01		
		.1501497-01											
		.6080635-01	-.8591144-01	.1200227+01	.8315887-00		-.3013419+08	.2230745+08			.1326203-05		
42	4	.58898	.55202	1.356	8.074	5645.91	100.817	.27020-01	6168.68	.0000	.000	3	2
		.4880000-02	.1865664-02	.1329938-01	.8147499-00		.4711111-03	.1290115-01			.8055791-01		
		.7127372-01											
		.6633706-01	-.9447104-01	.1197264+01	.7427863-00		-.2821737+08	.1902628+08			.1177192-05		
42	6	.90248	.76670	1.636	15.354	5444.01	65.153	.18298-01	7265.40	.0000	.000	0	2
		.4880000-02	.1623655-02	.1225026-01	.8311322-00		.4711111-03	.1094089-01			.7141146-01		
		.6728922-01											
42	4	.92504	.78372	1.641	15.329	5441.86	64.515	.18134-01	7287.84	.0000	.000	2	2
		.4880000-02	.1616582-02	.1222266-01	.8315405-00		.4711111-03	.1088988-01			.7122550-01		
		.6715248-01											
		.3173521-01	-.4477372-01	.1196180+01	.7383098-00		-.4737493+08	.2655632+08			.1281500-05		
42	4	.92504	.78372	1.616	15.329	4803.75	64.515	.14924-01	7967.70	.0000	.000	2	3
		.4575003-02	.1454577-02	.6154282-01	.9209853-00		.4416669-03	.2946974-03			.1028965-01		
		.4146787-03											
		.1986343-01	-.2654633-01	.1214230+01	.9445833-00		-.4337750+08	.3174210+08			.1654029+05		
42	5	1.24004	1.02748	1.691	15.000	4728.73	57.030	.13423-01	8268.54	1.4385	311.919	3	3
		.4575003-02	.1292816-02	.6159332-01	.9227837-00		.4416669-03	.2244394-03			.8771162-02		
		.3162273-03											
		.1176182-01	-.1560220-01	.1214651+01	.9415663-00		-.4586167+08	.3418437+08			.1728535-05		
42	4	.93001	.80190	1.647	15.268	5438.04	63.917	.17982-01	7308.88	.0000	.000	2	2
		.4880000-02	.1610960-02	.1219850-01	.8319092-00		.4711111-03	.1084636-01			.7103190-01		
		.6705071-01											
		.3050293-01	-.4302384-01	.1196153+01	.7382213-00		-.4755640+08	.2670985+08			.1296401-05		
42	4	.93001	.80190	1.621	15.268	4798.21	63.917	.14804-01	7991.07	.0000	.000	2	3
		.4575003-02	.1442330-02	.6154638-01	.9211251-00		.4416669-03	.2889889-03			.1017216-01		
		.4066900-03											
		.1909710-01	-.2550999-01	.1214259+01	.9443634-00		-.4356312+08	.3192862+08			.1668930-05		
42	5	1.24548	1.04778	1.698	15.000	4720.88	56.392	.13296-01	8295.26	1.4413	312.535	3	3
		.4575003-02	.1285322-02	.6159448-01	.9228878-00		.4416669-03	.2210054-03			.8681366-02		
		.3116612-03											
		.1178212-01	-.1559419-01	.1214717+01	.9412518-00		-.4608318+08	.3440567+08			.1728535-05		

MASS FLOW POINT 46 = .13360+02 AREA RATIO = .1551+01

LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	O		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
43	1	.35795	.42175	1.204	3.415	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1

		.4758002-02	.2404398-02	.2793065-01	.8932279-00	.4593335-03	.5090038-02	.5137489-01		
		.1475343-01								
		.6122574-01	-.8640247-01	.1200186+01	.8311258-00	-.3077729+08	.2297425+08	.1341105-05		
43	4	.59309	.58028 1.380	8.480 5628.86	97.370	.26196-01	6265.22 .0000	.000 3		2
		.4860000-02	.1846634-02	.1321763-01	.8160450-00	.4711111-03	.1274312-01	.7981307-01		
		.7098228-01								
		.6701218-01	-.9531199-01	.1197185+01	.7424284-00	-.2882098+08	.1962652+08	.1177192-05		
43	6	.91237	.80285 1.647	15.263 5436.05	63.853	.17969-01	7310.97 .0000	.000 0		2
		.4880000-02	.1611479-02	.1219832-01	.8319237-00	.4711111-03	.1084704-01	.7099889-01		
		.6706823-01								
43	4	.93499	.82017 1.652	15.201 5434.21	63.333	.17835-01	7329.52 .0000	.000 2		2
		.4880000-02	.1605549-02	.1217505-01	.8322675-00	.4711111-03	.1080430-01	.7084226-01		
		.6695294-01								
		.2952977-01	-.4161844-01	.1196127+01	.7381326-00	-.4773461+08	.2686091+08	.1296401-05		
43	4	.93499	.82017 1.627	15.201 4792.72	63.333	.14688-01	8014.00 .0000	.000 2		3
		.4575003-02	.1430511-02	.6154981-01	.9212603-00	.4416669-03	.2835246-03	.1005846-01		
		.3990503-03								
		.1839370-01	-.2455875-01	.1214288+01	.9441450-00	-.4374577+08	.3211207+08	.1668930-05		
43	5	1.25095	1.06822 1.705	15.000 4712.90	55.751	.13168-01	8322.29 1.4442	313.150 3		3
		.4575003-02	.1277800-02	.6159566-01	.9229923-00	.4416669-03	.2175814-03	.8591192-02		
		.3071063-03								
		.1178324-01	-.1558423-01	.1214785+01	.9409309-00	-.4630792+08	.3463021+08	.1713634-05		
43	4	.93993	.83841 1.658	15.129 5430.37	62.764	.17691-01	7349.76 .0000	.000 2		2
		.4880000-02	.1600348-02	.1215230-01	.8326157-00	.4711111-03	.1076366-01	.7065646-01		
		.6685912-01								
		.2868930-01	-.4042356-01	.1196103+01	.7380438-00	-.4790973+08	.2700951+08	.1296401-05		
43	4	.93993	.83841 1.633	15.129 4787.26	62.764	.14574-01	8036.48 .0000	.000 2		3
		.4575003-02	.1419154-02	.6155309-01	.9213906-00	.4416669-03	.2783111-03	.9948713-02		
		.3917700-03								
		.1775859-01	-.2369793-01	.1214319+01	.9439280-00	-.4392547+08	.3229249+08	.1668930-05		
43	5	1.25643	1.08868 1.712	15.000 4704.84	55.111	.13040-01	8349.42 1.4470	313.762 3		3
		.4575003-02	.1270296-02	.6159683-01	.9230965-00	.4416669-03	.2141907-03	.8501254-02		
		.3025925-03								
		.1176617-01	-.1555316-01	.1214855+01	.9406061-00	-.4653426+08	.3485637+08	.1728535-05		

MASS FLOW POINT 47 = .13623+02 AREA RATIO = .1579+01

LRC	ID	R / AR / C2	X / H	MACH	THETA / H2	T (DEG.R) / H2O	P (PSI) / N2	DENSITY / O	VELOCITY / OH	CF	ISP	IT	ZONE
		AA	BB		GAMMA	CP(BTU/LB)	SUM CI*HI	V**2/2			1-SUM C(I)		
44	1	.33558	.42931	1.204	3.249	5668.06	130.839	.30637-01	5869.35	.0000	.000 0		1
		.4758002-02	.2637667-02		.2851504-01	.8823969-00	.4593335-03	.6120145-02			.5802866-01		
		.1708295-01											
		.7488028-01	-.1065767+00		.1200649+01	.8348638-00	-.2741878+08	.1722461+08			.1311302-05		
44	4	.59745	.60881	1.439	8.882	5496.46	93.966	.22854-01	6878.02	.0000	.000 3		1
		.4758002-02	.2378008-02		.2786358-01	.8944730-00	.4593335-03	.4976453-02			.5060095-01		
		.1448934-01											
		.6153759-01	-.8672373-01		.1200148+01	.8306485-00	-.3143124+08	.2365360+08			.1341105-05		
44	4	.59745	.60881	1.404	8.882	5611.43	93.966	.25379-01	6362.11	.0000	.000 3		2
		.4880000-02	.1827437-02		.1313456-01	.8173597-00	.4711111-03	.1258372-01			.7905637-01		
		.7068593-01											
		.6748763-01	-.9589071-01		.1197106+01	.7420600-00	-.2943549+08	.2023820+08			.1177192-05		
44	6	.92223	.83914	1.659	15.134	5428.33	62.652	.17665-01	7353.56	.0000	.000 0		2
		.4860000-02	.1600304-02		.1215005-01	.8326602-00	.4711111-03	.1076046-01			.7061134-01		
		.6686535-01											
44	4	.94488	.85676	1.663	15.053	5426.47	62.201	.17549-01	7369.85	.0000	.000 2		2
		.4880000-02	.1595288-02		.1212998-01	.8329579-00	.4711111-03	.1072395-01			.7047243-01		
		.6676807-01											

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         .4575003-02    .1408156-02    .6155623-01    .9215174-00    .4416669-03    .2732933-02    .9841795-02
         .3847738-03
         .1717509-01   -.2290802-01    .1214351+01    .9437096-00   -.4410429+08    .3247195+08    .1683831-05
 44  5   1.26195   1.10928   1.719   15.000    4696.67     54.470    .12912-01   8376.78  1.4498  314.374  3                3
         .4575003-02    .1262769-02    .6159803-01    .9232008-00    .4416669-03    .2108148-03    .8411098-02
         .2960954-03
         .1174523-01   -.1551516-01    .1214925+01    .9402757-00   -.4676331+08    .3508525+08    .1728535-05
 44  4    .94979    .87507   1.668   14.975    5422.53     61.647    .17409-01   7389.78   .0000   .000  2           2
         .4880000-02    .1590378-02    .1210810-01    .8332937-00    .4711111-03    .1068521-01    .7029027-01
         .6667993-01
         .2754280-01   -.3876752-01    .1196060+01    .7378629-00   -.4825699+08    .2730441+08    .1311302-05
 44  4    .94979    .87507   1.644   14.975    4776.27     61.647    .14351-01   8080.88   .0000   .000  2           3
         .4575003-02    .1397560-02    .6155923-01    .9216403-00    .4416669-03    .2684833-03    .9737983-02
         .3780790-03
         .1665112-01   -.2219714-01    .1214384+01    .9434898-00   -.4428212+08    .3265034+08    .1683831-05
 44  5   1.26748   1.12989   1.726   15.000    4688.43     53.831    .12784-01   8404.24  1.4526  314.981  3                3
         .4575003-02    .1255274-02    .6159922-01    .9233047-00    .4416669-03    .2074772-03    .8321296-02
         .2936465-03
         .1171194-01   -.1546228-01    .1214997+01    .9399412-00   -.4699387+08    .3531566+08    .1728535-05
MASS FLOW POINT   48   =      .13869+02   AREA RATIO =      .1607+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2                H2O        N2            O          OH
          C2
          AA           BB                GAMMA             CP(BTU/LB)  SUM CI*HI     V**2/2      1-SUM C(I)
 45  1    .31321    .43639   1.204    3.073    5668.06     130.839    .30637-01   5869.35   .0000   .000  0           1
         .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
         .1708295-01
         .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
 45  4    .60206    .63764   1.462    9.279    5477.12     90.613    .22133-01   6977.70   .0000   .000  3           1
         .4758002-02    .2351443-02    .2779596-01    .8957289-00    .4593335-03    .4862824-02    .4981887-01
         .1422334-01
         .6169511-01   -.8681942-01    .1200112+01    .8301572-00   -.3209471+08    .2434416+08    .1341105-05
 45  4    .60206    .63764   1.428    9.279    5593.64     90.613    .24572-01   6459.12   .0000   .000  3           2
         .4880000-02    .1808114-02    .1305032-01    .8186914-00    .4711111-03    .1242329-01    .7828944-01
         .7038518-01
