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COMPUTER PROGRAM FOR DETERMINING EFFECTS OF CHEMICAL KINETICS ON EXHAUST-NOZZLE PERFORMANCE

by Leo C. Franciscus and Jeanne A. Healy

Lewis Research Center
Cleveland, Ohio

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COMPUTER PROGRAM FOR DETERMINING EFFECTS OF CHEMICAL KINETICS ON EXHAUST-NOZZLE PERFORMANCE

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SUMMARY

A computer program is described that can be used to compute nozzle performance, including chemical kinetic losses in the nozzle for rockets and subsonic or supersonic combustion ramjets. The kinetic analysis is designed for any chemical system in which the change in molecular weight is due to the three-body recombination reactions only and one in which the energy exchange through the bimolecular reactions is small in comparison with that of the other reactions. The analysis makes use of Bray's sudden freezing criterion to determine a freezing point in the nozzle. The engine performance is then determined by assuming that the composition of the exhaust gas remains unchanged or frozen from the freezing point to the nozzle exit. The program can also be used for equilibrium and frozen or specified freezing point calculations for any rocket propellant system or ramjet fuel.

INTRODUCTION

The performance of hypersonic ramjets and rockets can be strongly dependent on the chemical kinetic processes of the exhaust gases. These engines usually have combustion temperatures high enough to cause a high degree of dissociation of the products of combustion. If the recombination process is fast enough to keep up with the expansion through the exhaust nozzle, the energy of dissociation is converted to useful thrust. If the recombination process is not fast enough, some of the dissociation energy is lost with a consequent penalty in thrust and specific impulse.

For example, figure 1 shows that, if the exhaust gases of a hydrogen fluorine rocket engine are assumed completely frozen, the loss can range from 13 percent of the equilibrium specific impulse at an oxidant-fuel ratio of 7 to 21 percent at an oxidant-fuel ratio of 19. Consequently, it is important to be able to estimate the extent of these losses. A

number of computer programs have been developed for exact solutions of nozzle chemical kinetics with multiple chemical reactions (refs. 1 to 6). However, these programs require extensive machine time and can become somewhat cumbersome when many solutions are required. A short, simple method requiring only a fraction of the computing time incurred by the exact methods would be valuable when many solutions are required, such as in parametric studies or preliminary design work. This report describes a computer program for the IBM 7094 computer for an approximate solution of nozzle chemical kinetics that can be used for a variety of propellant combinations. In this program, nonequilibrium effects on nozzle performance are determined by making use of Bray's criterion (ref. 7). With this approach, the gases at the nozzle entrance are assumed to be in chemical equilibrium; that is, the composition is that corresponding to a complete or steady-state adjustment to local temperature and pressures at each point in the exhaust nozzle. At some later point in the nozzle (as located by using Bray's criterion), the flow is assumed to "freeze"; that is, the composition no longer varies throughout the remainder of the nozzle expansion. A complete description of this analysis applied to the hydrogen-air system, comparisons with experimental data, and results from exact solutions are given in references 8 and 9. Comparisons of results using a Bray analysis with exact solutions for the systems hydrogen-oxygen and nitrogen tetroxide with a mixture of 50 percent hydrazine and 50 percent UDMH (unsymmetrical dimethyl hydrazine) are presented in reference 10. In all cases the Bray approach was found to yield reasonably accurate results. Some additional data to confirm the validity of the Bray approach are presented in this report.

The FORTRAN IV program is available to computing centers if a request is made to the authors. The program is for use on the IBM 7094 model 2 computer. With modifications this program can be used on all machines that have a FORTRAN compiler.

SYMBOLS

A	cross-sectional area, m^2
a, b, c, d, e	constants in equations defining nozzle contour
C	recombination rate constants, $(^{\circ}K)(cm^6)/(mole^2)(sec)$
C_D	overall combustion-chamber drag coefficient
C_F	thrust coefficient
C_V	nozzle-velocity coefficient
c_p	specific heat at constant pressure, $cal/(g)(^{\circ}K)$
c^*	characteristic velocity, m/sec

D	dissociation rate, mole/(cc)(sec)
F_{net}	net stream thrust, N
f/a	fuel-air ratio
g	gravitational constant, m/sec^2
H	static enthalpy, cal/g
I	specific impulse, sec
I_{net}	net fuel specific impulse, sec
I_{vac}	vacuum specific impulse, sec
i, j, k, l	exponents in equations defining nozzle contour
J	mechanical equivalent of heat, 4186 joules/(kg)(cal)
K	constant in eq. (A5)
k_r	forward reaction rate for reaction r, $cm^6/(mole^2)(sec)$
k_{-r}	reverse reaction rate for reaction r, $cm^3/(mole)(sec)$
M	Mach number
$\mathscr{M}$	average gram molecular weight, g/mole
m	mass flow rate, kg/sec
N	number of moles per unit mass of mixture, mole/g
$\mathscr{N}$	number of species in r^{th} reaction equation
n	number of moles
P	static pressure, atm (N/m^2)
Q	net rate of molar change, mole/(cc)(sec)
q	dynamic pressure, $\rho V^2/2$, kg/cm^2
R	recombination rate, mole/(cc)(sec)
$\mathscr{R}$	universal gas constant, 1.98726 cal/(mole)(^oK), (joules/(mole)(^oK))
r_i	reaction i
T	static temperature, ^oK
t	time, sec
V	velocity, m/sec
$V_i^{r'}$	stoichiometric coefficient, left side of reaction equation

$V_i^{r''}$ stoichiometric coefficient, right side of reaction equation

w weight flow rate, kg/sec

X mole fraction

x length or longitudinal coordinate, m

y normal coordinate, m

α fuel injection angle, deg

γ ratio of specific heats

ρ mass density, g/cc

φ equivalence ratio, $(f/a)/(f/a)_{stoichiometric}$

Subscripts:

a air

c combustion chamber

e nozzle exit

f fuel

i species

j species in r^{th} reaction equation

j' species on left side of rth reaction equation

j'' species on right side of rth reaction equation

K, L radicals in r^{th} recombination equation

k molar species

M molecular species in r^{th} recombination equation

m number of molecular species

n nozzle

p static pressure

S static entropy

t static temperature

0 free stream

1 ramjet inlet entrance

2 combustion-chamber entrance

3 combustion-chamber exit

Superscript:

* nozzle minimum cross-sectional area

METHOD OF ANALYSIS

Bray's criterion is applied in this analysis by determining in the nozzle a sudden freezing point that is characterized by the net rate of change in the number of moles becoming approximately equal to the recombination rate. The present application of the Bray criterion to any chemical system with multiple chemical reactions requires that the bimolecular reaction rates be much faster than the recombination reaction rates and that the energy exchange of the bimolecular reactions be small in comparison with that of the recombination reactions; that is, the overall reaction rate is assumed to be limited by the three-body recombination reactions through which the major part of the dissociation energy is recovered. After the freezing point is determined, any energy change resulting from the bimolecular reactions is neglected. There also must be a detectable molecular weight variation with temperature and pressure, and this variation must result from the recombination reactions only. For example, consider the hydrogen-air system, the reactions of which are presented in table I. The bimolecular reactions for this system ((1) to (6)) are much faster than the recombination reactions ((7) to (12)). A partial equilibrium concept (ref. 11) can be adopted in which the bimolecular reaction rates are assumed equal to their equilibrium values. The bimolecular reactions then form a sufficient quantity of radicals for the recombination reactions. The bimolecular reactions produce no change in the number of moles and result in only small energy changes. In general, then, the change in the total number of moles for a system of this type may be determined by considering the recombination reactions only. The change in the number of moles n is the sum of the change in the number of moles of species k in the recombination reactions. That is,

$$\frac{dn}{dt} = \sum_{k=1}^{k=m} \frac{dn_k}{dt} \tag{1}$$

TABLE I. - HYDROGEN-AIR SYSTEM REACTIONS

Hydrogen-oxygen bimolecular reactions	Recombination reactions	Nitric oxide shuffle reactions
1. $H_2 + OH \underset{K_{-1}}{\overset{K_1}{\rightleftharpoons}} H_2O + H$	7. $H + H + M \underset{K_{-7}}{\overset{K_7}{\rightleftharpoons}} H_2 + M$	13. $N_2 + O \underset{K_{-13}}{\overset{K_{13}}{\rightleftharpoons}} NO + N$
2. $H + O_2 \underset{K_{-2}}{\overset{K_2}{\rightleftharpoons}} OH + O$	8. $O + O + M \underset{K_{-8}}{\overset{K_8}{\rightleftharpoons}} O_2 + M$	14. $O_2 + N \underset{K_{-14}}{\overset{K_{14}}{\rightleftharpoons}} NO + O$
3. $O + H_2 \underset{K_{-3}}{\overset{K_3}{\rightleftharpoons}} OH + H$	9. $O + H + M \underset{K_{-9}}{\overset{K_9}{\rightleftharpoons}} OH + M$	
4. $OH + OH \underset{K_{-4}}{\overset{K_4}{\rightleftharpoons}} H_2 + O_2$	10. $OH + H + M \underset{K_{10}}{\overset{K_{10}}{\rightleftharpoons}} H_2O + M$	
5. $OH + OH \underset{K_{-5}}{\overset{K_5}{\rightleftharpoons}} H_2O + O$	11. $N + N + M \underset{K_{-11}}{\overset{K_{11}}{\rightleftharpoons}} N_2 + M$	
6. $O + H_2O \underset{K_{-6}}{\overset{K_6}{\rightleftharpoons}} H_2 + O_2$	12. $O + N + M \underset{K_{-12}}{\overset{K_{12}}{\rightleftharpoons}} NO + M$	

Converting to moles per unit mass of mixture results in

$$\frac{dN}{dt} = \frac{d\left(\frac{1}{m}\right)}{dt} = \sum_{k=1}^{k=m} \frac{dN_k}{dt} \tag{2}$$

The rate of formation of species i, in the moles per unit mass, is given by

$$\frac{d}{dt}\frac{X_i}{\mathscr{M}} = \frac{1}{\rho}\sum_{r=1}^{r=m}\left(V_i^{r''}V_i^{r'}\right)\left[k_r \prod_{j=1}^{j=j'}\left(\frac{\rho X_j}{\mathscr{M}}\right)^{V_{jr'}} k_{-r}\prod_{j=1}^{j=j''}\left(\frac{\rho X_j}{\mathscr{M}}\right)^{V_{jr''}}\right] \tag{3}$$

Substituting the recombination reaction equations into equations (2) and (3) results in the

general net rate equation

$$\frac{\rho}{\mathcal{M}} \frac{d \ln \mathcal{M}}{dt} \left(\frac{\rho}{\mathcal{M}}\right)^3 \sum_{r=1}^{r=m} k_r X_K X_L - \left(\frac{\rho}{\mathcal{M}}\right)^2 \sum_{r=1}^{r=m} k_{-r} X_M \tag{4}$$

Equation (4) is in the form $Q = R - D$, where Q is the net rate of molar change and R and D are the recombination and dissociation rates, respectively.

When the reactions proceed at rates fast enough to keep the overall reaction close to equilibrium, R and D are approximately equal and they are much greater than Q. Similarly, a near frozen condition exists when R is much smaller than Q. According to the Bray criterion, the transition from the near equilibrium to the near frozen condition is very rapid, and the location of the transition may be signified where R and D become of the same order of magnitude as Q. In the present method, R is evaluated from known reaction rates by using mole fractions and assuming the gases to be in chemical equilibrium. The value of Q is determined from equilibrium values of density, molecular weight, and the change in molecular weight with respect to time. The freezing point is assumed to be located where $Q = R$. Therefore, at the freezing point

$$\frac{\rho}{\mathcal{M}} \frac{d \ln \mathcal{M}}{dt} = \left(\frac{\rho}{\mathcal{M}}\right)^3 \sum_{r=1}^{r=m} k_r X_K X_L \tag{5}$$

The reaction rates k_r of equation (5) are converted to rate constants by assuming a temperature dependence of T^{-1}; that is, $C_r = k_r T$. The recombination rate constants for the hydrogen-air reactions are presented in table II.

TABLE II. - HYDROGEN-AIR REACTIONS

RECOMBINATION-RATE CONSTANTS

Constant, $(^{\circ}K)(cm^6)/(mole^2)(sec)$	Reference
$C_7 = 3\times10^{18}$	16
$C_8 = 4.8\times10^{18}$	17
$C_9 = 4.8\times10^{18}$	8 and 9
$C_{10} = 7.5\times10^{19}$	8 and 9
$C_{11} = 5.4\times10^{17}$	17
$C_{12} = 1.8\times10^{18}$	18

When ρ/M is converted to P/RT, the right side of equation (5) becomes

$$R = \left(\frac{P^3}{R^3T^4}\right) \sum_{r=1}^{r=m} C_r X_K X_L \tag{6}$$

The left side of equation (5) is put in the form

$$Q = \left(\frac{\rho}{\mathcal{M}}\right) \frac{d \ln \mathcal{M}}{dt} = \left(\frac{\rho V}{\mathcal{M}}\right)\left(\frac{d \ln \mathcal{M}}{dx}\right)$$

and converted to parameters determined by the program. Therefore,

$$Q = \left[\frac{P_n V}{RT\left(\frac{A}{A_t}\right)} \frac{d\left(\frac{A}{A_t}\right)}{dx}\right]\left[\frac{\partial \ln\left(\frac{P_c}{P_n}\right)}{\partial \ln\left(\frac{A}{A_t}\right)}\right]_S \left\{\left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P \left[\frac{\partial \ln T}{\partial \ln\left(\frac{P_c}{P_n}\right)}\right]_S - \left(\frac{\partial \ln \mathcal{M}}{\partial \ln P_n}\right)_T\right\} \tag{7}$$

The freezing point is then determined by the simultaneous solution of equations (6) and (7).

Equations (6) and (7) are solved first at the minimum area of the nozzle, which is the sonic point for rockets and subsonic combustion ramjets or the nozzle entrance for supersonic combustion ramjets (scramjets). However, because equation (7) is discontinuous at the sonic point, this solution is actually made slightly upstream of the sonic point. If the net rate Q is greater than the recombination rate R, the freezing point is located in the subsonic nozzle for rockets and ramjets, and the nozzle is completely frozen for scramjets. If Q is less than R, the freezing point is downstream of the minimum area. After the region in which freezing occurs is determined, the exact location is found by the following iteration. The freezing point is searched for in terms of the static-pressure ratio P_c/P_n at that point in the nozzle. To start the iteration, two trial values are assumed. The corresponding values of Q/R are calculated from equations (6) and (7). An estimate of the correct P_c/P_n is then found by

$$\frac{d \ln\left(\frac{Q}{R}\right)}{d \ln\left(\frac{P_c}{P_n}\right)} = \frac{\ln\left(\frac{Q}{R}\right)_i - \ln\left(\frac{Q}{R}\right)_{i-1}}{\ln\left(\frac{P_c}{P_n}\right)_i - \ln\left(\frac{P_c}{P_n}\right)_{i-1}} \tag{8}$$

$$\left(\frac{P_c}{P_n}\right)_{i+1} = \text{antilog}\left\{\ln\left(\frac{P_c}{P_n}\right)_i - \frac{\ln\left(\frac{Q}{R}\right)_i}{\left[\frac{d\ \ln(Q/R)}{d\ \ln(P_c/P_n)}\right]}\right\} \tag{9}$$

and the value of $(Q/R)_{i+1}$ is determined from equations (6) and (7). The procedure is repeated until $\left|(Q/R)_{i+1} - 1.0\right| \leq$ tolerance. When this occurs, the freezing point has been determined and the rest of the nozzle calculations are computed for frozen gas composition. A graphical solution for a typical freezing point calculation is presented in figure 2.

COMPUTER PROGRAM

General Description

The chemical equilibrium and rocket performance program of reference 12 was used to write the computer program of this report. The subroutine titles and nomenclature of the parts of that program that are used were retained. The present program is designed for use on the IBM 7094 model 2 computer with a 32K core. The compiler is a version 5 FORTRAN IV compiler of the IBSYS version XIII operating system. With modifications the program can be used on all machines that have a FORTRAN compiler. The entire program is written in FORTRAN IV except subroutine "SHIFT" and "BCREAD," which are written in basic machine language (MAP). The FORTRAN IV listing of the program is shown in appendix C.

The program computes nozzle performance for rockets and subsonic or supersonic combustion ramjets. For both engines, the combustion process is calculated first. For rocket engines, the combustion is assumed to take place at constant pressure. The combustion-chamber pressure, the oxidant-fuel ratio, and either the combustion temperature or the enthalpies of the reactants entering the combustion chamber must be specified. For ramjet engines, the combustion process may be calculated for either a combustor-exit to inlet-static-pressure ratio or an area ratio. The properties of the air and fuel entering the combustor must be specified. The properties of the entering air that must be specified are the following:

(1) Static pressure
(2) Static temperature
(3) Static enthalpy
(4) Velocity
(5) Molecular weight
(6) Ratio of specific heats

The fuel is assumed to be a gas when it enters the combustor. The fuel properties are the following:

(1) Static temperature
(2) Molecular weight
(3) Velocity
(4) Static enthalpy
(5) Fuel-air ratio
(6) Fuel injection angle

The ramjet combustor-exit conditions are then calculated using the iteration solutions described in appendix A.

The thermodynamic properties of the gas in the combustor and nozzle are determined by the method described in reference 12. For both engines, the nozzle performance is calculated for a specified ratio of combustor-exit to nozzle static pressure and includes the following performance parameters for ideal one-dimensional flow:

Exit velocity:

$$V_e = \sqrt{2gJ(h_c - h_e) + V_c^2} \qquad (V_c = 0 \text{ for rockets}) \tag{10}$$

Mach number:

$$M_e = \frac{V_e}{\sqrt{\gamma_e g \mathscr{R} T_e / \mathscr{M}_e}} \tag{11}$$

For rocket engines:

Vacuum specific impulse:

$$I_{vac} = \frac{V_e}{g} + \frac{\mathscr{R} T_e}{\mathscr{M}_e V_e} \tag{12}$$

Characteristic velocity:

$$C^* = g\mathscr{R} P_c \left(\frac{T}{P \mathscr{M} V}\right)_t \tag{13}$$

Vacuum thrust coefficient:

$$C_F = \frac{gI_{vac}}{C^*} \tag{14}$$

For ramjets:

Fuel specific impulse:

$$I_{net} = \frac{F_{net}}{w_f} = \frac{1 + \frac{f}{a}}{\frac{f}{a}} \left(C_V \frac{V_e}{g} + \frac{1 - \frac{P_0}{P_e}}{C_V \mathscr{M}_e V_e} \mathscr{R} T_e \right) - \frac{V_0}{\frac{f}{a} g} \tag{15}$$

Thrust coefficient:

$$C_F = \frac{2I_{net}}{V_0} g \frac{A_0}{A_1} \frac{f}{a} \tag{16}$$

For the calculation of the preceding ramjet parameters, the following must also be specified:

(1) Free-stream velocity
(2) Free-stream static pressure
(3) Ratio of engine inlet to capture area
(4) Ratio of engine free-stream dynamic pressure to vehicle dynamic pressure (1.0 if engine is not in a vehicle pressure field)

Both rocket and ramjet nozzle calculations may be carried out using the following types of analysis for the nozzle expansion:

(1) Equilibrium
(2) Frozen
(3) Specified freezing point
(4) Approximate kinetic

The equilibrium, frozen, and specified freezing point type of nozzle calculations may be made for any rocket propellant combination or ramjet fuel. The kinetic calculations may be made for any rocket propellant combination or ramjet fuel that is subject to the conditions discussed in METHOD OF ANALYSIS.

Description of Input

The input is programmed for a fixed format, as shown in table III, which gives the program input. Table IV shows the arrangement of the input for the various calculation options.

TABLE III. - PROGRAM INPUT

Card	Format	Parameters
1	12A6	Identification
2	3(F10.5)	Enthalpy, cal/(g)(mole); temperature, ^{o}K; density, g/cc
	2(A1)	Fuel or oxidant, F or O; liquid, gas, or solid, L, G, or S
	F8.5	Relative weight
	4(A2, F8.5)	Reactant formula, maximum of 5 per card
3		BLANK CARD
4	11I3	KOK, JADDI, MNFR, IDEBUG, IPROB, ICONST, IRAM, IZE1AR, IROU, ICON, IFREZ
[a]5	5F10.2	PCP schedule, maximum of 24
6	4F10.2	SUB1, SUB2, SUB3, YT
7	I3	NZTYP
8	5I3	ITYP
9	5F10.4	CON, maximum of 20
10	5F10.4	EEXP, maximum of 20
11	2I3	NMOL, NAK
12	I5, 5X, 2A6	NUMBER, MOLECULE
13	E10.5, 315	AK, NUMBER
14	7F10.4	COSTH, CD, CDA, TFS, WMF, VT, DELH
15	5F10.4	P2, T2, AMOL2, V2, GAM2
16	5F10.4	PFIELD, VO, AOAC, QIQO, P3P2
[b]17	6F10.4	EQRAT, OF, FPCT, PC, TC, CV
18		BLANK CARD

[a]If KOK = 1, set the first two PCP's equal to 1.0.

[b]Card 17 may be repeated for multiple cases of OF ratios. Card 18 indicates another problem follows.

TABLE IV. - ARRANGEMENT OF INPUT FOR FORTRAN IV PROGRAM

TITLE	PROJECT NUMBER	ANALYST	SHEET ____ OF ____

STATEMENT NUMBER (1–5)	CONT (6)	FORTRAN STATEMENT (7–72)	IDENTIFICATION (73–80)

Card 1 Title (12A6)

Card 2 Propellant (310.5, 2I1, F8.5, 4(2A, F8.5))

ENTH	Temp	Density	O or F	G or S, L	% Wt	Mol	Number	Mol	Number	Mol	Number	Mol	Number

Card 3

Blank card

Card 4 Codes (20I3)

KOK	JADDI	MNFR	IDEBUG	IPROB	ICONST	IRAM	IZEIAR	IROU	ICON	IFREZ

Card 5 Pressure ratio schedule (JADDI tells how many coming in) (5F10.0)

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TABLE IV. - Continued. ARRANGEMENT OF INPUT FOR FORTRAN IV PROGRAM

TITLE	PROJECT NUMBER	ANALYST	SHEET ____ OF ____

STATEMENT NUMBER (1–5)	CONT (6)	FORTRAN STATEMENT (7–72)	IDENTIFICATION (73–80)
Card 6		If MNFR = -2 Read in the following: (5F10.0	
SUB 1		SUB 2 SUB 3 YT	
Card 7		0 = bell nozzle; 1 = plug nozzle (I3)	
NZTYP			
Card 8		ITYP I = 5 (20I5)	
Card 9		CON = 1, ICON (5F10.5)	
		EEXP = ε	
Card 10		I = 1, ICON (5F10.5)	

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TABLE IV. - Continued. ARRANGEMENT OF INPUT FOR FORTRAN IV PROGRAM

TITLE	PROJECT NUMBER	ANALYST	SHEET ____ OF ____

STATEMENT NUMBER	CONT	FORTRAN STATEMENT	IDENTIFICATION

1 2 3 4 5 | 6 | 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

Card 11

NMOL NAK (20I3)

Card 12

NUMBER NAME OF MOLECULE AS IT APPEARS IN STORAGE (I5, 5x, 2A6)

Card 13 AK numbers (E10.5, 3I5)

1 2 3 4 5 | 6 | 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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TABLE IV. - Concluded. ARRANGEMENT OF INPUT FOR FORTRAN IV PROGRAM

TITLE	PROJECT NUMBER	ANALYST	SHEET ____ OF ____

STATEMENT NUMBER (1–5)	CONT (6)	FORTRAN STATEMENT (7–72)	IDENTIFICATION (73–80)
Card 14		If IRAM = 1 (7F10.5)	
COSTH		CD CDA TFS WMF VT DELH	
Card 15			
P2		T2 AMOL2 V2 GAM2 (5F10.5)	
Card 16			
PFIELD		VO AOAC Q1Q0 P3P2	
Card 17		(6F10.5)	
EQRAT		OF FPCT PC TC CV	
Card 18			
		Blank card	

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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The definitions of the input parameters are as follows:

Common to rockets and ramjets:

CV	nozzle-velocity coefficient
[1]EQRAT	equivalence ratio
[1]FPCT	percent fuel
IDEBUG	allows intermediate output for debugging (IDEBUG=1, intermediate output; IDEBUG=0, no intermediate output)
IFREZ	sequential number of the freezing pressure ratio if specified freezing point is to be calculated (IFREZ=0 if specified freezing point calculation is not to be made)
IPROB	type of combustion calculation (IPROB=1, specified enthalpy and pressure; IPROB=2, specified temperature and pressure)
IRAM	type of engine (IRAM=0, rocket; IRAM=1, ramjet)
JADDI	number of input pressure ratios
KOK	indicates subsonic or supersonic combustion (KOK=0, rocket or subsonic combustion ramjet; KOK=1, supersonic combustion ramjet)
MNFR	indicates type of nozzle expansion (MNFR=0, equilibrium; MNFR=1, frozen; MNFR=-2, approximate kinetic; MNFR=-1, specified freezing point)
[1]OF	ratio of oxidant to fuel weight
PC	combustion-chamber pressure, atm (set equal to combustor entrance static pressure for ramjet calculations)
PCP	ratio of chamber pressure to nozzle static pressure for rockets (for ramjet calculations, ratio of combustor-exit static pressure to nozzle static pressure)
TC	combustion temperature, $^{\circ}$K (not necessary for an assigned enthalpy calculation; for ramjet calculations, set equal to combustor-entrance static temperature)

Applicable to ramjets only:

AMOL2	molecular weight of air entering ramjet combustor
AOAC	capture area ratio

[1]One of the parameters EQRAT, FPCT, and OF is input. The other two are set equal to zero.

CD	combustor drag coefficient to account for friction or momentum losses due to hardware obstructions, etc; $CD = D/\left(1/2\rho_3 V_3^2\right)$
CDA	additive drag coefficient; $CDA = (1 - A_0/A_1)(P_1/P_0 - 1)P_0/q_0$
COSTH	cosine of fuel injection angle (COSTH=1.0, downstream injection; COSTH=0.0, normal injection)
DELH	static enthalpy of fuel, cal/g
GAM2	ratio of specific heats α of air entering combustor
ICONST	type of combustion calculation (ICONST=0, specified pressure ratio; ICONST=1, specified area ratio)
PFIELD	external pressure of ramjet nozzle, atm
P2	static pressure of air entering combustor, atm
P3P2	combustor area ratio or pressure ratio
Q1QO	ratio of dynamic pressure of air entering ramjet inlet to free-stream dynamic pressure
TFS	fuel static temperature, ^{o}K
T2	static temperature of air entering combustor, ^{o}K
VT	velocity of fuel entering combustor, m/sec
VO	velocity of air entering ramjet inlet, m/sec
V2	velocity of air entering ramjet combustor, m/sec
WMF	fuel molecular weight, g/mole

Applicable to kinetic calculations:

AK	reaction rate constant
CON	constant for nozzle-contour equation
EEXP	exponent in nozzle-contour equation
ICON	number of constants and exponents defining dx/dy of nozzle (ICON=0 if a kinetic calculation is not to be made)
IROU	indicates axisymmetric or two-dimensional nozzle (IROU=1, axisymmetric; IROU=0, two-dimensional)
ITYP	type of equation defining nozzle contour (ITYP=1, polynomial; ITYP=2, circle; equations defining each section of nozzle contour must be indicated as ITYP 1 or 2)

MOLECULE	name of each species
NAK	number of reaction rate constants
NMOL	number of species considered for kinetic calculation
NUMBER	identification number for each species
NZTYP	NZTYP=0 indicates conical or bell nozzle contour
SUB1, SUB2, SUB3	nozzle-area ratios separating five sections where each equation defining dx/dy of contour is applicable
YT	nozzle-throat radius or half-height for rockets and subsonic combustion ramjets, or nozzle-entrance radius or half-height for supersonic combustion ramjets, cm

A set of thermodynamic and atom tables described in reference 12 is placed immediately after the program as permanent input. The input cards in table III are then placed after these. Cards 1 to 5 are always used. There may be any number of reactant cards (card 2) but no more than 15 elements. For ramjets, one of these reactant cards must be for air. Each reactant card contains the chemical formula, enthalpy, temperature, and relative weight. In addition, the letter F or O in column 31 indicates whether the reactant is a fuel or an oxidant. The letter L, G, or S in column 32 indicates a liquid, a gas, or a solid. The relative weight is the percent of the total fuel or oxidant for the reactant that appears on that particular card. The sum of the relative weights of a fuel or an oxidant must be 100. For equilibrium, frozen, or specified freezing point nozzle expansion, cards 17 and 18 are used for rockets and cards 14 to 18 are used for ramjets. For kinetic calculations, cards 6 to 13 are placed after card 5. Appendix B explains both the contour equation limits, SUB1, SUB2, and SUB3 (card 6), and the nozzle-contour equation constants and exponents, CON and EEXP (cards 9 and 10). Table V gives four sample input arrangements for hydrogen fluorine rocket-engine performance calculations for equilibrium, frozen, specified freezing point, and kinetic nozzle expansions. The combustion calculations are for an assigned enthalpy and pressure. Table VI gives sample input arrangements for a hydrogen-fueled, subsonic-combustion ramjet and a supersonic-combustion ramjet.

Table VII presents sample output for the rocket engine used for the sample input. The format for the equilibrium and frozen nozzle expansions is identical to that described in reference 12. The specified freezing point and kinetic nozzle expansion have the equilibrium points up to the freezing point printed out on the first page. The second page then contains the frozen expansion for the points from the freezing point to the last pressure ratio in the schedule. For rockets and subsonic-combustion ramjets, the throat parameters are printed out on the first page if the freezing point is downstream of the

TABLE V. - SAMPLE INPUT ARRANGEMENTS FOR HYDROGEN FLUORINE

ROCKET-ENGINE PERFORMANCE CALCULATIONS

```
 HYDROGEN  FLUORINE  ROCKET  PC=60 PSIA  EQUILIBRIUM  NOZZLE  EXPANSION
-1893.67                     FL100.00  H 2.0
-3030.89                     OL100.00  F 2.0

  0 10  0  0  1  0  0  0  0  0  0
1.0       1.75      5.00      10.00     15.00
40.00     100.00    200.00    400.00    600.00
          13.0                4.083               1.0

 HYDROGEN  FLUORINE  ROCKET  PC=60 PSIA  FROZEN  NOZZLE  EXPANSION
-1893.67                     FL100.00  H 2.0
-3030.89                     OL100.00  F 2.0

  0 10  1  0  1  0  0  0  0  0  0
1.0       1.75      5.00      10.00     15.00
40.00     100.00    200.00    400.00    600.00
          13.0                4.083               1.0

 HYDROGEN  FLUORINE  ROCKET  PC=60 PSIA  SPECIFIED  FREEZING  POINT
-1893.67                     FL100.00  H 2.0
-3030.89                     OL100.00  F 2.0

  0 10 -1  0  1  0  0  0  0  0  3
1.0       1.75      5.00      10.00     15.00
40.00     100.00    200.00    400.00    600.00
          13.0                4.083               1.0

 HYDROGEN-FLOURINE  ROCKET  PC=60 PSIA  KINETIC  NOZZLE  EXPANSION
-1893.67                     FL100.0   H 2.0
-3030.89                     OL100.0   F 2.0

  0 10 -2  0  1  0  0  0  1 20  0
1.0       1.75      80.0      100.0     800.0
1000.0    1500.0    2000.0    2500.0    3000.0
1.54      1.145     50.0      10.20

  1  2  2  1  1
-1.73                                   -517.50
61.0      -1.0                -517.50   61.0
-1.0                3.73
          3.73
1.0

                    1.0
          1.0
  2  2
    1     H1(G)
    2     F1(G)
   7.5E 18    1    1
   7.5E 18    1    2
          13.0                4.083               1.0
```

TABLE VI. - SAMPLE INPUT ARRANGEMENTS FOR RAMJETS

```
 SUBSONIC  COMBUSTION  RAMJET  FLIGHT  MACH  NUMBER  8
4942.90                        FG100.00  H 2.0
12277.00                       OG100.00  N 1.5618  O .419     AR.0096

  0 10  0  0  1  1  1  0  0  0  0
 1.0       1.75      5.00      10.00     15.00
40.00      100.0     200.0     400.0     600.00
1.0        .003      0.00      1000.00   2.016     1798.32   2471.45
43.34      2582.04   28.94     192.9384  1.2485
.0164      2400.7998 1.0       1.0       1.0
1.0                              43.34               .98

 SUPERSONIC  COMBUSTION  RAMJET  FLIGHT  MACH  NUMBER  8
4942.90                        FG100.00  H 2.0
2840.00                        OG100.00  N 1.5618  O .419     AR.0096

  1  6  0  0  1  1  1  0  0  0  0
1.0        1.0       5.0       10.0      15.0
18.0
1.0        .003      0.00      1000.00   2.016     1798.32   2471.45
.5304      682.55    28.962    2201.9971 1.3665
.0164      2400.7998 1.0       1.0       1.35
1.0                              .5304               .98
```

TABLE VII. - ROCKET ENGINE PERFORMANCE EQUILIBRIUM NOZZLE EXPANSION

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2	1.00000	-1893.670	L	-0.	-0.
OXIDANT	F 2	1.00000	-3030.890	L	-0.	-0.

O/F= 13.00000, PERCENT FUEL= 7.1429, EQUIVALENCE RATIO= 1.4499, DENSITY= 0.