         .6784499-01   -.9628080-01    .1197029+01    .7416816-00   -.3005973+08    .2086013+08    .1177192-05
 45  6    .93204    .87559   1.670   14.982    5420.59     61.511    .17376-01   7394.47   .0000   .000  0           2
         .4880000-02    .1589885-02    .1210434-01    .8333594-00    .4711111-03    .1067911-01    .7023826-01
         .6667671-01
 45  4    .95470    .89350   1.674   14.895    5418.52     61.095    .17269-01   7409.70   .0000   .000  2           2
         .4880000-02    .1585552-02    .1208644-01    .8336268-00    .4711111-03    .1064697-01    .7010835-01
         .6659352-01
         .2718015-01   -.3823004-01    .1196040+01    .7377704-00   -.4843068+08    .2745181+08    .1311302-05
 45  4    .95470    .89350   1.649   14.895    4770.68     61.095    .14240-01   8102.98   .0000   .000  2           3
         .4575003-02    .1387259-02    .6156210-01    .9217606-00    .4416669-03    .2638296-03    .9636283-02
         .3716140-03
         .1617673-01   -.2155193-01    .1214419+01    .9432670-00   -.4446041+08    .3282913+08    .1683831-05
 45  5   1.27304   1.15067   1.733   15.000    4680.09     53.193    .12656-01   8431.88  1.4554  315.589  3                3
         .4575003-02    .1247763-02    .6160043-01    .9234086-00    .4416669-03    .2041591-03    .8231429-02
         .2892195-03
         .1167395-01   -.1540152-01    .1215071+01    .9396019-00   -.4722668+08    .3554832+08    .1743436-05
 45  4    .95958    .91190   1.679   14.814    5414.45     60.547    .17131-01   7429.60   .0000   .000  2           2
         .4880000-02    .1580829-02    .1206504-01    .8339563-00    .4711111-03    .1060936-01    .6992695-01
         .6650911-01
         .2693050-01   -.3785592-01    .1196021+01    .7376763-00   -.4860474+08    .2759945+08    .1311302-05
 45  4    .95958    .91190   1.655   14.814    4765.03     60.547    .14131-01   8125.04   .0000   .000  2           3
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 45  5   1.27861   1.17145   1.741   15.000    4671.67     52.356    .12528-01   8459.61  1.4582  316.193  3                3
         .4575003-02    .1240297-02    .6160163-01    .9235120-00    .4416669-03    .2008833-03    .8142004-02
         .2848466-03
         .1162623-01   -.1532895-01    .1215145+01    .9392583-00   -.4746100+08    .3578252+08    .1743436-05
MASS FLOW POINT   49  =     .14099+02   AREA RATIO =      .1635+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT          ZONE
          AR              H                   H2                H2O              N2              O                OH
          C2
          AA              BB                  GAMMA             CP(BTU/LB)     SUM CI*HI       V**2/2          1-SUM C(I)
 46  1    .29084    .44298   1.204   2.889     5668.06    130.839    .30637-01   5869.35   .0000     .000  0          1
         .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
         .1708295-01
         .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
 46  4    .60692    .66677   1.487   9.669     5457.40     87.322    .21422-01   7077.35   .0000     .000  3          1
         .4758002-02    .2324774-02    .2772797-01    .8969923-00    .4593335-03    .4749474-02    .4903065-01
         .1395617-01
         .6163832-01   -.8662724-01    .1200080+01    .8296525-00   -.3276611+08    .2504442+08    .1356006-05
 46  4    .60692    .66677   1.453   9.669     5575.52     87.322    .23777-01   6556.06   .0000     .000  3          2
         .4880000-02    .1788716-02    .1296511-01    .8200368-00    .4711111-03    .1226227-01    .7751406-01
         .7008075-01
         .6801503-01   -.9640508-01    .1196952+01    .7412938-00   -.3069230+08    .2149096+08    .1192093-05
 46  6    .94178    .91220   1.680   14.817    5412.67     60.404    .17096-01   7434.62   .0000     .000  0          2
         .4880000-02    .1580002-02    .1206024-01    .8340359-00    .4711111-03    .1060123-01    .6987185-01
         .6649847-01
 46  4    .96447    .93041   1.684   14.733    5410.30     59.999    .16992-01   7449.58   .0000     .000  2          2
         .4880000-02    .1576146-02    .1204368-01    .8342855-00    .4711111-03    .1057193-01    .6974474-01
         .6642556-01
         .2673393-01   -.3756639-01    .1196002+01    .7375806-00   -.4878035+08    .2774816+08    .1311302-05
 46  4    .96447    .93041   1.660   14.733    4759.27     59.999    .14021-01   8147.19   .0000     .000  2          3
         .4575003-02    .1367583-02    .6156745-01    .9219929-00    .4416669-03    .2549919-03    .9439343-02
         .3593745-03
         .1535716-01   -.2043691-01    .1214494+01    .9428111-00   -.4481886+08    .3318838+08    .1683831-05
 46  5   1.28423   1.19240   1.748   15.000    4663.17     51.921    .12400-01   8487.47  1.4610  316.796  3          3
         .4575003-02    .1232822-02    .6160285-01    .9236152-00    .4416669-03    .1976306-03    .8052640-02
         .2805006-03
         .1157068-01   -.1524545-01    .1215221+01    .9389103-00   -.4769719+08    .3601860+08    .1743436-05
 46  4    .96931    .94890   1.690   14.652    5406.07     59.453    .16854-01   7469.64   .0000     .000  2          2
         .4880000-02    .1571530-02    .1202245-01    .8346132-00    .4711111-03    .1053483-01    .6956220-01
         .6634335-01
         .2664138-01   -.3741936-01    .1195985+01    .7374829-00   -.4895722+08    .2789775+08    .1311302-05
 46  4    .96931    .94890   1.666   14.652    4753.42     59.453    .13912-01   8169.41   .0000     .000  2          3
         .4575003-02    .1358158-02    .6156993-01    .9221056-00    .4416669-03    .2507802-03    .9343619-02
         .3535602-03
         .1501312-01   -.1996539-01    .1214534+01    .9425771-00   -.4499980+08    .3336964+08    .1683831-05
 46  5   1.28985   1.21337   1.759   15.000    4654.59     51.288    .12272-01   8515.42  1.4637  317.396  3          3
         .4575003-02    .1225405-02    .6160406-01    .9237177-00    .4416669-03    .1944239-03    .7963806-02
         .2762138-03
         .1150995-01   -.1515507-01    .1215299+01    .9385580-00   -.4793490+08    .3625619+08    .1743436-05
MASS FLOW POINT   50  =     .14312+02   AREA RATIO =      .1664+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF        ISP     IT          ZONE
          AR              H                   H2                H2O              N2              O                OH
          C2
          AA              BB                  GAMMA             CP(BTU/LB)     SUM CI*HI       V**2/2          1-SUM C(I)
 47  1    .26847    .44908   1.204   2.697     5668.06    130.839    .30637-01   5869.35   .0000     .000  0          1
         .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
         .1708295-01
         .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
 47  4    .60692    .66677   1.487   9.669     5457.40     87.322    .21422-01   7176.69   .0000     .000  3          1
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,4758002-02 .2298076-02 .2765981-01 .8982594-00 .4593335-03 .4636746-02 .4823868-01
,1368859-01
,6142602-01 -.8620256-01 .1200050+01 .8291357-00 -.3344347+08 .2575241+08 .1356006-05
47 4 .61203 .69621 1.477 10.051 5557.14 84.102 .22995-01 6652.66 .0000 .000 3 2
,4880000-02 .1769299-02 .1287918-01 .8213922-00 .4711111-03 .1210112-01 .7673255-01
,6977337-01
,6799153-01 -.9624809-01 .1196878+01 .7408976-00 -.3133134+08 .2212892+08 .1192093-05
47 6 .95146 .94900 1.691 14.648 5404.48 59.313 .16819-01 7474.59 .0000 .000 0 2
,4880000-02 .1570471-02 .1201700-01 .8347008-00 .4711111-03 .1052547-01 .6950673-01
,6632722-01
47 4 .97416 .96751 1.695 14.572 5401.77 58.906 .16716-01 7489.82 .0000 .000 2 2
,4880000-02 .1566920-02 .1200115-01 .8349421-00 .4711111-03 .1049779-01 .6937835-01
,6626130-01
,2660616-01 -.3734584-01 .1195968+01 .7373837-00 -.4913612+08 .2804872+08 .1311302-05
47 4 .97416 .96751 1.672 14.572 4747.47 58.906 .13802-01 8191.77 .0000 .000 2 3
,4575003-02 .1348923-02 .6157233-01 .9222168-00 .4416669-03 .2466693-03 .9249072-02
,3478954-03
,1469039-01 -.1952513-01 .1214575+01 .9423386-00 -.4518238+08 .3355252+08 .1698732-05
47 5 1.29551 1.23450 1.763 15.000 4645.94 50.658 .12145-01 8543.45 1.4665 317.995 2 3
,4575003-02 .1217987-02 .6160528-01 .9238200-00 .4416669-03 .1912443-03 .7875168-02
,2719587-03
,1143474-01 -.1504722-01 .1215378+01 .9382018-00 -.4817403+08 .3649525+08 .1743436-05
47 4 .97898 .98610 1.700 14.492 5397.39 58.359 .16578-01 7510.12 .0000 .000 2 2
,4880000-02 .1562355-02 .1197989-01 .8352707-00 .4711111-03 .1046092-01 .6919362-01
,6618007-01
,2661080-01 -.3734107-01 .1195952+01 .7372825-00 -.4931675+08 .2820094+08 .1326203-05
47 4 .97898 .98610 1.677 14.492 4741.41 58.359 .13693-01 8214.24 .0000 .000 2 3
,4575003-02 .1339940-02 .6157462-01 .9223259-00 .4416669-03 .2426812-03 .9156134-02
,3424116-03
,1440124-01 -.1912962-01 .1214619+01 .9420955-00 -.4536646+08 .3373684+08 .1698732-05
47 5 1.30117 1.25565 1.770 15.000 4637.21 50.031 .12018-01 8571.57 1.4692 318.590 2 3
,4575003-02 .1210638-02 .6160649-01 .9239215-00 .4416669-03 .1881134-03 .7787134-02
,2677671-03
,1136507-01 -.1494361-01 .1215458+01 .9378411-00 -.4841473+08 .3673587+08 .1743436-05

MASS FLOW POINT 51 = .14510+02 AREA RATIO = .1693+01

LRC	ID	R / AR / C2	X / H	MACH	THETA	T (DEG.R) / H2	P (PSI) / H2O	DENSITY / N2	VELOCITY / O	CF / OH	ISP	IT	ZONE
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
48	1	.24609	.45470	1.204	2.498	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		,4758002-02	.2637667-02		.2851504-01		.8823969-00	.4593335-03		.6120145-02			.5802866-01
		,1708295-01											
		,7488028-01	-.1065767+00		.1200649+01		.8348638-00	-.2741878+08		.1722461+08			.1311302-05
48	4	.61741	.72596	1.535	10.423	5417.03	80.963	.20040-01	7275.44	.0000	.000	3	1
		,4758002-02	.2271427-02		.2759171-01		.8995263-00	.4593335-03		.4525000-02			.4744546-01
		,1342145-01											
		,6102034-01	-.8550423-01		.1200024+01		.8286079-00	-.3412477+08		.2646601+08			.1356006-05
48	4	.61741	.72596	1.502	10.423	5538.55	80.963	.22230-01	6748.65	.0000	.000	3	2
		,4880000-02	.1749920-02		.1279276-01		.8227536-00	.4711111-03		.1194032-01			.7594722-01
		,6946389-01											
		,6772550-01	-.9576070-01		.1196804+01		.7404941-00	-.3197501+08		.2277213+08			.1192093-05
48	6	.96107	.98599	1.702	14.478	5396.00	58.229	.16545-01	7514.77	.0000	.000	0	2
		,4880000-02	.1561148-02		.1197411-01		.8353619-00	.4711111-03		.1045081-01			.6913949-01
		,6616021-01											
48	4	.98581	1.00481	1.706	14.414	5392.95	57.811	.16439-01	7530.56	.0000	.000	2	2
		,4880000-02	.1557772-02		.1195949-01		.8356016-00	.4711111-03		.1042386-01			.6900728-01

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                .4575003-02    .1331104-02    .6157683-01    .9224338-00    .4416669-03    .2387755-03    .9064104-02
                .3370496-03
                .1413525-01   -.1876467-01    .1214664+01    .9418480-00   -.4555232+08    .3392291+08    .1713634-05
48  5           1.30689   1.27698   1.778   15.000   4628.43    49.407    .11892-01   8599.72   1.4720   319.185  2
                .4575003-02    .1203296-02    .6160772-01    .9240226-00    .4416669-03    .1850125-03    .7699397-02
                .2636110-03
                .1127767-01   -.1481949-01    .1215539+01    .9374769-00   -.4865652+08    .3697762+08    .1758337-05
48  4            .98860   1.02351   1.712   14.337   5388.43    57.263    .16300-01   7551.13    .0000     .000  2
                .4880000-02    .1553217-02    .1193707-01    .8359330-00    .4711111-03    .1038692-01    .6881986-01
                .6661750-01
                .2673199-01   -.3747459-01    .1195921+01    .7370752-00   -.4968448+08    .2850980+08    .1326203-05
48  4            .98860   1.02351   1.689   14.337   4728.98    57.263    .13474-01   8259.62    .0000     .000  2
                .4575003-02    .1322486-02    .6157894-01    .9225400-00    .4416669-03    .2349761-03    .8973430-02
                .3318437-03
                .1369774-01   -.1843708-01    .1214711+01    .9415957-00   -.4573987+08    .3411062+08    .1713634-05
48  5           1.31261   1.29832   1.785   15.000   4619.56    48.786    .11766-01   8627.97   1.4747   319.776  2
                .4575003-02    .1196033-02    .6160892-01    .9241228-00    .4416669-03    .1819624-03    .7612316-02
                .2595217-03
                .1119186-01   -.1469598-01    .1215622+01    .9371080-00   -.4889992+08    .3722097+08    .1758337-05
MASS FLOW POINT   52  =      .14691+02   AREA RATIO =      .1723+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)    DENSITY      VELOCITY     CF        ISP      IT        ZONE
          AR                    H                 H2                    H2O           N2           O         OH
          C2
          AA                   BB                GAMMA              CP(BTU/LB)    SUM CI*HI      V**2/2     1-SUM C(I)
49  1      .22372     .45982   1.204   2.292    5668.06    130.839   .30637-01   5869.35    .0000     .000  0        1
                .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
                .1708295-01
                .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
49  4            .62304     .75605   1.559   10.783   5396.53    77.915    .19373-01   7373.27    .0000     .000  3        1
                .4758002-02    .2244916-02    .2752391-01    .9007882-00    .4593335-03    .4414625-02    .4665398-01
                .1315564-01
                .6039339-01   -.8450255-01    .1200001+01    .8280712-00   -.3480731+08    .2718255+08    .1370907-05
49  4            .62304     .75605   1.526   10.783   5519.82    77.915    .21484-01   6843.71    .0000     .000  3        2
                .4880000-02    .1730642-02    .1270616-01    .8241162-00    .4711111-03    .1178044-01    .7516112-01
                .6915321-01
                .6725156-01   -.9497008-01    .1196733+01    .7400846-00   -.3262078+08    .2341816+08    .1192093-05
49  6            .97061   1.02319   1.713   14.312   5387.23    57.146    .16271-01   7555.34    .0000     .000  0        2
                .4880000-02    .1551931-02    .1193119-01    .8360244-00    .4711111-03    .1037656-01    .6876820-01
                .6599534-01                                                                                              2
49  4            .99340   1.04233   1.717   14.261   5383.87    56.715    .16161-01   7571.84    .0000     .000  2
                .4880000-02    .1548631-02    .1191546-01    .8362672-00    .4711111-03    .1034972-01    .6863079-01
                .6593579-01
                .2679185-01   -.3754762-01    .1195905+01    .7369693-00   -.4987150+08    .2866634+08    .1341105-05
49  4            .99340   1.04233   1.695   14.261   4722.62    56.715    .13364-01   8282.51    .0000     .000  2        3
                .4575003-02    .1313986-02    .6158099-01    .9226452-00    .4416669-03    .2312458-03    .8883499-02
                .3267391-03
                .1366802-01   -.1812251-01    .1214760+01    .9413393-00   -.4592906+08    .3429997+08    .1713634-05
49  5           1.31857   1.31984   1.793   15.000   4610.65    48.169    .11640-01   8656.22   1.4774   320.366  2        3
                .4575003-02    .1188784-02    .6161015-01    .9242226-00    .4416669-03    .1789458-03    .7525670-02
                .2554723-03
                .1109401-01   -.1455787-01    .1215706+01    .9367362-00   -.4914401+08    .3746504+08    .1773238-05
49  4            .99816   1.06114   1.723   14.186   5379.23    56.166    .16022-01   7592.67    .0000     .000  2        2
                .4880000-02    .1544065-02    .1189382-01    .8366022-00    .4711111-03    .1031258-01    .6844054-01
                .6585442-01
                .2691008-01   -.3769573-01    .1195891+01    .7368615-00   -.5006049+08    .2882435+08    .1341105-05
49  4            .99816   1.06114   1.701   14.186   4716.16    56.166    .13254-01   8305.54    .0000     .000  2        3
                .4575003-02    .1305676-02    .6158296-01    .9227488-00    .4416669-03    .2276096-03    .8794758-02
                .3247714-03                                                                                              3
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 49  5   1.32415   1.34138   1.801  15.000    4601.65     47.559     .11515-01   8684.55  1.4801  320.952  2                3
         .4575003-02    .1181624-02    .6161134-01    .9243214-00    .4416669-03    .1759818-03    .7439727-02
         .2514926-03
         .1099807-01   -.1442100-01    .1215791+01    .9363596-00   -.4938974+08    .3771074+08    .1773238-05
MASS FLOW POINT   53  =      .14857+02   AREA RATIO =      .1753+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)    DENSITY     VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2              H2O          N2           O                     OH
          C2
          AA           BB                  GAMMA          CP(BTU/LB)   SUM CI*HI     V**2/2                1-SUM C(I)
 50  1    .20135     .46446   1.204   2.080    5668.06    130.839     .30637-01   5869.35   .0000     .000  0          1
         .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
         .1708295-01
         .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
 50  4    .62893     .78646   1.583  11.126    5375.92     74.969     .18726-01   7469.83   .0000     .000  3          1
         .4758002-02    .2218623-02    .2745668-01    .9020407-00    .4593335-03    .4305989-02    .4586726-01
         .1289205-01
         .5957052-01   -.8322414-01    .1199981+01    .8275277-00   -.3548840+08    .2789915+08    .1356006-05
 50  4    .62893     .78646   1.550  11.126    5501.04     74.969     .20760-01   6937.50   .0000     .000  3          2
         .4880000-02    .1711526-02    .1261967-01    .8254750-00    .4711111-03    .1162201-01    .7437724-01
         .6884223-01
         .6653883-01   -.9384550-01    .1196664+01    .7396710-00   -.3326611+08    .2406445+08    .1192093-05
 50  6    .98010    1.06060   1.724  14.150    5378.19     56.064     .15996-01   7596.38   .0000     .000  0          2
         .4880000-02    .1542751-02    .1188802-01    .8366915-00    .4711111-03    .1030229-01    .6839200-01
         .6583109-01                                                                                                    2
 50  4   1.00294    1.08008   1.729  14.113    5374.55     55.617     .15883-01   7613.63   .0000     .000  2
         .4880000-02    .1539457-02    .1187198-01    .8369402-00    .4711111-03    .1027513-01    .6824866-01
         .6577217-01
         .2698726-01   -.3779334-01    .1195876+01    .7367527-00   -.5025160+08    .2898367+08    .1341105-05
 50  4   1.00294    1.08008   1.707  14.113    4709.61     55.617     .13144-01   8328.69   .0000     .000  2          3