PARAMETERS

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.000	1.743	5.000	10.000	15.000	40.000	100.000	200.000	400.000	600.000
P, ATM	4.083	2.342	0.8166	0.4083	0.2722	0.1021	0.0408	0.0204	0.0102	0.0068
T, DEG K	4043	3826	3438	3196	3059	2739	2443	2204	1938	1771
H, CAL/G	-141.2	-440.8	-951.6	-1250.2	-1412.2	-1768.8	-2059.8	-2254.2	-2426.1	-2515.7
S, CAL/(G)(K)	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920
M, MOL WT	14.359	14.635	15.139	15.458	15.639	16.051	16.379	16.563	16.667	16.692
(DLM/DLP)T	0.05858	0.05047	0.03755	0.03063	0.02684	0.01764	0.00927	0.00413	0.00110	0.00036
(DLM/DLT)P	-0.9464	-0.8416	-0.6600	-0.5598	-0.5043	-0.3607	-0.2097	-0.1028	-0.0309	-0.0111
CP, CAL/(G)(K)	2.7271	2.5083	2.1010	1.8743	1.7523	1.4387	1.0847	0.8047	0.5884	0.5171
GAMMA	1.1543	1.1536	1.1555	1.1577	1.1591	1.1651	1.1826	1.2154	1.2727	1.3072
MACH NUMBER	0.	1.000	1.763	2.159	2.375	2.870	3.309	3.626	3.942	4.150
CSTAR, M/SEC		2393	2393	2393	2393	2393	2393	2393	2393	2393
CF		1.235	1.391	1.509	1.571	1.703	1.804	1.867	1.920	1.946
AE/AT		1.000	1.515	2.358	3.126	6.427	12.94	21.99	36.95	49.63
IVAC, SEC		301.5	339.5	368.2	383.4	415.5	440.2	455.6	468.4	474.7
I, SEC		161.5	265.6	310.6	332.6	376.3	408.6	428.8	445.9	454.5

DERIVATIVES

(DLI/DLPC)PC/P		0.01662	0.01511	0.01417	0.01363	0.01227	0.01087	0.00960	0.00812	0.00721
(DLT/DLPC)PC/P	0.04803	0.04453	0.03784	0.03315	0.03011	0.02090	0.00772	-0.00756	-0.02631	-0.03484
(DLAR/DLPC)PC/P		-0.	-0.00476	-0.00801	-0.01008	-0.01639	-0.02571	-0.03698	-0.05125	-0.05771
(DLCS/DLPC)PC/P		0.01491	0.01491	0.01491	0.01491	0.01491	0.01491	0.01491	0.01491	0.01491
(DLI/DHC)PC/P*		0.08944	0.09232	0.09446	0.09574	0.09906	0.10312	0.10761	0.11395	0.11831
(DLT/DHC)PC/P*	0.09070	0.09861	0.11773	0.13196	0.14116	0.17192	0.22803	0.30739	0.42035	0.47834
(DLAR/DHC)PC/P*		0.	0.01094	0.01922	0.02444	0.04270	0.08056	0.13922	0.22722	0.27318
(DLCS/DHC)PC/P*		0.09216	0.09216	0.09216	0.09216	0.09216	0.09216	0.09216	0.09216	0.09216
*(HC IN KCAL/G)										
(DLI/DLPCP)S		0.86684	0.27844	0.18524	0.15290	0.10418	0.07725	0.06258	0.05056	0.04441
(DLT/DLPCP)S	-0.09878	-0.09970	-0.10371	-0.10599	-0.10909	-0.11709	-0.13531	-0.16444	-0.20889	-0.23280
(DLAR/DLPCP)S		0.	0.58693	0.67849	0.70981	0.75411	0.76832	0.76018	0.73518	0.72055

MOLE FRACTIONS

F1(G)	0.05430	0.03921	0.01781	0.00922	0.00595	0.00172	0.00038	0.00008	0.00001	0.00000
H1(G)	0.22640	0.20853	0.16957	0.13995	0.12153	0.07641	0.03849	0.01676	0.00440	0.00145
H2(G)	0.07183	0.07625	0.09057	0.10459	0.11416	0.13913	0.16103	0.17377	0.18105	0.18280
HF1(G)	0.64748	0.67602	0.72206	0.74623	0.75836	0.78274	0.80011	0.80940	0.81454	0.81575

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

F2(G)

INPUT, G-ATOMS/G

	H	F
FUEL	0.9920635E 00	0.
OXIDANT	0.	0.5263158E-01
PROPELLANT	0.7086168E-01	0.4887218E-01

CASE NO. 0 60.0 13.000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VII. - Continued. ROCKET ENGINE PERFORMANCE FROZEN NOZZLE EXPANSION

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2	1.00000	-1893.670	L	-0.	-0.
OXIDANT	F 2	1.00000	-3030.890	L	-0.	-0.

O/F= 13.00000, PERCENT FUEL= 7.1429, EQUIVALENCE RATIO= 1.4499, DENSITY= 0.

PARAMETERS

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.000	1.858	5.000	10.000	15.000	40.000	100.000	200.000	400.000	600.000
P, ATM	4.083	2.197	0.8166	0.4083	0.2722	0.1021	0.0408	0.0204	0.0102	0.0068
T, DEG K	4043	3458	2677	2226	1993	1515	1160	943	763	673
H, CAL/G	-141.2	-462.1	-880.4	-1114.9	-1233.2	-1470.1	-1638.8	-1739.4	-1820.9	-1861.1
S, CAL/(G)(K)	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920
M, MOL WT	14.359	14.359	14.359	14.359	14.359	14.359	14.359	14.359	14.359	14.359
CP, CAL/(G)(K)	0.5530	0.5437	0.5265	0.5129	0.5046	0.4846	0.4673	0.4565	0.4507	0.4490
GAMMA	1.3338	1.3415	1.3565	1.3695	1.3779	1.3997	1.4207	1.4351	1.4431	1.4455
MACH NUMBER	0.	1.000	1.715	2.149	2.397	3.010	3.623	4.132	4.696	5.053
CSTAR, M/SEC		2270	2270	2270	2270	2270	2270	2270	2270	2270
CF		1.260	1.370	1.456	1.500	1.585	1.643	1.677	1.704	1.717
AE/AT		1.000	1.373	1.989	2.523	4.635	8.362	13.15	20.76	27.17
IVAC, SEC		291.7	317.2	337.1	347.2	366.9	380.3	388.1	394.3	397.3
I, SEC		167.1	253.6	291.1	308.3	340.0	361.0	372.9	382.3	386.9

MOLE FRACTIONS

F1(G)	0.05430	H1(G)	0.22640	H2(G)	0.07183	H1F1(G)	0.64748

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

F2(G)

INPUT, G-ATOMS/G

	H	F
FUEL	0.9920635E 00	0.
OXIDANT	0.	0.5263158E-01
PROPELLANT	0.7086168E-01	0.4887218E-01

CASE NO. 0 60.0 13.000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VII. - Continued. ROCKET ENGINE PERFORMANCE SPECIFIED FREEZING POINT

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2	1.00000	-1893.670	L	-0.	-0.
OXIDANT	F 2	1.00000	-3030.890	L	-0.	-0.

O/F= 13.00000, PERCENT FUEL= 7.1429, EQUIVALENCE RATIO= 1.4499, DENSITY= 0.

PARAMETERS

	CHAMBER	THROAT	EXIT
PC/P	1.000	1.743	5.000
P, ATM	4.083	2.342	0.8166
T, DEG K	4043	3826	3438
H, CAL/G	-141.2	-440.8	-951.6
S, CAL/(G)(K)	3.7920	3.7920	3.7920
M, MOL WT	14.359	14.635	15.139
(DLM/DLP)T	0.05858	0.05047	0.03755
(DLM/DLT)P	-0.9464	-0.8416	-0.6600
CP, CAL/(G)(K)	2.7271	2.5083	2.1010
GAMMA	1.1543	1.1536	1.1555
MACH NUMBER	0.	1.000	1.763
CSTAR, M/SEC		2393	2393
CF		1.235	1.391
AE/AT		1.000	1.515
IVAC, SEC		301.5	339.5
I, SEC		161.5	265.6

DERIVATIVES

(DLI/DLPC)PC/P		0.01662	0.01511
(DLT/DLPC)PC/P	0.04803	0.04453	0.03784
(DLAR/DLPC)PC/P		-0.	-0.00476
(DLCS/DLPC)PC/P		0.01491	0.01491
(DLI/DHC)PC/P*		0.08944	0.09232
(DLT/DHC)PC/P*	0.09070	0.09861	0.11773
(DLAR/DHC)PC/P*		0.	0.01094
(DLCS/DHC)PC/P*		0.09216	0.09216
*(HC IN KCAL/G)			
(DLI/DLPCP)S		0.86684	0.27844
(DLT/DLPCP)S	-0.09878	-0.09970	-0.10371
(DLAR/DLPCP)S		0.	0.58693

MOLE FRACTIONS

F1(G)	0.05430	0.03921	0.01781
H1(G)	0.22640	0.20853	0.16957
H2(G)	0.07183	0.07625	0.09057
H1F1(G)	0.64748	0.67602	0.72206

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

F2(G)

INPUT, G-ATOMS/G

	H	F
FUEL	0.9920635E 00	0.
OXIDANT	0.	0.5263158E-01
PROPELLANT	0.7086168E-01	0.4887218E-01

CASE NO. 0 60.0 13.000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VII. - Continued. ROCKET ENGINE PERFORMANCE SPECIFIED FREEZING POINT

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2	1.00000	-1893.670	L	-0.	-0.
OXIDANT	F 2	1.00000	-3030.890	L	-0.	-0.

O/F= 13.00000, PERCENT FUEL= 7.1429, EQUIVALENCE RATIO= 1.4499, DENSITY= 0.

PARAMETERS

	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	5.000	10.000	15.000	40.000	100.000	200.000	400.000	600.000
P, ATM	0.8166	0.4083	0.2722	0.1021	0.0408	0.0204	0.0102	0.0068
T, DEG K	3438	2899	2619	2035	1592	1313	1077	957
H, CAL/G	-951.6	-1239.3	-1386.0	-1684.3	-1931.5	-2033.3	-2141.8	-2195.8
S, CAL/(G)(K)	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920
M, MOL WT	15.139	15.139	15.139	15.139	15.139	15.139	15.139	15.139
CP, CAL/(G)(K)	0.5397	0.5277	0.5200	0.4997	0.4803	0.4663	0.4533	0.4468
GAMMA	1.3214	1.3311	1.3377	1.3563	1.3761	1.3919	1.4077	1.4160
MACH NUMBER	1.649	2.082	2.327	2.919	3.499	3.971	4.483	4.806
CSTAR, M/SEC	2393	2393	2393	2393	2393	2393	2393	2393
CF	1.391	1.486	1.535	1.632	1.699	1.739	1.770	1.786
AE/AT	1.515	2.195	2.794	5.198	9.519	15.15	24.18	31.79
IVAC, SEC	339.5	362.7	374.6	398.1	414.6	424.2	432.0	435.8
I, SEC	265.6	309.1	329.1	366.4	391.4	405.8	417.2	422.8

MOLE FRACTIONS

F1(G)	0.01781	H1(G)	0.16957	H2(G)	0.09057	HF(G)	0.72206

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

F2(G)

INPUT, G-ATOMS/G

	H	F
FUEL	0.9920635E 00	0.
OXIDANT	0.	0.5263158E-01
PROPELLANT	0.7086168E-01	0.4887218E-01

CASE NO. 6 12.0 13.000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VII. - Continued. ROCKET ENGINE PERFORMANCE KINETIC NOZZLE EXPANSION

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2	1.00000	-1893.670	L	-0.	-0.
OXIDANT	F 2	1.00000	-3030.890	L	-0.	-0.

O/F= 13.00000, PERCENT FUEL= 7.1429, EQUIVALENCE RATIO= 1.4499, DENSITY= 0.

PARAMETERS

	CHAMBER	THROAT	EXIT
PC/P	1.000	1.743	5.000
P, ATM	4.683	2.342	0.8166
T, DEG K	4043	3826	3438
H, CAL/G	-141.2	-440.8	-951.6
S, CAL/(G)(K)	3.7920	3.7920	3.7920
M, MOL WT	14.359	14.635	15.139
(DLM/DLP)T	0.05858	0.05047	0.03755
(DLM/DLT)P	-0.9464	-0.8416	-0.6600
CP, CAL/(G)(K)	2.7271	2.5083	2.1010
GAMMA	1.1543	1.1536	1.1555
MACH NUMBER	0.	1.000	1.763
CSTAR, M/SEC		2393	2393
CF		1.235	1.391
AE/AT		1.000	1.515
IVAC, SEC		301.5	339.5
I, SEC		161.5	265.6

DERIVATIVES

(DLI/DLPC)PC/P		0.01662	0.01511
(DLT/DLPC)PC/P	0.04803	0.04453	0.03784
(DLAR/DLPC)PC/P		-0.	-0.00476
(DLCS/DLPC)PC/P		0.01491	0.01491
(DLI/DHC)PC/P*		0.08944	0.09232
(DLT/DHC)PC/P*	0.09070	0.09861	0.11773
(DLAR/DHC)PC/P*		0.	0.01094
(DLCS/DHC)PC/P*		0.09216	0.09216
*(HC IN KCAL/G)			
(DLI/DLPCP)S		0.86684	0.27844
(DLT/DLPCP)S	-0.09878	-0.09970	-0.10371
(DLAR/DLPCP)S		0.	0.58693

MOLE FRACTIONS

F1(G)	0.05430	0.03921	0.01781
H1(G)	0.22640	0.20853	0.16957
H2(G)	0.07183	0.07625	0.09057
H1F1(G)	0.64748	0.67602	0.72206

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

F2(G)

INPUT, G-ATOMS/G

	H	F
FUEL	0.9920635E 00	0.
OXIDANT	0.	0.5263158E-01
PROPELLANT	0.7086168E-01	0.4887218E-01

CASE NO. 0 60.0 13.000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VII. - Concluded. ROCKET ENGINE PERFORMANCE KINETIC NOZZLE EXPANSION

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2	1.00000	-1893.670	L	-0.	-0.
OXIDANT	F 2	1.00000	-3030.890	L	-0.	-0.

O/F= 13.00000, PERCENT FUEL= 7.1429, EQUIVALENCE RATIO= 1.4499, DENSITY= 0.

PARAMETERS

	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	5.000	80.000	100.000	800.000	1000.000	1500.000	2000.000	2500.000	3000.000
P, ATM	0.8166	0.0510	0.0408	0.0051	0.0041	0.0027	0.0020	0.0016	0.0014
T, DEG K	3438	1691	1592	879	823	729	669	626	592
H, CAL/G	-951.6	-1853.4	-1901.5	-2230.5	-2255.4	-2296.7	-2323.1	-2342.0	-2356.6
S, CAL/(G)(K)	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920	3.7920
M, MOL WT	15.139	15.139	15.139	15.139	15.139	15.139	15.139	15.139	15.139
CP, CAL/(G)(K)	0.5397	0.4850	0.4803	0.4436	0.4417	0.4391	0.4379	0.4373	0.4369
GAMMA	1.3214	1.3711	1.3761	1.4202	1.4229	1.4264	1.4280	1.4289	1.4295
MACH NUMBER	1.649	3.354	3.499	5.049	5.245	5.619	5.898	6.124	6.313
CSTAR, M/SEC	2393	2393	2393	2393	2393	2393	2393	2393	2393
CF	1.391	1.684	1.699	1.796	1.803	1.814	1.822	1.827	1.831
AE/AT	1.515	8.204	9.519	38.61	44.91	59.12	71.88	83.68	94.75
IVAC, SEC	339.5	411.0	414.6	438.2	439.9	442.7	444.5	445.8	446.8
I, SEC	265.6	386.0	391.4	426.4	428.9	433.1	435.7	437.6	439.1

MOLE FRACTIONS

F1(G)	0.01781	H1(G)	0.16957	H2(G)	0.09057	H1F1(G)	0.72206

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

F2(G)

INPUT, G-ATOMS/G

	H	F
FUEL	0.9920635E 00	0.
OXIDANT	0.	0.5263158E-01
PROPELLANT	0.7686168E-01	0.4887218E-01

CASE NO. 0 12.0 13.000

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VIII. - SUBSONIC COMBUSTION RAMJET ENGINE PERFORMANCE EQUILIBRIUM NOZZLE EXPANSION

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	1.00000	4942.900	G	-0.	-0.
OXIDANT	N 1.56180 O 0.41900 AR 0.00960	1.00000	12277.000	G	-0.	-0.

O/F= 34.29030, PERCENT FUEL= 2.8336, EQUIVALENCE RATIO= 1.0000, DENSITY= 0.

PARAMETERS

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.000	1.719	5.000	10.000	15.000	40.000	100.000	200.000	400.000	600.000
P, ATM	43.34	25.21	8.668	4.334	2.889	1.084	0.4334	0.2167	0.1084	0.0722
T, DEG K	3221	3012	2611	2351	2199	1837	1524	1313	1125	1025
H, CAL/G	486.5	346.1	99.6	-40.2	-115.0	-274.7	-398.7	-477.9	-545.9	-581.0
S, CAL/(G)(K)	2.4990	2.4990	2.4990	2.4990	2.4990	2.4990	2.4990	2.4990	2.4990	2.4990
M, MOL WT	23.788	24.010	24.356	24.503	24.560	24.629	24.644	24.646	24.646	24.646
(DLM/DLP)T	0.01289	0.00946	0.00419	0.00201	0.00119	0.00023	0.00003	0.00000	0.00000	0.00000
(DLM/DLT)P	-0.2551	-0.2011	-0.1034	-0.0552	-0.0349	-0.0081	-0.0013	-0.0002	-0.0000	-0.0000
CP, CAL/(G)(K)	0.8583	0.7855	0.6293	0.5360	0.4906	0.4167	0.3833	0.3678	0.3545	0.3468
GAMMA	1.1634	1.1662	1.1816	1.1997	1.2128	1.2447	1.2672	1.2809	1.2944	1.3029
MACH NUMBER	0.	1.000	1.742	2.125	2.335	2.836	3.324	3.717	4.132	4.387
CSTAR, M/SEC		1626	1626	1626	1626	1626	1626	1626	1626	1626
CF		-0.243	-0.039	0.112	0.190	0.348	0.461	0.528	0.580	0.604
AE/AT		1.000	1.533	2.361	3.096	6.124	11.79	19.46	32.24	43.33
IVAC, SEC		-1018.3	-160.8	473.1	802.4	1471.9	1958.8	2256.4	2504.1	2629.0
I, SEC		-1020.5	-164.2	467.8	795.6	1458.4	1932.8	2213.4	2432.7	2533.1

DERIVATIVES

(DLI/DLPC)PC/P		0.00829	0.00657	0.00544	0.00480	0.00344	0.00250	0.00198	0.00159	0.00140
(DLT/DLPC)PC/P	0.02483	0.02020	0.01031	0.00381	0.00039	-0.00527	-0.00731	-0.00786	-0.00820	-0.00839
(DLAR/DLPC)PC/P		-0.	-0.00589	-0.00995	-0.01210	-0.01551	-0.01636	-0.01636	-0.01630	-0.01630
(DLCS/DLPC)PC/P		0.00652	0.00652	0.00652	0.00652	0.00652	0.00652	0.00652	0.00652	0.00652
(DLI/DHC)PC/P*		0.23172	0.24499	0.25641	0.26385	0.28233	0.29757	0.30710	0.31518	0.31937
(DLT/DHC)PC/P*	0.36166	0.39519	0.49333	0.57918	0.63283	0.74500	0.80985	0.84390	0.87570	0.89500
(DLAR/DHC)PC/P*		0.	0.05641	0.11184	0.14808	0.22579	0.27037	0.29404	0.31760	0.33270
(DLCS/DHC)PC/P*		0.24293	0.24293	0.24293	0.24293	0.24293	0.24293	0.24293	0.24293	0.24293
*(HC IN KCAL/G)										
(DLI/DLPCP)S		0.82347	0.26771	0.17731	0.14525	0.09596	0.06858	0.05428	0.04346	0.03830
(DLT/DLPCP)S	-0.12215	-0.12655	-0.14307	-0.15968	-0.17069	-0.19522	-0.21063	-0.21924	-0.22745	-0.23247
(DLAR/DLPCP)S		0.	0.54463	0.62222	0.64531	0.67349	0.68658	0.69246	0.69509	0.69524

MOLE FRACTIONS

AR1(G)	0.00766	0.00773	0.00784	0.00789	0.00791	0.00793	0.00794	0.00794	0.00794	0.00794
H1(G)	0.00905	0.00578	0.00173	0.00055	0.00024	0.00002	0.00000	0.00000	0.	0.
H2(G)	0.04044	0.03175	0.01636	0.00874	0.00548	0.00121	0.00017	0.00003	0.00000	0.00000
H2O1(G)	0.27700	0.29364	0.32103	0.33350	0.33854	0.34479	0.34621	0.34639	0.34642	0.34642
N1(G)	0.00001	0.00000	0.00000	0.00000	0.	0.	0.	0.	0.	0.
N2(G)	0.61736	0.62475	0.63614	0.64097	0.64285	0.64508	0.64557	0.64563	0.64564	0.64554
N1H1(G)	0.00001	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.	0.
N1O1(G)	0.01154	0.00844	0.00376	0.00182	0.00107	0.00020	0.00002	0.00000	0.00000	0.00000
N1O2(G)	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
O1(G)	0.00327	0.00202	0.00055	0.00016	0.00006	0.00000	0.00000	0.	0.	0.
O2(G)	0.00888	0.00749	0.00442	0.00257	0.00169	0.00042	0.00007	0.00001	0.00000	0.00000
O1H1(G)	0.02477	0.01840	0.00816	0.00379	0.00214	0.00034	0.00003	0.00000	0.00000	0.00000

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

N1H2(G) N1H3(G) N2O1(G) N2O4(G) H2O1(S) H2O1(L)

INPUT, G-ATOMS/G

	H	N	O	AR
FUEL	0.9920635E 00	0.	0.	0.
OXIDANT	0.	0.5391996E-01	0.1446566E-01	0.3314327E-03
PROPELLANT	0.2811150E-01	0.5239206E-01	0.1405575E-01	0.3220411E-03

CASE NO. 0 636.9 34.290

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE VIII. - Concluded. SUPERSONIC COMBUSTION RAMJET ENGINE PERFORMANCE EQUILIBRIUM NOZZLE EXPANSION

	CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	1.00000	4942.900	3	-0.	-0.
OXIDANT	N 1.56180 O 0.41900 AR 0.03960	1.00000	2840.000	3	-0.	-0.

O/F= 34.29030, PERCENT FUEL= 2.8336, EQUIVALENCE RATIO= 1.0000, DENSITY= 0.

PARAMETERS

	CHAMBER	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.000	1.000	5.000	10.000	15.000	18.000
P, ATM	2.326	2.326	0.4652	0.2326	0.1551	0.1292
T, DEG K	2802	2802	2304	2077	1940	1878
H, CAL/G	303.8	303.8	-35.2	-158.6	-224.5	-252.6
S, CAL/(G)(K)	2.6826	2.6826	2.6826	2.6826	2.6826	2.6826
M, MOL WT	23.791	23.791	24.388	24.533	24.584	24.601
(DLM/DLP)T	0.01347	0.01347	0.00382	0.00162	0.00086	0.00063
(DLM/DLT)P	-0.3007	-0.3007	-0.1051	-0.0495	-0.0282	-0.0213
CP, CAL/(G)(K)	0.9920	0.9920	0.6488	0.5270	0.4735	0.4541
GAMMA	1.1481	1.1481	1.1759	1.2015	1.2190	1.2269
MACH NUMBER	0.	1.763	2.594	2.919	3.111	3.198
CSTAR, M/SEC		513	513	513	513	513
CF		0.050	0.400	0.513	0.568	0.590
AE/AT		1.020	3.068	5.106	6.890	7.883
IVAC, SEC		221.7	1717.8	2216.8	2470.8	2576.5
I, SEC		208.4	1677.9	2150.4	2381.1	2473.9

DERIVATIVES

(DLI/DLPC)PC/P		0.01869	0.00695	0.00567	0.00495	0.00464
(DLT/DLPC)PC/P	0.02532	0.02532	0.01004	0.00281	-0.00087	-0.00227
(DLAR/DLPC)PC/P		-0.	-0.00045	-0.00512	-0.00749	-0.00837
(DLCS/DLPC)PC/P		0.00078	0.00078	0.00078	0.00078	0.00078
(DLI/DHC)PC/P*		0.16831	0.26202	0.27973	0.29116	0.29638
(DLT/DHC)PC/P*	0.35978	0.35978	0.55014	0.67727	0.75379	0.78595
(DLAR/DHC)PC/P*		0.	0.04627	0.13139	0.18427	0.20663
(DLCS/DHC)PC/P*		0.29965	0.29965	0.29965	0.29965	0.29965
*(HC IN KCAL/G)						
(DLI/DLPCP)S		0.26917	0.12133	0.09378	0.08142	0.07652
(DLT/DLPCP)S	-0.10952	-0.10952	-0.13880	-0.16132	-0.17555	-0.18167
(DLAR/DLPCP)S		-0.	0.12726	0.13670	0.13709	0.13673

MOLE FRACTIONS

AR1(G)	0.00766	0.00766	0.00785	0.00790	0.00792	0.00792
H1(G)	0.01059	0.01059	0.00175	0.00047	0.00017	0.00010
H2(G)	0.03881	0.03881	0.01463	0.00709	0.00407	0.00306
H2O1(G)	0.27929	0.27928	0.32407	0.33619	0.34074	0.34221
N2(G)	0.61937	0.61937	0.63774	0.64218	0.64376	0.64426
N1O1(G)	0.00772	0.00772	0.00225	0.00097	0.00052	0.00038
O1(G)	0.00371	0.00371	0.00051	0.00012	0.00004	0.00002
O2(G)	0.01083	0.01083	0.00476	0.00246	0.00147	0.00112
O1H1(G)	0.02202	0.02202	0.00643	0.00262	0.00132	0.00093

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDITIONS

N1(G) N1H1(G) N1H2(G) N1H3(G) N1O2(G) N2O1(G) N2O4(G) H2O1(S) H2O1(L)

INPUT, G-ATOMS/G

	H	N	O	AR
FUEL	0.9920635E 00	0.	0.	0.
OXIDANT	0.	0.5391996E-01	0.1446565E-01	0.3314327E-03
PROPELLANT	0.2811150E-01	0.5239206E-01	0.1405575E-01	0.3220411E-03

CASE NO. 0 34.2 34.290

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

throat, or are printed out on the second page if the freezing point is upstream of the throat.

Table VIII presents the sample output for an equilibrium nozzle expansion for a subsonic-combustion ramjet and a supersonic-combustion ramjet. The pressure ratio and area ratios for the supersonic-combustion ramjet are based on the combustor-exit static pressure and area, respectively.

COMPARISON OF APPROXIMATE KINETIC SOLUTION WITH EXACT KINETIC METHOD

To indicate the utility of the approximate kinetic analysis to various chemical systems, calculations from this method were compared with those from the exact kinetic solution of reference 4. Both methods were used to compute the vacuum specific impulse for rockets and the net fuel specific impulse for ramjets as a function of the nozzle-area ratio. Inasmuch as the chemical kinetics are affected significantly by nozzle geometry, the same nozzle geometry was used for both methods. In figure 3, the fuel specific impulse calculated by the two methods is shown for the hydrogen-air system for an equivalence ratio of 1. The nozzle geometry is shown in the figure and is a 7°-conical nozzle with a throat radius of 4.064 centimeters. It can be seen that the approximate solution agrees quite well with the exact solution. At an area ratio of 40, the difference in fuel specific impulse calculated by the two methods is only 60 seconds, or about 2 percent.

A comparison for the propellant system of nitrogen tetroxide with a mixture of 50 percent hydrazine and 50 percent UDMH is shown in figure 4. The important recombination reactions for this system are the same as those for the hydrogen-air system presented in table I (p. 6). The nozzle geometry used in these calculations is a 20° conical nozzle with a throat diameter of 1.3 inches, described in reference 10 and shown in figure 4. Again, this figure shows that the impulse curves determined by the two methods are in close agreement. The specific impulse calculated by the approximate method is only 6 seconds, or about 2 percent, above that of the exact solution at an area ratio of 100.

As mentioned previously, the application of the approximate solution to the two systems, hydrogen-air and nitrogen tetroxide with a 50-50 mixture of hydrazine and UDMH, was investigated in references 8 to 10 with similar favorable results. However, the use of the approximate solution for the hydrogen-fluorine system has not been fully evaluated. A comparison between the two methods was made in reference 13 for hydrogen-fluorine at oxidant-fuel ratios of 8 and 14. In this comparison, the calculated specific impulses determined by the approximate method were about 12 seconds lower than those calculated

TABLE IX. - HYDROGEN-FLUORINE

RECOMBINATION REACTIONS AND

REACTION RATE CONSTANTS

Recombination reactions	
$H + F + M \underset{K_{-1}}{\overset{K_1}{\rightleftharpoons}} HF + M$	
$H + H + M \underset{K_{-2}}{\overset{K_2}{\rightleftharpoons}} H_2 + M$	
Recombination rate constant $(^{o}K)(cm^6)/(mole^2)(sec)$	Reference
$C_1 = 7.5\times10^{18}$ $C_2 = 7.5\times10^{18}$	14 14

by exact method. In the present study, the comparison of the two methods for this system was extended to cover a range of oxidant-fuel ratios from 7 to 19 for two nozzle geometries. The recombination reactions and rate constants for this study were taken from reference 14 and are presented in table IX. The nozzle geometries used are the contoured bell and the 15°-conical nozzles described in reference 15. Figure 5 presents the vacuum specific impulse calculated by the two methods as a function of nozzle-area ratio for the contoured bell nozzle for an oxidant-fuel ratio of 9. The difference in specific impulse calculated by the two methods is 4 seconds, or about 1 percent, at an area ratio of 100. The agreement then is quite good for this oxidant-fuel ratio and nozzle geometry. The calculated specific impulse for the same nozzle for an area ratio of 100 and oxidant-fuel ratios ranging from 7 to 19 is presented in figure 6. The impulse curve determined by the approximate solution is in agreement with that of the exact method. The difference in impulse calculated by the two methods increases somewhat with increasing oxidant-fuel ratios. Impulse differences are 4 seconds, or 1 percent at an oxidant-fuel ratio of 9 and 10 seconds, or $2\frac{1}{2}$ percent at an oxidant-fuel ratio of 15. Figure 7 shows the specific impulse calculated by the two methods for the 15°-conical nozzle for the same range of oxidant-fuel ratios. The approximate method is in general agreement with the exact method but is about 10 to 15 seconds lower, or $2\frac{1}{2}$ to 3 percent. However, considering that the difference between the equilibrium and frozen curves increases from 50 seconds at an oxidant-fuel ratio of 7 to 95 seconds at an oxidant-fuel ratio of 19, the approximate method does agree well with the exact method for the range of oxidant-fuel ratios considered.

CONCLUDING REMARKS

The approximate kinetic analysis used in the program was shown to predict dissociation losses that agree reasonably well with exact solutions for the propellant systems hydrogen-air, hydrogen-fluorine, and nitrogen tetroxide with a 50-50 mixture of hydrazine and UDMH. The approximate program uses about a 1/4-minute execution time per case.

The program may be used for kinetic calculations for other similar systems subject to the following conditions:

(1) Bimolecular reactions involving small energy changes

(2) A detectable molecular weight change with temperature and pressure resulting from the recombination reactions only

For systems that do not fulfill completely the above limitations, preliminary comparisons of the results from the approximate analysis with those from an exact solution (ref. 4) would indicate the extent of the error involved.

The program may be obtained by a request to the authors. It is preferred to copy the the program on magnetic tape instead of IBM cards. Therefore, a blank magnetic tape of 556 or 800 bits sent with the request would be desirable.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 26, 1967,
126-15-03-08-22.

APPENDIX A

RAMJET COMBUSTOR ANALYSIS

To give the program the capability of calculating engine performance for a wide variety of ramjet configurations, the combustor solution is designed for either a specified combustor pressure ratio or area ratio. For other then constant pressure or area calculations, then, some assumption for the pressure distribution is necessary. In this analysis, a linear distribution of pressure with a cross-sectional area is assumed. The determination of the flow properties at the combustor exit requires an iterative solution for five unknowns (enthalpy, temperature, velocity, molecular weight, and either pressure or area) and the use of the four conservation equations (momentum, energy, mass, and state). Assume that conditions at the combustor inlet are known. Let subscript 2 indicate combustor inlet, 3 combustor exit, and f fuel.

Applying the conservation of mass, momentum, and state equations yields the velocity at the combustor exit:

$$m_3V_3 + P_3A_3 = m_2V_2 + P_2A_2 + \int_2^3 PdA + (m_fV_f + P_fA_f)$$

$$\cos\alpha - C_D \frac{m_3V_3}{2 - 0} \tag{A1}$$

$$m_3 = m_2 + m_f$$

Assume

$$\int_2^3 PdA = \frac{1}{2}(P_3 + P_2)(A_3 - A_2) \tag{A2}$$

The equation of state when applied to the fuel momentum yields

$$m_fV_f + P_fA_f = \left(\frac{m_f}{m_2}\right)_{m_2} \left(\frac{V_f + gRT}{\mathscr{M}V}\right)_f \tag{A3}$$

From the conservation of energy,

$$H_3 = \frac{1}{\left(1 + \frac{f}{a}\right)}\left(\frac{V_2^2}{2gJ} + H_2\right) + \frac{\frac{f}{a}}{\left(1 + \frac{f}{a}\right)}\left(\frac{V_f^2}{2gJ} + H_f\right) \frac{-V_3^2}{2gJ} \tag{A4}$$

Solution for Specified Area Ratio

Combining equations (A1) to (A3) and letting $K = A_3/A_2$ yield the velocity at the combustor exit:

$$V_3 = \frac{1}{\left(1 + \frac{C_D}{2}\right)\left(1 + \frac{f}{a}\right)}\left\{\left[V_2 + \frac{gRT_2}{2\mathscr{M}_2 V_2}(1 + K)\left(1 - \frac{P_3}{P_2}\right)\right] + \frac{f}{a}\cos\alpha\left(V_f + \frac{gRT_f}{\mathscr{M}_f V_f}\right)\right\} \tag{A5}$$

The continuity equation yields

$$T_3 = \frac{P_3}{P_2}\frac{\mathscr{M}_3}{\mathscr{M}_2}\frac{V_3}{V_2}\frac{T_2 K}{1 + \left(\frac{f}{a}\right)}$$

Use H_3 from equation (A4) and an assumed P_3. The thermodynamic routines of the program are used to compute the temperature T_3'.

The combustor-exit conditions are then determined by an iteration between T_3'/T_3 and P_3/P_2, which converges at the pressure ratio P_3/P_2 at which $|T_3'/T_3 - 1 - 0| \leq$ tolerance.