         .4575003-02    .1297458-02    .6158489-01    .9228517-00    .4416669-03    .2240322-03    .8706633-02
         .3168888-03
         .1326998-01   -.1757233-01    .1214861+01    .9408131-00   -.4631243+08    .3468358+08    .1728535-05
 50  5   1.32997    1.36310   1.808  15.000    4592.63     46.947     .11391-01   8712.85  1.4828  321.539  2          3
         .4575003-02    .1174485-02    .6161255-01    .9244196-00    .4416669-03    .1730531-03    .7354305-02
         .2475555-03
         .1089119-01   -.1427088-01    .1215877+01    .9359804-00   -.4963588+08    .3795687+08    .1773238-05
 50  4   1.00768    1.09900   1.734  14.040    5369.80     55.068     .15743-01   7634.72   .0000     .000  2          2
         .4880000-02    .1534867-02    .1185007-01    .8372792-00    .4711111-03    .1023773-01    .6805561-01
         .6569012-01
         .2711514-01   -.3795577-01    .1195861+01    .7366420-00   -.5044468+08    .2914449+08    .1341105-05
 50  4   1.00768    1.09900   1.713  14.040    4702.95     55.068     .13033-01   8351.99   .0000     .000  2          3
         .4575003-02    .1289410-02    .6158674-01    .9229532-00    .4416669-03    .2205392-03    .8619563-02
         .3121284-03
         .1309010-01   -.1732371-01    .1214915+01    .9405433-00   -.4650664+08    .3487787+08    .1728535-05
 50  5   1.33579    1.38484   1.816  15.000    4583.51     46.345     .11267-01   8741.25  1.4855  322.120  2          3
         .4575003-02    .1167443-02    .6161372-01    .9245169-00    .4416669-03    .1701780-03    .7269622-02
         .2436897-03
         .1078707-01   -.1412309-01    .1215965+01    .9355961-00   -.4988370+08    .3820469+08    .1773238-05
MASS FLOW POINT   54  =      .15007+02   AREA RATIO =      .1784+01

LRC ID    R          X          MACH   THETA  T (DEG.R)   P (PSI)    DENSITY     VELOCITY    CF        ISP     IT          ZONE
          AR           H                   H2              H2O          N2           O                     OH
          C2
          AA           BB                  GAMMA          CP(BTU/LB)   SUM CI*HI     V**2/2                1-SUM C(I)
 51  1    .17898     .46861   1.204   1.863    5668.06    130.839     .30637-01   5869.35   .0000     .000  0          1
         .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
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      ,4758002-02    .2192634-02    .2739030-01    .9032784-00    .4593335-03    .4199485-02    .4508886-01
      ,1263162-01
      ,5851709-01   -.8163209-01    .1199965+01    .8269805-00   -.3616444+08    .2861216+08    .1356006-05
51  4   .63506    .81721   1.574   11.450    5482.31    72.135    .20061-01   7029.61    .0000    .000  3      2
      ,4880000-02    .1692639-02    .1253366-01    .8268244-00    .4711111-03    .1146564-01    .7359946-01
      ,6853192-01
      ,6555953-01   -.9235172-01    .1196598+01    .7392557-00   -.3390761+08    .2470770+08    .1192093-05
51  6   .98954   1.09825   1.735   13.994    5368.92    54.982    .15721-01   7637.88    .0000    .000  0      2
      ,4880000-02    .1533565-02    .1184447-01    .8373648-00    .4711111-03    .1022775-01    .6801064-01
      ,6566646-01
51  4  1.01244   1.11807   1.740   13.970    5365.02    54.520    .15604-01   7655.91    .0000    .000  2      2
      ,4880000-02    .1530232-02    .1182797-01    .8376212-00    .4711111-03    .1020001-01    .6786103-01
      ,6560711-01
      ,2720910-01   -.3807119-01    .1195847+01    .7365304-00   -.5063970+08    .2930650+08    .1341105-05
51  4  1.01244   1.11807   1.719   13.970    4696.22    54.520    .12923-01   8375.38    .0000    .000  2      3
      ,4575003-02    .1281436-02    .6158856-01    .9230540-00    .4416669-03    .2170982-03    .8533046-02
      ,3074418-03
      ,1291830-01   -.1708545-01    .1214969+01    .9402700-00   -.4670220+08    .3507351+08    .1728535-05
51  5  1.34166   1.40676   1.824   15.000    4574.38    45.741    .11145-01   8769.55  1.4882  322.702  2      3
      ,4575003-02    .1160430-02    .6161491-01    .9246135-00    .4416669-03    .1673407-03    .7185569-02
      ,2398697-03
      ,1066657-01   -.1395689-01    .1216054+01    .9352100-00   -.5013154+08    .3845254+08    .1773238-05
51  4  1.01716   1.13711   1.746   13.900    5360.15    53.972    .15464-01   7677.24    .0000    .000  2      2
      ,4880000-02    .1525615-02    .1180579-01    .8379643-00    .4711111-03    .1016234-01    .6766523-01
      ,6552427-01
      ,2733246-01   -.3822938-01    .1195833+01    .7364168-00   -.5083668+08    .2947004+08    .1356006-05
51  4  1.01716   1.13711   1.725   13.900    4689.39    53.972    .12813-01   8398.92    .0000    .000  2      3
      ,4575003-02    .1273618-02    .6159031-01    .9231536-00    .4416669-03    .2137342-03    .8447486-02
      ,3028661-03
      ,1275814-01   -.1686330-01    .1215028+01    .9399919-00   -.4689956+08    .3527093+08    .1743436-05
51  5  1.34755   1.42871   1.831   15.000    4565.15    45.144    .11022-01   8797.97  1.4909  323.279  2      3
      ,4575003-02    .1153520-02    .6161607-01    .9247090-00    .4416669-03    .1645577-03    .7102297-02
      ,2361224-03
      ,1055400-01   -.1379840-01    .1216145+01    .9348185-00   -.5038109+08    .3870210+08    .1788139-05
MASS FLOW POINT   55  =     .15141+02   AREA RATIO =     .1816+01

LRC ID    R          X          MACH     THETA  T (DEG.R)   P (PSI)    DENSITY      VELOCITY    CF        ISP     IT      ZONE
          AR           H                    H2                H2O          N2             O          OH
          C2
          AA           BB                 GAMMA              CP(BTU/LB)   SUM CI*HI      V**2/2               1-SUM C(I)
52  1    .15660     .47227   1.204   1.640    5668.06    130.839    .30637-01   5869.35    .0000    .000  0      1
      ,4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
      ,1708295-01
      ,7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
52  4    .64145     .84830   1.631   11.751    5334.94    69.426    .17500-01   7657.35    .0000    .000  3      1
      ,4758002-02    .2167031-02    .2732509-01    .9044958-00    .4593335-03    .4095510-02    .4432258-01
      ,1237531-01
      ,5725354-01   -.7974770-01    .1199952+01    .8264333-00   -.3683154+08    .2931750+08    .1370907-05
52  4    .64145     .84830   1.598   11.751    5463.78    69.426    .19389-01   7119.58    .0000    .000  3      2
      ,4880000-02    .1674046-02    .1244851-01    .8281580-00    .4711111-03    .1131196-01    .7283192-01
      ,6822328-01
      ,6431240-01   -.9048535-01    .1196533+01    .7388415-00   -.3454157+08    .2534422+08    .1206994-05
52  6    .99892   1.13612   1.747   13.843    5359.43    53.901    .15446-01   7679.83    .0000    .000  0      2
      ,4880000-02    .1524351-02    .1180048-01    .8380449-00    .4711111-03    .1015283-01    .6762420-01
      ,6550089-01
52  4   1.02190   1.15630   1.752   13.833    5355.27    53.423    .15324-01   7698.66    .0000    .000  2      2
      ,4880000-02    .1520951-02    .1178341-01    .8383105-00    .4711111-03    .1012433-01    .6746795-01
      ,6544044-01
      ,2744248-01   -.3834416-01    .1195818+01    .7363024-00   -.5103552+08    .2963471+08    .1356006-05
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         .4575003-02    .1265861-02     .6159203-01    .9232525-00    .4416669-03   .2104169-03    .8362420-02
         .2983557-03
         .1259959-01    -.1664413-01    .1215083+01    .9397104-00   -.4709820+08   .3546963+08    .1743436-05
 52  5   1.35347   1.45083   1.839  15.000   4555.92   44.555   .10901-01  8826.26  1.4935   323.856  2      3
         .4575003-02    .1146645-02     .6161724-01    .9248037-00    .4416669-03   .1618143-03    .7019739-02
         .2324253-03
         .1043111-01    -.1362783-01    .1216236+01    .9344256-00   -.5063035+08   .3895141+08    .1773238-05
 52  4   1.02661   1.17547   1.758  13.766   5350.30   52.877   .15185-01  7720.23   .0000      .000  2      2
         .4880000-02    .1516307-02     .1176097-01    .8386577-00    .4711111-03   .1008639-01    .6726940-01
         .6535680-01
         .2754768-01    -.3849864-01    .1195805+01    .7361859-00   -.5123634+08   .2980099+08    .1356006-05
 52  4   1.02661   1.17547   1.737  13.766   4675.49   52.877   .12592-01  8446.32   .0000      .000  2      3
         .4575003-02    .1258248-02     .6159369-01    .9233503-00    .4416669-03   .2071709-03    .8278240-02
         .2939474-03
         .1245669-01    -.1644425-01    .1215142+01    .9394241-00   -.4729870+08   .3567017+08    .1758337-05
 52  5   1.35941   1.47299   1.847  15.000   4546.59   43.967   .10780-01  8854.65  1.4962   324.428  2      3
         .4575003-02    .1139881-02     .6161836-01    .9248974-00    .4416669-03   .1591251-03    .6937976-02
         .2287975-03
         .1031133-01    -.1346035-01    .1216329+01    .9340273-00   -.5088137+08   .3920245+08    .1788139-05
MASS FLOW POINT   56    =     .15259+02    AREA RATIO =        .1848+01

LRC ID   R           X        MACH    THETA  T (DEG.R)   P (PSI)   DENSITY     VELOCITY   CF       ISP     IT       ZONE
         AR               H                H2               H20               N2           O                OH
         C2
         AA               BB               GAMMA           CP(BTU/LB)        SUM CI*HI     V**2/2           1-SUM C(I)