Solution for Specified Pressure Ratio

Combining equations (A1) to (A3) and letting $K = P_3/P_2$ yield the velocity at the combustor exit:

$$V_3^2 - \frac{V_3}{\left(1 + \frac{f}{a}\right)\left(1 + \frac{C_D}{2}\right)}\left[\left(V_2 + \frac{gRT_2}{2\mathscr{M}_2 V_2}\right)(1 - K) + \left(\frac{f}{a}\right)\cos\alpha\left(V_f + \frac{gRT}{\mathscr{M} V}\right)_f\right] - \frac{\frac{gRT_3(K - 1)}{K}}{2M_3\left(1 + \frac{C_D}{2}\right)} = 0 \tag{A6}$$

Let

$$C1 = -\frac{1}{\left(1 + \frac{f}{a}\right)\left(1 + \frac{C_D}{2}\right)} \left\{\left[V_2 + \frac{gRT_2(1 - K)}{2\mathscr{M}_2 V_2}\right] + \left(\frac{f}{a}\right)\cos\alpha\left(V + \frac{gRT}{\mathscr{M}V}\right)_f\right\}$$

and

$$C2 = \frac{\frac{gRT_3(K - 1)}{K}}{2\mathscr{M}_3\left(1 + \frac{C_D}{2}\right)}$$

then

$$V_3 = \frac{-C1 + \sqrt{C1^2 - 4C2}}{2} \tag{A7}$$

Rearranging equation (A4) also yields the velocity at the combustor exit:

$$\frac{V_3^2}{2gJ} = \frac{1}{\left(1 + \frac{f}{a}\right)}\left(\frac{V_2^2}{2gJ} + H_2\right) + \frac{\frac{f}{a}}{\left(1 + \frac{f}{a}\right)}\left(\frac{V_f^2}{2gJ} + H_f\right) - H_3 \tag{A8}$$

Let

V_3 velocity determined by eq. (A7)

V_3' velocity determined by eq. (A8)

The combustor-exit conditions are then determined by an iteration between V_3/V_3' and H_3, which converges at the enthalpy H_3 at which $|V_3/V_3' - 1.0| \leq$ tolerance.

APPENDIX B

NOZZLE CONTOUR INPUT FOR KINETIC CALCULATIONS

The solution of equation (7) in the section Approximate Kinetic Analysis requires the determination of the derivative of the nozzle cross-sectional area ratio $d(A_n/A_t)$ with respect to length x_n. This determination is accomplished by using the nozzle throat dimension y_t and knowing the equation of the nozzle contour, $x_n = f(y_n)$.

The derivative of x_n with y_n is

$$\frac{dx_n}{dy_n} = \frac{df}{dy_n} \tag{B1}$$

For axisymmetric nozzles, the derivative of the area ratio with y_n is

$$\frac{d\left(\frac{A_n}{A_t}\right)}{dy_n} = \frac{2y_n}{y_t^2} \tag{B2}$$

Therefore,

$$\frac{d\left(\frac{A_n}{A_t}\right)}{dx_n} = \frac{\frac{2y_n}{y_t^2}}{\frac{df}{dy_n}} \tag{B3}$$

For two-dimensional nozzles, the derivative of the area ratio with respect to y_n is

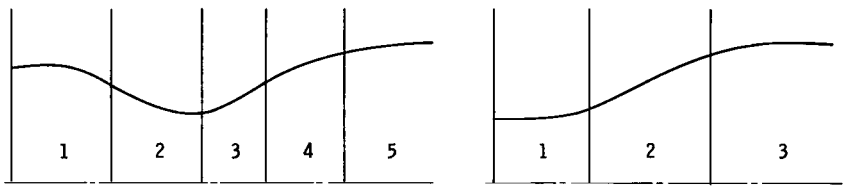
$$\frac{d\left(\frac{A_n}{A_t}\right)}{dy_n} = \frac{1.0}{y_t} \tag{B4}$$

Therefore,

$$\frac{d\left(\frac{A_n}{A_t}\right)}{dx_n} = \frac{\frac{2y_n}{y_n^2}}{\frac{df}{dy_n}} \tag{B5}$$

The nozzle contour may be defined by more than one equation by dividing it into a maximum of five sections for rockets and subsonic-combustion ramjets or into three sections for supersonic-combustion ramjets. The limits of the sections are the input parameters SUB1, SUB2, and SUB3, which are referred to in Description of Input. The equations for each section are defined by the input constants and the exponents CON and EEXP.

The following sketches show how the nozzle contour is defined in equation form:



(a) Rocket or subsonic-combustion ramjet. (b) Supersonic-combustion ramjet.

where

SUB1 A_n/A_t separating sections 1 and 2

SUB2 A_n/A_t separating sections 3 and 4 for rockets or subsonic-combustion ramjets

SUB2 A_n/A_t separating sections 2 and 3 for supersonic-combustion ramjets

SUB3 A_n/A_t separating sections 4 and 5

The nozzle contour for each section may be described by either a polynomial of five arbitrary coefficients and four arbitrary exponents or the equation of a circle. For a polynomial,

$$x = a + by^i + cy^j + dy^k + ey^l$$

$$\frac{dx}{dy} = biy^{i-1} + cjy^{j-1} + dky^{k-1} + el y^{l-1}$$

where the values of CON and EEXP are

$$CON(1) = b \qquad EEXP(1) = i$$

$$CON(2) = c \qquad EEXP(2) = j$$

$$CON(3) = d \qquad EEXP(3) = k$$

$$CON(4) = e \qquad EEXP(4) = l$$

For a circle,

$$(x - a)^2 + (y - b)^2 = c^2$$

$$\frac{dx}{dy} = \frac{b - y}{\left[c^2 - (y - b)^2\right]^{1/2}}$$

where the values of CON are

$$CON(1) = b$$

$$CON(2) = c$$

$$CON(3) = 0$$

$$CON(4) = 0$$

The exponents, EEXP, are not used

The following example will illustrate the manner in which these input parameters are used. Assume that a rocket nozzle has a contour that may be described as in the following table:

Section	Limits	Equation type
1	Combustor to $A/A_T = 10$	Polynomial
2	$A/A_T = 10$ - $A/A_T = 1$	Circle
3	$A/A_T = 1$ - $A/A_T = 20$	Circle
4	$A/A_T = 20$ - $A/A_T = 50$	Polynomial
5	$A/A_T = 50$ - $A/A_T = 200$	Polynomial

The values of ITYP, CON, and EEXP are presented in table X.

TABLE X. - INPUT FOR DEFINING NOZZLE CONTOUR

TITLE	PROJECT NUMBER	ANALYST	
Sample Input Data			SHEET ____ OF ____

STATEMENT NUMBER	CONT	FORTRAN STATEMENT					IDENTIFICATION
10.00		20.00	50.00	10.40			(SUB1, SUB2, SUB3, YT)
0							(NZTYP)
1	2	2	1	1			(ITYP)
	b 1	c 1	d 1	e 1	b 2		
	c 2	0.0	0.0	b 3	c 3		(CON)
	0.0	0.0	b 4	c 4	d 4		
	e 4	b 5	c 5	d 5	e 5		
	i 1	j 1	k 1	m 1	0.0		
	0.0	0.0	0.0	0.0	0.0		(EEXP)
	0.0	0.0	i 4	j 4	k 4		
	m 4	i 5	j 5	k 5	m 5		

1 2 3 4 5 | 6 | 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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APPENDIX C