 53  1   .13423    .47544    1.204   1.414   5668.06  130.839   .30637-01  5869.35   .0000      .000  0      1
         .4758002-02    .2637667-02     .2851504-01    .8823969-00    .4593335-03   .6120145-02    .5802866-01
         .1708295-01
         .7488028-01    -.1065767+00    .1200649+01    .8348638-00   -.2741878+08   .1722461+08    .1311302-05
 53  4   .64806    .87973    1.653  12.025   5314.84   66.850   .16926-01  7747.38   .0000      .000  3      1
         .4758002-02    .2141898-02     .2726136-01    .9056874-00    .4593335-03   .3994437-02    .4357217-01
         .1212408-01
         .5578154-01    -.7758018-01    .1199941+01    .8258901-00   -.3748579+08   .3001098+08    .1370907-05
 53  4   .64806    .87973    1.621   12.025   5445.57   66.850   .18747-01  7206.98   .0000      .000  3      2
         .4880000-02    .1655812-02     .1236461-01    .8294695-00    .4711111-03   .1116161-01    .7207881-01
         .6791734-01
         .6280095-01    -.8825689-01    .1196470+01    .7384315-00   -.3516423+08   .2597025+08    .1206994-05
 53  6   1.00827   1.17424   1.758  13.699   5349.73   52.823   .15171-01  7722.20   .0000      .000  0      2
         .4880000-02    .1515100-02     .1175603-01    .8387321-00    .4711111-03   .1007749-01    .6723283-01
         .6533410-01
 53  4   1.03133   1.19478   1.764  13.703   5345.32   52.332   .15045-01  7741.87   .0000      .000  2      2
         .4880000-02    .1511615-02     .1173832-01    .8390079-00    .4711111-03   .1004812-01    .6706950-01
         .6527212-01
         .2760924-01    -.3857825-01    .1195791+01    .7360687-00   -.5143886+08   .2996827+08    .1341105-05
 53  4   1.03133   1.19478   1.743  13.703   4668.43   52.332   .12482-01  8470.17   .0000      .000  2      3
         .4575003-02    .1250689-02     .6159534-01    .9234475-00    .4416669-03   .2039682-03    .8194533-02
         .2895988-03
         .1231146-01    -.1624273-01    .1215202+01    .9391345-00   -.4750033+08   .3587185+08    .1758337-05
 53  5   1.36539   1.49531   1.855  15.000   4537.28   43.383   .10661-01  8882.88  1.4988   325.000  2      3
         .4575003-02    .1133158-02     .6161950-01    .9249902-00    .4416669-03   .1564776-03    .6857029-02
         .2252225-03
         .1017821-01    -.1327803-01    .1216423+01    .9336281-00   -.5113169+08   .3945282+08    .1803041-05
 53  4   1.03602   1.21407   1.770  13.639   5340.25   51.786   .14906-01  7763.66   .0000      .000  2      2
         .4880000-02    .1506944-02     .1171562-01    .8393591-00    .4711111-03   .1000991-01    .6686834-01
         .6518770-01
         .2774828-01    -.3874852-01    .1195778+01    .7359493-00   -.5164336+08   .3013721+08    .1356006-05
 53  4   1.03602   1.21407   1.750  13.639   4661.25   51.786   .12372-01  8494.17   .0000      .000  2      3
         [illegible]    [illegible]     [illegible]    .9235434-00    .4416669-03   .2008323-03    .8111650-02
```

53	5	1.37138	1.51767	1.863	15.000	4527.87	42.811	.10542-01	8911.22	1.5014	325.567	2	3
		.4575003-02	.1126551-02	.6162059-01	.9250819-00	.4416669-03	.1538845-03	.6776905-02					
		.2217209-03											
		.1005590-01	-.1310666-01	.1216519+01	.9332233-00	-.5138378+08	.3970496+08	.1803041-05					
MASS FLOW POINT 57 = .15362+02 AREA RATIO = .1881+01													
LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	O		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
54	1	.11186	.47813	1.204	1.184	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		.4758002-02	.2637667-02	.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01					
		.1708295-01											
		.7488028-01	-.1065767+00	.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05					
54	4	.65490	.91148	1.676	12.267	5295.20	64.414	.16382-01	7834.35	.0000	.000	3	1
		.4758002-02	.2117305-02	.2719938-01	.9068482-00	.4593335-03	.3896587-02	.4284111-01					
		.1137875-01											
		.5409511-01	-.7513354-01	.1199932+01	.8253550-00	-.3812342+08	.3068851+08	.1370907-05					
54	4	.65490	.91148	1.643	12.267	5427.82	64.414	.18138-01	7291.37	.0000	.000	3	2
		.4880000-02	.1637996-02	.1228234-01	.8307531-00	.4711111-03	.1101512-01	.7134409-01					
		.6761503-01											
		.6103277-01	-.8568432-01	.1196410+01	.7380285-00	-.3577197+08	.2658206+08	.1206994-05					
54	6	1.01757	1.21259	1.770	13.561	5339.83	51.749	.14896-01	7764.97	.0000	.000	0	2
		.4880000-02	.1505810-02	.1171111-01	.8394264-00	.4711111-03	.1000173-01	.6683662-01					
		.6516602-01											
54	4	1.04073	1.23351	1.776	13.579	5335.16	51.241	.14766-01	7785.51	.0000	.000	2	2
		.4880000-02	.1502226-02	.1169271-01	.8397132-00	.4711111-03	.9971383-02	.6666583-01					
		.6510222-01											
		.2782013-01	-.3883537-01	.1195764+01	.7358293-00	-.5184950+08	.3030712+08	.1356006-05					
54	4	1.04073	1.23351	1.756	13.579	4654.03	51.241	.12262-01	8518.23	.0000	.000	2	3
		.4575003-02	.1235890-02	.6159849-01	.9236391-00	.4416669-03	.1977365-03	.8029219-02					
		.2811464-03											
		.1204167-01	-.1586654-01	.1215327+01	.9385422-00	-.4790850+08	.3628010+08	.1773238-05					
54	5	1.37742	1.54020	1.870	15.000	4518.48	42.242	.10424-01	8939.37	1.5040	326.134	2	3
		.4575003-02	.1119991-02	.6162170-01	.9251726-00	.4416669-03	.1513333-03	.6697647-02					
		.2182712-03											
		.9919366-02	-.1291985-01	.1216615+01	.9328180-00	-.5163495+08	.3995620+08	.1803041-05					
54	4	1.04541	1.25293	1.782	13.519	5329.98	50.697	.14627-01	7807.53	.0000	.000	2	2
		.4880000-02	.1497533-02	.1166975-01	.8400683-00	.4711111-03	.9932940-02	.6646206-01					
		.6501701-01											
		.2793514-01	-.3897815-01	.1195752+01	.7357070-00	-.5205762+08	.3047873+08	.1356006-05					
54	4	1.04541	1.25293	1.762	13.519	4646.69	50.697	.12152-01	8542.45	.0000	.000	2	3
		.4575003-02	.1228645-02	.6160000-01	.9237336-00	.4416669-03	.1947038-03	.7947568-02					
		.2770372-03											
		.1191708-01	-.1569131-01	.1215391+01	.9382394-00	-.4811509+08	.3648671+08	.1773238-05					
54	5	1.38346	1.56276	1.878	15.000	4508.98	41.676	.10307-01	8967.64	1.5066	326.697	2	3
		.4575003-02	.1113551-02	.6162275-01	.9252623-00	.4416669-03	.1488359-03	.6619218-02					
		.2140945-03											
		.9789680-02	-.1274014-01	.1216713+01	.9324070-00	-.5188793+08	.4020924+08	.1803041-05					
MASS FLOW POINT 58 = .15450+02 AREA RATIO = .1914+01													
LRC	ID	R	X	MACH	THETA	T (DEG.R)	P (PSI)	DENSITY	VELOCITY	CF	ISP	IT	ZONE
		AR	H		H2		H2O	N2	O		OH		
		C2											
		AA	BB		GAMMA		CP(BTU/LB)	SUM CI*HI	V**2/2		1-SUM C(I)		
55	1	.08949	.48033	1.204	.951	5668.06	130.839	.30637-01	5869.35	.0000	.000	0	1
		.4758002-02	.2637667-02	.2851504-01	.8823969-00	.4593335-03	.6120145-02	.5802866-01					
		.1708295-01											
		.7488028-01	-.1065767+00	.1200649+01	.8348638-00	-.2741878+08	.1722461+08	.1311302-05					

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        .4758002-02    .2093310-02    .2713945-01    .9079732-00    .4593335-03    .3802248-02    .4213293-01
        .1164013-01
        .5226055-01   -.7248310-01    .1199924+01    .8248324-00   -.3874028+08    .3134566+08    .1370907-05
55  4     .66193    .94357   1.665  12.474    5410.67     62.127   .17564-01   7372.34    .0000     .000  3          2
        .4880000-02    .1620646-02    .1220206-01    .8320027-00    .4711111-03    .1087305-01    .7063202-01
        .6731722-01
        .5906457-01   -.8282976-01    .1196350+01    .7376364-00   -.3636078+08    .2717567+08    .1206994-05
55  6   1.02683   1.25119   1.782  13.431    5329.74     50.678   .14622-01   7808.14    .0000     .000  0          2
        .4880000-02    .1496484-02    .1166574-01    .8401275-00    .4711111-03    .9925585-02    .6643570-01
        .6499666-01                                                                                                  2
55  4   1.05010   1.27250   1.788  13.463    5324.80     50.155   .14488-01   7829.58    .0000     .000  2
        .4880000-02    .1492793-02    .1164660-01    .8404261-00    .4711111-03    .9894191-02    .6625713-01
        .6493079-01
        .2798771-01   -.3904129-01    .1195739+01    .7355842-00   -.5226715+08    .3065113+08    .1356006-05
55  4   1.05010   1.27250   1.769  13.463    4639.31     50.155   .12042-01   8566.70    .0000     .000  2          3
        .4575003-02    .1221442-02    .6160150-01    .9238276-00    .4416669-03    .1917100-03    .7866390-02
        .2729798-03
        .1178480-01   -.1550817-01    .1215457+01    .9379339-00   -.4832252+08    .3669417+08    .1773238-05
55  5   1.38955   1.58548   1.886  15.000    4499.53     41.120   .10191-01   8995.66   1.5092  327.258  2          3
        .4575003-02    .1107164-02    .6162382-01    .9253509-00    .4416669-03    .1463820-03    .6541753-02
        .2115715-03
        .9648378-02   -.1254787-01    .1216811+01    .9319962-00   -.5213956+08    .4046095+08    .1803041-05
55  4   1.05477   1.29204   1.794  13.406    5319.52     49.614   .14349-01   7851.78    .0000     .000  2          2
        .4880000-02    .1488079-02    .1162340-01    .8407847-00    .4711111-03    .9855542-02    .6605098-01
        .6484487-01
        .2810281-01   -.3917924-01    .1195726+01    .7354591-00   -.5247862+08    .3082521+08    .1370907-05
55  4   1.05477   1.29204   1.775  13.406    4631.82     49.614   .11932-01   8591.11    .0000     .000  2          3
        .4575003-02    .1214366-02    .6160294-01    .9239205-00    .4416669-03    .1887765-03    .7785975-02
        .2690078-03