FORTRAN IV PROGRAM LISTING

```
C      MAIN PROGRAM
C       NEW COMMON
C
       COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
      2IFREZ
       COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
      2ITYP(5),CON(20),EEXP(20),AK(20)
       COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
      2SAPE1,SAPE2,INUME,PPT
       COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
       COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
      2PFIELD,VO,AOAC,Q1QO,P3P2
       COMMON/RM2/PP3P2,CV,V4,JRAM
       COMMON/KN4/ANAME(2,20),IJK(20),NUM(3,20)
      2,NMOL,NAK
C
C       END OF NEW COMMON
C
C
       DIMENSION  G(20,21),  A(15,90),  EN(90),  EN LN(90)
       DIMENSION  DEL N(90),  HHO(90),  S(90),  X(20)
       DIMENSION DELTA(20), BO(15), PCP(25), PROD(3)
       DIMENSION   COEFX(20),  DX(20),     FORM(15)
       DIMENSION COEFT1(15,90) , COEFT2(15,90)
       DIMENSION   ELMT(15),   DATA(23),   DATUM(3),   FORMLA(18)
       DIMENSION   BOX(15),    BOF(15),    ANS(454),   SYSTM(15)
       DIMENSION LLMT(15),MTSYS(15),MDATA(23)
       DIMENSION   ANSLAB(454),   COEFT(15,90)
       DIMENSION   MATOM(101,3),     ATOM(101,3)
       COMMON  G
       COMMON QOOOCM(7700)
C      COMMON C
       EQUIVALENCE   (G(1),      C(1)),     (G(420),     C(420))
       EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),    C(874))
       EQUIVALENCE   (HSUM,      C(424)),  (SSUM,       C(425))
       EQUIVALENCE   (WTMOL,     C(426)),  (CP,         C(427))
       EQUIVALENCE   (DLMPT,     C(428)),  (DLMTP,      C(429))
       EQUIVALENCE   (GAMMA,     C(430)),  (ARATIO,     C(431))
       EQUIVALENCE   (VMACH,     C(432)),  (SP IMP,     C(433))
       EQUIVALENCE   (VACI,      C(434)),  (CF,         C(436))
       EQUIVALENCE   (RHOI,      C(437)),  (RHOVAC,     C(438))
       EQUIVALENCE   (RHO,       C(439))
       EQUIVALENCE   (T PI,      C(440)),  (PI I,       C(441))
       EQUIVALENCE   (EP PI,     C(442)),  (AW PI,      C(443))
       EQUIVALENCE   (T ETA,     C(445))
       EQUIVALENCE   (ETA I,     C(446)),  (EP ETA,     C(447))
       EQUIVALENCE   (AW ETA,    C(448)),  (T SIG,      C(450))
       EQUIVALENCE   (SIG I,     C(451)),  (EP SIG,     C(452))
       EQUIVALENCE   (AW SIG,    C(453))
       EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
       EQUIVALENCE   (FORM(1),   C(1329)), (FORM(15),  C(1343))
       EQUIVALENCE   (ELMT(1),   C(1344)),  (ELMT(15), C(1358))
       EQUIVALENCE   (LLMT(1),   C(1344)),  (LLMT(15), C(1358))
       EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))


       EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
       EQUIVALENCE   (EN(1),   C(1382)),  (EN(90),   C(1471))
       EQUIVALENCE   (ISYS,     C(1472)),   (JEAN,     C(1473))
       EQUIVALENCE   (ACX,      C(1474)),   (ACF,     C(1475))
       EQUIVALENCE   (AMX,       C(1476)),   (AMF,      C(1477))
       EQUIVALENCE   (RHOX,      C(1478)),   (RHOF,     C(1479))
       EQUIVALENCE   (COEFX(1),    C(1480)),  (COEFX(20),  C(1499))
       EQUIVALENCE   (DX(1),    C(1500)),  (DX(20),   C(1519))
       EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
       EQUIVALENCE   (MMLA(1),   C(1520)),  (MMLA(18), C(1537))
```

```
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))
      EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),   C(1555))
      EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE   (OF,      C(1556)),    (FPCT,   C(1557))
      EQUIVALENCE   (EQRAT,      C(1558))
      EQUIVALENCE (KODE,    C(1559)),   (KASE,       C(1560))
      EQUIVALENCE(NF,C(1562))
      EQUIVALENCE   (NO,         C(1563)), (NE,         C(1564))
      EQUIVALENCE   (NOEQ, C(1565))
      EQUIVALENCE   (BOX(1),     C(1771)), (BOX(15),    C(1785))
      EQUIVALENCE   (BOF(1),     C(1786)), (BOF(15),    C(1800))
      EQUIVALENCE   (HX,         C(1801)), (HF,         C(1802))
      EQUIVALENCE   (VXPLS,      C(1803)), (VXMIN,      C(1804))
      EQUIVALENCE   (VFPLS,      C(1805)), (VFMIN,      C(1806))
      EQUIVALENCE   (EN LN(1),   C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE   (DEL N(1),   C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE   (HO(1),      C(2041)), (HO(90),     C(2130))
      EQUIVALENCE   (S(1),       C(2131)), (S(90),      C(2220))
      EQUIVALENCE   (X(1),       C(2221)), (X(20),      C(2240))
      EQUIVALENCE   (DELTA(1),   C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),      C(2261)), (BO(15),     C(2275))
      EQUIVALENCE   (PO,         C(2276)), (HSUBO,      C(2277))
      EQUIVALENCE   (SO,         C(2278)), (T LN,       C(2279))
      EQUIVALENCE   (T,          C(2280)), (AAY LN,     C(2281))
      EQUIVALENCE   (AAY,        C(2282)), (CPSUM,      C(2283))
      EQUIVALENCE   (HC,         C(2284)), (TC LN,      C(2285))
      EQUIVALENCE   (PCP(1),     C(2286)), (PCP(25),    C(2310))
      EQUIVALENCE   (DATUM(1),   C(2311)), (DATUM(3),   C(2313))
      EQUIVALENCE   (PC,         C(2314)), (TC,         C(2315))
      EQUIVALENCE   (IPROB,      C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (IHS,        C(2318)), (ICOND,      C(2319))
      EQUIVALENCE   (ISYM,       C(2320)), (IPROD,      C(2321))
      EQUIVALENCE   (IDID,       C(2322)), (LDRUM,      C(2323))
      EQUIVALENCE   (IDRM,       C(2323)), (KDRUM,      C(2324))
      EQUIVALENCE   (L,          C(2325)), (L1,         C(2326))
      EQUIVALENCE   (M,          C(2327)), (M1,         C(2328))
      EQUIVALENCE   (N,          C(2329)), (IQ,         C(2330))
      EQUIVALENCE   (IQ1,        C(2331)), (IQ2,        C(2332))
      EQUIVALENCE   (IQ3,        C(2333)), (KMAT,       C(2334))
      EQUIVALENCE   (IMAT,       C(2335)), (IUSE,       C(2335))
      EQUIVALENCE   (IADD,       C(2336)), (ITNUMB,     C(2337))
      EQUIVALENCE   (ITAPE,      C(2338)), (P,          C(2339))
      EQUIVALENCE   (IDEBUG,     C(2340)), (IFROZ,      C(2341))
      EQUIVALENCE   (A(1),       C(2342)),  (A(1350),   C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))


      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      EQUIVALENCE (KORE, C(8047))
      EQUIVALENCE(MT,DMT)
      EQUIVALENCE (HS,MHS),(TS,MTS),(PT,MPT),(TP,MTP),(DET,MDET)
      EQUIVALENCE (PROB,MPROB),(END,MEND)
      EQUIVALENCE (TMLM,MTMLM) , (BLK,MBLK)
C
C
C
      DATA Q000CT/0307362606060/
 1    H S=Q000CT
      DATA Q001CT/0637362606060/
      T S=Q001CT
      DATA Q002CT/0477363606060/
      P T=Q002CT
      DATA Q003CT/0637347606060/
      T P=Q003CT
      DATA Q004CT/0242563456060/
      DET=Q004CT
      DATA Q005CT/0254524606060/
      END=Q005CT
      DATA Q006CT/060/
      BLK=Q006CT
      DATA Q007CT/0464431636060/
```

```
      UMIT=Q007CT
      DATA Q008CT/0606060606060/
      UMT=Q008CT
C
C
C     READ IN INPUT DATA
C
      IF (ISYS-99) 401,403,401
  403 READ  (3)(G(I,1),I=1,8044)
      REWIND 3
      CALL SSWTCH(6,K000FX)
       GO TO(651,3003),K000FX
  401 ISYS=99
      IFROZ=0
      REWIND 4
 5000 CONTINUE
  429 CALL INPUT
C      INPUT READS PROPELLANT CARDS
      IF(L.EQ.0)GO TO 651
      READ(5,10)
     2KOK,JADDI,MNFR,IDEBUG,
     2IPROB,ICONST,IRAM,IZEIAR,
     2IROU,ICON,IFREZ
   10 FORMAT(20I3)
      DEBUG
     2KOK,JADDI,MNFR,IDEBUG,
     2IPROB,ICONST,IRAM,IZEIAR,
     2IROU,ICON,IFREZ
      KAT1= JADDI
      KAT2= IFREZ


      WRITE(6,4)
    4 FORMAT(24HOPRESSURE RATIO SCHEDULE)
      DIMENSION ZPCP(25)
      READ(5,7)
     2(ZPCP(I),I=1,JADDI)
    7 FORMAT(5F10.5)
      WRITE(6,12)
     2(ZPCP(I),I=1,JADDI)
   12 FORMAT(5G17.8)
      IF(MNFR.NE.-2)GO TO 20
      READ(5,7)SUB1,SUB2,SUB3,YT
      READ(5,10)NZTYP
      READ(5,10)(ITYP(I),I=1,5)
      READ(5,7)(CON(I),I=1,ICON)
      READ(5,7)(EEXP(I),I=1,ICON)
      READ(5,10)NMOL,NAK
      READ(5,41)(IJK(I),(ANAME(J,I),J=1,2),I=1,NMOL)
   41 FORMAT(I5,5X,2A6)
      READ(5,43)(
     2AK(I),(NUM(J,I),J=1,3),I=1,NAK)
   43 FORMAT(E10.5,3I5)
      WRITE(6,15)
   15 FORMAT(34HOCONSTANTS FOR KINETIC CALCULATION)
      DEBUG SUB1,SUB2,SUB3,YT,NZTYP
      WRITE(6,16)(ITYP(I),I=1,5)
   16 FORMAT(5HOITYP,2X,10I3)
      WRITE(6,17)(CON(I),I=1,ICON)
   17 FORMAT(4HOCON/(5G17.8))
      WRITE(6,18)(EEXP(I),I=1,ICON)
   18 FORMAT(5HOEEXP/(5G17.8))
      WRITE(6,42)
   42 FORMAT(27HOMOLECULES AND AK CONSTANTS)
      WRITE(6,41)(IJK(I),(ANAME(J,I),J=1,2),I=1,NMOL)
      WRITE(6,44)(I,
     2AK(I),(NUM(J,I),J=1,3),I=1,NAK)
   44 FORMAT(1HO/(1X,3HAK(,I1,2H)=G15.8,3I3))
   20 CONTINUE
      IF(IRAM.NE.1)GO TO 21
      WRITE(6,30)
   30 FORMAT(33HOCONSTANTS FOR RAMJET CALCULATION)
      READ(5,77)
     2COSTH,CD,CDA,TFS,WMF,VT,DELH,
```

```
      2P2,T2,AMOL2,V2,GAM2,
      2PFIELD,VO,AOAC,Q1QO,P3P2
       DEBUG
      2COSTH,CD,CDA,TFS,WMF,VT,DELH,
      2P2,T2,AMOL2,V2,GAM2,
      2PFIELD,VO,AOAC,Q1QO,P3P2
       V2=V2/.3048
       VO=VO/.3048
       VT=VT/.3048
       TF = VT + 89548.2 * TFS/(WMF * VT)
       HEATC = VT * * 2.0/90185.76 + DELH
   77 FORMAT(7F10.5/5F10.5/5F10.5)
   21 CONTINUE
       IF(IPROB.EQ.1)MPROB=MHS


       IF(IPROB.EQ.2)MPROB=MTS
       KASE=0
       WRITE (6,443)HX,VXPLS,VXMIN,HF,VFPLS,VFMIN              , (ELMT(I),B
      1OX(I),BOF(I),I=1,L)
  443 FORMAT (10HJOXIDANT  3E16.6/10H FUEL     3E15.6/(1H A6,2E20.8))
C
C      RIGHT ADJUST ELEMENT SYMBOLS
C
       DO 447 K=1,L
       TMLM = ELMT(K)
       ELMT(K) =AARS(24, TMLM)
       DATA Q009CT/077/
       TMLM =AND(ELMT(K),Q009CT)
       IF (MTMLM-MBLK) 447,1447,447
 1447 TMLM = ELMT(K)
       ELMT(K) =AARS(6, TMLM)
  447 CONTINUE
       IF(SYSTM(L+1))453,920,453
  920 IF (SYSTM(L)) 921,453,921
  921 DO 449 K=1,L
       DO 448 J=1,L
       IF (LLMT(K)-MTSYS(J)) 448,449,448
  448 CONTINUE
       GO TO 453
  449 CONTINUE
C
C      CANCEL ---OMITS---FROM PREVIOUS PROBLEM
C
  452 DO 1452 J=1,M
       COEFT1(1,J) = DMT
       COEFT2(1,J) = DMT
 1452 COEFT(1,J) = DMT
       IUSE=1
       GO TO 598
  453 DO 459 K=1,15
  459 SYSTM(K)=ELMT(K)
       CALL SEARCH
  598 IF (IUSE-2) 600,635,635
C
C      SET ARRAY  PROD  TO BYPASS ALL CONDENSED PHASES
C
  600 PROD(1)=0.0
       PROD(2)=0.0
       IF (M-35) 198,198,1198
 1198 IF (M-70) 199,199,1199
 1199 IF (M-90) 200,200,635
       DATA Q010CT/0377777777777/
 198  PROD(2)=Q010CT
       DATA Q011CT/0377777777777/
       PROD(3)=Q011CT
       TMP=PROD(2)
       PROD(1)=AARS(M,TMP)
       GO TO 201
  199 M12 = M-35
       DATA Q012CT/0377777777777/
       PROD(3)=Q012CT
```

```
      TMP=PROD(3)
      PROD(2)=AARS(M12,TMP)
      GO TO 201
  200 M12 = M-70
      DATA Q013CT/0377777777777/
      PROD(3)=Q013CT
      TMP=PROD(3)
      PROD(3)=AARS(M12,TMP)
  201 IQ=L
      IQ1=IQ+1
      IQ2=IQ1+1
      IQ3=IQ2+1
      L1=IQ1
      M1=M+1
C
C     DETERMINE CONDENSED SPECIES TO BE USED IN THE FIRST ITERATION
C
      DO 222 J=1,M
      CALL BYPASS(J,1)
      IF (IPROD - 2) 221,222,221
  221 COEFT1(1,J) = OMIT
      COEFT2(1,J)=OMIT
  222 CONTINUE
C
C     ARRANGE ANSWER REGION
C
      I=1
      DO 602 J=1,N
      ANS(I)=COEFT2(1,J)
      ANS(I+1)=COEFT2(2,J)
      ANS(I+2)=COEFT2(3,J)
      ANS(I+3) = 0.0
  602 I=I+4
      K=4*N
  605 I=K+34
      ANS(I)=ANS(K)
      K=K-1
      IF (K) 651,607,605
  607 DO 609 K=1,34
  609 ANS(K) = 0.0
      DO 1700  K= 1, 454
 1700 ANSLAB(K) = ANS(K)
      DO 1701 J = 1, 15
      DO 1701 K = 1, 90
 1701 COEFT(J,K) = COEFT1(J,K)
C
C     DETERMINE THE TYPE OF PROBLEM
C
  700 IFROZ=1
      IF (MPROB-MHS) 705,901,705
  901 IPROB=1
      GO TO 719
  705 IF (MPROB-MTS) 707,902,707
  902 IPROB=2
      GO TO 719
  707 IF (MPROB-MPT) 709,903,709


  903 IPROB=3
      GO TO 719
  709 IF (MPROB-MTP) 711,904,711
  904 IPROB=4
      GO TO 719
  711 IF (MPROB-MT)631,429,631
C
C     DETERMINE THE ASSIGNED VALUES FOR THE PROBLEM
C
 3003 CONTINUE
  719 READ(5,35)EQRAT,OF,FPCT,PC,TC,CV
   35 FORMAT(7F10.5)
      IF(PC.EQ.0.0)GO TO 429
      DEBUG CV
```

```
 9999 IF (EQRAT) 725, 725, 723
  723 U F=(-EQRAT*VFMIN-VFPLS)/(VXPLS+EQRAT*VXMIN)
      F PCT=100.0/(1.0+U F)
      GO TO 745
  725 IF (U F) 731,731,727
  727 F PCT=100.0/(1.0+U F)
  729 EQRAT=ABS((U F*VXPLS+VFPLS)/(U F*VXMIN+VFMIN))
      GO TO 745
  731 IF (F PCT) 700,700,733
  733 U F=(100.0-F PCT)/F PCT
      IF (U F)   719,1733,729
 1733 IF (VFMIN) 729, 746,729
  745 IF (U F) 719,746,746
  746 DO 747 I=1,L
  747 BO(I)=(U F*BOX(I)+BOF(I))/(1.0+U F)
      IF (IPROB-1) 651,749,748
  748 HSUBO=0.0
      GO TO 755
  749 HSUBO=(U F*HX+HF)/(1.0+U F)
  755 WRITE (6,760)KASE,PROB,U F,F PCT,EQRAT,PC,HSUBO,        (BO(I),I=1
     1,L)
  760 FORMAT (1H1I5,3X,A6/1H 4E17.8/(1H 7E17.8))
      HSUBO=HSUBO/1.98726
      DO 1771 I = 1, 454
 1771 ANS(I) = ANSLAB(I)
      RHO=RHOX+U F*RHOF
      IF (RHO) 772,772,771
  771 RHO=(1.0+U F)*RHOX*RHOF/RHO
  772 DO 1772 I = 1, 454
 1772 ANSLAB(I) = ANS(I)
  775 IF (IFROZ) 777,651,779
  777  CONTINUE
  779 CONTINUE
  715 DO 716 K=1,25
      SPCP(K)=0.0
  716 PCP(K)=0.0
      JADDI = KAT1
      IFREZ= KAT2
      IF(MPROB.EQ.MHS)IPROB=1
      IF(MPROB.EQ.MTS)IPROB=2
      DO 40 I=1,JADDI
      PCP(I)=ZPCP(I)


   40 SPCP(I)=ZPCP(I)
C
      PP3PZ=0.0
      V4=0.0
      JEAM=0
      ITIMEZ=0.0
      CONVER=0.0
      IF(KOK.EQ.0)KONT=2
      IF(KOK.EQ.1)KONT=1
      KAPPA=0
      IJN = 0
C
      CALL CORE2
      GO TO 1
C
C     ERROR PRINT OUT
C
  631 WRITE (6,633)PROB,KASE
  633 FORMAT (21H1THERE IS NO PROBLEM A6,2X,I5)
      GO TO 651
  635 WRITE (6,637)
  637 FORMAT (47H1TROUBLE IN COMPILING MASTER THERMODYNAMIC TAPE)
      REWIND 4
  639 READ  (4)(DATA(I),I=1,23)
      WRITE (6,640)(DATA(I),I=1,23)
  640 FORMAT (1H 3A6,2F10.1/(1H 2F8.1,7E14.6))
      IF (MDATA(1)-MEND) 639,900,639
  900 WRITE (6,643)((COEFT1(K,J),K=1,14),J=1,N)
      WRITE (6,643)((COEFT2(K,J),K=1,14),J=1,N)
  643 FORMAT (1H 3A6,2F15.2/2F8.1,7E12.4//)
  651 REWIND 4
      STOP
      END
```

```
      SUBROUTINE BYPASS (J,IARG)
C
C
      DIMENSION   G(20,21),   A(15,90),   EN(90),     EN LN(90)
      DIMENSION   DEL N(90),  HO(90),     S(90),      X(20)
      DIMENSION DELTA(20), BO(15), PCP(25), PROD(3)
      DIMENSION   COEFX(20),  DX(20),     FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),   DATA(23),   DATUM(3),   FORMLA(18)
      DIMENSION   BOX(15),    BOF(15),    ANS(454),   SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),   COEFT(15,90)
      DIMENSION   MATOM(101,3),     ATOM(101,3)
      COMMON  G
      COMMON QOOOCM(7700)
C     COMMON C
      EQUIVALENCE   (G(1),      C(1)),    (G(420),     C(420))
      EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),     C(874))
      EQUIVALENCE   (HSUM,      C(424)),  (SSUM,       C(425))
      EQUIVALENCE   (WTMOL,     C(426)),  (CP,         C(427))
      EQUIVALENCE   (DLMPT,     C(428)),  (DLMTP,      C(429))
      EQUIVALENCE   (GAMMA,     C(430)),  (ARATIO,     C(431))
      EQUIVALENCE   (VMACH,     C(432)),  (SP IMP,     C(433))
      EQUIVALENCE   (VACI,      C(434)),  (CF,         C(436))
      EQUIVALENCE   (RHOI,      C(437)),  (RHOVAC,     C(438))
      EQUIVALENCE   (RHO,       C(439))
      EQUIVALENCE   (T PI,      C(440)),  (PI I,       C(441))
      EQUIVALENCE   (EP PI,     C(442)),  (AW PI,      C(443))
      EQUIVALENCE   (T ETA,     C(445))
      EQUIVALENCE   (ETA I,     C(446)),  (EP ETA,     C(447))
      EQUIVALENCE   (AW ETA,    C(448)),  (T SIG,      C(450))
      EQUIVALENCE   (SIG I,     C(451)),  (EP SIG,     C(452))
      EQUIVALENCE   (AW SIG,    C(453))
      EQUIVALENCE   (ANSLA3(1), C(875)), (ANSLAB(454), C(1328))
      EQUIVALENCE   (FORM(1),   C(1329)), (FORM(15),  C(1343))
      EQUIVALENCE   (ELMT(1),   C(1344)),  (ELMT(15), C(1358))
      EQUIVALENCE   (LLMT(1),   C(1344)),  (LLMT(15), C(1358))
      EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
      EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
      EQUIVALENCE   (EN(1),   C(1382)),  (EN(90),   C(1471))
      EQUIVALENCE   (ISYS,     C(1472)),   (JEAN,     C(1473))
      EQUIVALENCE   (ACX,      C(1474)),   (ACF,     C(1475))
      EQUIVALENCE   (AMX,       C(1476)),   (AMF,      C(1477))
      EQUIVALENCE   (RHOX,      C(1478)),   (RHOF,     C(1479))
      EQUIVALENCE   (COEFX(1),    C(1480)),  (COEFX(20),  C(1499))
      EQUIVALENCE   (DX(1),    C(1500)),  (DX(20),   C(1519))
      EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
      EQUIVALENCE   (MMLA(1),   C(1520)),  (MMLA(13), C(1537))
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))
      EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),   C(1555))
      EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE   (OF,     C(1556)),    (FPCT,   C(1557))
      EQUIVALENCE   (EQRAT,     C(1558))
      EQUIVALENCE (KODE,    C(1559)),   (KASE,      C(1560))


      EQUIVALENCE   (KONT,   C(1561)),   (NF,         C(1562))
      EQUIVALENCE   (NO,        C(1563)), (NE,        C(1564))
      EQUIVALENCE   (NOEQ, C(1565))
      EQUIVALENCE   (BOX(1),    C(1771)), (BOX(15),   C(1785))
      EQUIVALENCE   (BOF(1),    C(1786)), (BOF(15),   C(1800))
      EQUIVALENCE   (HX,        C(1801)), (HF,        C(1802))
      EQUIVALENCE   (VXPLS,     C(1803)), (VXMIN,     C(1804))
      EQUIVALENCE   (VFPLS,     C(1805)), (VFMIN,     C(1806))
      EQUIVALENCE   (EN LN(1),  C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE   (DEL N(1),  C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE   (HO(1),     C(2041)), (HO(90),    C(2130))
      EQUIVALENCE   (S(1),      C(2131)), (S(90),     C(2220))
      EQUIVALENCE   (X(1),      C(2221)), (X(20),     C(2240))
      EQUIVALENCE   (DELTA(1),  C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),     C(2261)), (BO(15),    C(2275))
      EQUIVALENCE   (PO,        C(2276)), (HSUBO,     C(2277))
      EQUIVALENCE   (SO,        C(2278)), (T LN,      C(2279))
      EQUIVALENCE   (T,         C(2280)), (AAY LN,    C(2281))
      EQUIVALENCE   (AAY,       C(2282)), (CPSUM,     C(2283))
      EQUIVALENCE   (HC,        C(2284)), (TC LN,     C(2285))
      EQUIVALENCE   (DATUM(1),  C(2311)), (DATUM(3),  C(2313))
      EQUIVALENCE   (PC,        C(2314)), (TC,        C(2315))
```

```
      EQUIVALENCE   (IPROB,      C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (IHS,        C(2318)), (ICOND,      C(2319))
      EQUIVALENCE   (ISYM,       C(2320)), (IPROD,      C(2321))
      EQUIVALENCE   (IDID,       C(2322)), (LDRUM,      C(2323))
      EQUIVALENCE   (IDRM,       C(2323)), (KDRUM,      C(2324))
      EQUIVALENCE   (L,          C(2325)), (L1,         C(2326))
      EQUIVALENCE   (M,          C(2327)), (M1,         C(2328))
      EQUIVALENCE   (N,          C(2329)), (IQ,         C(2330))
      EQUIVALENCE   (IQ1,        C(2331)), (IQ2,        C(2332))
      EQUIVALENCE   (IQ3,        C(2333)), (KMAT,       C(2334))
      EQUIVALENCE   (IMAT,       C(2335)), (IUSE,       C(2335))
      EQUIVALENCE   (IADD,       C(2336)), (ITNUMB,     C(2337))
      EQUIVALENCE   (ITAPE,      C(2338)), (P,          C(2339))
      EQUIVALENCE   (IDEBUG,     C(2340)), (IFROZ,      C(2341))
      EQUIVALENCE   (A(1),       C(2342)),  (A(1350),   C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      EQUIVALENCE   (PCP(1),    C(2286)), (PCP(25),    C(2310))
      EQUIVALENCE (CONS,JFCONS),    (MTEMP, TEMP)
C
C
C
C
C     IARG=1 MEANS TEST ONLY, IARG=2 MEANS ELIMINATE A SPECIES, IARG=3
C     MEANS ADD ANOTHER SPECIES
C
      DATA Q000CT/01/
      CONS=Q000CT
      MLM=J
      IF (J-35) 2,2,102
  102 IF (J-70) 1,1,101
            BYPASS

  101 K=3
      MLM=J-70
      GO TO 3
    1 K=2
      MLM=J-35
      GO TO 3
    2 K=1
    3 IF (IARG-2) 4,5,7
    4 IPROD=2
      KLM = 35-MLM
      TEMP = PROD(K)
      TEMP = ALRS(KLM,TEMP)
      IF (BOOL(AND(TEMP,CONS)))12,10,12
   12 IPROD = 1
      GO TO 10
    5 KLM = 35 - MLM
      TEMP = PROD(K)
      TEMP = ALRS(KLM,TEMP)
      IF (BOOL(AND(TEMP ,CONS)))10,6,10
      DATA Q001CT/01/
 6    TEMP =OR(TEMP ,Q001CT)
      PROD(K) = ALLS(KLM,TEMP)
      IF(M-J)11,10,10
   11 IQ3=IQ2
      IQ2=IQ1
      IQ1=IQ
      IQ =IQ-1
      GO TO 9
    7 KLM = 35 - MLM
      TEMP = PROD(K)
      TEMP = ALRS(KLM,TEMP)
      DATA Q002CT/01/
      IF (BOOL(AND(TEMP ,Q002CT)))110,10,110
  110 MTEMP=MTEMP-JFCONS
      PROD(K) = ALLS(KLM,TEMP)
      IF(M-J)121,10,10
  121 IQ = IQ1
      IQ1=IQ2
      IQ2=IQ3
      IQ3=IQ3+1
    9 CALL SLITE (4)
   10 RETURN
      END
```

```
      SUBROUTINE  CORE2
C      NEW COMMON

C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VO,AOAC,Q1Q0,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
C
C      END OF NEW COMMON
      DIMENSION   G(20,21),   A(15,90),   EN(90),     EN LN(90)
      DIMENSION   DEL N(90),  HO(90),     S(90),      X(20)
      DIMENSION   DELTA(20),  BO(15),     PCP(25),    PROD(3)
      DIMENSION   COEFX(20),  DX(20),     FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),   DATA(23),   DATUM(3),   FORMLA(18)
      DIMENSION   BOX(15),    BOF(15),    ANS(454),   SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),   COEFT(15,90)
      DIMENSION   MATOM(101,3),     ATOM(101,3)
      DIMENSION MX(20),MCOEFT(15,90)
      DIMENSION MFORM(15)
      REAL LRS
      REAL LLS
      COMMON  G
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (G(1),      C(1)),     (G(420),     C(420))
      EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),     C(874))
      EQUIVALENCE   (HSUM,      C(424)),  (SSUM,       C(425))
      EQUIVALENCE   (WTMOL,     C(426)),  (CP,         C(427))
      EQUIVALENCE   (DLMPT,     C(428)),  (DLMTP,      C(429))
      EQUIVALENCE   (GAMMA,     C(430)),  (ARATIO,     C(431))
      EQUIVALENCE   (VMACH,     C(432)),  (SP IMP,     C(433))
      EQUIVALENCE   (VACI,      C(434)),  (CF,         C(436))
      EQUIVALENCE   (RHOI,      C(437)),  (RHOVAC,     C(438))
      EQUIVALENCE   (RHO,       C(439))
      EQUIVALENCE   (T PI,      C(440)),  (PI I,       C(441))
      EQUIVALENCE   (EP PI,     C(442)),  (AW PI,      C(443))
      EQUIVALENCE   (T ETA,     C(445))
      EQUIVALENCE   (ETA I,     C(446)),  (EP ETA,     C(447))
      EQUIVALENCE   (AW ETA,    C(448)),  (T SIG,      C(450))
      EQUIVALENCE   (SIG I,     C(451)),  (EP SIG,     C(452))
      EQUIVALENCE   (AW SIG,    C(453))
      EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
      EQUIVALENCE   (FORM(1),   C(1329)), (FORM(15),   C(1343))
      EQUIVALENCE   (MFORM(1),  C(1329)), (MFORM(15), C(1343))


      EQUIVALENCE   (ELMT(1),   C(1344)),  (ELMT(15), C(1358))
      EQUIVALENCE   (LLMT(1),   C(1344)),  (LLMT(15), C(1358))
      EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
      EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
      EQUIVALENCE   (EN(1),   C(1382)),  (EN(90),   C(1471))
      EQUIVALENCE   (ISYS,     C(1472)),   (JEAN,     C(1473))
      EQUIVALENCE   (ACX,      C(1474)),   (ACF,      C(1475))
      EQUIVALENCE   (AMX,       C(1476)),   (AMF,      C(1477))
      EQUIVALENCE   (RHOX,      C(1478)),   (RHOF,     C(1479))
      EQUIVALENCE   (COEFX(1),    C(1480)),  (COEFX(20),  C(1499))
      EQUIVALENCE   (DX(1),    C(1500)),  (DX(20),   C(1519))
C
      EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
      EQUIVALENCE   (MMLA(1),   C(1520)),  (MMLA(13), C(1537))
      EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),   C(1555))
      EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE   (OF,     C(1556)),    (FPCT,   C(1557))
      EQUIVALENCE   (EQRAT,     C(1558))
      EQUIVALENCE (KODE,    C(1559)),   (KASE,      C(1560))
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```
      EQUIVALENCE(NF,C(1562))
      EQUIVALENCE   (NO,        C(1563)), (NE,        C(1564))
      EQUIVALENCE   (NOEQ, C(1565))
      EQUIVALENCE   (BOX(1),    C(1771)), (BOX(15),   C(1785))
      EQUIVALENCE   (BOF(1),    C(1786)), (BOF(15),   C(1800))
      EQUIVALENCE   (HX,        C(1801)), (HF,        C(1802))
      EQUIVALENCE   (VXPLS,     C(1803)), (VXMIN,     C(1804))
      EQUIVALENCE   (VFPLS,     C(1805)), (VFMIN,     C(1806))
      EQUIVALENCE   (EN LN(1),  C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE   (DEL N(1),  C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE   (HO(1),     C(2041)), (HO(90),    C(2130))
      EQUIVALENCE   (S(1),      C(2131)), (S(90),     C(2220))
      EQUIVALENCE   (MX(1),    C(2221)), (MX(20),    C(2240))
      EQUIVALENCE   (X(1),      C(2221)), (X(20),     C(2240))
      EQUIVALENCE   (DELTA(1),  C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),     C(2261)), (BO(15),    C(2275))
      EQUIVALENCE   (PO,        C(2276)), (HSUBO,     C(2277))
      EQUIVALENCE   (SO,        C(2278)), (T LN,      C(2279))
      EQUIVALENCE   (T,         C(2280)), (AAY LN,    C(2281))
      EQUIVALENCE   (AAY,       C(2282)), (CPSUM,     C(2283))
      EQUIVALENCE   (HC,        C(2284)), (TC LN,     C(2285))
      EQUIVALENCE   (PCP(1),    C(2286)), (PCP(25),   C(2310))
      EQUIVALENCE   (DATUM(1),  C(2311)), (DATUM(3),  C(2313))
      EQUIVALENCE   (PC,        C(2314)), (TC,        C(2315))
      EQUIVALENCE   (IPROB,     C(2316)), (IFIXT,     C(2317))
      EQUIVALENCE   (IHS,       C(2318)), (ICOND,     C(2319))
      EQUIVALENCE   (ISYM,      C(2320)), (IPROD,     C(2321))
      EQUIVALENCE   (IDID,      C(2322)), (LDRUM,     C(2323))
      EQUIVALENCE   (IDRM,      C(2323)), (KDRUM,     C(2324))
      EQUIVALENCE   (L,         C(2325)), (L1,        C(2326))
      EQUIVALENCE   (M,         C(2327)), (M1,        C(2328))
      EQUIVALENCE   (N,         C(2329)), (IQ,        C(2330))
      EQUIVALENCE   (IQ1,       C(2331)), (IQ2,       C(2332))
      EQUIVALENCE   (IQ3,       C(2333)), (KMAT,      C(2334))
      EQUIVALENCE   (IMAT,      C(2335)), (IUSE,      C(2335))
      EQUIVALENCE   (IADD,      C(2336)), (ITNUMB,    C(2337))
      EQUIVALENCE   (ITAPE,     C(2338)), (P,         C(2339))


      EQUIVALENCE   (IDEBUG,    C(2340)), (IFROZ,     C(2341))
      EQUIVALENCE   (A(1),      C(2342)),  (A(1350),  C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (MCOEFT(1),  C(6392)), (MCOEFT(1350),  C(7741))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      EQUIVALENCE (KORE, C(8047))
      EQUIVALENCE (DLNT,LNT),(SUM,MSUM),(BLK,MBLK),(TMP,MTMP),(MT,BMT)
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))
      COMMON/APE12/HCC,PCC,SOO,ZN2,ZN3,SAV(3),SAV1(3)
C
C
      DATA Q000CT/0606060606060/
 1    BMT =Q000CT
      DATA Q001CT/027/
      GAS =Q001CT
      DATA Q002CT/060/
      BLK =Q002CT
C
      JRAM=1
      REWIND 3
      NO EQ=0
      ITEST=M1
      SIZE=18.5
  555 IF (IPROB-3) 557,563,565
  557 CONTINUE
      PO=PC
      IF (TC) 559,559,561
  559 TC LN= 8.25
      GO TO 431
  561 TCLN=ALOG(TC)
      GO TO 431
  563 PO=PC
      GO TO 431
```

```
  565 T=TC
      PO=0.0
      TLN=ALOG(T)
C
C     START CALCULATION FOR NEW OVERALL COMPOSITION
C
  431 IADD=1
      IF (IFROZ) 1565,379,1432
 1565 IF (IUSE) 1432,1432,433
 1432 DO 432 K=1,N
      EN(K)=0.0
      EN LN(K)=0.0
  432 DEL N(K)=0.0
      AAY LN=5.0
  433 CALL SLITE (0)
      IF (IPROB-2) 435,445,434
  434 IF (IPROB-4) 455,465,379
  435 IF (IADD-1) 379,436,441
  436 CALL SLITE (1)
  437 T LN=TC LN
          CORE2

      ITROT=3
  438 IF (PCP(IADD)) 231,231,439
  439 CALL SLITE (4)
      PO=PC/PCP(IADD)
      GO TO 13
  441 IF (IADD-25) 438,438,231
  445 IF (IADD-1) 379,447,441
  447 CALL SLITE (2)
      GO TO 437
  455 IF (IADD-25) 459,459,231
  459 IF (PCP(IADD)) 231,231,460
  460 T=PCP(IADD)
      TLN= ALOG(T)
      GO TO 473
  465 IF (IADD-25) 469,469,231
  469 IF (PCP(IADD)) 231,231,470
  470 PO=PCP(IADD)
  473 CALL SLITE (2)
      CALL SLITE (4)
C
C     BEGIN CALCULATIONS FOR CURRENT POINT
C
   13 PO LN=ALOG(PO)
C
C     CHECK TEMPERATURE RANGE OF THERMODYNAMIC DATA
C
      IF (IPROB-2) 17,17,19
   17 T=EXP(T LN)
   19 IF (COEFT(7,1)-T) 21,27,27
   21 IF (COEFT(7,1)-5000.0) 23,31,231
   23 DO 1123 K=1,15
      DO 1123 J = 1,90
 1123 COEFT(K,J)=COEFT1(K,J)
      CALL SLITE (4)
      GO TO 19
   25 DO 1125 K = 1,15
      DO 1125 J = 1,90
 1125 COEFT(K,J)=COEFT2(K,J)
      CALL SLITE (4)
      GO TO 19
   27 IF (T-COEFT(6,1)) 29,37,37
   29 IF (300.0-COEFT(6,1)) 25,31,231
   31 CALL SLITET(4,KOOOFX)
       GO TO(38,305),KOOOFX
C
C     ELIMINATE THOSE SPECIES WHICH DO NOT HAVE DATA IN THIS INTERVAL
C
   37 CALL SLITET(4,KOOOFX)
       GO TO(38,142),KOOOFX
   38 CALL SLITE (4)
      DO 40 J=1,N
      IF (COEFT(8,J)) 40,39,40
   39 CALL BYPASS (J,2)
```

```
      EN LN(J)=0.0
      EN(J)=0.0
   40 CONTINUE


C
C     BEGIN  ITERATION FOR COMPOSITION
C
   42 IQ=IQ
      IQ1=IQ1
      IQ2=IQ2
      IQ3=IQ3
      ITNUMB=30
   43 DO 48 J=1,M
      CALL BYPASS (J,1)
      IF (IPROD-2) 48,45,48
   45 IF (EN LN(J)+SIZE-PO LN) 46,46,47
   46 EN(J)=0.0
      GO TO 48
   47 EN(J)=EXP(EN LN(J))
   48 CONTINUE
      IF (IPROB-2) 49,49,51
   49 T=EXP(T LN)
   51 AAY=EXP(AAY LN)
C
C     CALCULATE HEAT CAPACITY, ENTHALPY AND ENTROPY
C
      IFIXT=3
      CALL SLITET(2,KOOOFX)
       GO TO(52,55),KOOOFX
   52 CALL SLITE (2)
      CALL SLITET(4,KOOOFX)
       GO TO(53,55),KOOOFX
   53 CALL SLITE (4)
      IFIXT=1
      IF (ITNUMB-30) 55,54,55
   54 IFIXT=2
   55 CPSUM=0.0
      DO 60 J=1,N
      CALL BYPASS (J,1)
      IF (IPROD-2) 60,56,60
   56 IF (IFIXT-2) 59,58,57
   57 CPSUM=CPSUM+((((COEFT(12,J)*T+COEFT(11,J))*T+COEFT(10,J))*T+COEFT(
     19,J))*T+COEFT(8,J))*EN(J)
   58 HO(J)=((((COEFT(12,J)/5.0)*T+COEFT(11,J)/4.0)*T+COEFT(10,J)/3.0)*T
     1+COEFT(9,J)/2.0)*T +COEFT(13,J)/T+COEFT(8,J)
   59 S(J)=((((COEFT(12,J)/4.0 )*T+COEFT(11,J)/3.0)*T+COEFT(10,J)/2.0)*T
     1+COEFT(9,J))*T+COEFT(8,J)*T LN+COEFT(14,J)-EN LN(J)
   60 CONTINUE
C
C     CONSTRUCT MATRIX AND SOLVE THE EQUATIONS
C
      CALL MATRIX
      CALL SLITET(4,KOOOFX)
       GO TO(61,171),KOOOFX
   61 CALL SLITE (4)
      CALL GAUSS
      IF (IDEBUG) 910,80,910
  910 DO 911 I=1,IMAT
  911 WRITE (6,912)(G(I,K),K=1,KMAT),DELTA(I)
      WRITE (6,912)(X(I),I=1,IMAT)


   80 IF (IDID-IMAT) 81,85,81
   81 IF (SIZE-18.5) 83,83,311
   83 SIZE=27.5
      GO TO 43
   85 ITNUMB=ITNUMB-1
      DO 87 K=1,IMAT
      IF (ABS(DELTA(K))-0.5E-4) 87,87,315
   87 CONTINUE
C
C     OBTAIN CORRECTIONS TO THE ESTIMATES
C
      D LN T=X(IQ2)
```

```
   91 IF (IFIXT-2) 93,95,379
   93 D LN T=0.0
   95 DO  101 J=1,M
      CALL BYPASS (J,1)
      IF (IPROD-2) 96,97,96
   96 DEL N(J)=0.0
      GO TO 101
   97 DEL N(J)=HO(J)*D LN T-HO(J)+S(J)
      DO  99 K=1,L
   99 DEL N(J)=DEL N(J)+A(K,J)*X(K)
  101 CONTINUE
      IF (L-IQ) 103,109,109
  103 J=M1
      DO 107 K=L1,IQ
  104 CALL BYPASS (J,1)
      IF (IPROD-2) 105,106,105
  105 DEL N(J)=0.0
      J=J+1
      GO TO 104
  106 DEL N(J)=X(K)
      J=J+1
  107 CONTINUE
  109 AMBDA=1.0
      AMBDA1=1.0
      IF (IABS(LNT)-IABS(MX(IQ1))) 501,913,913
  501 SUM = ABS(X(IQ1))
      GO TO 915
  913 SUM=ABS(D LN T)
  915 DO 917 J=1,M
      IF (EN(J)) 917,1915,916
  916 SUM=AMAX1(DELN(J),SUM)
      GO TO 917
 1915 IF (EN LN(J)) 917,917,1917
 1917 SUM1=ABS((PO LN-9.212-EN LN(J))/DEL N(J))
      AMBDA1=AMIN1(SUM1,AMBDA1)
  917 CONTINUE
      IF (SUM-2.0) 1110,1110,110
  110 AMBDA=2.0/SUM
 1110 AMBDA=AMIN1(AMBDA,AMBDA1)
  920 IF (IDEBUG) 921,111,921
  921 WRITE (6,923)T,P,AAY, AMBDA, ((COEFT(K,J),K=1,3),        EN(J),EN L
     1N(J),DEL N(J),HO(J),S(J),J=1,N)
C
C     APPLY CORRECTIONS TO THE ESTIMATES


C
  111 DO 113 J=1,M
  113 EN LN(J)=EN LN(J)+AMBDA*DEL N(J)
      IF (ICOND-2) 115,121,375
  115 DO 117 J=M1,N
  117 EN(J)=EN(J)+AMBDA*DEL N(J)
  121 T LN=T LN +AMBDA*D LN T
      AAY LN=AAY LN- AMBDA*X(IQ1)
      CALL SSWTCH(6,KOOOFX)
       GO TO(122,124),KOOOFX
  122 IF (IDEBUG) 1122,123,1122
 1122 IDEBUG=0
      GO TO 231
  123 IDEBUG=1
C
C     TEST  FOR CONVERGENCE OF ITERATION
C
  124 IF (ITNUMB) 125,132,125
  125 IF (AMBDA-1.0) 43,1124,231
 1124 P=0.0
      DO 1126 J=1,M
      IF (EN LN(J)) 2125,1126,2125
 2125 P=P+EXP(EN LN(J))
 1126 CONTINUE
      IF (ABS((PO-P)/PO)-0.5E-5) 126,126,43
  126 SUM=P
      IF(ICOND-2)127,129,375
  127 DO 128 J=M1,N
  128 SUM=SUM+ABS(EN(J))
```

```
  129 DO 130 J=1,N
      IF (J-M) 1129,1129,1130
 1129 IF (ABS(EN(J)*DEL N(J)/SUM)-0.5E-5) 130,130,43
 1130 IF (ABS(DEL N(J)/SUM)-0.5E-5) 130,130,43
  130 CONTINUE
  132 CALL SLITET(4,KOOOFX)
       GO TO(133,133),KOOOFX
  133 GO TO 13
C
C     ELIMINATE THOSE SPECIES WITH NO DATA AT THIS TEMPERATURE, ADD
C     THOSE WITH DATA AT THIS TEMPERATURE
C
  142 DO 170 J=1,N
      IF (MCOEFT(1,J)-MT) 170,500,170
  500 IF (COEFT(5,J) + 100.0-T) 285,143,143
  143 IF (T-COEFT(4,J)+100.0) 295,144,144
  285 IF (5000.0-COEFT(5,J)) 144,144,301
  295 IF (COEFT(4,J)-300.0) 144,144,301
  144 IF (J-M) 145,145,146
  145 CALL BYPASS (J,3)
      GO TO 170
  301 CALL BYPASS (J,2)
      EN(J)=0.0
      EN LN(J)=0.0
      DEL N(J)=0.0
      GO TO 170
  146 IF (EN(J)) 147,148,170


  147 EN(J)=0.0
      DEL N(J)=0.0
      CALL BYPASS (J,2)
      GO TO 42
C
C     SKIP CONDENSATION CHECK IF T IS HIGHER THAN MELTING POINT WHEN
C     TESTING SOLID, OR LOWER THAN MELTING POINT WHEN TESTING LIQUID
C
  148 IF (COEFT(4,J)-COEFT(5,J-1)) 150,149,150
  149 IF (COEFT(4,J)-T) 153,153,170
  150 IF (COEFT(5,J)-COEFT(4,J+1)) 153,151,153
  151 IF (T-COEFT(5,J)) 153,153,170
C
C     CHECK FOR CONDENSATION
C     IF MORE THAN ONE CONDENSED PHASE OF ANY SPECIES CAN EXIST THE
C     PHASE STABLE AT THE HIGHER TEMPERATURE MUST PRECEED THAT STABLE AT
C     THE LOWER TEMPERATURE ON MASTER TAPE
C
  153 DO 155 K=2,3
      SUM=COEFT(K,J)
      DO 154 I=1,6
      TMP=AARS(30,SUM)
      SUM=AALS(6,SUM)
      IF(MTMP-MBLK)  154,156,154
  154 CONTINUE
  155 CONTINUE
      K=3
      I=5
      GO TO 159
  156 I=I-2
      IF (I) 157,158,159
  157 K=2
      I=5
      GO TO 159
  158 K=2
      I=6
  159 FORM(2)=COEFT(2,J)
      FORM(3)=COEFT(3,J)
      I=6*I
      JJ=42-I
      I=I
      JJ=JJ
      SUM = FORM(K)
      SUM =AARS(JJ,SUM)
      MJJ=JJ-6
      TMLJ = FORM(K)
```

```
      TMLJ =ALRS(MJJ,TMLJ)
      MJJ=36-I
      SUM1=ALLS(MJJ,GAS)
      TEMP=ALRS(JJ,SUM1)
      MJJ=42-I
      FORM(K)=ALLS(MJJ,SUM)
      DO 160 K=1,M
      IF (MFORM(2)-MCOEFT(2,K)) 160,1160,160
 1160 IF (MFORM(3)-MCOEFT(3,K)) 160,162,160
  160 CONTINUE


      CALL BYPASS (J,3)
      GO TO 170
  162 CALL BYPASS (K,1)
      IF (IPROD-2) 170,163,170
  163 HO(J)=((((COEFT(12,J)/5.0)*T+COEFT(11,J)/4.0)*T+COEFT(10,J)/3.0)*T
     1+COEFT(9,J)/2.0)*T +COEFT(13,J)/T+COEFT(8,J)
      S(J)=((((COEFT(12,J)/4.0 )*T+COEFT(11,J)/3.0)*T+COEFT(10,J)/2.0)*T
     1+COEFT(9,J))*T+COEFT(8,J)*T LN+COEFT(14,J)
      IF (HO(J)-S(J)-HO(K)+S(K)) 164,164,170
  164 CALL BYPASS (J,3)
      EN(J)=0.0
      GO TO 42
  170 CONTINUE
C
C     IF COMPOSITION HAS BEEN CORRECTLY DETERMINED CALCULATE THE
C     EQUILIBRIUM PROPERTIES, OTHERWISE CONTINUE ITERATION
C
      CALL SLITET(4,KOOOFX)
       GO TO(1170,1172),KOOOFX
 1170 CALL SLITE (4)
      GO TO 42
 1172 IF (ITNUMB) 42,971,42
  971 WRITE (6,973)IADD
      GO TO 42
C
C     CALCULATE EQUILIBRIUM PROPERTIES
C
  171 DO 1171 I = 1,454
 1171 ANS(I) = ANSLAB(I)
      WTMOL=AAY/P
      HSUM=G(IQ2,IQ1)*T/AAY
      SSUM=0.0
      DO 183 J=1,N
      CALL BYPASS (J,1)
      IF (IPROD-2) 183,181,183
  181 SSUM=SSUM+S(J)*EN(J)
  183 CONTINUE
 1183 SSUM=SSUM/AAY
      IMAT=IMAT-1
      CALL GAUSS
      IF (IDID-IMAT) 172,174,172
  172 CPR=CPSUM/AAY
      GAMMA=CPR/(CPR-(1.0/WTMOL))
      DLMTP=0.0
      DLMPT=0.0
      GO TO 185
  174 DLMTP=X(IQ1)
      IF (ABS(DLMTP)-27.5) 1174,1174,172
 1174 CPR=G(IQ2,IQ2)
      DO 175 J=1,IQ1
  175 CPR=CPR-G(IQ2,J)*X(J)
      CPR=CPR/AAY
 1175 IMAT=IMAT-1
      CALL GAUSS
      DLMPT=0.0
      DO 179 J=1,L


  179 DLMPT=DLMPT+G(IQ1,J)*X(J)
      DLMPT=(P-DLMPT)/DLMPT
      IF (DLMPT-27.5) 180,180,172
  180 GAMMA=1.0/(1.0+DLMPT-((1.0-DLMTP)**2)/(CPR*WTMOL))
      IF (GAMMA) 172,172,185
```

```
  185 IF (IPROB-2) 186,186,207
  186 IF (IADD-2) 187,191,197
  187 WTMOLC=WTMOL
      TC=T
      PC=P
      HC=HSUM
      SO=SSUM
      PCC        = PC
      HCC        = HC
      SOO        = SO
      ZN2=WTMOL
      IPROB S=IPROB
      IF(IRAM.EQ.0)GO TO 188
      IF(JRAM.EQ.0)GO TO 11188
      IPROB=1
      CALL COMB
      GO TO 433
11188 IPROB=IPROB S
  188 T PI=-DLMTP/(WTMOL*CPR)
      TEM1=V4/32.2
      T ETA=1000.0/(CPR*TC*1.98726)
      ZN3=TETA
      T SIG=-(1.0-DLMTP)/(WTMOL*CPR)
      IF(KOK) 4101,207,4101
4101  AWT=(86.4579*T)/(AAY*14.696006*TEM 1)
      GO TO 207
C
C     CHECK FOR CONVERGENCE AT THROAT
C
  191 IF(KOK.NE.0)GO TO 197
 4002 DHSTAR=(HC-HSUM+V4**2/1.79223E05)*CV**2
     2-GAMMA*T/(2.0*WTMOL)
      IF (ABS(DHSTAR/(HC+V4**2/1.79223E+05-HSUM))-0.4E-04) 197,197,192
  192 IF(ITROT) 193,197,193
  193 PCP(2)=PCP(2)/(1.0+2.0*DHSTAR*WTMOL/(T*(GAMMA+1.0)))
      PO=PC/PCP(IADD)
      ITROT=ITROT-1
      IF (IDEBUG) 929,194,929
  929 WRITE (6,923)DHSTAR,HC,HSUM,PCP(IADD)
  194 CALL SLITE (4)
      GO TO 13
C
C     CALCULATE PERFORMANCE PARAMETERS
C
  197 CONTINUE
1977  SP IMP = SQRT(172.9178*(HC-HSUM)+V4**2*9.6447E-4)
     2*CV
      RHOI=RHO*SP IMP
      SUM=T/(2.0*(HC-HSUM))
      PI I=SUM*(WTMOL-WTMOLC)/(WTMOL*WTMOLC)
      ETA I=SUM*(TC-T)/(TC*T*1.98726)*1000.0


      SSSM =T/(2.0*(HC - HSUM +V4**2*5.57965E-6) )
      SIG I = SSSM/WTMOL
      T PI=(((WTMOLC-WTMOL)/WTMOLC)-DLMTP)/(WTMOL*CPR)
      T ETA=1000.0/(CPR*TC*1.98726)
      T SIG=-(1.0-DLMTP)/(WTMOL*CPR)
      AW=(86.4579*T)/(AAY*14.696006*SP IMP)
      AW PI=- ((1.0-DLMTP)/(WTMOLC*CPR)+1.0/GAMMA+PI I)
      AW ETA=T ETA*(1.0-DLMTP)-ETA I
      AW SIG=1.0/GAMMA-SIG I
      IF(IADD-2) 203,2201,203
2201   IF(KOK) 2202,201,2202
201   AWT=AW
      PCP T=PCP(2)
2202   CSTAR=32.174*PC*14.696006*AWT
      CSTRPI=1.0+AW PI
      STR ETA=AW ETA
      STR SIG=0.0
      AWT PI=AW PI
      AWT ETA=AW ETA
      AWT SIG=AW SIG
  203 IF(IRAM.EQ.0)GO TO 22203
      SPNET   1.0 OF * SPIMP   86.4* 1.0-PFIELD/P *T/ SPIMP*WTMOL  -VO*O
```

```
      IF* 1.0  CDA /32.2
      CF=64.4*SPNET*AUAC*Q1QO/(VO*OF)
      GO TO 11203
22203 CONTINUE
11203 CONTINUE
      ARATIO=AW/AWT
      VACI=SP IMP+P*14.696006*AW
      IF(IRAM.EQ.1)VACI=86.4*(1.0+OF)*PFIELD*T/
     2(P*WTMOL*SPIMP)+SPNET
      IF(IRAM.EQ.0)CF=32.174*VACI/CSTAR
      RHOVAC=RHO*VACI
      VMACH=SP IMP/SQRT(86.4579*GAMMA*T/WTMOL)
      EP PI=AW PI-AWT PI
      EP ETA=AW ETA-AWT ETA
      EP SIG=AW SIG-AWT SIG
      SAV=AWT PI
      SAV(2)=AWT ETA
      SAV(3)=AWT SIG
  207 HSUM=HSUM*1.98726
      SSUM=SSUM*1.98726
      CP=CPR*1.98726
C
C     OBTAIN COMPOSITION IN MOLE FRACTIONS
C
      SUM=P
      IF (ICOND-2) 209,213,375
  209 DO 211 J=M1,N
  211 SUM=SUM+EN(J)
  213 DO 215 J=1,N
  215 ANS(4*J+34)=EN(J)/SUM
      IF (IPROB-2) 217,217,220
  217 ANS(1)=PCP(IADD)
  218 IF (IADD-2) 220,219,219
  219 ANS(15)=CSTAR


      ANS(24)=CSTRPI
      ANS(29)=STR ETA
      ANS(34)=STR SIG
  220 ANS(2)=P
      ANS(3)=T
      IF  IRAM .EQ. 1   SPIMP = SPNET
      K=34+4*N
C
C     PRINT OUT THE CALCULATED ANSWERS
C
      IF (IDEBUG) 1221,222,1221
 1221 WRITE (6,221)(ANS(I),I=1,K)
      GO TO 2223
  222 IF(MNFR.EQ.1)GO TO 11237
      WRITE(3)(ANS(I),I=1,454)
      IF((KOK.EQ.0).AND.(IADD.EQ.2))PPT=P
      IF(MNFR.EQ.0)GO TO 2000
      IF((MNFR.LT.0).AND.(IFREZ.EQ.IADD))GO TO 11237
      IF(MNFR.EQ.-1)GO TO 2000
      IF(CONVER.EQ.1.0)GO TO 2000
      IF(IADD.EQ.KONT)GO TO 20000
      GO TO 2000
20000 IF(IJN.NE.0)GO TO 20001
      KONT=KONT+1
      IJN=1
20001 CALL ALEO
      IF(CONVER.EQ.1.0)GO TO 21000
      PCP(IADD+1)=SAPE
      GO TO 2000
21000 NOEQ=NOEQ-1
      IADD=IADD-1
      BACKSPACE 3
      DO 21001 I=KONT,JADDI
      IF (SAPE .GT. SPCP (I)) GO TO 21002
      PCP (I) = SAPE
      IFREZ = I
      JADDI = JADDI + 1
      GO TO 2000
21002 PCP(I)=SPCP(I)
```

```
21001 CONTINUE
C     THIS SHOULD NEVER HAPPEN
 2000 NOEQ=NOEQ+1
 2223 IF((KOK.NE.0).AND.(IADD.EQ.1))GO TO 1223
      IF(IADD-2)223,225,225
  223 IF(IPROB-2)224,1224,1223
  224 IF(IFROZ)1223,1224,1224
 1224 PCP(2)=((GAMMA+1.0)/2.0)**(GAMMA/(GAMMA-1.0))
      TLN=TLN+ALOG(2.0/(GAMMA+1.0))
 1223 DO 1225 I=1,454
 1225 ANSLAB(I)=ANS(I)
  225 IADD=IADD+1
      GO TO 433
C
  231 IF (NO EQ) 378,378,1231
 1231 IF (IFROZ) 232,379,235
  232 IF (IADD-2) 378,233,378


  233 IF (IDEBUG) 378,234,378
  234  CONTINUE
  235 IF (IPROB-2) 237,237,239
  237 IF(MMFR.EQ.0)GO TO 239
11237 CALL CORE3
      RETURN
  239 WRITE (3)(G(I,1), I=1,8044)
      CALL CORE5
      RETURN
C
C     ERROR PRINT OUT
C
  305 WRITE (6,306)T,IADD
      IF (6000.0-T) 309,307,307
  307 IF (T-200.0) 1309,308,308
  308 GO TO 142
 1309 IF (IADD-1) 309,1310,309
 1310 IF (IPROB-2) 1311,309,309
 1311 IF (ITEST-N) 1312,1312,309
 1312 DO 1313 J=ITEST,N
      CALL BYPASS(J,1)
      IF (IPROB-2) 1315,1313,1313
 1313 CONTINUE
      GO TO 309
 1315 ITEST=J+1
      CALL BYPASS(J,3)
      GO TO 555
  309 IADD=25
      CALL SLITET(4,K000FX)
       GO TO(42,42),K000FX
  311 WRITE (6,312)IMAT,IDID
      GO TO 375
  315 WRITE (6,316)
  375 IF (IDEBUG) 231,377,231
  377 IDEBUG=1
      IF (IPROB-3) 1377,555,555
 1377 PC=PC*14.696006
      GO TO 555
  378 WRITE (3)(G(I,1),I=1,8044)
      BACKSPACE 3
      RETURN
  379 REWIND 4
      STOP
  912 FORMAT (8E14.6)
  923 FORMAT (4E25.8/(1X,3A6,5E15.6))
  973 FORMAT (7CHL30 ITERATIONS DID NOT SATISFY CONVERGENCE REQUIREMENTS
     1 FOR THE POINT I5)
 4001 FORMAT(1H0,14HCOMB. IMPULSE=G20.8/1X,15HCOMB. MACH NO.=G20.8)
  221 FORMAT (1H ////5E20.8/5E20.8/5E20.8/4E20.8/5E20.8/5E20.8/5E20.8///
     1 (3(7X,3A6,F8.5)))
  306 FORMAT (17HLTHE TEMPERATURE=E12.4,34H K, IS OUT OF RANGE FOR THE P
     1OINT I5)
  312 FORMAT (/15H1TRIED TO SOLVE I3,22H EQUATIONS, ELIMINATED I3)
  316 FORMAT (/47H1RESIDUALS FROM SUBROUTINE GAUSS EXCEED  0.5E-4)
      END
```

```
      SUBROUTINE COMP
C
C     OUTPUTS COMPOSITION
C
C
      DIMENSION                TITLE(3,105),IOMIT(105),ILESS(105)
      DIMENSION AMOL(13,90)
      DIMENSION FMT(4),TEM(4)
      DIMENSION MTITLE (3,105)
      COMMON  C
      COMMON QOOOCM(7700)
C     COMMON C
      EQUIVALENCE (AMOL(1),  C(9268)),  (AMOL(1170),  C(10437))
      EQUIVALENCE (NANA, C(1768)), (IN, C(8046))
      EQUIVALENCE (ME, C(1769)), (N, C(2329))
      EQUIVALENCE   (TITLE(1),    C(8055)), (TITLE(315), C(8369))
      EQUIVALENCE   (MTITLE(1), C(8055)),  (MTITLE(315),   C(8369))
      EQUIVALENCE (OMIT,MOMIT)
    1 FORMAT (1X,2A6,2X,13F9.5)
    3 FORMAT (1H0,   118HADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT W
     1HOSE MOLE FRACTIONS WERE LESS THAN 0.000005 FOR ALL ASSIGNED CONDI
     2TIONS//)
    4 FORMAT (1H0,    59HPRODUCTS WHICH WERE INTENTIONALLY OMITTED FROM
     1CALCULATIONS//)
      DATA QC00CT/0464431636060/
      OMIT=QC00CT
      DATA QC01CT/0606007677302/
      TEM(1)=QC01CT
      DATA QC02CT/0600306677302/
      TEM(2)=QC02CT
      DATA QC03CT/0600604677302/
      TEM(3)=QC03CT
      DATA QC04CT/0601102677302/
      TEM(4)=QC04CT
      DATA QC05CT/0740130207360/
      FMT(1)=QC05CT
      DATA QC06CT/0210673261033/
      FMT(3)=QC06CT
      DATA QC07CT/053460606060/
      FMT(4)=QC07CT
      K=0
      KK=4
      IOM=0
      ILE=0
      IF(ME-1)61,60,61
   61 WRITE (6,44)
   60 II=0
      DO 9 I=1,N
      IF (MTITLE(1,I)-MOMIT) 10,100,10
  100 IOM=IOM+1
      IOMIT(IOM)=I
      GO TO 9
   10 DO 11 J=1,IN
      IF(AMOL(J,I)-.5E-05)11,12,12


   11 CONTINUE
      ILE=ILE+1
      ILESS(ILE)=I
      GO TO 9
   12 IF(ME-1)51,50,51
   50 WRITE (6,1)TITLE(2,I),TITLE(3,I),(AMOL(JJ,I),JJ=1,IN)
      GO TO 9
   51 II=II+1
      IF(II-KK)200,200,201
  200 K=K+1
      GO TO 5
  201 K=1
      KK=KK+4
      WRITE (6,44)
   44 FORMAT (1H )
    5 FMT(2)=TEM(K)
      WRITE (6,FMT)TITLE(2,I),TITLE(3,I),AMOL(1,I)
    9 CONTINUE
      IF(ILE) 21,20,21
   21 WRITE (6,44)
      WRITE (6,3)
      CALL ONCE (ILE,ILESS(1))
   20 IF(IOM) 31,30,31
   31 WRITE (6,44)
      WRITE (6,4)
      CALL ONCE (IOM,IOMIT(1))
   30 RETURN
      END
```

```
      SUBROUTINE ONCE (N,M)
C
C     OUTPUTS ODD PRODUCTS
C
C
      DIMENSION M(105),TITLE(3,105) ,TEM(10),FMT(3)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (TITLE(1),    C(8055)), (TITLE(315), C(8369))
      WRITE (6,1)
      DATA Q000CT/0740130207360/
      FMT(1)=Q000CT
      DATA Q001CT/0210634606060/
      FMT(3)=Q001CT
      DATA Q002CT/0606001677302/
      TEM(1)=Q002CT
      DATA Q003CT/0600104677302/
      TEM(2)=Q003CT
      DATA Q004CT/0600207677302/
      TEM(3)=Q004CT
      DATA Q005CT/0600400677302/
      TEM(4)=Q005CT
      DATA Q006CT/0600503677302/
      TEM(5)=Q006CT
      DATA Q007CT/0600606677302/
      TEM(6)=Q007CT
      DATA Q008CT/0600711677302/
      TEM(7)=Q008CT
      DATA Q009CT/0601102677302/
      TEM(8)=Q009CT
      DATA Q010CT/010005677302/
      TEM(9)=Q010CT
      DATA Q011CT/0101110677302/
      TEM(10)=Q011CT
      K=0
      KK=10
      DO 10 I=1,N
      J=M(I)
      IF(I-KK) 20,20,21
   20 K=K+1
      GO TO 5
   21 K=1
      KK=KK+10
      WRITE (6,1)
    1 FORMAT (1H )
    5 FMT(2)=TEM(K)
      WRITE (6,FMT)TITLE(2,J),TITLE(3,J)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SEARCH
C
C
      DIMENSION   G(20,21),   A(15,90),   EN(90),      EN LN(90)
      DIMENSION   DEL N(90),  HO(90),     S(90),       X(20)
      DIMENSION   DELTA(20),  BO(15),     PCP(25),     PROD(3)
      DIMENSION   COEFX(20),  DX(20),     FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),   DATA(23),   DATUM(3),    FORMLA(18)
      DIMENSION   BOX(15),    BOF(15),    ANS(454),    SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),   COEFT(15,90)
      DIMENSION   MATUM(101,3),     ATUM(101,3)
      DIMENSION MMLA(18)
      COMMON  G
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (G(1),      C(1)),    (G(420),    C(420))
```

```
EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),     C(874))
EQUIVALENCE   (HSUM,      C(424)),  (SSUM,       C(425))
EQUIVALENCE   (WTMOL,     C(426)),  (CP,         C(427))
EQUIVALENCE   (DLMPT,     C(428)),  (DLMTP,      C(429))
EQUIVALENCE   (GAMMA,     C(430)),  (ARATIO,     C(431))
EQUIVALENCE   (VMACH,     C(432)),  (SP IMP,     C(433))
EQUIVALENCE   (VACI,      C(434)),  (CF,         C(436))
EQUIVALENCE   (RHOI,      C(437)),  (RHOVAC,     C(438))
EQUIVALENCE   (RHO,       C(439))
EQUIVALENCE   (T PI,      C(440)),  (PI I,       C(441))
EQUIVALENCE   (EP PI,     C(442)),  (AW PI,      C(443))
EQUIVALENCE   (T ETA,     C(445))
EQUIVALENCE   (ETA I,     C(446)),  (EP ETA,     C(447))
EQUIVALENCE   (AW ETA,    C(448)),  (T SIG,      C(450))
EQUIVALENCE   (SIG I,     C(451)),  (EP SIG,     C(452))
EQUIVALENCE   (AW SIG,    C(453))
EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
EQUIVALENCE   (FORM(1),   C(1329)), (FORM(15),  C(1343))
EQUIVALENCE   (ELMT(1),   C(1344)),  (ELMT(15), C(1358))
EQUIVALENCE   (LLMT(1),   C(1344)),  (LLMT(15), C(1358))
EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
EQUIVALENCE   (EN(1),   C(1382)),  (EN(90),   C(1471))
EQUIVALENCE   (ISYS,     C(1472)),   (JEAN,     C(1473))
EQUIVALENCE   (ACX,      C(1474)),   (ACF,     C(1475))
EQUIVALENCE   (AMX,       C(1476)),   (AMF,      C(1477))
EQUIVALENCE   (RHOX,      C(1478)),   (RHOF,     C(1479))
EQUIVALENCE   (COEFX(1),    C(1480)),  (COEFX(20),  C(1499))
EQUIVALENCE   (DX(1),    C(1500)),  (DX(20),   C(1519))
EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
EQUIVALENCE   (MMLA(1),   C(1520)),  (MMLA(18), C(1537))
EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))
EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),   C(1555))
EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
EQUIVALENCE   (OF,     C(1556)),    (FPCT,   C(1557))
EQUIVALENCE   (EQRAT,     C(1558))


EQUIVALENCE (KODE,    C(1559)),   (KASE,      C(1560))
EQUIVALENCE   (KONT,   C(1561)),   (NF,         C(1562))
EQUIVALENCE   (NO,        C(1563)), (NE,        C(1564))
EQUIVALENCE   (NOEQ, C(1565))
EQUIVALENCE   (BOX(1),    C(1771)), (BOX(15),   C(1785))
EQUIVALENCE   (BOF(1),    C(1786)), (BOF(15),   C(1800))
EQUIVALENCE   (HX,        C(1801)), (HF,        C(1802))
EQUIVALENCE   (VXPLS,     C(1803)), (VXMIN,     C(1804))
EQUIVALENCE   (VFPLS,     C(1805)), (VFMIN,     C(1806))
EQUIVALENCE   (EN LN(1),  C(1861)), (EN LN(90), C(1950))
EQUIVALENCE   (DEL N(1),  C(1951)), (DEL N(90), C(2040))
EQUIVALENCE   (HO(1),     C(2041)), (HO(90),    C(2130))
EQUIVALENCE   (S(1),      C(2131)), (S(90),     C(2220))
EQUIVALENCE   (X(1),      C(2221)), (X(20),     C(2240))
EQUIVALENCE   (DELTA(1),  C(2241)), (DELTA(20), C(2260))
EQUIVALENCE   (BO(1),     C(2261)), (BO(15),    C(2275))
EQUIVALENCE   (PO,        C(2276)), (HSUBO,     C(2277))
EQUIVALENCE   (SO,        C(2278)), (T LN,      C(2279))
EQUIVALENCE   (T,         C(2280)), (AAY LN,    C(2281))
EQUIVALENCE   (AAY,       C(2282)), (CPSUM,     C(2283))
EQUIVALENCE   (HC,        C(2284)), (TC LN,     C(2285))
EQUIVALENCE   (PCP(1),    C(2286)), (PCP(25),   C(2310))
EQUIVALENCE   (DATUM(1),  C(2311)), (DATUM(3),  C(2313))
EQUIVALENCE   (PC,        C(2314)), (TC,        C(2315))
EQUIVALENCE   (IPROB,     C(2316)), (IFIXT,     C(2317))
EQUIVALENCE   (IHS,       C(2318)), (ICOND,     C(2319))
EQUIVALENCE   (ISYM,      C(2320)), (IPROD,     C(2321))
EQUIVALENCE   (IDID,      C(2322)), (LDRUM,     C(2323))
EQUIVALENCE   (IDRM,      C(2323)), (KDRUM,     C(2324))
EQUIVALENCE   (L,         C(2325)), (L1,        C(2326))
EQUIVALENCE   (M,         C(2327)), (M1,        C(2328))
EQUIVALENCE   (N,         C(2329)), (IQ,        C(2330))
EQUIVALENCE   (IQ1,       C(2331)), (IQ2,       C(2332))
EQUIVALENCE   (IMAT,      C(2335)), (IUSE,      C(2335))
EQUIVALENCE   (IQ3,       C(2333)), (KMAT,      C(2334))
EQUIVALENCE   (IADD,      C(2336)), (ITNUMB,    C(2337))
EQUIVALENCE   (ITAPE,     C(2338)), (P,         C(2339))
```

```
      EQUIVALENCE   (IDEBUG,     C(2340)), (IFROZ,      C(2341))
      EQUIVALENCE   (A(1),       C(2342)),  (A(1350),   C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      EQUIVALENCE (C12,MM),(E,ME),(END,MEND),(BLK,MBLK),(RPN,MRPN)
      EQUIVALENCE (GAS,MGAS),(SOL,MSOL),(BLIQ,MLIQ),(BLPN,MLPN)
      EQUIVALENCE (C10,MC10),(PLS,MPLS),(SYMBL,MBL),(BMIN,MMIN)
      EQUIVALENCE (TMP1, MTMP1)
C
C
C
C
      DATA Q000CT/060/
      BLK=Q000CT
      DATA Q001CT/034/
      RPN=Q001CT


      DATA Q002CT/074/
      BLPN=Q002CT
      DATA Q003CT/027/
      GAS=Q003CT
      DATA Q004CT/062/
      SOL=Q004CT
      DATA Q005CT/043/
      BLIQ=Q005CT
      DATA Q006CT/020/
      PLS=Q006CT
      DATA Q007CT/040/
      BMIN=Q007CT
      DATA Q008CT/025/
      E=Q008CT
      DATA Q009CT/0254524606060/
      END=Q009CT
      DATA Q010CT/012/
      C10=Q010CT
      DATA Q011CT/014000000/
      C12=Q011CT
      DATA Q012CT/012000000/
      CF10=Q012CT
C
C
      KION=2
      DO 1 K=1,L
      IF (LLMT(K)-ME) 1,2,1
    1 CONTINUE
      GO TO 3
    2 KION=1
      TEMP=ELMT(K)
      ELMT(K)=ELMT(L)
      ELMT(L)=TEMP
    3 ISOL=0
      M=0
      DO 4 J=1,15
      DO 4 K=1,90
      COEFT2(J,K) = 0.0
    4 COEFT1(J,K) = 0.0
      DO 6 J=1,1350
    6 A(J,1) = 0.0
      REWIND 4
    7 READ  (4)(DATA(I),I=1,23)
      IF (MDATA(1)-MEND) 900,171,900
C
C     UNPACK THE BCD FORMULA FOR THE PRODUCT
C
  900 DO 16 I=1,2
   16 DATUM(I)=DATA(I)
      J=1
      I=1
   13 K=0
   17 TMP1 = DATUM(I)
      FORMLA(J) =AARS(30,TMP1)
      DATUM(I)=AALS(6,TMP1)
      J=J+1
```

```
      IF (K-4) 925,925,21
  925 K = K+1
      GO TO 17
   21 IF(I-1) 926,926,25
  926 I=I+1
      GO TO 13
C
C     BEGIN SEARCH FOR FIRST NON BLANK ALPHANUMERIC CHARACTER
C
   25 J=12
   29 J=J
      IF (MMLA(J)-MBLK) 35,950,35
  950 IF (J-1) 30,30,951
  951 J = J-1
      GO TO 29
   30 WRITE (6,31)(DATA(I),I=1,3)
   31 FORMAT (14H THE FORMULA  3A6,33H  IS INCORRECT ON THE MASTER TAPE)
      GO TO 7
   35 IF (MMLA(J)-MRPN) 30,952,30
  952 J = J-1
      IF (MMLA(J)-MGAS) 953,39,953
  953 IF (MMLA(J)-MSOL) 954,41,954
  954 IF (MMLA(J)-MLIQ) 30,41,30
   39 ITYPE=1
      GO TO 47
   41 ITYPE=2
   47 J=J-1
      IF (MMLA(J)-MLPN) 30,955,30
  955 J=J-1
C
C     OBTAIN AND STORE THE FORMULA NUMBERS A(K,J)
C
      DO 48 K=1,15
   48 FORM(K)=0.0
   51 NLSW=1
      NUMB=0
   55 ICNT=0
   57 JCNT=J-ICNT
      IF (JCNT) 30,81,59
   59 IF (MMLA(JCNT) - MC10) 958,67,67
  958 GO TO (63,85),NLSW
   63 ICNT=ICNT+1
      GO TO 57
   67 GO TO (69,63),NLSW
   69 IF (ICNT) 959,330,959
  330 IF(K10N-1)30,333,30
  333 NLSW=2
      GO TO 57
  959 IF (ICNT-2) 77,73,30
   73 NUMB = MMLA(J-1) * 10
   77 NUMB=NUMB+MMLA(J)
      VALUE = NUMB
      J=J-ICNT
      NLSW=2
      GO TO 55
   81 GO TO (30,85),NLSW


   85 IF (ICNT) 960,30,960
  960 SYMBL = 0.0
      IF(NUMB)86,95,86
   86 IF (ICNT-2) 93,89,30
   89 TMP1 = FORMLA(J-1)
      SYMBL =AALS(6,TMP1)
   93 MBL = MBL + MMLA(J)
      GO TO 107
   95 IF(JCNT)30,30,96
   96 IF (MMLA(J)-MPLS) 97,970,97
  970 FORM(L)=-ICNT
      GO TO 109
   97 IF (MMLA(J)-MMIN) 107,975,107
  975 FORM(L)=ICNT
  101 GO TO 109
```

```
  107 DO 111 K=1,L
      IF (MBL-LLMT(K)) 111,105,111
  111 CONTINUE
      GO TO 7
  105 FORM(K)=VALUE
  109 J=J-ICNT
      IF (J) 30,121,51
  121 IF (ITYPE-1) 30,133,137
  133 M=M+1
      J=M
      GO TO 145
  137 J=90-ISOL
      ISOL=ISOL+1
  145 DO 147 K=1,L
      A(K,J)=FORM(K)
  147 CONTINUE
C
C     ARRANGE THERMODYNAMIC DATA IN CORE ORDERED BY INTERVAL
C
  151 IT=0
      TEMP = DATA(1)
      DATA(1) = DATA(3)
      DATA(3) = DATA(2)
      DATA(2) = TEMP
      DO 155 K=1,5
  155 COEFT1(K,J) = DATA(K)
      DO 159 K=6,14
      KIT= K+IT
  159 COEFT1(K,J) = DATA(KIT)
      IT=IT+9
      DO1955 K=1,5
 1955 COEFT2(K,J) = DATA(K)
         DO1959 K=6,14
      KIT = K+IT
 1959 COEFT2(K,J) = DATA(KIT)
      GO TO 7
C
C     GO TO NEXT MOLECULE
C
C
C     ELIMINATE GAP BETWEEN GASES AND CONDENSED PHASES


C
  171 N=M+ISOL
      IUSE=1
  173 IF (N-90) 175,225,181
  175 IF (ISOL) 177,225,184
  177 IUSE=2
      GO TO 225
  181 WRITE (6,182)
  182 FORMAT (45H TOO MANY REACTION PRODUCTS FOUND ON THE TAPE)
      IUSE=2
      GO TO 225
  184 KK = 90-ISOL
      DO 186 J = 1, ISOL
      MJ = M+J
      KJ = KK + J
      DO 186 K = 1,15
  186 COEFT1(K,MJ) = COEFT1(K,KJ)
      DO 185 J = 1,ISOL
      MJ = M+J
      KJ = KK + J
      DO 185 K = 1,15
  185 COEFT2(K,MJ) = COEFT2(K,KJ)
      DO 219 J=1,ISOL
      MJ=M+J
      KJ = KK +J
      DO 217 K=1,15
      A(K,MJ) = A(K,KJ)
  217 CONTINUE
  219 CONTINUE
      GO TO 225
  225 RETURN
      END
```

```
                    $TEXT  SHIFT

                                                  ENTRY   AARS
                                                  ENTRY   AALS
                                                  ENTRY   ALRS
                                                  ENTRY   ALLS

BINARY CARD (NOT PUNCHED)
       00000  0500 60 4 00003  10000  AARS   CLA*    3,4