        .1166370-01   -.1533821-01    .1215525+01    .9376232-00   -.4853189+08    .3690357+08    .1788139-05
55  5   1.39565   1.60825   1.894  15.000    4489.97     40.565   .10076-01   9023.80   1.5118  327.815  2          3
        .4575003-02    .1100899-02    .6162483-01    .9254384-00    .4416669-03    .1439811-03    .6465122-02
        .2083208-03
        .9517430-02   -.1236631-01    .1216911+01    .9315795-00   -.5239303+08    .4071449+08    .1817942-05
MASS FLOW POINT   59   =      .15521+02   AREA RATIO =      .1948+01

LRC ID    R          X          MACH    THETA  T (DEG,R)   P (PSI)    DENSITY     VELOCITY    CF        ISP     IT     ZON
          AR                    H                H2                    H2O          N2                  O                OH
          C2
          AA                   BB                        GAMMA                CP(BTU/LB)     SUM CI*HI        V**2/2          1-SUM C(I)
56  1     .06712    .48203   1.204    .715    5668.06     130.839   .30637-01   5869.35    .0000     .000  0          1
        .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
        .1708295-01
        .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
56  4     .66915    .97596   1.718  12.642    5257.94     59.993   .15386-01   7997.30    .0000     .000  3          1
        .4758002-02    .2069968-02    .2708182-01    .9090582-00    .4593335-03    .3711667-02    .4145076-01
        .1140888-01
        .5026642-01   -.6962864-01    .1199917+01    .8243270-00   -.3933273+08    .3197839+08    .1385808-05
56  4     .66915    .97596   1.686  12.642    5394.26     59.993   .17025-01   7449.48    .0000     .000  3          2
        .4880000-02    .1603811-02    .1212412-01    .8332128-00    .4711111-03    .1073587-01    .6994635-01
        .6702474-01
        .5687010-01   -.7968080-01    .1196293+01    .7372582-00   -.3692710+08    .2774739+08    .1206994-05
56  6   1.03606   1.29003   1.794  13.308    5319.46     49.612   .14348-01   7851.67    .0000     .000  0          2
        .4880000-02    .1487128-02    .1161994-01    .8408351-00    .4711111-03    .9849095-02    .6603033-01
        .6482606-01                                                                                                  2
56  4   1.05945   1.31174   1.800  13.354    5314.24     49.075   .14210-01   7874.00    .0000     .000  2
        .4880000-02    .1483321-02    .1160002-01    .8411458-00    .4711111-03    .9816611-02    .6584382-01
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        .4575003-02    .1207331-02    .6160438-01    .9240128-00    .4416669-03    .1858808-03    .7706055-02
        .2650856-03
        .1153421-01   -.1515941-01    .1215593+01    .9373100-00   -.4874193+08    .3711364+08    .1788139-05
56  5   1.40179   1.63117   1.902  15.000    4480.47     40.020    .99622-02   9051.68   1.5144  328.371  2          3
        .4575003-02    .1094692-02    .6162585-01    .9255247-00    .4416669-03    .1416240-03    .6389502-02
        .2051245-03
        .9375853-02   -.1217343-01    .1217011+01    .9311635-00   -.5264489+08    .4096645+08    .1817942-05
56  4   1.06411   1.33141   1.806  13.301    5308.87     48.537    .14072-01   7896.37   .0000     .000  2          2
        .4880000-02    .1478593-02    .1157660-01    .8415077-00    .4711111-03    .9777794-02    .6563552-01
        .6467135-01
        .2824184-01   -.3934044-01    .1195702+01    .7352058-00   -.5290586+08    .3117632+08    .1370907-05
56  4   1.06411   1.33141   1.788  13.301    4616.66     48.537    .11713-01   8640.09   .0000     .000  2          3
        .4575003-02    .1200417-02    .6160576-01    .9241042-00    .4416669-03    .1830432-03    .7626892-02
        .2612450-03
        .1142061-01   -.1499811-01    .1215663+01    .9369917-00   -.4895387+08    .3732559+08    .1788139-05
56  5   1.40795   1.65413   1.910  15.000    4470.86     39.473    .98489-02   9079.67   1.5169  328.923  2          3
        .4575003-02    .1088611-02    .6162682-01    .9256101-00    .4416669-03    .1393187-03    .6314711-02
        .2019991-03
        .9239977-02   -.1198671-01    .1217114+01    .9307415-00   -.5289859+08    .4122024+08    .1817942-05
MASS FLOW POINT   60  =      .15577+02   AREA RATIO =      .1932+01

LRC ID    R          X          MACH    THETA  T (DEG.R)   P (PSI)    DENSITY     VELOCITY    CF        ISP     IT      ZONE
          AR           H                   H2                H2O          N2           O                 OH
          C2
          AA          BB                  GAMMA              CP(BTU/LB)   SUM CI*HI     V**2/2          1-SUM C(I)
57  1     .04474     .48325    1.204     .478     5668.06     130.839    .30637-01   5869.35   .0000     .000  0          1
        .4758002-02    .2637667-02    .2851504-01    .8823969-00    .4593335-03    .6120145-02    .5802866-01
        .1708295-01
        .7488028-01   -.1065767+00    .1200649+01    .8348638-00   -.2741878+08    .1722461+08    .1311302-05
57  4     .67652   1.00867   1.737  12.768    5240.59     58.014    .14937-01   8072.58   .0000     .000  3          1
        .4758002-02    .2047318-02    .2702667-01    .9100997-00    .4593335-03    .3625012-02    .4079707-01
        .1118558-01
        .4815935-01   -.6663086-01    .1199909+01    .8238426-00   -.3989775+08    .3258329+08    .1385808-05
57  4     .67652   1.00867   1.705  12.768    5378.70     58.014    .16523-01   7522.52   .0000     .000  3          2
        .4880000-02    .1587527-02    .1204880-01    .8343789-00    .4711111-03    .1060395-01    .6929018-01
        .6673832-01
        .5452747-01   -.7633160-01    .1196236+01    .7368969-00   -.3746797+08    .2829414+08    .1206994-05
57  6   1.04526   1.32912   1.806  13.192    5308.99     48.553    .14076-01   7895.54   .0000     .000  0          2
        .4880000-02    .1477750-02    .1157373-01    .8415488-00    .4711111-03    .9772316-02    .6562075-01
        .6465432-01                                                                                               2
57  4   1.06879   1.35123   1.813  13.252    5303.51     48.002    .13934-01   7918.74   .0000     .000  2
        .4880000-02    .1473822-02    .1155301-01    .8418719-00    .4711111-03    .9738715-02    .6542634-01
        .6458378-01
        .2826974-01   -.3936766-01    .1195690+01    .7350777-00   -.5312146+08    .3135322+08    .1370907-05
57  4   1.06879   1.35123   1.795  13.252    4608.99     48.002    .11604-01   8664.65   .0000     .000  2          3
        .4575003-02    .1193545-02    .6160714-01    .9241949-00    .4416669-03    .1802423-03    .7548236-02
        .2574524-03
        .1129349-01   -.1482265-01    .1215734+01    .9366711-00   -.4916629+08    .3753805+08    .1788139-05
57  5   1.41414   1.67725   1.918  15.000    4461.30     38.945    .97374-02   9107.39   1.5194  329.473  2          3
        .4575003-02    .1082591-02    .6162779-01    .9256942-00    .4416669-03    .1370570-03    .6240967-02
        .1989280-03
        .9095026-02   -.1179045-01    .1217217+01    .9303204-00   -.5315055+08    .4147229+08    .1832843-05

$$$$$$$$$$ FINAL EXECUTION TIME THIS CASE =       4.772  (MIN) $$$$$$$$$$
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 3 ZONE TDK TEST CASE,LOX/GH2
XITAB(  1)= -.20718+01, YITAB(  1)=  .17321+01, PITAB(  1)=  .97659-00,
XITAB(  2)= -.20108+01, YITAB(  2)=  .17311+01, PITAB(  2)=  .97652-00,
XITAB(  3)= -.19358+01, YITAB(  3)=  .17274+01, PITAB(  3)=  .97629-00,
XITAB(  4)= -.18607+01, YITAB(  4)=  .17209+01, PITAB(  4)=  .97586-00,
XITAB(  5)= -.17857+01, YITAB(  5)=  .17115+01, PITAB(  5)=  .97523-00,
XITAB(  6)= -.17106+01, YITAB(  6)=  .16992+01, PITAB(  6)=  .97437-00,
XITAB(  7)= -.16356+01, YITAB(  7)=  .16839+01, PITAB(  7)=  .97325-00,
XITAB(  8)= -.15605+01, YITAB(  8)=  .16656+01, PITAB(  8)=  .97182-00,
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XITAB( 10)= -.14104+01, YITAB( 10)=  .16195+01, PITAB( 10)=  .96776-00,
XITAB( 11)= -.13354+01, YITAB( 11)=  .15915+01, PITAB( 11)=  .96490-00,
XITAB( 12)= -.12603+01, YITAB( 12)=  .15600+01, PITAB( 12)=  .96128-00,
XITAB( 13)= -.11853+01, YITAB( 13)=  .15248+01, PITAB( 13)=  .95663-00,
XITAB( 14)= -.11102+01, YITAB( 14)=  .14857+01, PITAB( 14)=  .95057-00,
XITAB( 15)= -.10352+01, YITAB( 15)=  .14430+01, PITAB( 15)=  .94316-00,
XITAB( 16)= -.96015-00, YITAB( 16)=  .13966+01, PITAB( 16)=  .93420-00,
XITAB( 17)= -.88510-00, YITAB( 17)=  .13563+01, PITAB( 17)=  .92326-00,
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XITAB( 19)= -.73501-00, YITAB( 19)=  .12697+01, PITAB( 19)=  .89256-00,
XITAB( 20)= -.65996-00, YITAB( 20)=  .12263+01, PITAB( 20)=  .87040-00,
XITAB( 21)= -.58491-00, YITAB( 21)=  .11830+01, PITAB( 21)=  .84080-00,
XITAB( 22)= -.50987-00, YITAB( 22)=  .11397+01, PITAB( 22)=  .80526-00,
XITAB( 23)= -.43482-00, YITAB( 23)=  .10995+01, PITAB( 23)=  .76587-00,
XITAB( 24)= -.35977-00, YITAB( 24)=  .10670+01, PITAB( 24)=  .72294-00,
XITAB( 25)= -.28472-00, YITAB( 25)=  .10414+01, PITAB( 25)=  .67690-00,
XITAB( 26)= -.20967-00, YITAB( 26)=  .10222+01, PITAB( 26)=  .62837-00,
XITAB( 27)= -.13463-00, YITAB( 27)=  .10091+01, PITAB( 27)=  .57806-00,
XITAB( 28)=  .00000   , YITAB( 28)=  .10000+01, PITAB( 28)=  .48459-00,
XITAB( 29)=  .12643-01, YITAB( 29)=  .10001+01, PITAB( 29)=  .47469-00,
XITAB( 30)=  .25693-01, YITAB( 30)=  .10003+01, PITAB( 30)=  .46451-00,
XITAB( 31)=  .39224-01, YITAB( 31)=  .10008+01, PITAB( 31)=  .45409-00,