       00001  0621 00 0 01002  10011         STA     *+2
       00002  4500 60 4 00004  10000         CAL*    4,4
       00003  0771 00 0 00000  10000         ARS     **
       00004  4130 00 0 00000  10000         XCL
       00005  0131 00 0 00000  10000         XCA
       00006  0020 00 4 00001  10000         TRA     1,4
       00007  0500 60 4 00003  10000  AALS   CLA*    3,4
       00010  0621 00 0 01002  10011         STA     *+2
       00011  4500 60 4 00004  10000         CAL*    4,4
       00012  0767 00 0 00000  10000         ALS     **
       00013  4130 00 0 00000  10000         XCL
       00014  0131 00 0 00000  10000         XCA
       00015  0020 00 4 00001  10000         TRA     1,4
       00016  0500 60 4 00003  10000  ALRS   CLA*    3,4
       00017  0621 00 0 01003  10011         STA     *+3
       00020  4500 60 4 00004  10000         CAL*    4,4
       00021  0560 00 0 00040  10001         LDQ     TEMP
       00022  0765 00 0 00000  10000         LRS     **

BINARY CARD (NOT PUNCHED)
       00023  4600 00 0 00040  10001         STQ     TEMP
       00024  4130 00 0 00000  10000         XCL
       00025  0131 00 0 00000  10000         XCA
       00026  0020 00 4 00001  10000         TRA     1,4
       00027  0500 60 4 00003  10000  ALLS   CLA*    3,4
       00030  0621 00 0 01003  10011         STA     *+3
       00031  4500 60 4 00004  10000         CAL*    4,4
       00032  0560 00 0 00040  10001         LDQ     TEMP
       00033  0763 00 0 00000  10000         LLS     **
       00034  4600 00 0 00040  10001         STQ     TEMP
       00035  4130 00 0 00000  10000         XCL
       00036  0131 00 0 00000  10000         XCA
       00037  0020 00 4 00001  10000         TRA     1,4
       00040  000000000000     10000  TEMP   OCT
                        00000  01111         END
           CONTROL DICTIONARY

                    $CDICT SHIFT

BINARY CARD (NOT PUNCHED)
              000041000000              PREFACE     START=0,LENGTH=33,TYPE=7094,CMPLX=5
              000004000005
              623031266360        SHIFT  DECK        LOC=0,LENGTH=33
              000041000000
              212151626060        AARS   REAL        LOC=0,LENGTH=0
              000000000000
              212143626060        AALS   REAL        LOC=7,LENGTH=0
              000000000007
              214351626060        ALRS   REAL        LOC=16,LENGTH=0
              000000000016
              214343626060        ALLS   REAL        LOC=27,LENGTH=0
              000000000027

                    $DKEND SHIFT                                                  001763

NO MESSAGES FOR THIS ASSEMBLY
```

```
      SUBROUTINE SPEC
C
C     OUTPUTS FUEL AND OXIDANT FROM SUBROUTINE INPUT
C
C
      DIMENSION A(15,46),TEM(5),ANAME(5),ELMT(15)
      DIMENSION II(5)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE (KONT, C(1763))
      EQUIVALENCE (I, C(1764)), (M,C(1765))
      EQUIVALENCE (A(1),  C(8578)),  (A(690),  C(9267))
      EQUIVALENCE (ELMT(1),  C(1807)), (ELMT(15),  C(1821))
   55 FORMAT (10X,4HFUEL)
   66 FORMAT (10X,7HOXIDANT)
      IF (M ) 2,1,2
    1 WRITE (6,66)
      GO TO 3
    2 WRITE (6,55)
    3 K=0
      DO 11 J=1,15
      KK=I+M
      IF(A(J,KK))12,11,12
   12 K=K+1
      TEM(K)=A(J,KK)
      ANAME(K)=ELMT(J)
      II(K)=TEM(K)
   11 CONTINUE
      IF(KONT)21,20,21
   20 WRITE (6,4)(ANAME(I),II(I),I=1,K)
    4 FORMAT(1H+,18X,5(A2,I2,5X))
      GO TO 13
   21 WRITE (6,5)(ANAME(I),TEM(I),I=1,K)
    5 FORMAT (1H+,18X,5(A2,F8.5,3X))
   13 RETURN
      END
```

```
      SUBROUTINE INPUT
      COMMON/ATOMS/ATEM(101,3)
      COMMON/APE11/ZN1
C
C
      DIMENSION A6(12)
      DIMENSION TELMT(15)
      DIMENSION   G(20,21),    A(15,46),    EN(90),      EN LN(90)
      DIMENSION   DEL N(90),   HO(90),      S(90),       X(20)
      DIMENSION   DELTA(20),   BO(15),      PCP(25),     PROD(3)
      DIMENSION   COEFX(20),   DX(20),      FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),    DATA(23),    DATUM(3),    FORMLA(18)
      DIMENSION   BOX(15),     BOF(15),     ANS(454),    SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),    COEFT(15,90)
      DIMENSION   MATOM(101,3),      ATOM(101,3)
      DIMENSION MANAME(5),      ANAME(5),       ANUM(5)
      COMMON  G
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE    (G(1),       C(1)),     (G(420),     C(420))
      EQUIVALENCE    (ANS(1),  C(421)),   (ANS(454),     C(874))
      EQUIVALENCE    (HSUM,       C(424)),   (SSUM,       C(425))
      EQUIVALENCE    (WTMOL,      C(426)),   (CP,         C(427))
      EQUIVALENCE    (DLMPT,      C(428)),   (DLMTP,      C(429))
      EQUIVALENCE    (GAMMA,      C(430)),   (ARATIO,     C(431))
      EQUIVALENCE    (VMACH,      C(432)),   (SP IMP,     C(433))
      EQUIVALENCE    (VACI,       C(434)),   (CF,         C(436))
      EQUIVALENCE    (RHOI,       C(437)),   (RHOVAC,     C(438))
      EQUIVALENCE    (RHO,        C(439))
```

```
EQUIVALENCE   (T PI,      C(440)),  (PI I,      C(441))
EQUIVALENCE   (EP PI,     C(442)),  (AW PI,     C(443))
EQUIVALENCE   (T ETA,     C(445))
EQUIVALENCE   (ETA I,     C(446)),  (EP ETA,    C(447))
EQUIVALENCE   (AW ETA,    C(448)),  (T SIG,     C(450))
EQUIVALENCE   (SIG I,     C(451)),  (EP SIG,    C(452))
EQUIVALENCE   (AW SIG,    C(453))
EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
EQUIVALENCE   (FORM(1),   C(1329)), (FORM(15),  C(1343))
EQUIVALENCE   (ELMT(1),   C(1344)),  (ELMT(15), C(1358))
EQUIVALENCE   (LLMT(1),   C(1344)),  (LLMT(15), C(1358))
EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
EQUIVALENCE   (EN(1),   C(1382)),  (EN(90),   C(1471))
EQUIVALENCE   (ISYS,     C(1472)),   (JEAN,     C(1473))
EQUIVALENCE   (ACX,      C(1474)),   (ACF,     C(1475))
EQUIVALENCE   (AMX,       C(1476)),   (AMF,      C(1477))
EQUIVALENCE   (RHOX,      C(1478)),   (RHOF,     C(1479))
EQUIVALENCE   (COEFX(1),    C(1480)),  (COEFX(20),  C(1499))
EQUIVALENCE   (DX(1),    C(1500)),  (DX(20),   C(1519))
EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
EQUIVALENCE   (MMLA(1),   C(1520)),  (MMLA(18), C(1537))
EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))


EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),   C(1555))
EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
EQUIVALENCE   (OF,     C(1556)),    (FPCT,   C(1557))
EQUIVALENCE   (EQRAT,     C(1558))
EQUIVALENCE (KODE,    C(1559)),   (KASE,      C(1560))
EQUIVALENCE   (KONT,   C(1561)),   (NF,         C(1562))
EQUIVALENCE   (NO,        C(1563)), (NE,        C(1564))
EQUIVALENCE   (NOEQ, C(1565))
EQUIVALENCE (KD, C(1763))
EQUIVALENCE   (BOX(1),    C(1771)), (BOX(15),   C(1785))
EQUIVALENCE   (BOF(1),    C(1786)), (BOF(15),   C(1800))
EQUIVALENCE   (HX,        C(1801)), (HF,        C(1802))
EQUIVALENCE   (VXPLS,     C(1803)), (VXMIN,     C(1804))
EQUIVALENCE   (VFPLS,     C(1805)), (VFMIN,     C(1806))
EQUIVALENCE (TELMT(1), C(1807)), (TELMT(15), C(1821))
EQUIVALENCE   (EN LN(1),  C(1861)), (EN LN(90), C(1950))
EQUIVALENCE   (DEL N(1),  C(1951)), (DEL N(90), C(2040))
EQUIVALENCE   (HO(1),     C(2041)), (HO(90),    C(2130))
EQUIVALENCE   (S(1),      C(2131)), (S(90),     C(2220))
EQUIVALENCE   (X(1),      C(2221)), (X(20),     C(2240))
EQUIVALENCE   (DELTA(1),  C(2241)), (DELTA(20), C(2260))
EQUIVALENCE   (BO(1),     C(2261)), (BO(15),    C(2275))
EQUIVALENCE   (PO,        C(2276)), (HSUBO,     C(2277))
EQUIVALENCE   (SO,        C(2278)), (T LN,      C(2279))
EQUIVALENCE   (T,         C(2280)), (AAY LN,    C(2281))
EQUIVALENCE   (AAY,       C(2282)), (CPSUM,     C(2283))
EQUIVALENCE   (HC,        C(2284)), (TC LN,     C(2285))
EQUIVALENCE   (PCP(1),    C(2286)), (PCP(25),   C(2310))
EQUIVALENCE   (DATUM(1),  C(2311)), (DATUM(3),  C(2313))
EQUIVALENCE   (PC,        C(2314)), (TC,        C(2315))
EQUIVALENCE   (IPROB,     C(2316)), (IFIXT,     C(2317))
EQUIVALENCE   (IHS,       C(2318)), (ICOND,     C(2319))
EQUIVALENCE   (ISYM,      C(2320)), (IPROD,     C(2321))
EQUIVALENCE   (IDID,      C(2322)), (LDRUM,     C(2323))
EQUIVALENCE   (IDRM,      C(2323)), (KDRUM,     C(2324))
EQUIVALENCE   (L,         C(2325)), (L1,        C(2326))
EQUIVALENCE   (M,         C(2327)), (M1,        C(2328))
EQUIVALENCE   (N,         C(2329)), (IQ,        C(2330))
EQUIVALENCE   (IQ1,       C(2331)), (IQ2,       C(2332))
EQUIVALENCE   (IQ3,       C(2333)), (KMAT,      C(2334))
EQUIVALENCE   (IMAT,      C(2335)), (IUSE,      C(2335))
EQUIVALENCE   (IADD,      C(2336)), (ITNUMB,    C(2337))
EQUIVALENCE   (ITAPE,     C(2338)), (P,         C(2339))
EQUIVALENCE   (IDEBUG,    C(2340)), (IFROZ,     C(2341))
EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
```

```
      EQUIVALENCE(A(1), C(8578)),  (A(690), C(9267))
      EQUIVALENCE (MANAME(1),ANAME(1)),(MANAME(5),ANAME(5))
C
C
C
C  SUBROUTINE TO COMPUTE PROPELLANTS
      ZN1=0.0


      DATA Q000CT/0466060606060/
      DX=Q000CT
      IF(JEAN-222)51,50,51
   51 CONTINUE
      DO 5000 I=1,101
      DO 5000 J=1,3
 5000 ATOM(I,J)=ATEM(I,J)
   50 DO 52 I=1,15
      DATA Q001CT/000000/
      ELMT(I)=Q001CT
      BOF(I)=0
      BOX(I)=0
      DO 52 J=1,46
      A(I,J)=0
   52 CONTINUE
      TOTAL=0.0
      NF=0
      NO=0
      NE=0
      WRITE (6,400)
  400 FORMAT(8H1  INPUT//)
      READ  (5,2)A6
      WRITE (6,2)A6
    2 FORMAT (12A6)
      WRITE (6,3)
    3 FORMAT(1HJ,58X,10HPERCENT WT,10H  ENTHALPY,7X,4HTEMP,7X,7HDENSITY)
  100 READ  (5,1)ENTH,TEMP,DENS,ETHR,DEN,PECWT                  ,(ANAME(I
     1),ANUM(I),I=1,4)
    1 FORMAT(3F10.5,2A1,F8.5,4(A2,F8.5))
      IF(ANUM(1).EQ.0.0) GO TO 200
   99 WRITE (6,402)(ANAME(I),ANUM(I),I=1,5),PECWT,ENTH,DEN,  TEMP,ETHR,D
     1ENS
  402 FORMAT (1X,5(A2,1X,F7.4,2X),F8.4,2X,F9.2,2X,A1,2X,F8.3,2X,
     1A1,3X,F8.5)
      DO 9 I=1,5
    9 TOTAL=TOTAL+ANUM(I)
      IF(ETHR-DX)11,10,11
   10 NO=NO+1
      ZN1=ZN1+ENTH
      KK=NO
      KKK=NO
      NN=31
      GO TO 12
   11 NF=NF+1
      KK=NF+15
      KKK=NF
      NN=32
   12 DO 98 J=1,5
      IF(ANUM(J)) 96,97,96
   96 DO 31 I=1,15
      IF(ANAME(J)-ELMT(I)) 21,20,21
   20 NHUT=0
   33 KT=I
      GO TO 30
   21 IF(ELMT(I)) 31,22,31
   22 ELMT(I)=ANAME(J)


      NE=NE+1
      NHUT=1
      GO TO 33
   31 CONTINUE
   30 IF(NHUT)14,15,14
   14 DO 16 I=1,101
      IF (MATOM(I,1)-MANAME(J)) 16,17,16
```

```
   17 II=I
      GO TO 18
   16 CONTINUE
      WRITE (6,199)
  199 FORMAT (32H0 THERE IS A BAD PROPELLANT CARD)
      L=-1
      RETURN
   18 A(NE,37)=ATOM(II,2)
      A(NE,38)=ATOM(II,3)
   15 A(KT,KK)=ANUM(J)
   98 CONTINUE
   97 A(KKK,NN)=ENTH
      A(KKK,NN+2)=PECWT
      A(KKK,NN+4)=DENS
      A(KKK,NN+10)=DEN
      A(KKK,NN+12)=TEMP
      A(KKK,NN+14)=ETHR
      GO TO 100
  200 IF(NE)202,201,202
  201 L=0
      RETURN
  202 JEAN=222
      WX=0
      WF=0
      HX=0
      HF=0
      RHOX=0
      RHOF=0
      VXPLS=0
      VXMIN=0
      VFPLS=0
      VFMIN=0
      ACX=0
      ACF=0
      AMX=0
      AMF=0
      DO552 J=1,NO
      DO552 I=1,NE
  552 A(J,39)=A(J,39)+A(I ,37)*A(I ,J )
      DO 53 J=1,NF
      DO 53 I=1,NE
   53 A(J,40)=A(J,40)+A(I,37)*A(I,J+15)
      IF (NO) 1000,1001,1000
 1000 DO 550 I=1,NO
   54 HX=HX+A(I,31)*A(I,33)/A(I,39)
  550 WX=WX+A(I,33)
 1001 IF (NF) 1002,1003,1002
 1002 DO 551 I=1,NF
   55 HF=HF+A(I,32)*A(I,34)/A(I,40)


  551 WF=WF+A(I,34)
 1003 IF (NO) 1004,1005,1004
 1004 DO 42 I=1,NO
      ACX=ACX+A(I,35)*A(I,33)/A(I,39)
   42 AMX=AMX+A(I,33)/A(I,39)
      ACX=ACX/WX
      AMX=WX/AMX
 1005 IF (NF) 1006,1007,1006
 1006 DO 43 I=1,NF
      ACF=ACF+A(I,36)*A(I,34)/A(I,40)
   43 AMF=AMF+A(I,34)/A(I,40)
      ACF=ACF/WF
      AMF=WF/AMF
 1007 IF (WX) 1020,1021,1020
 1020 HX=HX/WX
 1021 IF (WF) 1022,1023,1022
 1022 HF =HF/WF
 1023 DO 60 I=1,NO
      IF(A(I,35))60,71,60
   60 RHOX=RHOX+A(I,33)/A(I,35)
      RHOX=WX/RHOX
   73 DO 61 I=1,NF
      IF(A(I,36))61,71,61
```

```
   61 RHOF=RHOF+A(I,34)/A(I,36)
      RHOF=WF/RHOF
      GO TO 74
   71 RHOX = 0.0
   72 RHOF = 0.0
   74 IF (NO) 1008,1009,1008
 1008 DO 57 I=1,NE
      DO 56 J=1,NO
   56 BOX(I)=BOX(I)+A(I,J)*A(J,33)/A(J,39)
   57 BOX(I)=BOX(I)/WX
 1009 IF (NF) 1010,1011,1010
 1010 DO 59 I=1,NE
      DO 58 J=1,NF
   58 BOF(I)=BOF(I)+A(I,J+15)*A(J,34)/A(J,40)
   59 BOF(I)=BOF(I)/WF
 1011 DO 62 I=1,NE
      IF(A(I,38))63,62,64
   64 VXPLS=VXPLS+BOX(I)*A(I,38)
   67 VFPLS=VFPLS+BOF(I)*A(I,38)
      GO TO 62
   63 VXMIN=VXMIN+BOX(I)*A(I,38)
   66 VFMIN=VFMIN+BOF(I)*A(I,38)
   62 CONTINUE
      IF (WX) 1030,1031,1030
 1030 DO 40 I=1,NO
   40 A(I,33)=A(I,33)/WX
 1031 IF(WF) 1040,1050,1040
 1040 DO 1041 I= 1,NF
 1041 A(I,34)=A(I,34)/WF
C
C     SAVE ELEMENT ARRAY FOR CORE 4
C
 1050 DO 2000 I=1,15


 2000 TELMT(I) = ELMT(I)
      L=NE
      TOTAL= AMOD(TOTAL,1.0)
      IF(TOTAL)1142,1143,1142
 1142 KD=1
      RETURN
 1143 KD=0
      RETURN
      END
```

```
$IBFTC GAUSS

      SUBROUTINE  GAUSS
C
C
C     SUBROUTINE GAUSS SOLVES ANY LINEAR SET OF UP TO TWENTY EQUATIONS,
C     BY ITERATION IF NECESSARY
C
C     FORTRAN MONITOR UNDER NORMAL OPERATING CONDITIONS WILL TAKE CARE
C     OF OVER'UNDER FLOW
C
      DIMENSION   G 20,21 ,   A 15,90 ,   EN 90 ,     EN LN 90
      DIMENSION   DEL N 90 ,  HO 90 ,     S 90 ,      X 20
      DIMENSION DELTA 20 , BO 15 , PCP 25 , PROD 3
      DIMENSION   COEFX 20 ,  DX 20 ,     FORM 15
      DIMENSION COEFT1 15,90  , COEFT2 15,90
      DIMENSION   ELMT 15 ,   DATA 23 ,   DATUM 3 ,   FORMLA 18
      DIMENSION   BOX 15 ,    BOF 15 ,    ANS 454 ,   SYSTM 15
      DIMENSION LLMT 15 ,MTSYS 15 ,MDATA 23
      DIMENSION   ANSLAB 454 ,   COEFT 15,90
      DIMENSION   MATOM 101,3 ,     ATOM 101,3
      DIMENSION  DRUM 20,21
      COMMON  G
      COMMON Q000CM 7700
```

```
C     COMMON C
      EQUIVALENCE    G 1 ,       C 1  ,      G 420 ,     C 420
      EQUIVALENCE    ANS 1 ,  C 421  ,   ANS 454 ,     C 874
      EQUIVALENCE    HSUM,       C 424  ,   SSUM,       C 425
      EQUIVALENCE    WTMOL,      C 426  ,   CP,         C 427
      EQUIVALENCE    DLMPT,      C 428  ,   DLMTP,      C 429
      EQUIVALENCE    GAMMA,      C 430  ,   ARATIO,     C 431
      EQUIVALENCE    VMACH,      C 432  ,   SP IMP,     C 433
      EQUIVALENCE    VACI,       C 434  ,   CF,         C 436
      EQUIVALENCE    RHOI,       C 437  ,   RHOVAC,     C 438
      EQUIVALENCE    RHO,        C 439
      EQUIVALENCE    T PI,       C 440  ,   PI I,       C 441
      EQUIVALENCE    EP PI,      C 442  ,   AW PI,      C 443
      EQUIVALENCE    T ETA,      C 445
      EQUIVALENCE    ETA I,      C 446  ,   EP ETA,     C 447
      EQUIVALENCE    AW ETA,     C 448  ,   T SIG,      C 450
      EQUIVALENCE    SIG I,      C 451  ,   EP SIG,     C 452
      EQUIVALENCE    AW SIG,     C 453
      EQUIVALENCE    ANSLAB 1 , C 875  ,  ANSLAB 454 , C 1328
      EQUIVALENCE    FORM 1 ,    C 1329  ,  FORM 15 ,  C 1343
      EQUIVALENCE    ELMT 1 ,    C 1344  ,   ELMT 15 , C 1358
      EQUIVALENCE    LLMT 1 ,    C 1344  ,   LLMT 15 , C 1358
      EQUIVALENCE    DATA 1 ,  C 1359  ,   DATA 23 ,  C 1381
      EQUIVALENCE    MDATA 1 ,  C 1359  ,   MDATA 23 , C 1381
      EQUIVALENCE    EN 1 ,    C 1382  ,   EN 90 ,    C 1471
      EQUIVALENCE    ISYS,      C 1472  ,    JEAN,      C 1473
      EQUIVALENCE    ACX,       C 1474  ,    ACF,      C 1475
      EQUIVALENCE    AMX,        C 1476  ,    AMF,       C 1477
      EQUIVALENCE    RHOX,       C 1478  ,    RHOF,     C 1479
      EQUIVALENCE    COEFX 1 ,     C 1480  ,   COEFX 20 ,  C 1499
      EQUIVALENCE    DX 1 ,    C 1500  ,   DX 20 ,    C 1519
      EQUIVALENCE    FORMLA 1 ,  C 1520  ,   FORMLA 18 ,  C 1537

      EQUIVALENCE    MMLA 1 ,    C 1520  ,   MMLA 18 , C 1537
      EQUIVALENCE    PROD 1 ,  C 1538  ,   PROD 3 ,   C 1540
      EQUIVALENCE    SYSTM 1 ,  C 1541  ,   SYSTM 15 ,   C 1555
      EQUIVALENCE    MTSYS 1 , C 1541  ,  MTSYS 15 ,  C 1555
      EQUIVALENCE    OF,     C 1556  ,     FPCT,    C 1557
      EQUIVALENCE    EQRAT,      C 1558
      EQUIVALENCE  KODE,    C 1559  ,    KASE,      C 1560
      EQUIVALENCE    KONT,   C 1561  ,    NF,         C 1562
      EQUIVALENCE    NO,         C 1563  ,  NE,         C 1564
      EQUIVALENCE    NOEQ, C 1565
      EQUIVALENCE    BOX 1 ,     C 1771  ,  BOX 15 ,    C 1785
      EQUIVALENCE    BOF 1 ,     C 1786  ,  BOF 15 ,    C 1800
      EQUIVALENCE    HX,         C 1801  ,  HF,         C 1802
      EQUIVALENCE    VXPLS,      C 1803  ,  VXMIN,      C 1804
      EQUIVALENCE    VFPLS,      C 1805  ,  VFMIN,      C 1806
      EQUIVALENCE    EN LN 1 ,  C 1861  ,  EN LN 90 , C 1950
      EQUIVALENCE    DEL N 1 ,  C 1951  ,  DEL N 90 , C 2040
      EQUIVALENCE    HO 1 ,      C 2041  ,  HO 90 ,     C 2130
      EQUIVALENCE    S 1 ,       C 2131  ,  S 90 ,      C 2220
      EQUIVALENCE    X 1 ,       C 2221  ,  X 20 ,      C 2240
      EQUIVALENCE    DELTA 1 ,  C 2241  ,  DELTA 20 , C 2260
      EQUIVALENCE    BO 1 ,      C 2261  ,  BO 15 ,     C 2275
      EQUIVALENCE    PO,         C 2276  ,  HSUBO,      C 2277
      EQUIVALENCE    SO,         C 2278  ,  T LN,       C 2279
      EQUIVALENCE    T,          C 2280  ,  AAY LN,     C 2281
      EQUIVALENCE    AAY,        C 2282  ,  CPSUM,      C 2283
      EQUIVALENCE    HC,         C 2284  ,  TC LN,      C 2285
      EQUIVALENCE    DATUM 1 ,  C 2311  ,  DATUM 3 ,   C 2313
      EQUIVALENCE    PC,         C 2314  ,  TC,         C 2315
      EQUIVALENCE    IPROB,      C 2316  ,  IFIXT,      C 2317
      EQUIVALENCE    IHS,        C 2318  ,  ICOND,      C 2319
      EQUIVALENCE    ISYM,       C 2320  ,  IPROD,      C 2321
      EQUIVALENCE    IDID,       C 2322  ,  LDRUM,      C 2323
      EQUIVALENCE    IDRM,       C 2323  ,  KDRUM,      C 2324
      EQUIVALENCE    L,          C 2325  ,  L1,         C 2326
      EQUIVALENCE    M,          C 2327  ,  M1,         C 2328
      EQUIVALENCE    N,          C 2329  ,  IQ,         C 2330
      EQUIVALENCE    IQ1,        C 2331  ,  IQ2,        C 2332
      EQUIVALENCE    IQ3,        C 2333  ,  KMAT,       C 2334
      EQUIVALENCE    IMAT,       C 2335  ,  IUSE,       C 2335
```

```
      EQUIVALENCE    IADD,       C 2336  ,  ITNUMB,     C 2337
      EQUIVALENCE    ITAPE,      C 2338  ,  P,          C 2339
      EQUIVALENCE    IDEBUG,     C 2340  ,  IFROZ,      C 2341
      EQUIVALENCE    A 1 ,       C 2342  ,   A 1350 ,  C 3691
      EQUIVALENCE    COEFT1 1 ,  C 3692  ,  COEFT1 1350 , C 5041
      EQUIVALENCE    COEFT2 1 , C 5042  ,  COEFT2 1350 , C 6391
      EQUIVALENCE    COEFT 1 ,  C 6392  ,   COEFT 1350 , C 7741
      EQUIVALENCE    ATOM 1 ,  C 7742  ,  ATOM 303 , C 8044
      EQUIVALENCE    MATOM 1 ,  C 7742  ,  MATOM 303 ,  C 8044
      EQUIVALENCE    PCP 1 ,    C 2286  ,  PCP 25 ,   C 2310
C
      DATA Q000CT/0377777777777/
      BIGNO Q000CT
      IDID 0
      DETN 0.0
      IF IUSE  80,80,81


   81 IUSE1 IUSE 1
      DO 1 K 1,IUSE
      X K  0.0
    1 DELTA K  0.0
      ITERA 0
      KAPUT 1
      DSUM1 BIGNO
C
C     SAVE MATRIX IN DRUM
C
      DO 82 ID 1,IUSE
      DO82  JN 1, IUSE1
   82 DRUM ID,JN  G ID,JN
C
C     BEGIN ELIMINATION OF NNTH VARIABLE
C
    6 DO 45 NN 1,IUSE
      IF  NN-IUSE  8,83,8
  83  IF G NN,NN  31,23,31
C
C     SEARCH FOR MAXIMUM COEFFICIENT IN EACH ROW
C
    8 DO 18 I NN,IUSE
      J NN
      IF G I,J   99,14,99
  99  COEFX I  0.0
  10 J J 1
      IF IUSE1-J  12,84,84
  84 IF  ABS G 1,J   - ABS COEFX I     10,100,100
 100 COEFX I  ABS G I,J
      GO TO 10
  12 COEFX I   ABS COEFX I /G I,NN
      GO TO 18
  14 COEFX I  BIGNO
  18 CONTINUE
  19 TEMP BIGNO
      I 0
  20 DO 22 J NN,IUSE
      IF  COEFX J -TEMP  87,22,22
  87 TEMP COEFX J
      I J
  22 CONTINUE
      IF I  28,23,28
  23 IDID NN-1
      GO TO 80
C
C     INDEX I LOCATES EQUATION TO BE USED FOR ELIMINATING THE NTH
C     VARIABLE FROM THE REMAINING EQUATIONS
C
C      INTERCHANGE EQUATIONS I AND NN
C
  28 IF NN-I  29,31,29
  29 DO 30 J NN,IUSE1
      Z G I,J
      G I,J  G NN,J
  30 G NN,J  Z
```

```
C
C     DIVIDE NTH ROW BY NTH DIAGONAL ELEMENT AND ELIMINATE THE NTH
C     VARIABLE FROM THE REMAINING EQUATIONS
C
   31 K   NN   1
      DO 36 J   K, IUSE1
           IF G NN,NN   36, 23, 36
   36      G NN,J    G NN,J  / G NN,NN
      IF K-IUSE1  88,45,88
   88 DO 44 I   K,IUSE
   40 DO 44 J   K, IUSE1
           G I,J    G I,J  - G I,NN *G NN,J
   44 CONTINUE
   45 CONTINUE
C
C     BACKSOLVE FOR THE VARIABLES
C
  991 IDID   IUSE
      K   IUSE
   47 J   K   1
      SUM   0.0
      IF IUSE - J  51,48,48
   48 DO 50 I   J,IUSE
   50      SUM   SUM   G K,I *DX I
   51 DX K    G K,IUSE1  - SUM
      X K    X K    DX K
      K   K - 1
      IF  K  47,151,47
  151 DO 90 ID   1,IUSE
      DO 90 JD   1, IUSE1
   90      G ID,JD    DRUM ID,JD
C
C     CALCULATE RESIDUALS  DELTA RIGHT HAND SIDE
C
   52 DSUM   0.0
      DO 62 I   1, IUSE
           SUM   0.0
           DO 56 J   1, IUSE
   56           SUM   SUM   G I,J *X J
           DELTA I    G I,IUSE1  - SUM
           IF ABS G I,IUSE1   - 1.0  62, 62, 60
   60      DELTA I    DELTA I  / G I,IUSE1
   62      DSUM   ABS DELTA I     DSUM
      GO TO 66,80 , KAPUT
   66 IF DSUM - DSUM1  74,80,68
   68 KAPUT   2
      DO 72 K   1,IUSE
   72      X K    X K  - DX K
      GO TO 52
   74 DSUM1   DSUM
      ITERA   ITERA   1
      IF ITERA -  4  92,80,92
   92 DO 78 I   1,IUSE
           IF ABS G I,IUSE1   - 1.0  75,75,76
   75      G I,IUSE1    DELTA I
           GO TO 78


   76      G I,IUSE1    DELTA I  * G I,IUSE1
   78      CONTINUE
      GO TO 6
   80 RETURN
      END
```

```
$IBFTC MATRIX
      SUBROUTINE MATRIX
C
C
      DIMENSION   G(20,21),   A(15,90),   EN(90),     EN LN(90)
      DIMENSION   DEL N(90),  HO(90),     S(90),      X(20)
      DIMENSION   DELTA(20),  BO(15),     PCP(25),    PROD(3)
      DIMENSION   COEFX(20),  DX(20),     FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),   DATA(23),   DATUM(3),   FORMLA(18)
      DIMENSION   BOX(15),    BOF(15),    ANS(454),   SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),   COEFT(15,90)
      DIMENSION   MATUM(101,3),     ATOM(101,3)
      COMMON  G
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (G(1),       C(1)),     (G(420),     C(420))
      EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),     C(874))
      EQUIVALENCE   (HSUM,       C(424)),  (SSUM,       C(425))
      EQUIVALENCE   (WTMOL,      C(426)),  (CP,         C(427))
      EQUIVALENCE   (DLMPT,      C(428)),  (DLMTP,      C(429))
      EQUIVALENCE   (GAMMA,      C(430)),  (ARATIO,     C(431))
      EQUIVALENCE   (VMACH,      C(432)),  (SP IMP,     C(433))
      EQUIVALENCE   (VACI,       C(434)),  (CF,         C(436))
      EQUIVALENCE   (RHOI,       C(437)),  (RHOVAC,     C(438))
      EQUIVALENCE   (RHO,        C(439))
      EQUIVALENCE   (T PI,       C(440)),  (PI I,       C(441))
      EQUIVALENCE   (EP PI,      C(442)),  (AW PI,      C(443))
      EQUIVALENCE   (T ETA,      C(445))
      EQUIVALENCE   (ETA I,      C(446)),  (EP ETA,     C(447))
      EQUIVALENCE   (AW ETA,     C(448)),  (T SIG,      C(450))
      EQUIVALENCE   (SIG I,      C(451)),  (EP SIG,     C(452))
      EQUIVALENCE   (AW SIG,     C(453))
      EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
      EQUIVALENCE   (FORM(1),    C(1329)), (FORM(15),   C(1343))
      EQUIVALENCE   (ELMT(1),    C(1344)),  (ELMT(15), C(1358))
      EQUIVALENCE   (LLMT(1),    C(1344)),  (LLMT(15), C(1358))
      EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
      EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
      EQUIVALENCE   (EN(1),    C(1382)),  (EN(90),    C(1471))
      EQUIVALENCE   (ISYS,      C(1472)),   (JEAN,      C(1473))
      EQUIVALENCE   (ACX,       C(1474)),   (ACF,      C(1475))
      EQUIVALENCE   (AMX,        C(1476)),   (AMF,       C(1477))
      EQUIVALENCE   (RHOX,       C(1478)),   (RHOF,     C(1479))
      EQUIVALENCE   (COEFX(1),     C(1480)),  (COEFX(20),  C(1499))
      EQUIVALENCE   (DX(1),     C(1500)),  (DX(20),    C(1519))
      EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
      EQUIVALENCE   (MMLA(1),    C(1520)),  (MMLA(18), C(1537))
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),    C(1540))
      EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),    C(1555))
      EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE   (OF,      C(1556)),    (FPCT,    C(1557))
      EQUIVALENCE   (EQRAT,      C(1558))
      EQUIVALENCE (KODE,     C(1559)),   (KASE,       C(1560))


      EQUIVALENCE   (KONT,    C(1561)),    (NF,          C(1562))
      EQUIVALENCE   (NO,         C(1563)), (NE,          C(1564))
      EQUIVALENCE   (NOEQ, C(1565))
      EQUIVALENCE   (BOX(1),     C(1771)), (BOX(15),    C(1785))
      EQUIVALENCE   (BOF(1),     C(1786)), (BOF(15),    C(1800))
      EQUIVALENCE   (HX,         C(1801)), (HF,         C(1802))
      EQUIVALENCE   (VXPLS,      C(1803)), (VXMIN,      C(1804))
      EQUIVALENCE   (VFPLS,      C(1805)), (VFMIN,      C(1806))
      EQUIVALENCE   (EN LN(1),   C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE   (DEL N(1),   C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE   (HO(1),      C(2041)), (HO(90),     C(2130))
      EQUIVALENCE   (S(1),       C(2131)), (S(90),      C(2220))
      EQUIVALENCE   (X(1),       C(2221)), (X(20),      C(2240))
      EQUIVALENCE   (DELTA(1),   C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),      C(2261)), (BO(15),     C(2275))
      EQUIVALENCE   (PO,         C(2276)), (HSUBO,      C(2277))
      EQUIVALENCE   (SO,         C(2278)), (T LN,       C(2279))
      EQUIVALENCE   (T,          C(2280)), (AAY LN,     C(2281))
      EQUIVALENCE   (AAY,        C(2282)), (CPSUM,      C(2283))
      EQUIVALENCE   (HC,         C(2284)), (TC LN,      C(2285))
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```
      EQUIVALENCE   (PCP(1),     C(2286)), (PCP(25),    C(2310))
      EQUIVALENCE   (DATUM(1),   C(2311)), (DATUM(3),   C(2313))
      EQUIVALENCE   (PC,         C(2314)), (TC,         C(2315))
      EQUIVALENCE   (IPROB,      C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (IHS,        C(2318)), (ICOND,      C(2319))
      EQUIVALENCE   (ISYM,       C(2320)), (IPROD,      C(2321))
      EQUIVALENCE   (IDID,       C(2322)), (LDRUM,      C(2323))
      EQUIVALENCE   (IDRM,       C(2323)), (KDRUM,      C(2324))
      EQUIVALENCE   (L,          C(2325)), (L1,         C(2326))
      EQUIVALENCE   (M,          C(2327)), (M1,         C(2328))
      EQUIVALENCE   (N,          C(2329)), (IQ,         C(2330))
      EQUIVALENCE   (IQ1,        C(2331)), (IQ2,        C(2332))
      EQUIVALENCE   (IQ3,        C(2333)), (KMAT,       C(2334))
      EQUIVALENCE   (IMAT,       C(2335)), (IUSE,       C(2335))
      EQUIVALENCE   (IADD,       C(2336)), (ITNUMB,     C(2337))
      EQUIVALENCE   (ITAPE,      C(2338)), (P,          C(2339))
      EQUIVALENCE   (IDEBUG,     C(2340)), (IFROZ,      C(2341))
      EQUIVALENCE   (A(1),       C(2342)),  (A(1350),   C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
C
C
C     DETERMINE WHICH MATRIX IS TO BE SET UP
C     SENSE LIGHT        LIGHT ON                    LIGHT OFF
C          1         COMBUSTION TYPE              EXPANSION TYPE
C          2         ASSIGNED TEMPERATURE         UNASSIGNED TEMPERATJRE
C          4         NOT CONVERGED                CONVERGED
C
      IQ1=IQ1
      IQ2=IQ2
      IQ3=IQ3
      CALL SLITET(2,KOOOFX)