XITAB( 32)=  .52723-01, YITAB( 32)=  .10014+01, PITAB( 32)=  .44343-00,
XITAB( 33)=  .66446-01, YITAB( 33)=  .10022+01, PITAB( 33)=  .43254-00,
XITAB( 34)=  .80405-01, YITAB( 34)=  .10032+01, PITAB( 34)=  .42146-00,
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XITAB( 37)=  .12377+00, YITAB( 37)=  .10077+01, PITAB( 37)=  .38706-00,
XITAB( 38)=  .13875-00, YITAB( 38)=  .10097+01, PITAB( 38)=  .37524-00,
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XITAB( 42)=  .20158-00, YITAB( 42)=  .10205+01, PITAB( 42)=  .32639-00,
XITAB( 43)=  .21807-00, YITAB( 43)=  .10241+01, PITAB( 43)=  .31385-00,
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XITAB( 51)=  .53936-00, YITAB( 51)=  .11092+01, PITAB( 51)=  .26302-00,
XITAB( 52)=  .57169-00, YITAB( 52)=  .11179+01, PITAB( 52)=  .26011-00,
XITAB( 53)=  .61099-00, YITAB( 53)=  .11284+01, PITAB( 53)=  .25647-00,
XITAB( 54)=  .65456-00, YITAB( 54)=  .11401+01, PITAB( 54)=  .25222-00,
XITAB( 55)=  .69284-00, YITAB( 55)=  .11504+01, PITAB( 55)=  .24834-00,
XITAB( 56)=  .75089-00, YITAB( 56)=  .11659+01, PITAB( 56)=  .24204-00,
XITAB( 57)=  .80173-00, YITAB( 57)=  .11795+01, PITAB( 57)=  .23662-00,
XITAB( 58)=  .84738-00, YITAB( 58)=  .11918+01, PITAB( 58)=  .23174-00,
XITAB( 59)=  .88661-00, YITAB( 59)=  .12023+01, PITAB( 59)=  .22741-00,
XITAB( 60)=  .92629-00, YITAB( 60)=  .12129+01, PITAB( 60)=  .22290-00,
XITAB( 61)=  .96630-00, YITAB( 61)=  .12236+01, PITAB( 61)=  .21828-00,
XITAB( 62)=  .10066+01, YITAB( 62)=  .12344+01, PITAB( 62)=  .21359-00,
XITAB( 63)=  .10472+01, YITAB( 63)=  .12453+01, PITAB( 63)=  .20888-00,
XITAB( 64)=  .10882+01, YITAB( 64)=  .12563+01, PITAB( 64)=  .20414-00,
XITAB( 65)=  .11295+01, YITAB( 65)=  .12674+01, PITAB( 65)=  .19941-00,
XITAB( 66)=  .11711+01, YITAB( 66)=  .12785+01, PITAB( 66)=  .19470-00,
XITAB( 67)=  .12130+01, YITAB( 67)=  .12898+01, PITAB( 67)=  .19001-00,
XITAB( 68)=  .12554+01, YITAB( 68)=  .13011+01, PITAB( 68)=  .18535-00,
XITAB( 69)=  .12981+01, YITAB( 69)=  .13126+01, PITAB( 69)=  .18074-00,
XITAB( 70)=  .13412+01, YITAB( 70)=  .13241+01, PITAB( 70)=  .17618-00,
XITAB( 71)=  .13847+01, YITAB( 71)=  .13358+01, PITAB( 71)=  .17168-00,
XITAB( 72)=  .14286+01, YITAB( 72)=  .13475+01, PITAB( 72)=  .16725-00,
XITAB( 73)=  .14729+01, YITAB( 73)=  .13594+01, PITAB( 73)=  .16288-00,
XITAB( 74)=  .15176+01, YITAB( 74)=  .13714+01, PITAB( 74)=  .15859-00,
XITAB( 75)=  .15627+01, YITAB( 75)=  .13834+01, PITAB( 75)=  .15439-00,
XITAB( 76)=  .16081+01, YITAB( 76)=  .13956+01, PITAB( 76)=  .15026-00,
XITAB( 77)=  .16540+01, YITAB( 77)=  .14079+01, PITAB( 77)=  .14623-00,
XITAB( 78)=  .16771+01, YITAB( 78)=  .14141+01, PITAB( 78)=  .14424-00,
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8. ERROR DIAGNOSTICS

8.1 DISCUSSION OF PROGRAM USAGE

Error diagnostics* are printed by the program when it has either found an input card error or is unable to continue with its computations because it has obtained an impossible result. The analysis performed by the computer program is limited by the physical assumptions used in its development and by the numerical methods used. Consequently, an understanding of these assumptions and of the numerical methods that have been applied is necessary in order to correctly run cases using the computer program. Although the computer program contains many error diagnostics, it is not possible to diagnose all errors.

Input values given for the sample case (see Section7) can be used as a guide in preparing data for similar calculations. Special care must be taken, however, to avoid input errors of the type given below:

8.1.1 The computer program will not give valid results if the input kinetic reaction rate parameters are unrealistic. A common mistake is to input an implied third body reaction rate backwards; which gives a very large error. Tables 6-10 and 6-11 can be used as guide in preparing reaction rate data. It should be remembered that the computer program automatically calculates equilibrium constants from the input JANAF thermochemical data.

8.1.2 The computer program does not have the ability to calculate kinetic flow containing solid phase products. For example, if the program input is such that solid carbon is formed, then no kinetic calculation is possible.

8.1.3 A common mistake in using the computer program is to input inlet and throat geometry parameters that are physically impossible when compared with Figure 6-1.

8.1.4 A value RWTU < .5 should be used because of inaccuracies which can occur as a result of the transonic method of solution.[8]

*Error diagnostics can also be given by the computer systems subroutines. These vary with the operating system and are not discussed here.

8.1.5 For some chemical systems (e.g. H-F) it is possible that the two-dimensional throat Mach number will be subsonic as a result of the kinetic process. In this case the initial data line can be displaced downstream, increasing the Mach number, by use of the input parameter ALI (see Section 6.6.1). If ALI is input greater than zero, a symmetric throat is required and it is necessary that RWTD be set to the same value as RWTU.

8.1.6 An important consideration in preparing data for all but ØDE calculations concerns input of the nozzle wall. The derivative of the wall contour has an important effect on the nozzle flow field and it is required that wall derivatives vary slowly with respect to the local characteristic mesh spacing. In this respect the TDK program is no different than any other method of characteristics calculation. The TDK program is unable to calculate shock waves so that rapid compression of the nozzle wall must be avoided. Usually the most satisfactory method of specifying a nozzle wall contour is through the use of the spline fit contour option (IWALL=4). Too many points should not be input when using this option since a bad derivative could result. Never place points close together. Although the initial section of the contour is assumed to be a circular arc, a small value of THJ can be used if necessary.

In case of difficulty with the method of characteristics calculations, a useful procedure is to plot the (r,x) coordinates of mesh points in the region of difficulty. A plot of this type will frequently locate the cause of the problem. For this purpose it is necessary to print each calculated mesh point (i.e. N1=1 and N2=1).

8.2 LISTING OF ERROR DIAGNOSTICS

Errors printed by the program are listed in Table 8-1 in alphabetic order. Error diagnostics consist of two types: fatal errors and nonfatal errors. A fatal error will terminate the case being executed and the program will proceed to the next case. A nonfatal error serves only as a warning and the program will continue the case. If the error diagnostic is of the nonfatal type the symbol (NF) appears in the explanation. In processing input data cards the program will attempt to find as many input card errors as possible before terminating the case. When the discussion presented in Section 8.1 could apply to the error, the pertinent sub-section number appears in the explanation. The subroutine printing the error message is also listed in Table 8-1.

TABLE 8-1; ERROR DIAGNOSTICS

DIAGNOSTIC	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
ABOVE CARD IGNORED	(NF) Check this input card.	REAXIN
ABOVE DIRECTIVE IGNORED	(NF) Check this input card.	DRIVER
ALL REACTION RATE RATIOS INPUT AS 1.0	(NF) Informative, no action necessary.	PACK
AN IMPROPER INITIAL LINE POINT IS SOUGHT	Check input of nozzle throat geometry.	ERRORZ
BAD PROBLEM CARD-ILLEGAL OPTION OR NO OPTION SPECIFIED, LOOK FOR POSSIBLE CAUSE AT OR AROUND COLUMN _____	Self explanatory-correct problem card.	PRØBLM
CALCULATIONS WERE STOPPED BECAUSE NEXT POINT IS MORE THAN 50 DEG. BELOW TEMP. RANGE OF A CONDENSED SPECIES	(NF)ØDE frozen calculation can not be continued. No action required.	RØCKET
CONDENSED REACTANTS NOT PERMITTED IN DETN OR SHOCK PROBLEMS	Only gaseous reactants are permitted (see Ref. 9, pg. 70).	ØDES
CONSERVATION EQNS WERE NOT SATISFIED IN 8 ITERATIONS	On detonation option convergence is usually obtained in 3 or 4 iterations (see Ref. 9, pg 70).	DETØN
COULD NOT LOCATE PRES_____ FOR ZONE_____ AND POINT_____ IN ØDK GENERATED TRANSONIC TABLES	Check nozzle throat geometry and the initial line flow MACH number.	GETIL
DID NOT CONVERGE FOR AREA RATIO=_____	(NF) The area ratio is probably too close to 1.0 the usual number of iterations is less than 6. Here it exceeded 10. (see Ref. 9, pg. 71).	RØCKET
DID NOT CONVERGE FOR U1=____ ANSWERS PROBABLY NOT RELIABLE SOLUTION MAY NOT EXIST	U1 was probably less than the minimum value required for shock to occur (see Ref. 9, pg. 71).	SHCK
DID NOT CONVERGE ON ELECTRON BALANCE	Check input charge balance.	EQLBRM

DIAGNOSTIC	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
SINGULAR MATRIX	Assign a slightly modified equivalence ratio or O/F ratio (see Ref. 9, pg. 73).	EQLBRM
SPECIES____ IN REAX SET BUT NOT IN SPECIES SET	Self explanatory, check input.	REAXIN
SPECIES NAME TOO LONG	Only 12 characters are allowed in a species name, check input.	REAXIN
SPECIES NO.____ ____ NOT CONTAINED IN MASTER EQUILIBRIUM SPECIES TABLE	Check reaction species names against thermodynamic data species names.	SELECT
SPECIES ____ NOT IN SPECIES LIST	Check species named on reaction cards and correct.	REAXIN