       GO TO(1.4),KOOOFX


    1 CALL SLITE (2)
      CALL SLITET(4,KOOOFX)
       GO TO(2,3),KOOOFX
    2 CALL SLITE (4)
      IFIXT=1
      ISYM=IQ1
      GO TO 10
    3 IFIXT=2
      IHS=1
      ISYM=IQ2
      GO TO 10
    4 IFIXT=2
      CALL SLITET(1,KOOOFX)
       GO TO(5,6),KOOOFX
    5 CALL SLITE (1)
      IHS=1
      ISYM= IQ2
      GO TO 10
    6 CALL SLITET(4,KOOOFX)
       GO TO(7,8),KOOOFX
    7 CALL SLITE (4)
      IHS=2
      ISYM=IQ1
      GO TO 10
    8 IHS=1
      ISYM=IQ2
C
C     CLEAR MATRIX STORAGES TO ZERO
C
   10 DO 212 I=1,IQ2
      DO 211 K=1,IQ3
      G(I,K)= 0.0
  211 CONTINUE
  212 CONTINUE
      ICOND=1
      IF (L-IQ) 14,213,14
  213 ICOND=2
C
C     BEGIN SET UP OF ITERATION MATRIX
C
```

```
   14 DO 65  J=1,M
      CALL BYPASS (J,1)
      IF (IPROD-2) 65,214,65
  214 IF (EN(J)) 65,65,12
C
C     CALCULATE THE ELEMENTS  R(I,K)
C
   12 DO 20  I=1, L
      IF (A(I,J)) 13,20,13
   13 TERM= A(I,J)*EN(J)
      DO 15  K=I, L
      G(I,K)= G(I,K) + A(K,J)*TERM
   15 CONTINUE
C
C     COMPLETE COLUMN  A FOR THE GAS MOLECULE
C


      G(I,IQ1)=G(I,IQ1)+TERM
   20 CONTINUE
      G(IQ1,IQ1)= G(IQ1,IQ1)+EN(J)
C
C     STATEMENT 24 IS FOR FIXED T, 30 IS FOR VARIABLE  T AND CONVERGED
C     FIXED T
C
   21 IF (IFIXT-2) 24,30,30
C
C     FOR ASSIGNED T BYPASS ENERGY ROW AND T COLUMN WHILE ITERATING
C
   24 TERM= (HO(J)-S(J))*EN(J)
      DO 25  I=1, L
      G(I,IQ2)=G(I,IQ2)+A(I,J)*TERM
   25 CONTINUE
      G(IQ1,IQ2)=G(IQ1,IQ2)+TERM
      GO TO 65
C
C     FILL IN TEMPERATURE COLUMN AND RIGHT HAND SIDE
C
   30 TERM=HO(J)*EN(J)
      DO 35 I=1,L
      G(I,IQ2)= G(I,IQ2)+A(I,J)*TERM
   35 CONTINUE
      G(IQ1,IQ2)= G(IQ1,IQ2)+TERM
      TERM1=(HO(J)-S(J))*EN(J)
      DO 40 I=1,L
      G(I,IQ3)= G(I,IQ3)+A(I,J)*TERM1
   40 CONTINUE
      G(IQ1,IQ3)=G(IQ1,IQ3)+TERM1
C
C     STATEMENT 50 IS FOR ENTHALPY , 55 IS FOR ENTROPY EQUATION
C
   45 IF (IHS-2) 50,55,55
   50 G(IQ2,IQ2)=G(IQ2,IQ2)+HO(J)*TERM
      G(IQ2,IQ3)=G(IQ2,IQ3)+HO(J)*TERM1
      GO TO 65
C
C     DURING EXPANSION THE ENTROPY ROW IS FILLED IN
C
   55 TERM=S(J)*EN(J)
      DO 60  K=1,L
   60 G(IQ2,K)= G(IQ2,K)+A(K,J)*TERM
      CONTINUE
      G(IQ2,IQ1)=G(IQ2,IQ1)+TERM
      G(IQ2,IQ2)=G(IQ2,IQ2)+HO(J)*TERM
      G(IQ2,IQ3)=G(IQ2,IQ3)+(HO(J)-S(J))*TERM
   65 CONTINUE
C
C     AT THIS POINT PROCESSING OF GASEOUS PRODUCTS HAS BEEN COMPLETED
C     AND CONDENSED PHASE PROCESSING IS BEGUN
C
C     STATEMENT 70 IS FOR CONDENSED PRODUCTS, 101 IS FOR NO CONDENSED
C
   66 IF (ICOND-2) 70,101,101
   70 K=L1


      DO 100 J= M1,N
      CALL BYPASS (J,1)
      IF (IPROD-2) 100,74,100
```

```
   74 DO 75  I=1,L
      G(I,K)=A(I,J)
   75 CONTINUE
C
C     STATEMENT 80 IS FOR FIXED T, 85 IS FOR VARIABLE T AND CONVERGED
C     FIXED T
C
      IF (IFIXT-2) 80,85,85
   80 G(K,IQ2)= HO(J)-S(J)
      GO TO 95
   85 G(K,IQ2)= HO(J)
      G(K,IQ3)= HO(J)-S(J)
C
C     STATEMENT 95 IS FOR ENTHALPY, STATEMENT 90 IS FOR ENTROPY EQUATION
C
      IF (IHS-2) 95,90,90
   90 G(IQ2,K)=S(J)
   95 K= K+1
  100 CONTINUE
C
C     REFLECT SYMMETRIC PORTIONS OF THE MATRIX BEFORE COMPLETING THE
C     CONDENSED PHASE CONTRIBUTIONS TO THE MATRIX
C
  101 DO 104 I=1,ISYM
      DO 102 J=I,ISYM
      G(J,I)=G(I,J)
  102 CONTINUE
  104 CONTINUE
C
C     THE ADDRESS OF THE NEXT INSTRUCTION IF SET DURING INITIALIZATION
C     STATEMENT 105 IS FOR CONDENSED,130  IS FOR NO CONDENSED
C
      IF (ICOND-2) 105,130,130
C
C     COMPLETE COLUMN A OF MATRIX
C
  105 DO 125 J=M1,N
      CALL BYPASS (J,1)
      IF (IPROD-2) 125,106,125
  106 DO 107 I=1,L
      G(I,IQ1)=G(I,IQ1)+A(I,J)*EN(J)
  107 CONTINUE
      IF (IFIXT-2) 125,109,109
  109 IF (IHS-2) 110,115,115
  110 G(IQ2,IQ1)= G(IQ2,IQ1)+HO(J)*EN(J)
      GO TO 125
  115 G(IQ2,IQ1)= G(IQ2,IQ1)+S(J)*EN(J)
  125 CONTINUE
  130 GO TO (131,133),IFIXT
  131 KMAT=IQ2
      GO TO 136
  133 KMAT=IQ3
  136 IMAT=KMAT-1
C
C     COMPLETE THE RIGHT HAND SIDE
C
      DO 145 I=1,IMAT
      G(I,KMAT)=G(I,KMAT)-G(I,IQ1)
  145 CONTINUE
      DO 150 I=1,L
      G(I,KMAT)= G(I,KMAT)+ AAY*BO(I)
  150 CONTINUE
      P= G(IQ1,IQ1)
  160 G(IQ1,KMAT) = G(IQ1,KMAT)+ PO
      G(IQ1,IQ1)=0.0
C
C     COMPLETE ENERGY ROW AND TEMPERATURE COLUMN
C
      IF (KMAT-IQ2) 165,185,165
  165 IF (IHS-2) 166,168,168
  166 ENERGY=AAY*(HSUBO/T)
      GO TO 169
  168 ENERGY= AAY* SO+PO-P
  169 G(IQ2,IQ3)=G(IQ2,IQ3)+ ENERGY
      G(IQ2,IQ2)= G(IQ2,IQ2)+CPSUM
  185 RETURN
      END
```

```
$IBFTC DDARDX
      SUBROUTINE DDARDX(ARATIO,IADD,P)
C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VO,ADAC,Q1QO,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
C
C      END OF NEW COMMON
C     DIVIDE NOZZLE CONTOUR IN 4 SECTIONS
C     SECTIONS 1 AND 2 ARE SUBSONIC
C     SECTIONS 3,4 AND 5 ARE SUPERSONIC
C     FOR SUPERSONIC COMBUSTION SECTIONS 1,2 AND 3 ARE USED
      EQUIVALENCE(SUB3,SUP3)
      IF(IROU) 26,27,26
   26 Y = YT*SQRT(ARATIO)
      DARDY = 2.0*Y/(YT**2)
      GO TO 28
   27 Y = YT*ARATIO
      DARDY = 1.0/YT
   28 IF(KOK) 20,1,20
    1 IF(P-PPT) 5,2,2
    2 IF(ARATIO-SUB1) 4,3,3
    3 NCON = 1
      ITYPE = ITYP(1)
      GO TO 25
    4 NCON = 5
      ITYPE = ITYP(2)
      GO TO 25
    5 IF(ARATIO-SUB2)6,6,7
    6 NCON = 9
      ITYPE = ITYP(3)
      GO TO 25
    7 IF(ARATIO - SUP3)8,8,9
    8 NCON = 13
      ITYPE = ITYP(4)
      GO TO 25
    9 NCON = 17
      ITYPE = ITYP(5)
      GO TO 25
   20 IF(ARATIO - SUB1)3,3,22
   22 IF(ARATIO - SUB2)4,4,6
   25 IF(ITYPE - 1)30,31,30
   31 DXDY = CON(NCON)*EEXP(NCON)*(Y**(EEXP(NCON) -1.0)) + CON(NCON+1)*
     1      EEXP(NCON+1)*(Y**(EEXP(NCON+1) -1.0)) + CON(NCON+2)*EEXP(NCON
     2      +2)*(Y**(EEXP(NCON+2)-1.0)) + CON(NCON+3)*EEXP(NCON+3)*
     3      (Y**(EEXP(NCON+3) - 1.0))
      GO TO 32


   30 SAV=ABS(CON(NCON)+CON(NCON+1)*Y+CON(NCON+2)*Y**2)
      DXDY=(CON(NCON+1)+2.0*CON(NCON+2)*Y)/(2.0*SQRT(SAV))
   32 DARDX=DARDY/DXDY
      RETURN
      END
```

```
$IBFTC COMB
      SUBROUTINE COMB
      COMMON/APE11/ZN1
C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
```

```
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VU,AOAC,Q1Q0,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
C
C      END OF NEW COMMON
      DIMENSION    G(20,21),    A(15,90),    EN(90),      EN LN(90)
      DIMENSION    DEL N(90),   HO(90),      S(90),       X(20)
      DIMENSION    DELTA(20),   BO(15),      PCP(25),     PROD(3)
      DIMENSION    COEFX(20),   DX(20),      FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION    ELMT(15),    DATA(23),    DATUM(3),    FORMLA(18)
      DIMENSION    BOX(15),     BOF(15),     ANS(454),    SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION    ANSLAB(454),    COEFT(15,90)
      DIMENSION    MATOM(101,3),      ATOM(101,3)
      DIMENSION MX(20),MCOEFT(15,90)
      DIMENSION MFORM(15)
      REAL LRS
      REAL LLS
      COMMON  G
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE    (G(1),       C(1)),     (G(420),     C(420))
      EQUIVALENCE    (ANS(1),  C(421)),   (ANS(454),     C(874))
      EQUIVALENCE    (HSUM,       C(424)),   (SSUM,       C(425))
      EQUIVALENCE    (WTMOL,      C(426)),   (CP,         C(427))
      EQUIVALENCE    (DLMPT,      C(428)),   (DLMTP,      C(429))
      EQUIVALENCE    (GAMMA,      C(430)),   (ARATIO,     C(431))
      EQUIVALENCE    (VMACH,      C(432)),   (SP IMP,     C(433))
      EQUIVALENCE    (VACI,       C(434)),   (CF,         C(436))
      EQUIVALENCE    (RHOI,       C(437)),   (RHOVAC,     C(438))
      EQUIVALENCE    (RHO,        C(439))
      EQUIVALENCE    (T PI,       C(440)),   (PI I,       C(441))
      EQUIVALENCE    (EP PI,      C(442)),   (AW PI,      C(443))
      EQUIVALENCE    (T ETA,      C(445))
      EQUIVALENCE    (ETA I,      C(446)),   (EP ETA,     C(447))
      EQUIVALENCE    (AW ETA,     C(448)),   (T SIG,      C(450))
      EQUIVALENCE    (SIG I,      C(451)),   (EP SIG,     C(452))
      EQUIVALENCE    (AW SIG,     C(453))
      EQUIVALENCE    (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
      EQUIVALENCE    (FORM(1),    C(1329)), (FORM(15),  C(1343))
      EQUIVALENCE    (MFORM(1),   C(1329)), (MFORM(15), C(1343))
      EQUIVALENCE    (ELMT(1),    C(1344)),  (ELMT(15), C(1358))


      EQUIVALENCE    (LLMT(1),    C(1344)),  (LLMT(15), C(1358))
      EQUIVALENCE    (DATA(1),   C(1359)),  (DATA(23),  C(1381))
      EQUIVALENCE    (MDATA(1),   C(1359)),  (MDATA(23), C(1381))
      EQUIVALENCE    (EN(1),    C(1382)),  (EN(90),    C(1471))
      EQUIVALENCE    (ISYS,      C(1472)),   (JEAN,      C(1473))
      EQUIVALENCE    (ACX,       C(1474)),   (ACF,      C(1475))
      EQUIVALENCE    (AMX,        C(1476)),   (AMF,       C(1477))
      EQUIVALENCE    (RHOX,       C(1478)),   (RHOF,      C(1479))
      EQUIVALENCE    (COEFX(1),     C(1480)),  (COEFX(20),  C(1499))
      EQUIVALENCE    (DX(1),     C(1500)),  (DX(20),    C(1519))

      EQUIVALENCE    (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
      EQUIVALENCE    (MMLA(1),    C(1520)),  (MMLA(18), C(1537))
      EQUIVALENCE    (SYSTM(1),   C(1541)),  (SYSTM(15),    C(1555))
      EQUIVALENCE    (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE    (OF,      C(1556)),     (FPCT,    C(1557))
      EQUIVALENCE    (EQRAT,      C(1558))
      EQUIVALENCE (KODE,     C(1559)),    (KASE,       C(1560))
      EQUIVALENCE(NF,C(1562))
      EQUIVALENCE    (NO,         C(1563)), (NE,         C(1564))
      EQUIVALENCE    (NUEQ, C(1565))
      EQUIVALENCE    (BOX(1),     C(1771)), (BOX(15),    C(1785))
      EQUIVALENCE    (BOF(1),     C(1786)), (BOF(15),    C(1800))
      EQUIVALENCE    (HX,         C(1801)), (HF,         C(1802))
      EQUIVALENCE    (VXPLS,      C(1803)), (VXMIN,      C(1804))
      EQUIVALENCE    (VFPLS,      C(1805)), (VFMIN,      C(1806))
      EQUIVALENCE    (EN LN(1),   C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE    (DEL N(1),   C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE    (HO(1),      C(2041)), (HO(90),    C(2130))
      EQUIVALENCE    (S(1),       C(2131)), (S(90),     C(2220))
```

```
      EQUIVALENCE   (MX(1),     C(2221)), (MX(20),     C(2240))
      EQUIVALENCE   (X(1),       C(2221)), (X(20),      C(2240))
      EQUIVALENCE   (DELTA(1),  C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),     C(2261)), (BO(15),     C(2275))
      EQUIVALENCE   (PO,        C(2276)), (HSUBO,      C(2277))
      EQUIVALENCE   (SO,        C(2278)), (T LN,       C(2279))
      EQUIVALENCE   (T,         C(2280)), (AAY LN,     C(2281))
      EQUIVALENCE   (AAY,       C(2282)), (CPSUM,      C(2283))
      EQUIVALENCE   (HC,        C(2284)), (TC LN,      C(2285))
      EQUIVALENCE   (PCP(1),    C(2286)), (PCP(25),    C(2310))
      EQUIVALENCE   (DATUM(1),  C(2311)), (DATUM(3),   C(2313))
      EQUIVALENCE   (PC,        C(2314)), (TC,         C(2315))
      EQUIVALENCE   (IPROB,     C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (IHS,       C(2318)), (ICOND,      C(2319))
      EQUIVALENCE   (ISYM,      C(2320)), (IPROD,      C(2321))
      EQUIVALENCE   (IDID,      C(2322)), (LDRUM,      C(2323))
      EQUIVALENCE   (IDRM,      C(2323)), (KDRUM,      C(2324))
      EQUIVALENCE   (L,         C(2325)), (L1,         C(2326))
      EQUIVALENCE   (M,         C(2327)), (M1,         C(2328))
      EQUIVALENCE   (N,         C(2329)), (IQ,         C(2330))
      EQUIVALENCE   (IQ1,       C(2331)), (IQ2,        C(2332))
      EQUIVALENCE   (IQ3,       C(2333)), (KMAT,       C(2334))
      EQUIVALENCE   (IMAT,      C(2335)), (IUSE,       C(2335))
      EQUIVALENCE   (IADD,      C(2336)), (ITNUMB,     C(2337))
      EQUIVALENCE   (ITAPE,     C(2338)), (P,          C(2339))
      EQUIVALENCE   (IDEBUG,    C(2340)), (IFROZ,      C(2341))


      EQUIVALENCE   (A(1),       C(2342)),  (A(1350),   C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (MCOEFT(1),  C(6392)), (MCOEFT(1350),  C(7741))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      EQUIVALENCE (KORE, C(8047))
      EQUIVALENCE (DLNT,LNT),(SUM,MSUM),(BLK,MBLK),(TMP,MTMP),(MT,BMT)
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))
C
C
      IF(PP3P2)2401,5,2401
    5 H22=ZN1/AMOL2
      ICOMBN = 0
      VMACH2=SQRT(89548.2*GAM2*T2/AMOL2)
      VMACH2= V2/ VMACH2
      TOTPC= ((GAM2 - 1.0)/2.0)*VMACH2**2.0
      TOTPC = (1.0 + TOTPC)**(GAM2/(GAM2 - 1.0))
      TOTPC = P2*TOTPC
       JICOM=0
      PAR2 = T2/(AMOL2*V2)
 2401 IF(ICONST)2550,2560,2550
 2550 T3 = PP3P2*WTMOL*VC*PAR2*DRAG2*P3P2
      DT3 = T3/T
      IF(ABS(DT3 - 1.0) - .0075)2557,2557,2551
 2551 IF(PP3P2)2559,2552,2559
 2552 PP3P2 = 1.0
      DRAG1 = 1.0/(1.0+CD/2.0)
      DRAG2 = 1.0/(1.0+1.0/OF)
      VFUL = TF        *COSTH*DRAG1/(1.0 + OF)
      PP3P4 = DRAG1*DRAG2
      PP3P3=89548.2*PAR2*(1.0 + P3P2       )/2.0
      PP3P5=PP3P4*V2 + VFUL
      PP3P6 = (V2**2.0/90185.4 + H22)/(1.0 + 1.0/OF) +HEATC/
     1(1.0 + OF)
      GO TO 2557
 2559 IF(ICOMBN - 1)2555,2554,2555
 2554 IF(KOK)2570,2572,2570
 2570 DT1 = DT3
      DP1 = PP3P2
      IF(DT3 - 1.0)2631,2556,2632
 2631 PC = 1.2*P2
      PP3P2 = 1.2
      GO TO 2557
 2632 PC = .75*P2
      PP3P2 = .75
      GO TO 2557
 2555 DTDP = (DT3 - DT1)/(PP3P2 - DP1)
      DT1 = DT3
```

```
      DP1 = PP3P2
      IF(KOK)2711,2701,2711
 2701 IF(DTDP)2634,2702,2702
 2702 PP3P2= 1.02*DP1
 2704 PC = P2*PP3P2
      GO TO 2557


 2711 IF(DTDP)2703,2703,2634
 2703 PP3P2 = .975*DP1
      GO TO 2704
 2634 PP3P2 = (1.0 - DT3)/DTDP + PP3P2
      PC = PP3P2 * P2
       IF (PP3P2)2630,2706,2706
 2630 PP3P2 = DP1*.5
      PC = PP3P2*P2
 2706 IF(KOK)2557,2707,2557
 2707 IF(PC - TOTPC)2557,2708,2708
 2708 PC = .98*TOTPC
      PP3P2 = PC/P2
 2557 PP3P1=(1.0 - PP3P2)*PP3P3
      VC = PP3P4*PP3P1 + PP3P5
      SPEED=VC
      HSUBO=PP3P6 - VC**2.0/90185.4
      HSUBO = HSUBO/1.98726
      HSUM = HSUBO
      HC = HSUBO
      VMACH = SPEED/SQRT(89548.2*GAMMA*T/WTMOL)
      WRITE(6,2616) DP1,DT3,VMACH,P3P2
 2616 FORMAT(4F10.4)
      IF(ABS(DT3 - 1.0) - .0075)2556,2556,2639
 2639 ICOMBN = ICOMBN + 1
      IF(ICOMBN - 10)2600,2637,2637
 2637 WRITE(6,2638) P3P2
 2638 FORMAT(1HK,40X,51HCOMBUSTION  CALCULATION  NOT  CONVERGED  FOR  A3
     1A2=F5.2)
      P3P2=1.8*P3P2
      JICOM= JICOM + 1
      ICOMBN=0
      PP3P2=0.0
      IF(JICOM - 4)2550,3,3
 2600 IF(KOK)2553,1,2553
 2553 IF(VMACH - 1.)2561,2561,1
 2561 PP3P2 = .9*PP3P2
 2625 CONTINUE
 2563 PC = PP3P2*P2
      GO TO 1
 2572 DT1 = DT3
      DP1 = PP3P2
      PC = .95*P2
      PP3P2 = .95
       GO TO 2557
 2556 PP3P2 = 0.0
      ICOMBN = 0
      JICOM = 0
      GO TO 2
 2560 PARB2 = V2 + 44774.1*PAR2*(1.0 - P3P2)
      PC=P3P2*P2
      PARB2 = PARB2*(1.0/((1.0 + 1.0/OF)*(1.0+CD/2.0)))
      PARB2 = PARB2 + TF        *COSTH/((1.0+OF)*(1.0+CD/2.0))
      PARC2 = -44774.1*T*(1.0/P3P2-1.0)/((1.0+CD/2.0)*WTMOL)
      VC=(SQRT(PARB2**2-4.0*PARC2)+PARB2)/2.0
      SPEED = (V2**2/90185.4 + H22)/(1.0 + 1.0/OF) + HEATC/(1.0
     1+ OF) - HSUM*1.98726


      SPEED = SPEED*90185.4
      SPEED = SQRT(SPEED)
      DT3 = SPEED/VC
      IF(ABS(DT3 - 1.0) - .01)2,2,2564
 2564 IF(PP3P2)2566,2565,2566
 2565 PP3P2 = 1.
      DT1=DT3
      DP1=HSUM*1.98726
      HSUBO = (V2**2/90185.4 + H22)/(1.0 + 1.0/OF) + HEATC/(1.0
     1+ OF) - VC**2/90185.4
 2567 HSUBO = HSUBO/1.98726
      HSUM = HSUBO
```

```
      HC = HSUBO
      GO TO 1
 2566 DPDT = (DT3 - DT1)/(HSUM*1.98726 - DP1)
      DT1 = DT3
      DP1=HSUM*1.98726
      HSUBO = DP1 + (1.0 - DT3)/DPDT
      GO TO 2567
    1 JRAM = 1
       RETURN
    2 JRAM = 0
      V4=VC
      RETURN
    3 WRITE(6,4)
    4 FORMAT(1HK,45X,39HCOMBUSTION  CALCULATION  NOT  CONVERGED)
      PCP(IADD) = 0.0
      GO TO 2
      END
```

```
$IBFTC ALEO

      SUBROUTINE ALEO
C      NEW COMMON

C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VO,AOAC,Q1QO,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
      COMMON/KN4/ANAME(2,20),IJK(20),NUM(3,20)
     2,NMOL,NAK
C
C      END OF NEW COMMON
      DIMENSION IND(20),NAME(2,20)
      EQUIVALENCE(ANAME,NAME)
      EQUIVALENCE  (TEM1,ITEM1)
      EQUIVALENCE  (TEM2,ITEM2)
      DIMENSION   G(20,21),    A(15,90),    EN(90),      EN LN(90)
      DIMENSION   DEL N(90),   HO(90),      S(90),       X(20)
      DIMENSION   DELTA(20),   BO(15),      PCP(25),     PROD(3)
      DIMENSION   COEFX(20),   DX(20),      FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),    DATA(23),    DATUM(3),    FORMLA(18)
      DIMENSION   BOX(15),     BOF(15),     ANS(454),    SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),    COEFT(15,90)
      DIMENSION   MATOM(101,3),      ATOM(101,3)
      DIMENSION MX(20),MCOEFT(15,90)
      DIMENSION MFORM(15)
      REAL LRS
      REAL LLS
      COMMON  G
      COMMON QOOOCM(7700)
C     COMMON C
      EQUIVALENCE    (G(1),       C(1)),     (G(420),     C(420))
      EQUIVALENCE    (ANS(1),  C(421)),   (ANS(454),     C(874))
      EQUIVALENCE    (HSUM,       C(424)),   (SSUM,       C(425))
      EQUIVALENCE    (WTMOL,      C(426)),   (CP,         C(427))
      EQUIVALENCE    (DLMPT,      C(428)),   (DLMTP,      C(429))
      EQUIVALENCE    (GAMMA,      C(430)),   (ARATIO,     C(431))
      EQUIVALENCE    (VMACH,      C(432)),   (SP IMP,     C(433))
      EQUIVALENCE    (VACI,       C(434)),   (CF,         C(436))
      EQUIVALENCE    (RHOI,       C(437)),   (RHOVAC,     C(438))
      EQUIVALENCE    (RHO,        C(439))
      EQUIVALENCE    (T PI,       C(440)),   (PI I,       C(441))
      EQUIVALENCE    (EP PI,      C(442)),   (AW PI,      C(443))
      EQUIVALENCE    (T ETA,      C(445))
      EQUIVALENCE    (ETA I,      C(446)),   (EP ETA,     C(447))
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      EQUIVALENCE   (AW ETA,     C(448)),  (T SIG,      C(450))
      EQUIVALENCE   (SIG I,      C(451)),  (EP SIG,     C(452))
      EQUIVALENCE   (AW SIG,     C(453))
      EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
      EQUIVALENCE   (FORM(1),    C(1329)), (FORM(15),   C(1343))
      EQUIVALENCE   (MFORM(1),   C(1329)), (MFORM(15), C(1343))
      EQUIVALENCE   (ELMT(1),    C(1344)),  (ELMT(15), C(1358))
      EQUIVALENCE   (LLMT(1),    C(1344)),  (LLMT(15), C(1358))
      EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
      EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
      EQUIVALENCE   (EN(1),    C(1382)),  (EN(90),    C(1471))
      EQUIVALENCE   (ISYS,      C(1472)),   (JEAN,      C(1473))
      EQUIVALENCE   (ACX,       C(1474)),   (ACF,      C(1475))
      EQUIVALENCE   (AMX,        C(1476)),   (AMF,       C(1477))
      EQUIVALENCE   (RHOX,       C(1478)),   (RHOF,     C(1479))
      EQUIVALENCE   (COEFX(1),     C(1480)),  (COEFX(20),  C(1499))
      EQUIVALENCE   (DX(1),    C(1500)),  (DX(20),    C(1519))
C
      EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
      EQUIVALENCE   (MMLA(1),    C(1520)),  (MMLA(18), C(1537))
      EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),   C(1555))
      EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE   (OF,     C(1556)),     (FPCT,   C(1557))
      EQUIVALENCE   (EQRAT,      C(1558))
      EQUIVALENCE (KODE,    C(1559)),    (KASE,       C(1560))
      EQUIVALENCE(NF,C(1562))
      EQUIVALENCE   (NO,         C(1563)), (NE,         C(1564))
      EQUIVALENCE   (NDEQ, C(1565))
      EQUIVALENCE   (BOX(1),     C(1771)), (BOX(15),    C(1785))
      EQUIVALENCE   (BOF(1),     C(1786)), (BOF(15),    C(1800))
      EQUIVALENCE   (HX,         C(1801)), (HF,         C(1802))
      EQUIVALENCE   (VXPLS,      C(1803)), (VXMIN,      C(1804))
      EQUIVALENCE   (VFPLS,      C(1805)), (VFMIN,      C(1806))
      EQUIVALENCE   (EN LN(1),   C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE   (DEL N(1),   C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE   (HO(1),      C(2041)), (HO(90),     C(2130))
      EQUIVALENCE   (S(1),       C(2131)), (S(90),      C(2220))
      EQUIVALENCE   (MX(1),     C(2221)), (MX(20),     C(2240))
      EQUIVALENCE   (X(1),       C(2221)), (X(20),      C(2240))
      EQUIVALENCE   (DELTA(1),   C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),      C(2261)), (BO(15),     C(2275))
      EQUIVALENCE   (PO,         C(2276)), (HSUBO,      C(2277))
      EQUIVALENCE   (SO,         C(2278)), (T LN,       C(2279))
      EQUIVALENCE   (T,          C(2280)), (AAY LN,     C(2281))
      EQUIVALENCE   (AAY,        C(2282)), (CPSUM,      C(2283))
      EQUIVALENCE   (HC,         C(2284)), (TC LN,      C(2285))
      EQUIVALENCE   (PCP(1),     C(2286)), (PCP(25),    C(2310))
      EQUIVALENCE   (DATUM(1),   C(2311)), (DATUM(3),   C(2313))
      EQUIVALENCE   (PC,         C(2314)), (TC,         C(2315))
      EQUIVALENCE   (IPROB,      C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (IHS,        C(2318)), (ICOND,      C(2319))
      EQUIVALENCE   (ISYM,       C(2320)), (IPROD,      C(2321))
      EQUIVALENCE   (IDID,       C(2322)), (LDRUM,      C(2323))
      EQUIVALENCE   (IDRM,       C(2323)), (KDRUM,      C(2324))
      EQUIVALENCE   (L,          C(2325)), (L1,         C(2326))
      EQUIVALENCE   (M,          C(2327)), (M1,         C(2328))


      EQUIVALENCE   (N,          C(2329)), (IQ,         C(2330))
      EQUIVALENCE   (IQ1,        C(2331)), (IQ2,        C(2332))
      EQUIVALENCE   (IQ3,        C(2333)), (KMAT,       C(2334))
      EQUIVALENCE   (IMAT,       C(2335)), (IUSE,       C(2335))
      EQUIVALENCE   (IADD,       C(2336)), (ITNUMB,     C(2337))
      EQUIVALENCE   (ITAPE,      C(2338)), (P,          C(2339))
      EQUIVALENCE   (IDEBUG,     C(2340)), (IFROZ,      C(2341))
      EQUIVALENCE   (A(1),       C(2342)),  (A(1350),   C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (MCOEFT(1),  C(6392)), (MCOEFT(1350),  C(7741))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      EQUIVALENCE (KORE, C(8047))
      EQUIVALENCE (DLNT,LNT),(SUM,MSUM),(BLK,MBLK),(TMP,MTMP),(MT,BMT)
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),   C(1540))
C
```

```
C
      CONVER = 0.0
      IF(KOK)33,10,33
   10 IF(JEAM) 1,11,1
   11 SAPE = (PC/PPT)*1.05
      JEAM=-1
      IALEO = 1
      RETURN
   33 IF(IADD-1)1,34,1
   34 SAPE = 1.05
      JEAM = -1
      IALEO = 1
       RETURN
    1 CONTINUE
      IALEO = IALEO +1
      K=1
      DO 9 I=1,NMOL
      IND(I)=0
      J=1
      DO 3 MM=1,105
      TEM1=ANS(J+35)
      TEM2=ANS(J+36)
      IF(ITEM1-NAME(1,I))3,5,3
    5 IF(ITEM2-NAME(2,I))3,6,3
    6 IND(I)=J+37
      GO TO 9
    3 J=J+4
    9 K=K+2
      CALL DDARDX(ARATIO,IADD,P)
      DARDX=ABS(DARDX)
      IF((KOK.EQ.0).AND.(ANS(32).LT.0.0))DARDX=-DARDX
      Z=1.8136E-06*ANS(2)**3/ANS(3)**4
      ZZZ=0.0
      DO 200 I=1,NAK
      ZZ=1.0
      DO 201 J=1,3
      LL=NUM(J,I)
      IF(LL.EQ.0)GO TO 201


      K=IND(LL)
      ZZ=ZZ*ANS(K)
  201 CONTINUE
      ZZZ=ZZZ+AK(I)*ZZ
  200 CONTINUE
      Z=Z*ZZZ
      Q=11.9593*ANS(2)*ANS(13)*DARDX/(  ANS(3)*ANS(11)*ANS(32))*
     1(ANS(9)*ANS(30)-ANS(8))
      QAN = Q/Z
      WRITE(6,19) Z,Q,QAN
   19 FORMAT(1HK,28X,2HZ=E 12.5,5X,2HQ=E 12.5,5X,4HQAN=E 12.5)
      WRITE(6,119) DARDX,ANS(13),ANS(8),ANS(9),ANS(30),ANS(32)
  119 FORMAT(1HK,6HDARDX=F10.3,2X,6HSPIMP=F10.3,2X,7HANS(8)=E 12.5,
     12X,7HANS(9)=E 12.5,2X,8HANS(30)=E 12.5,2X,8HANS(32)=E 12.5)
      IF(ABS(QAN-1.0)-.01) 90,90,12
   12 IF(JEAM)13,20,20
   13 IF(KOK)16,14,16
   14 IF(QAN - 1.0)17,90,15
   15 INUME = 1
      SAPE = .90*SAPE
      JEAM = 1
      GO TO 60
   16 IF(QAN - 1.0) 17,90,90
   17 SAPE = 2.5
      SAPE1 = SAPE
      JEAM = 1
      GO TO 60
   20 IF(KOK) 26,21,26
   21 IF(P-PPT)26,24,24
   24 IF(ITIME2)30,25,30
   25 OLDAN = QAN
      SAPE1 = SAPE
      SAPE = .95 *SAPE
      ITIME2 = 1
      GO TO 60
   26 IF(ITIME2)30,27,30
   27 OLDAN = QAN
      SAPE1 = SAPE
```

```
      SAPE = 5.0
      ITIME2 = 1
      GO TO 60
   30 DIR = (ALOG(QAN) -ALOG(OLDAN))/(ALOG(SAPE)-ALOG(SAPE1))
      SAPE1 = SAPE
      SAPE= EXP(ALOG(SAPE)-ALOG(QAN)/DIR)
      OLDAN = QAN
      IF(KOK)40,43,40
   40 IF(SAPE - 1.05) 41,60,60
   41 SAPE = 1.07
      GO TO 60
   43 IF(INUME)44,50,44
   44 IF(SAPE - PC-PPT) 46,45,45
   45 SAPE = .98*PC/PPT
      GO TO 60
   46 IF(SAPE - 1.03) 47,47,60
   47 SAPE = 1.03
   50 IF(SAPE-PC/PPT)51,51,60


   51 SAPE = 1.03*PC/PPT
   60 NO EQ =NO EQ-1
      IADD = IADD-1
      BACKSPACE 3
      IF(IALEO - 25) 61,61,70
   61 RETURN
   90 IALEO = 0
      JEAM=0
      ITIME2=0
      CONVER=1.0
      SAPE2 = 0.0
      RETURN
   70 APE = 0.0
      SAPE = 0.0
      WRITE (6,71)
   71 FORMAT(1HJ,48X,35HALEO NOT CONVERGED IN 25 ITERATIONS)
      CALL PDUMP(G(1,1),SAPE2,1)
      RETURN
      END
```

```
$IBFTC CORE3

      SUBROUTINE  CORE3
C      NEW COMMON

C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VO,ADAC,Q1QO,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
C
C      END OF NEW COMMON
C
C     FROZEN COMPOSITION EXPANSION
C
C
      DIMENSION   G(20,21),   A(15,90),   EN(90),     EN LN(90)
      DIMENSION   DEL N(90),  HO(90),     S(90),      X(20)
      DIMENSION   DELTA(20),  BO(15),     PCP(25),    PROD(3)
      DIMENSION   COEFX(20),  DX(20),     FORM(15)
      DIMENSION COEFT1(15,90) , COEFT2(15,90)
      DIMENSION   ELMT(15),   DATA(23),   DATUM(3),   FORMLA(18)
      DIMENSION   BOX(15),    BOF(15),    ANS(454),   SYSTM(15)
      DIMENSION LLMT(15),MTSYS(15),MDATA(23)
      DIMENSION   ANSLAB(454),   COEFT(15,90)
      DIMENSION   MATOM(101,3),     ATOM(101,3)
```

```
      COMMON  G
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (G(1),       C(1)),     (G(420),     C(420))
      EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),     C(874))
      EQUIVALENCE   (HSUM,       C(424)),  (SSUM,       C(425))
      EQUIVALENCE   (WTMOL,      C(426)),  (CP,         C(427))
      EQUIVALENCE   (DLMPT,      C(428)),  (DLMTP,      C(429))
      EQUIVALENCE   (GAMMA,      C(430)),  (ARATIO,     C(431))
      EQUIVALENCE   (VMACH,      C(432)),  (SP IMP,     C(433))
      EQUIVALENCE   (VACI,       C(434)),  (CF,         C(436))
      EQUIVALENCE   (RHOI,       C(437)),  (RHOVAC,     C(438))
      EQUIVALENCE   (RHO,        C(439))
      EQUIVALENCE   (T PI,       C(440)),  (PI I,       C(441))
      EQUIVALENCE   (EP PI,      C(442)),  (AW PI,      C(443))
      EQUIVALENCE   (T ETA,      C(445))
      EQUIVALENCE   (ETA I,      C(446)),  (EP ETA,     C(447))
      EQUIVALENCE   (AW ETA,     C(448)),  (T SIG,      C(450))
      EQUIVALENCE   (SIG I,      C(451)),  (EP SIG,     C(452))
      EQUIVALENCE   (AW SIG,     C(453))
      EQUIVALENCE   (ANSLAB(1), C(875)), (ANSLAB(454), C(1328))
      EQUIVALENCE   (FORM(1),    C(1329)), (FORM(15),   C(1343))
      EQUIVALENCE   (ELMT(1),    C(1344)),  (ELMT(15), C(1358))


      EQUIVALENCE   (LLMT(1),    C(1344)),  (LLMT(15), C(1358))
      EQUIVALENCE   (DATA(1),  C(1359)),  (DATA(23),  C(1381))
      EQUIVALENCE   (MDATA(1),  C(1359)),  (MDATA(23), C(1381))
      EQUIVALENCE   (EN(1),    C(1382)),  (EN(90),    C(1471))
      EQUIVALENCE   (ISYS,      C(1472)),   (JEAN,      C(1473))
      EQUIVALENCE   (ACX,       C(1474)),   (ACF,      C(1475))
      EQUIVALENCE   (AMX,        C(1476)),   (AMF,       C(1477))
      EQUIVALENCE   (RHOX,       C(1478)),   (RHOF,      C(1479))
      EQUIVALENCE   (COEFX(1),     C(1480)),  (COEFX(20),  C(1499))
      EQUIVALENCE   (DX(1),     C(1500)),  (DX(20),    C(1519))