____ SPECIES NOT ON THERMØ TAPE	Check reaction species names against thermodynamic data species names.	PACK
SPECIES ____ REQUIRES ELEMENT ____ THIS ELEMENT IS NOT IN ELEMENT TABLE	Check input for misspelled species or element name.	PACK
SUM OF INPUT SPECIES CONCENTRATIONS FOR ABOVE POINTS NOT ONE	If problem is TDK(LFINL), check input (see section 6.8.2).	ERRØRZ
SUM OF MOLE FRACTIONS OF SELECTED SPECIES NOT ONE, THEIR SUM IS=____	See detailed discussion in section 6.5.3.4.	SELECT
TEMPERATURE IS OUT OF RANGE OF THE THERMØ DATA	Converged temperature for a shock problem is beyond TLØW/1.5 > T > 1.25* THIGH. Results may be inaccurate (see Ref. 9, pg. 73).	SHCK
THE CALCULATION FOR THE LAST POINT EXCEEDED MAXIMUM ITERATIONS	Check MOC output to see if run is in error. If no input errors are found and run is to be continued either increase IMAX and/or set IMAXF=0 (see 6.7.3, also 8.1.6).	ERRØRZ
THE FOLLOWING CARD WAS IGNORED ____	(NF) Check this card for error.	REAXIN

DIAGNOSTICS	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
THE LRC INSERTION TABLE HAS OVERFLOWED	The calculation has inserted more than 20 left running characteristics. Try more points on the initial line (see section 6.6).	ERRØRZ
THE MAXIMUM NO. OF POINTS FOR A LRC HAS BEEN EXCEEDED	More than 151 points are on the initial data line. Reduce by modifying $TRANS input (see section 6.6).	ERRØRZ
THE PROGRAM IS ATTEMPTING TO INSERT AN EXCESSIVE NUMBER OF FLOWFIELD POINTS	Probable cause is too few points on the initial line upstream of the region being computed. Try more points or a redistirbution of points on the intital line (see section 6.6).	ERRØRZ
THE PROGRAM IS ATTEMPTING TO LOCATE A WALL POINT UPSTREAM OF THE 1ST POINT IN THE WALL TABLE	Check input of intial line (see section 6.6) and nozzle wall (see section 6.7.1).	ERRØRZ
THE PROGRAM IS UNABLE TO LOCATE POINT 1 IN SUBROUTINE DSPT	Check input to be sure a value given in XM is not too small. If XM value is < .05, eliminate this zone and adjust mixture ratios.	ERRØRZ
THE PROGRAM IS UNABLE TO LOCATE POINT 1 IN SUBROUTINE INPT	See section 8.1.6. All $TRANS and $TDK input should be checked.	ERRØRZ
THE TEMPERATURE=____ IS OUT OF RANGE FOR POINT____	Converged temperature input on card following THERMØ card is beyond the allowed range: TLØW/1.5 > T > 1.25*THIGH (see Ref. 9, pg. 73).	EQLBRM
THIRD BODY REAX RATE RATIOS BEFORE END OF REAX	LAST REAX card was left out. Check for a mistake in reaction order.	REAXIN
THREE PHASES OF A CONDENSED SPECIES ARE OUT OF ORDER	THERMØ data for condensed species must be in either increasing or decreasing order depending on their temperature intervals (see Table 6-2).	EQLBRM
TRY REMOVING CONDENSED SPECIES	Use ØMIT cards on trace condensed species.	EQLBRM
UNABLE TO ROOT X(I) FOR CONSTANT PRESSURE INITIAL LINE. I=____, R(I)=____, X=_____, P=____	Check $TRANS input, especially the XM values. (see section 6.1.1).	TRAN

DIAGNOSTIC	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
DIMENSIONS IN/SPECIES/TOO SMALL TO CONSIDER	Too many species are possible for the system being input. Use OMIT cards or recompile program dimensions.	SEARCH
ENTIRE TRANSONIC TABLE FILE HAS BEEN READ	Occurs while constructing initial line for the method of characteristics. Check throat geometry.	GETIL
EP NOT REACHED	Refer to section 6.5.3.1 and discussion of EP	MAIN1D
ERRØR DETECTED DURING TRANSONIC CALC	Program can not calculate initial data line for method of characteristics, check XM values.	TRAN
ERRØR DETECTED DURING INPUT PROCESSING	Check input for bad reaction card.	REAXIN
ERRØR DURING LOW T THERMO EVAL, T=____	Low temperature out of range. Check LØW T CPHS input if used (see section 6.1.1).	THERM
ERRØR DURING REAX PARAMETER PROCESSING	Check input for bad reaction card.	REAXIN
ERRØR FROM BANDI____DIAGONAL ELEMENT REDUCED TO ZERO	Multi zone transonic calculation is in error. Check for bad input mass flow fraction, XM, section 6.6.	TRAN
ERRØR IN ABOVE CARD. CONTENTS IGNORED	A card is missing, extraneous, or in error (see Ref. 9, pg. 71).	ØDES
ERRØR IN ORDER OF CARDS FOR ____ ____ ___	THERMØ data cards for this species are out of order (see Ref. 9, pg. 71).	TTAPE
ERRØR IN REACTANT CARDS	Chemical symbol not left-justified, or not included in BLØCK DATA program (see Ref.9, pg. 71).	ØDES
ERRØR ON PROBLEM CARD-FOR____ ____ OPTION, NZØNES MUST BE 1-WAS INPUT AS___	Self explanatory, check input.	PRØBLM
EXIT PLANE OPTION REQUIRES GREATER WALL EXTENSION	Check nozzle wall input, section 6.7	CNTRL

DIAGNOSTIC	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
FATAL ERRØR ENCOUNTERED WHILE PROCESSING PROBLEM CARD-PROCESSED TO NEXT CASE	Correct bad problem card.	DRIVER
FIND VAR OUTSIDE TABLE	Interpolation was requested outside of the range of the input tables. Check input tables for range of independent variable.	FIND
FRØZEN DID NOT CONVERGE IN 8 ITERATIONS	ØDE could not converge in frozen calculations. If desired add more area and/or pressure ratios (see Ref. 9, pg. 71).	FRØZEN
INCOMPLETE TDK INITIAL LINE HAS BEEN GENERATED	Check $TRANS input, section 6.6.	ERRØRZ
INERT____ NOT IN MASTER SPECIES TABLE	Species not in thermo file, check species name and correct.	SELECT
INERTS FOUND IN TDK PROBLEM, INERTS NOT SPECIFIED, CAN NOT USE RELATIVE SELECTION CRITERION FOR TDK CASE	See section 6.5.3.4 for explanation of species selection.	SELECT
INLET GEOMETRY INCOMPATIBLE WITH INITIAL CONDITIONS	$\sqrt{EC} < 1+(R_u+R_i)\ (1-\cos\theta_i)$ see 8.1.3 and 5.4.17	PRES
35 ITERATIONS DID NOT SATISFY CONVERGENCE REQUIREMENTS FOR THE POINT ____	Check output for cause of non-convergence. If not obvious, re-run with intermidiate output (see Ref. 9, pg. 73).	EQLBRM
KIN EXPN CODE DIMENSIONED FOR MAX. OF 40 SPECIES, CURRENT CASE USES____	More than 40 species found. Check input	SELECT
LOW T THERMO EXTENSION AT T=___ DEG-K	(NF) LØW T CPHS input is being used, section 6.1.1.	THERM
LOW TEMPERATURE IMPLIES CONDENSED SPECIES SHOULD HAVE BEEN INCLUDED ON AN INSERT CARD, RESTART	An important condensed species has been omitted causing unrealistically low combustion temperature (see Ref. 9, pg. 72).	EQLBRM
MASS FRACTION SUM NOT 1	$\lvert 1-\Sigma c_i \rvert < .01$ the ØDK output subroutine has detected an error in mass conservation	ØUTPUT

DIAGNOSTIC	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
MASS OR MOLE FRACTIONS NOT SPECIFIED, MASS FRACTIONS ASSUMED	(NF) Informative - mass or mole fractions not specified on species card.	REAXIN
MAX. CHAR LOOKING FOR,	Check reaction cards for required ending comma.	REAXIN
MAX. SAVED SPECIES EXCEEDED	More than 40 species requested. Eliminate those of least importance.	REAXIN
MAX. SPECIES EXCEEDED FOR TBR RATIOS	The maximum of 2000 third body reaction rate ratios has been exceeded (see section 6.5.2.8).	REAXIN
MORE THAN 12 CHARACTERS SPECIFIED FOR AN INERT SPECIES NAME	Check inert species names (see section 6.5.2.7).	REAXIN
NE DID NOT CONVERGE	Unable to find an expansion coefficient, N_e, when generating ØDK pressure table (see section 5.4.17)	PRES
NØ ECRAT SPECIFIED FOR ØDK START-RUN ABORTED	Initial contraction ratio must be input (see section 5.4.17).	ØDES
NØ MORE THAN 151 POINTS MAY BE INPUT ON INITIAL LINE	Check input initial line and modify for 151 or less points.	ERRØRZ
NØ $ØDE VALUE GIVEN FOR OF, EQRAT, FA, OR FPCT	Input the desired value as true in $ØDE.	ØDES
NON-NUMERIC ENCOUNTERED IN ECNV WHILE DECODING. . . ____	Fatal error, correct bad number in data field.	ECNV
NOZZLE PWZS COORDINATES NOT MONOTONIC INCREASING AT PT____	Check input of nozzle wall and correct error (see section 6.5.3.1).	PACK
NUMBER OF SPECIES IN REACTIONS TOO LARGE MUST REDIMENSION ITABLE AND RESET MAXTAB	The ØDK program allows only 10 reactants or products per reaction. If possible rewrite reaction in steps. If program is to be modified to allow more, ITABLE must be redimensioned, and MAXTAB increased from 10.	REAXIN

DIAGNOSTIC	EXPLANATION OR POSSIBLE CORRECTIVE ACTION	SUBROUTINE
NUMBER OF SPECIES TOO LARGE FOR TABLES, MUST REDIMENSION	The ØDK program allows only 40 species per reaction. If possible omit unimportant species. Check input. If program is to be modified to allow more species various arrays must be redimensioned.	REAXIN
NUMBER OF TEMP VALUES OUTSIDE RANGE	Temperature below range specified in LØW T CPHS input, section 6.1.1.	LTCPHS
NUMERIC EXPECTED, NOT FOUND	Probable error on reaction card, further diagnostics will be printed.	REAXIN
NZØNES IMPROPERLY SPECIFIED-BAD CHARACTER IN COLUMN	Check input problem card.	PRØBLM
PRØG NOT DIMENSIONED FOR ___ POINTS AND ____ ZONES	The maximum number of initial line points (151) and/or mixture ratio zones (50) has been exceeded.	XPIL
PTB (____) =____ DID NOT CONVERGE	Unable to calculate P/P_e vs. area table entry in ØDK. See 5.4.17.	PRES
REACTANT ____ IS NOT IN THERMØDATA	Enthalpy can be computed only for those reactants included as reaction species in thermodynamic data (see Ref. 9, pg. 72).	HCALC
REACTANT TEMPERATURE OUT OF RANGE OF THERMØ DATA	Assigned temperature is more than 20% beyond temperature range over which thermodynamic data have been fitted (see Ref. 9, pg. 72).	HCALC
REACTION ____ HAS MASS IMBALANCE OF___	Fatal error: either stoichiometric coeffients do not match or a reaction or molecular weight input incorrectly in thermo data.	PACK
REACTION EXTENDS BEYOND CARD COL. 80	Ending comma left out of a reaction card.	REAXIN
SINGULARITY ____	(NF) Numerical singularity in matrix solution of Ax=b. Solution may be in error.	LESK, NESK

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