      EQUIVALENCE   (FORMLA(1),  C(1520)),  (FORMLA(18),  C(1537))
      EQUIVALENCE   (MMLA(1),    C(1520)),  (MMLA(18), C(1537))
      EQUIVALENCE   (PROD(1),  C(1538)),  (PROD(3),    C(1540))
      EQUIVALENCE   (SYSTM(1),  C(1541)),  (SYSTM(15),    C(1555))
      EQUIVALENCE   (MTSYS(1), C(1541)), (MTSYS(15),  C(1555))
      EQUIVALENCE   (DF,      C(1556)),    (FPCT,    C(1557))
      EQUIVALENCE   (EQRAT,      C(1558))
      EQUIVALENCE (KODE,    C(1559)),   (KASE,       C(1560))
      EQUIVALENCE(NF,C(1562))
      EQUIVALENCE   (NU,         C(1563)), (NE,         C(1564))
      EQUIVALENCE   (NUEQ, C(1565))
      EQUIVALENCE  (NUFROZ,  C(1566))
      EQUIVALENCE   (BOX(1),     C(1771)), (BOX(15),    C(1785))
      EQUIVALENCE   (BOF(1),     C(1786)), (BOF(15),    C(1800))
      EQUIVALENCE   (HX,         C(1801)), (HF,         C(1802))
      EQUIVALENCE   (VXPLS,      C(1803)), (VXMIN,      C(1804))
      EQUIVALENCE   (VFPLS,      C(1805)), (VFMIN,      C(1806))
      EQUIVALENCE   (EN LN(1),   C(1861)), (EN LN(90), C(1950))
      EQUIVALENCE   (DEL N(1),   C(1951)), (DEL N(90), C(2040))
      EQUIVALENCE   (HO(1),      C(2041)), (HO(90),     C(2130))
      EQUIVALENCE   (S(1),       C(2131)), (S(90),      C(2220))
      EQUIVALENCE   (X(1),       C(2221)), (X(20),      C(2240))
      EQUIVALENCE   (DELTA(1),   C(2241)), (DELTA(20), C(2260))
      EQUIVALENCE   (BO(1),      C(2261)), (BO(15),     C(2275))
      EQUIVALENCE   (PO,         C(2276)), (HSUBO,      C(2277))
      EQUIVALENCE   (SO,         C(2278)), (T LN,       C(2279))
      EQUIVALENCE   (T,          C(2280)), (AAY LN,     C(2281))
      EQUIVALENCE   (AAY,        C(2282)), (CPSUM,      C(2283))
      EQUIVALENCE   (HC,         C(2284)), (TC LN,      C(2285))
      EQUIVALENCE   (PCP(1),     C(2286)), (PCP(25),    C(2310))
      EQUIVALENCE   (DATUM(1),   C(2311)), (DATUM(3),   C(2313))
      EQUIVALENCE   (PC,         C(2314)), (TC,         C(2315))
      EQUIVALENCE   (IPROB,      C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (IHS,        C(2318)), (ICOND,      C(2319))
      EQUIVALENCE   (ISYM,       C(2320)), (IPROD,      C(2321))
      EQUIVALENCE   (IDID,       C(2322)), (LDRUM,      C(2323))
      EQUIVALENCE   (IDRM,       C(2323)), (KDRUM,      C(2324))
      EQUIVALENCE   (L,          C(2325)), (L1,         C(2326))
      EQUIVALENCE   (M,          C(2327)), (M1,         C(2328))
      EQUIVALENCE   (N,          C(2329)), (IQ,         C(2330))
```

```
      EQUIVALENCE   (IQ1,       C(2331)), (IQ2,       C(2332))
      EQUIVALENCE   (IQ3,       C(2333)), (KMAT,      C(2334))
      EQUIVALENCE   (IMAT,      C(2335)), (IUSE,      C(2335))
      EQUIVALENCE   (IADD,      C(2336)), (ITNUMB,    C(2337))
      EQUIVALENCE   (ITAPE,     C(2338)), (P,         C(2339))
      EQUIVALENCE   (IDEBUG,    C(2340)), (IFROZ,     C(2341))
           CORE3

      EQUIVALENCE   (A(1),      C(2342)),  (A(1350),  C(3691))
      EQUIVALENCE   (COEFT1(1),  C(3692)), (COEFT1(1350), C(5041))
      EQUIVALENCE   (COEFT2(1), C(5042)), (COEFT2(1350), C(6391))
      EQUIVALENCE   (COEFT(1),  C(6392)),  (COEFT(1350), C(7741))
      EQUIVALENCE   (ATOM(1),  C(7742)), (ATOM(303), C(8044))
      EQUIVALENCE   (MATOM(1),  C(7742)), (MATOM(303),  C(8044))
      COMMON/APE12/HCC,PCC,SOO,ZN2,ZN3,SAV(3),SAV1(3)
C
C
C
      OLDAWT=AWT
      NO FROZ=0
      MISSED=0
      IF(MNFR.EQ.0)GO TO 960
      IF(MNFR.EQ.1)GO TO 962
      NOEQ=NOEQ+1
      IF(KOK.EQ.1)GO TO 950
      IF(MNFR.EQ.-1)SAPE=PCP(IFREZ)
      IF ( SAPE .LT. PCPT) KAPPA = 99
C      IF KAPPA=99   AWT MUST BE FOUND IN CORE3
C      AND THROAT MUST COME OUT IN HEADING
C      CSTAR,CF, AND AE/AT MUST BE CHANGED
C      LOSE ONE PCP
  950 J=1
      DO 951 I=IFREZ,JADDI
      IF ( I .EQ. IFREZ) PCP (J) = SAPE
      IF ( I .NE. IFREZ) PCP (J) = SPCP (I - 1 )
      IF (MNFR.EQ. -1) PCP (J) = SPCP (I)
  951 J=J+1
      PCP(J)=0.0
  962 DO 952 J=1,454
  952 ANSLAB(J)=ANS(J)
  960 DO 1004 J=1,454
 1004 ANS(J)= ANSLAB(J)
  961 IADD=1
      ITROT=3
      ALPHA=0.0
      DO 7 J=1,N
      EN(J)=ANS(4*J+34)
      IF (EN(J)) 6,6,15
   15 IF (J-M) 5,5,7
    5 ENLN(J)=ALOG(EN(J))
      ALPHA=ALPHA+EN(J)
      GO TO 7
    6 EN LN(J)=0.0
      EN(J)=0.0
    7 CONTINUE
      WTMOLF=ALPHA*WTMOL
      PC=ANS(2)
      TLN=ALOG(ANS(3))
      HC=ANS(4)/1.98726
      SO= (ANS(5)*WTMOLF/1.98726)+ALPHA*ALOG(PC/ALPHA)
      DLMPT=0.0
      DLMTP=0.0
      IF (MNFR .GE. 0) GO TO 1
      PC         = PCC


      HC         = HCC
      P=ANS(2)
      POP=P
      SO= (ANS(5)*WTMOLF/1.98726)+ALPHA*ALOG(P /ALPHA)
    1 CONTINUE
C
C     BEGIN CALCULATIONS FOR CURRENT POINT
C     CHECK TEMPERATURE RANGE OF THERMODYNAMIC DATA
C
```

```
      DO 1117 J=1,454
 1117 ANSLAB(J)=ANS(J)
   17 T=EXP(T LN)
   19 IF (COEFT(7,1)-T) 21,27,27
   21 IF (COEFT(7,1)-5000.0) 23,22,451
   22 IF (IADD-2) 51,31,31
   23 DO 1123 K = 1,15
      DO 1123 J = 1,90
 1123 COEFT(K,J) = COEFT1(K,J)
      CALL SLITE (4)
      GO TO 19
   25 DO 1125 K = 1,15
      DO 1125 J = 1,90
 1125 COEFT(K,J)=COEFT2(K,J)
      CALL SLITE (4)
      GO TO 19
   27 IF (T-COEFT(6,1)) 29,35,35
   29 IF (300.0-COEFT(6,1)) 25,22,451
   31 CALL SLITET(4,KOOOFX)
       GO TO(38,305),KOOOFX
C
C     LEAVE FROZEN PROGRAM IF DATA FOR ANY SPECIES RUNS OUT
C
   35 IF (IADD-2) 51,37,37
   37 CALL SLITET(4,KOOOFX)
       GO TO(38,41),KOOOFX
   38 CALL SLITE (4)
      DO 40 J=1,N
      IF (COEFT(8,J)) 40,39,40
   39 IF (EN(J)) 40,40,309
   40 CONTINUE
      GO TO 49
   41 DO 44 J=1,N
      IF (EN(J)) 44,44,42
   42 IF (COEFT(5,J)+20.0-T) 285,43,43
   43 IF (T-COEFT(4,J)+20.0) 295,44,44
  285 IF (5000.0-COEFT(5,J)) 44,44,311
  295 IF (COEFT(4,J)-300.0) 44,44,311
   44 CONTINUE
C
C     BEGIN ITERATION
C
   49 PCPLN=ALOG(PCP(IADD))
      IF(MNFR.GE.0)GO TO 51
      P=PC/PCP(IADD)
      PCP LN=ALOG(POP/P)
   51 CPSUM=0.0


      T=EXP(T LN)
      DO 60 J=1,N
      IF (EN(J)) 60,60,57
   57 CPSUM=CPSUM+((((COEFT(12,J)*T+COEFT(11,J))*T+COEFT(10,J))*T+COEFT(
     19,J))*T+COEFT(8,J))*EN(J)
   58 HO(J)=((((COEFT(12,J)/5.0)*T+COEFT(11,J)/4.0)*T+COEFT(10,J)/3.0)*T
     1+COEFT(9,J)/2.0)*T +COEFT(13,J)/T+COEFT(8,J)
   59 S(J)=((((COEFT(12,J)/4.0 )*T+COEFT(11,J)/3.0)*T+COEFT(10,J)/2.0)*T
     1 +COEFT(9,J))*T+COEFT(8,J)*T LN+COEFT(14,J)-EN LN(J)
   60 CONTINUE
      SUM H=0.0
      SUM S=0.0
      DO 63 J=1,N
      SUM H=SUM H+HO(J)*EN(J)
   63 SUM S=SUM S+S(J)*EN(J)
      IF (IADD-2) 81,65,65
   65 CALL SLITET(4,KOOOFX)
       GO TO(66,81),KOOOFX
   66 CALL SLITE (4)
   67 D LN T=(SUM S+(ALPHA*PCP LN)-SO)/CPSUM
C
C     CHECK CONVERGENCE OF THE ITERATION
C
      T LN=T LN-D LN T
      IF (ABS(D LN T)-0.5E-4) 73,73,51
   73 CALL SLITET(4,KOOOFX)
```

```
      GO TO(17,17),KOOOFX
   81 DO 1181 J = 1,454
 1181 ANS(J) = ANSLAB(J)
      SUM H=T*SUM H/WTMOLF
      CPR=CPSUM/WTMOLF
      GAMMA=CPR/(CPR-(1.0/WTMOL))
      IF((MNFR.GE.0).AND.(IADD.EQ.1))GO TO 209
      IF((MNFR.GE.0).AND.(IADD.EQ.2))GO TO 191
      IF((IADD.EQ.2).AND.(KAPPA.EQ.99))GO TO 11191
      GO TO 197
11191 CONTINUE
      P=PC/PCP(IADD)
      FUM=T/(2.0*(HC-SUMH))
      FUM1=FUM*(WTMOL-ZN2)/(WTMOL*ZN2)
      SAVI (1) = -(1.0/(ZN2 * CPR) + 1.0/ GAMMA + FUM1)
      FUM1=FUM*(TC-T)/(TC*T*1.98726)*1000.0
      ZN3=1000.0/(CPR*TC*1.98726)
      SAVI(2)=ZN3-FUM1
      FUM1=T/(2.0*(HC-SUMH+V4**2*5.57965E-06))
      FUM1=FUM1/WTMOL
      SAVI(3)=1.0/GAMMA-FUM1
C
C     CHECK FOR CONVERGENCE AT THROAT
C
  191 CONTINUE
 4002 DHSTAR=(HC-SUMH+V4**2/1.79223E05)*CV**2
     2-GAMMA*T/(2.0*WTMOL)
      IF (ABS(DHSTAR/(HC+V4**2/1.79223E+05-SUMH))-0.4E-04) 197,197,192
  192 IF (ITROT) 193,197,193
  193 PCP(2)=PCP(2)/(1.0+2.0*DHSTAR*WTMOL/(T*(GAMMA+1.0)))


      CALL SLITE (4)
      ITROT=ITROT-1
      GO TO 49
C
C     CALCULATE PERFORMANCE PARAMETERS
C
  197 CONTINUE
1977  SP IMP = SQRT(172.9178*(HC-SUMH)+V4**2*9.6447E-4)
     2*CV
      P=PC/PCP(IADD)
      AW=(86.4579*T)/(P*WTMOL*14.696006*SP IMP)
      IF((MNFR.GE.0).AND.(IADD.EQ.2))AWT=AW
      IF((IADD.EQ.2).AND.(KAPPA.EQ.99))SAWT=AW
2202   CSTAR=32.174*PC*14.696006*AWT
  203 IF(IRAM.EQ.0)GO TO 22203
      SPNET   1.0 OF * SPIMP   86.4* 1.0-PFIELD/P *T/ SPIMP*WTMOL  -VO*O
     1F* 1.0  CDA /32.2
      CF=64.4*SPNET*AOAC*Q1QO/(VO*OF)
      GO TO 11203
22203 CONTINUE
11203 CONTINUE
      ARATIO=AW/AWT
      VACI=SP IMP+P*14.696006*AW
      IF(IRAM.EQ.1)VACI=86.4*(1.0+OF)*PFIELD*T/
     2(P*WTMOL*SPIMP)+SPNET
      IF(IRAM.EQ.0)CF=32.174*VACI/CSTAR
      VMACH=SP IMP/SQRT(86.4579*GAMMA*T/WTMOL)
  207 ANS(2)=P
      ANS(3)=T
  209 HSUM=SUM H*1.98726
      CP=CPR*1.98726
      ANS(1)=PCP(IADD)
      ANS(15)=CSTAR
      IF  IRAM .EQ. 1   SPIMP = SPNET
      WRITE (3)(ANS(I),I=1,454)
      NO FROZ=NO FROZ+1
      IF (MISSED) 451,223,451
  223 IADD=IADD+1
      IF((MNFR.LT.0).AND.(KAPPA.EQ.0))GO TO 1225
      IF(IADD-2)1225,224,1225
  224 PCP(2)=((GAMMA+1.0)/2.0)**(GAMMA/(GAMMA-1.0))
      TLN=TLN+ALOG(2.0/(GAMMA+1.0))
 1225 IF (IADD-25) 225,225,451
```

```
  225 IF (PCP(IADD)) 451,451,227
  227 CALL SLITE (4)
      GO TO 49
C
C     ERROR PRINT OUT
C
  305 WRITE (6,306)T,IADD
  306 FORMAT (17HLTHE TEMPERATURE=E12.4,26H K, IS OUT OF RANGE,POINT I5)
      IF (6000.0-T) 449,307,307
  307 IF (T-200.0) 449,308,308
  308 GO TO 41
  449 MISSED=1
      ITROT=0


      CALL SLITET(4,KOOOFX)
       GO TO(51,51),KOOOFX
  451 WRITE (3)(G(I,1), I=1,8044)
      IF(KAPPA.EQ.99)AWT=SAWT
      CALL CORE5
      RETURN
  309 WRITE (6,310)(COEFT(I,J),I=1,3),COEFT(6,J),COEFT(7,J)
  310 FORMAT (13H6THE SPECIES 3A6,29H HAS NO DATA IN THE INTERVAL 2F9.1)
      DO 1311 K = 1,15
      DO 1311 J = 1,90
 1311 COEFT(K,J) = COEFT1(K,J)
      GO TO 449
  311 WRITE (6,312)(COEFT(I,J),I=1,3),T
  312 FORMAT (13H6THE SPECIES 3A6,19H HAS NO DATA AT T= F9.1)
      GO TO 449
      END



$IBFTC CORE5

      SUBROUTINE  CORE5
C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/ZONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VO,AOAC,Q1QO,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
C
C      END OF NEW COMMON
      COMMON/APE10/MN1,MN2,MN3
C
C     OUTPUT ROUTINE
C
C
      DIMENSION        TITLE(3,105),PAR(13,16),DER(13,13),
     1            A(15,46),ELMT(15)
     2,ANS(454)
      DIMENSION BOX(15),BOF(15),BO(15)
      DIMENSION AMOL(13,90)
      DIMENSION          ASOL(13)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),    C(874))
      EQUIVALENCE   (PERCF,    C(1557)),    (EQUIV,    C(1558))
      EQUIVALENCE   (ODF,     C(1556))
      EQUIVALENCE (KODE,    C(1559)),   (KASE,      C(1560))
      EQUIVALENCE   (KONT,   C(1561)),   (NF,         C(1562))
      EQUIVALENCE   (NO,        C(1563)), (NE,        C(1564))
      EQUIVALENCE   (NOEQ, C(1565))
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```
      EQUIVALENCE   (NOFROZ,     C(1566))
      EQUIVALENCE (KD, C(1763)), (II, C(1764))
      EQUIVALENCE (MM, C(1765))
      EQUIVALENCE (LEN, C(1766)), (MAY, C(1767))
      EQUIVALENCE (NANA, C(1768)), (ME, C(1769))
      EQUIVALENCE (LOOP, C(1770)), (KTAPE, C(8045))
      EQUIVALENCE   (BOX(1),     C(1771)), (BOX(15),    C(1785))
      EQUIVALENCE   (BOF(1),     C(1786)), (BOF(15),    C(1800))
      EQUIVALENCE   (BO(1),      C(2261)), (BO(15),     C(2275))
      EQUIVALENCE   (IPROB,      C(2316)), (IFIXT,      C(2317))
      EQUIVALENCE   (N,          C(2329)), (IQ,         C(2330))
      EQUIVALENCE (IN, C(8046))
      EQUIVALENCE (KK, C(8048)), (KKK, C(8049))
      EQUIVALENCE   (TITLE(1),     C(8055)), (TITLE(315), C(8369))
      EQUIVALENCE (ELMT(1), C(1807)), (ELMT(15), C(1821))
      EQUIVALENCE (PAR(1),  C(8370)), (PAR(208),  C(8577))
      EQUIVALENCE(A(1), C(8578)),  (A(690), C(9267))
      EQUIVALENCE (AMOL(1),  C(9268)),  (AMOL(1170),  C(10437))


      EQUIVALENCE (DER(1), C(10438)),  (DER(169), C(10606))
      EQUIVALENCE (PC,C(2314)),  (HC,C(2284))
      DATA Q000CT/0256731636060/
      EXIT=Q000CT
      NAREA=0
    2 FORMAT (9HOCASE NO.I5,F8.1,F8.3)
    3 FORMAT (1H0,64X,46HWT FRACTION  ENTHALPY   STATE  TEMP    DENSITY/
     125X,16HCHEMICAL FORMULA,24X,10H(SEE NOTE),4X,7HCAL/MOL,10X,
     25HDEG K,4X,4HG/CC)
    4 FORMAT (1H0,84X,46HWT FRACTION  ENTHALPY   STATE  TEMP    DENSITY/
     1         25X,16HCHEMICAL FORMULA,44X,10H(SEE NOTE),4X,7HCAL/MOL,
     2         8X,5HDEG K,4X,4HG/CC)
    5 FORMAT(1H+,63X,F9.5,F12.3,4X,A1,F10.2,F11.6)
    6 FORMAT(1H+,83X,F9.5,F12.3,4X,A1,F10.2,F11.6)
    7 FORMAT (1H0,30X,4H0/F=F9.5,15H, PERCENT FUEL=F8.4,20H, EQUIVALENCE
     1 RATIO=F7.4,10H, DENSITY=F7.4)
      DO 60 I=1,13
   60 ASOL(I)=EXIT
      IF(IPROB-2)550,550,551
  550 NANA=2
      GO TO 552
  551 NANA=1
  552 REWIND 3
      KANE = NANA
      MEL = 1
      IF(MNFR.EQ.0)KANE=1
      IF(MNFR.EQ.1)MEL=2
      DO 200 ME=MEL,KANE
C      THIS SHOULD TAKE CARE OF HEADINGS
      IF((ME.EQ.2).AND.(MNFR.LT.0))IPROB=2
      KTAPE=0
  300 READ  (3)(ANS(I),I=1,454)
      KTAPE=KTAPE+1
      HAL=ANS(2)*14.696006
      HALL=ANS(19)
      IF(ME-1)202,201,202
  201 LEN=NOEQ
      GO TO 203
  202 LEN=NOFROZ
  203 IF(LEN-13)102,102,103
  102 KODE=0
      GO TO 106
  103 KONT=0
      KODE=13
  106 J=34
      DO 104 I=1,N
      DO 105 II=1,3
      KK=J+II
  105 TITLE(II,I)=ANS(KK)
  104 J=J+4
      MAY=1
 1000 WRITE (6,18)
   18 FORMAT (1H1)
      CALL HEAD
      ASSIGN 2000 TO LENN
 2002 ASSIGN 90 TO JEAN
```

```
   92 WRITE (6,2)KASE,HAL,OOF
      GO TO JEAN,(90,91)
   90 IF(KD)93,94,93
   94 WRITE (6,3)
      GO TO 97
   93 WRITE (6,4)
   97 IF(NF)351,350,351
  351 DO 100 I=1,NF
      II=I
      MM=15
      CALL SPEC
      IF(KD)401,400,401
  400 WRITE (6,5)A(I,34),A(I,32),A(I,42),A(I,44),A(I,36)
      GO TO 100
  401 WRITE (6,6)A(I,34),A(I,32),A(I,42),A(I,44),A(I,36)
  100 CONTINUE
  350 IF(NO)353,352,353
  353 DO 101 I=1,NO
      II=I
      MM=0
      CALL SPEC
      IF(KD)411,410,411
  410 WRITE (6,5)A(I,33),A(I,31),A(I,41),A(I,43),A(I,35)
      GO TO 101
  411 WRITE (6,6)A(I,33),A(I,31),A(I,41),A(I,43),A(I,35)
  101 CONTINUE
  352 CONTINUE
      WRITE (6,7)OOF,PERCF,EQUIV,HALL
      GO TO LENN,(2000,2001)
 2000 IF(KODE)51,50,51
   50 IN=LEN
      GO TO 56
   51 IF(KONT) 53,52,53
   52 IN=KODE
      KONT=1
      GO TO 56
   53 IN=LEN -13
      KODE=0
   56 CALL READ
      IF(IPROB-2)600,600,601
  601 WRITE (6,602)
  602 FORMAT (37HOEQUILIBRIUM THERMODYNAMIC PROPERTIES)
      CALL PERPAR
      GO TO 206
  600 WRITE (6,8)
    8 FORMAT (11HOPARAMETERS)
      MAYS       = MAY
      IF (MAY .EQ. 2) GO TO 7001
      IF (( KOK .EQ. 0) .AND. (ME .EQ. 1)) GO TO 7000
      IF (( KOK .EQ. 1) .AND. (ME .EQ. 1)) GO TO 7002
      IF(MNFR .NE.1) GO TO 7010
      IF( KOK.EQ.0 ) GO TO 7000
      GO TO 7002
C     ME = 2   AND I HAVE 6 EXITS
 7010 MAY = 2
      IF ((KOK.EQ.0) .AND. (KAPPA .EQ. 99)) GO TO 7003


      GO TO 7001
 7000 IF(KAPPA.EQ.99)GO TO 7002
      ASSIGN 63 TO MN3
      GO TO 9011
 7001 ASSIGN 64 TO MN3
      GO TO 9011
 7002 ASSIGN 9000 TO MN3
      GO TO 9011
 7003 ASSIGN 9002 TO MN3
 9011 CONTINUE
      GO TO MN3,(63,64,9000,9002)
   63 KK=IN-2
      WRITE (6,61)(ASOL(I),I=1, KK)
   61 FORMAT (1H0,16X,7HCHAMBER,4X,7HTHROAT ,10(3X,A6),3X,A4)
      MN1=1
      MN2=1
      GO TO 65
   64 WRITE (6,66)(ASOL(I),I=1,IN)
```

```
   66 FORMAT (1H0,15X,13(3X,A6))
      MN1=2
      MN2=2
      GO TO 65
 9000 KK=IN-2
      WRITE(6,9001)(ASOL(I),I=1,KK)
 9001 FORMAT(1H0,16X,7HCHAMBER,4X,7HEXIT    ,10(3X,A6),3X,A4)
      MN1=1
      MN2=1
      GO TO 65
 9002 KK=IN-2
      WRITE(6,9003)(ASOL(I),I=1,KK)
 9003 FORMAT(1H0,16X,7HEXIT    ,4X,7HTHROAT ,10(3X,A6),3X,A4)
      MN1=2
      MN2=2
   65 CONTINUE
      CALL PERPAR
      MAY = MAY S
      IF(ME.NE.1)GO TO 206
  205 WRITE (6,99)
   99 FORMAT(1H )
      WRITE (6,9)
    9 FORMAT (12HODERIVATIVES)
      GO TO (502,503),MN1
  503 CALL PERDER
      GO TO 504
  502 CALL PERDEY
  504 CONTINUE
  206 WRITE (6,99)
      WRITE (6,10)
   10 FORMAT (15HOMOLE FRACTIONS//)
      CALL COMP
      ASSIGN 3000 TO LENNN
  207 WRITE (6,16)
   16 FORMAT (1H0,30X,16HINPUT, G-ATOMS/G//)
      IF(NE-8)80,80,81
   80 KK=1
      KKK=NE


      LOOP=1
      GO TO 82
   81 KK=1
      KKK=8
      LOOP=2
   82 DO 85 J=1,LOOP
      WRITE (6,11)(ELMT(I),I=KK,KKK)
   11 FORMAT (11X,8(6X,A2,7X))
      WRITE (6,12)(BOF (I),I=KK,KKK)
   12 FORMAT (5H FUEL,6X,8E15.7)
      WRITE (6,13)(BOX (I),I=KK,KKK)
   13 FORMAT (8H OXIDANT,3X,8E15.7)
      WRITE (6,14)(BO  (I),I=KK,KKK)
   14 FORMAT (11H PROPELLANT,8E15.7)
      IF (LOOP-1) 86,85,86
   86 KK=9
      KKK=NE
      WRITE (6,15)
   15 FORMAT(1H0)
   85 CONTINUE
      ASSIGN 91 TO JEAN
      GO TO 92
   91 WRITE (6,119)
  119 FORMAT (6HONOTE.,2X,71HWEIGHT FRACTION OF FUEL IN TOTAL FUELS AND
     1OF OXIDANT IN TOTAL OXIDANTS)
      GO TO LENNN,(3000,3001)
 3000 IF(KODE)96,95,96
   96 MAY=MAY+1
      GO TO 1000
   95 IF(IPROB-2)700,700,701
  700 IF(NAREA)702,701,702
  702 IN=NAREA
      CONTINUE
      IF(KOP)4001,701,4001
 4001 IF(ME-1)70,71,70
   70 WRITE (6,4000)
 4000 FORMAT(1H1, 25X,75HTHEORETICAL ROCKET PERFORMANCE ASSJMING FROZEN
     1COMPOSITION DURING EXPANSION/
```

```
     245X,24HFOR ASSIGNED AREA RATIOS)
      GO TO 5050
   71 WRITE (6,5000)
 5000 FORMAT (1H1,25X,80HTHEORETICAL ROCKET PERFORMANCE ASSJMING EQJILIB
     1RIUM COMPOSITION DURING EXPANSION/
     245X,24HFOR ASSIGNED AREA RATIOS)
 5050 CONTINUE
      ASSIGN 2001 TO LENN
      GO TO 2002
 2001 CONTINUE
      ASSIGN 3001 TO LENNN
      GO TO 207
 3001 CONTINUE
  701 IF(NANA-1)208,200,208
  208 NANA=0
  200 CONTINUE
      RETURN
      END
```

```
$IBFTC PERPAR

      SUBROUTINE PERPAR
C      NEW COMMON
C      NEW COMMON
C
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
      COMMON/KN1/SUB1,SUB2,SUB3,YT,NZTYP,
     2ITYP(5),CON(20),EEXP(20),AK(20)
      COMMON/KN2/JEAM,ITIME2,DARDX,CONVER,APE,SAPE,
     2SAPE1,SAPE2,INUME,PPT
      COMMON/KN3/KONT,IJN,SPCP(25),KAPPA,AWT,OLDAWT,PCP T
      COMMON/RM1/COSTH,CD,CDA,TF,HEATC,P2,T2,AMOL2,V2,GAM2,
     2PFIELD,VO,AOAC,Q1QO,P3P2
      COMMON/RM2/PP3P2,CV,V4,JRAM
C
C      END OF NEW COMMON
      COMMON/APE10/MN1,MN2,MN3
C
C     OUTPUTS PERFORMANCE PARAMETERS
C
C
      DIMENSION PAR(13,16),NN(13)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE (KODE, C(1768))
      EQUIVALENCE (IN, C(8046)),  (MAY, C(1767))
      EQUIVALENCE (PAR(1), C(8370)), (PAR(208), C(8577))
      EQUIVALENCE  (ME, C(1769))
   10 FORMAT (5H PC/P,10X)
   11 FORMAT (8H P, ATM ,7X)
   12 FORMAT (9H T, DEG K,6X,13I9)
   13 FORMAT (9H H, CAL/G,6X,13F9.1)
   14 FORMAT (15H S, CAL/(G)(K) 13F9.4)
   15 FORMAT (10HOM, MOL WT,5X,13F9.3)
   16 FORMAT (11H (DLM/DLP)T,4X,13F9.5)
   17 FORMAT (11H (DLM/DLT)P,4X,13F9.4)
   18 FORMAT (15H CP, CAL/(G)(K)13F9.4)
   19 FORMAT (6H GAMMA,9X,13F9.4)
   20 FORMAT (12H MACH NUMBER,3X,13F9.3)
   21 FORMAT(13HOC STAR, M/SEC,2X,13I9)
   22 FORMAT (3H CF,12X,13F9.3)
   23 FORMAT (6H AE/AT,9X,13F9.3)
   24 FORMAT(10H IVAC, SEC,5X,13F9.1)
   25 FORMAT(7H I, SEC,8X,13F9.1)
      IF(KAPPA.EQ.0)GO TO 100
      DO 101 I=1,IN
      PAR(I,15)=PAR(I,15)*AWT/OLDAWT
      IF(IRAM.EQ.0)
     2PAR I,16  32.174*PAR I,14 /PAR I,15
      PAR(I,11)=PAR(I,11)*OLDAWT/AWT
  101 CONTINUE
  100 CONTINUE
      IF(KODE-1)2,1,2
```

```
    1 WRITE (6,111)
  111 FORMAT (8HOP, ATM ,7X)
      GO TO 3
    2 WRITE (6,10)
      CALL VAR(1,2)
      WRITE (6,11)
    3 CALL VAR(2,2)
      DO 60 I=1,IN
   60 NN(I)=PAR(I,3)+.5
      WRITE (6,12)(NN(I),I=1,IN)
      WRITE (6,13)(PAR(I,4),I=1,IN)
      WRITE (6,14)(PAR(I,5),I=1,IN)
      WRITE (6,15)(PAR(I,6),I=1,IN)
      IF (ME .EQ. 2) GO TO 5
    6 WRITE (6,16)(PAR(I,8),I=1,IN)
      WRITE (6,17)(PAR(I,9),I=1,IN)
    5 WRITE (6,18)(PAR(I,7),I=1,IN)
      WRITE (6,19)(PAR(I,10),I=1,IN)
      IF(KODE-1)41,40,41
   40 RETURN
   41 WRITE (6,20)(PAR(I,12),I=1,IN)
      DO 61 I=1,IN
   61 NN(I)=PAR(I,15)*.3048+.5
      MN2=MN2
      GO TO (50,51),MN2
   50 WRITE (6,31)(NN(I),I=2,IN)
      WRITE (6,32)(PAR(I,16),I=2,IN)
      WRITE (6,33)
      CALL VAR(11,2)
      WRITE (6,34)(PAR(I,14),I=2,IN)
      WRITE (6,35)(PAR(I,13),I=2,IN)
   31 FORMAT(13HOCSTAR, M/SEC,2X,9X,12I9)
   32 FORMAT (3H CF,21X,12F9.3)
   33 FORMAT (6H AE/AT,18X,12F9.3)
   34 FORMAT(10H IVAC, SEC,5X,9X,12F9.1)
   35 FORMAT(7H I, SEC,8X,9X,12F9.1)
      RETURN
   51 WRITE (6,21)(NN(I),I=1,IN)
      WRITE (6,22)(PAR(I,16),I=1,IN)
      WRITE (6,23)
      CALL VAR(11,2)
      WRITE (6,24)(PAR(I,14),I=1,IN)
      WRITE (6,25)(PAR(I,13),I=1,IN)
      RETURN
      END
```

```
$IBFTC PERDER
      SUBROUTINE PERDER
      COMMON/APE12/HCC,PCC,SOO,ZN2,ZN3,SAV(3),SAV1(3)
      COMMON/KN3/ANY(27),KAPPA,ANY1(3)
      COMMON/APE13/SPL(13)
C
C     OUTPUTS PERFORMANCE DERIVATIVES
C
C
      DIMENSION PER(13,13)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE (IN, C(8046))
      EQUIVALENCE (PER(1), C(10438)),  (PER(169), C(10606))
      IF(KAPPA.NE.99)GO TO 100
      DO 110 I=1,IN
      PER(I,3)=PER(I,4)-SAV1
      PER(I,8)=PER(I,9)-SAV1(2)
      PER(I,13)=SPL(I)-SAV1(3)
  110 CONTINUE
  100 CONTINUE
    1 FORMAT (15HO(DLI/DLPC)PC/P13F9.5)
    2 FORMAT (15H (DLT/DLPC)PC/P13F9.5)
    3 FORMAT (16H (DLAR/DLPC)PC/PF8.5,12F9.5)
```

```
    4 FORMAT (16H (DLCS/DLPC)PC/PF8.5,12F9.5)
    5 FORMAT (15HO(DLI/DHC)PC/P*13F9.5)
    6 FORMAT (15H (DLT/DHC)PC/P*13F9.5)
    7 FORMAT (16H (DLAR/DHC)PC/P*F8.5,12F9.5)
    8 FORMAT (16H (DLCS/DHC)PC/P*F8.5,12F9.5)
    9 FORMAT (16H *(HC IN KCAL/G))
   10 FORMAT (13HO(DLI/DLPCP)S,2X,13F9.5)
   11 FORMAT (13H (DLT/DLPCP)S,2X,13F9.5)
   12 FORMAT (15H (DLAR/DLPCP)S 13F9.5)
      WRITE (6,1)(PER(I,2),I=1,IN)
      WRITE (6,2)(PER(I,1),I=1,IN)
      WRITE (6,3)(PER(I,3),I=1,IN)
      WRITE (6,4)(PER(I,5),I=1,IN)
      WRITE (6,5)(PER(I,7),I=1,IN)
      WRITE (6,6)(PER(I,6),I=1,IN)
      WRITE (6,7)(PER(I,8),I=1,IN)
      WRITE (6,8)(PER(I,10),I=1,IN)
      WRITE (6,9)
      WRITE (6,10)(PER(I,12),I=1,IN)
      WRITE (6,11)(PER(I,11),I=1,IN)
      WRITE (6,12)(PER(I,13),I=1,IN)
      RETURN
       END
```

```
$IBFTC PERDEY
      SUBROUTINE PERDEY
      COMMON/APE12/HCC,PCC,SOO,ZN2,ZN3,SAV(3),SAV1(3)
      COMMON/KN3/ANY(27),KAPPA,ANY1(3)
      COMMON/APE13/SPL(13)
C
C     OUTPUTS PERFORMANCE DERIVATIVES
C
C
      DIMENSION PER(13,13)
      COMMON  C
      COMMON QOOOCM(7700)
C     COMMON C
      EQUIVALENCE (IN, C(8046))
      EQUIVALENCE (PER(1), C(10438)),  (PER(169), C(10606))
      IF(KAPPA.NE.99)GO TO 100
      DO 110 I=1,IN
      PER(I,3)=PER(I,4)-SAV1
      PER(I,8)=PER(I,9)-SAV1(2)
      PER(I,13)=SPL(I)-SAV1(3)
  110 CONTINUE
  100 CONTINUE
    1 FORMAT (15HO(DLI/DLPC)PC/P,9X,12F9.5)
    2 FORMAT (15H (DLT/DLPC)PC/P13F9.5)
    3 FORMAT (16H (DLAR/DLPC)PC/P,8X,12F9.5)
    4 FORMAT (16H (DLCS/DLPC)PC/P,8X,12F9.5)
    5 FORMAT (15HO(DLI/DHC)PC/P*,9X,12F9.5)
    6 FORMAT (15H (DLT/DHC)PC/P*13F9.5)
    7 FORMAT (16H (DLAR/DHC)PC/P*,8X,12F9.5)
    8 FORMAT (16H (DLCS/DHC)PC/P*,8X,12F9.5)
    9 FORMAT (16H *(HC IN KCAL/G))
   10 FORMAT (13HO(DLI/DLPCP)S,11X,12F9.5)
   11 FORMAT (13H (DLT/DLPCP)S,2X,13F9.5)
   12 FORMAT (15H (DLAR/DLPCP)S 9X,12F9.5)
      WRITE (6,1)(PER(I,2),I=2,IN)
      WRITE (6,2)(PER(I,1),I=1,IN)
      WRITE (6,3)(PER(I,3),I=2,IN)
      WRITE (6,4)(PER(I,5),I=2,IN)
      WRITE (6,5)(PER(I,7),I=2,IN)
      WRITE (6,6)(PER(I,6),I=1,IN)
      WRITE (6,7)(PER(I,8),I=2,IN)
      WRITE (6,8)(PER(I,10),I=2,IN)
      WRITE (6,9)
      WRITE (6,10)(PER(I,12),I=2,IN)
      WRITE (6,11)(PER(I,11),I=1,IN)
      WRITE (6,12)(PER(I,13),I=2,IN)
      RETURN
       END
```

```
$IBFTC VAR
      SUBROUTINE VAR(INDEX,K1)
C
C     SPECIAL FORMAT FOR PC/P,P, AND AE/AT
C
C
      DIMENSION FMT(3),PAR(13,16),TEM(4),AM(4),TEMM(13)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE (IN, C(8046)), (MAY, C(1767))
      EQUIVALENCE (PAR(1), C(8370)), (PAR(208), C(8577))
      DATA Q000CT/0113300346060/
      ZERO=Q000CT
      DATA Q001CT/0113301346060/
      ONE=Q001CT
      DATA Q002CT/0113302346060/
      TWO=Q002CT
      DATA Q003CT/0113303346060/
      THR=Q003CT
      DATA Q004CT/0113304346060/
      FR=Q004CT
      DATA Q005CT/0600104677326/
      TEMM(1)=Q005CT
      DATA Q006CT/0600203677326/
      TEMM(2)=Q006CT
      DATA Q007CT/0600302677326/
      TEMM(3)=Q007CT
      DATA Q008CT/0600401677326/
      TEMM(4)=Q008CT
      DATA Q009CT/0600500677326/
      TEMM(5)=Q009CT
      DATA Q010CT/0600511677326/
      TEMM(6)=Q010CT
      DATA Q011CT/0600610677326/
      TEMM(7)=Q011CT
      DATA Q012CT/0600707677326/
      TEMM(8)=Q012CT
      DATA Q013CT/0601006677326/
      TEMM(9)=Q013CT
      DATA Q014CT/0601105677326/
      TEMM(10)=Q014CT
      DATA Q015CT/010004677326/
      TEMM(11)=Q015CT
      DATA Q016CT/010103677326/
      TEMM(12)=Q016CT
      DATA Q017CT/010202677326/
      TEMM(13)=Q017CT
      DATA Q018CT/0740130207360/
      FMT(1)=Q018CT
      IF(K1-2)101,100,101
  100 IF(INDEX-K1)1,2,3
  101 IF(INDEX-K1)3,1,2
    1 TEM(1)=1.0E04
      TEM(2)=1.0E05


      TEM(3)=1.0E06
      AM(1)=THR
      AM(2)=TWO
      AM(3)=ONE
      AM(4)=ZERO
      GO TO 4
    2 TEM(1)=1.0
      TEM(2)=10.0
      TEM(3)=100.0
      AM(1)=FR
      AM(2)=THR
      AM(3)=TWO
      AM(4)=ONE
      GO TO 4
    3 TEM(1)=10.0
      TEM(2)=100.0
      TEM(3)=1000.0
      AM(1)=THR
      AM(2)=TWO
      AM(3)=ONE
```

```
      AM(4)=ZERO
    4 DO 5 I=1,IN
      IF (I-1) 53,50,53
   50 IF (MAY-1) 53,52,53
   52 IF(INDEX-11) 53,5,53
   53 CONTINUE
      FMT(2)=TEMM(I)
      DO 6 J=1,3
      IF(PAR(I,INDEX)-TEM(J))10,6,6
   10 FMT(3)=AM(J)
   11 WRITE (6,FMT)PAR(I,INDEX)
      GO TO 5
    6 CONTINUE
      FMT(3)=AM(4)
      WRITE (6,FMT)PAR(I,INDEX)
    5 CONTINUE
      RETURN
       END
```

```
$IBFTC HEAD
      SUBROUTINE HEAD
      COMMON/KDS/KOK,JADDI,MNFR,ICONST,IRAM,IZEIAR,IROU,ICON,
     2IFREZ
    1 FORMAT(1H1,10X,
     254HROCKET ENGINE PERFORMANCE EQUILIBRIUM NOZZLE EXPANSION)
    2 FORMAT(1H1,10X,
     249HROCKET ENGINE PERFORMANCE FROZEN NOZZLE EXPANSION)
    3 FORMAT(1H1,10X,
     272HROCKET ENGINE PERFORMANCE NOZZLE EXPANSION WITH SPECIFIED FREEZ
     3ING POINT)
    4 FORMAT(1H1,10X,
     250HROCKET ENGINE PERFORMANCE NOZZLE KINETIC EXPANSION)
    5 FORMAT(1H1,10X,
     276HSUPERSONIC COMBUSTION RAMJET ENGINE PERFORMANCE EQUILIBRIUM NOZ
     3ZLE EXPANSION)
    6 FORMAT(1H1,10X,
     271HSUPERSONIC COMBUSTION RAMJET ENGINE PERFORMANCE FROZEN NOZZLE E
     3XPANSION)
    7 FORMAT(1H1,10X,
     294HSUPERSONIC COMBUSTION RAMJET ENGINE PERFORMANCE NOZZLE EXPANSIO
     3N WITH SPECIFIED FREEZING POINT)
    8 FORMAT(1H1,10X,
     272HSUPERSONIC COMBUSTION RAMJET ENGINE PERFORMANCE NOZZLE KINETIC
     3EXPANSION)
    9 FORMAT(1H1,10X,
     274HSUBSONIC COMBUSTION RAMJET ENGINE PERFORMANCE EQUILIBRIUM NOZZL
     3E EXPANSION)
   10 FORMAT(1H1,10X,
     269HSUBSONIC COMBUSTION RAMJET ENGINE PERFORMANCE FROZEN NOZZLE EXP
     3ANSION)
   11 FORMAT(1H1,10X,
     292HSUBSONIC COMBUSTION RAMJET ENGINE PERFORMANCE NOZZLE EXPANSION
     3WITH SPECIFIED FREEZING POINT)
   12 FORMAT(1H1,10X,
     270HSUBSONIC COMBUSTION RAMJET ENGINE PERFORMANCE NOZZLE KINETIC EX
     3PANSION)
      IF((KOK.EQ.0).AND.(IRAM.EQ.0))GO TO 100
      IF((KOK.EQ.0).AND.(IRAM.EQ.1))GO TO 200
      IF((KOK.EQ.1).AND.(IRAM.EQ.1))GO TO 300
      GO TO 400
  100 CONTINUE
      IF(MNFR.EQ.0)
     2WRITE(6,1)
      IF(MNFR.EQ.1)
     2WRITE(6,2)
      IF(MNFR.EQ.-1)
     2WRITE(6,3)
      IF(MNFR.EQ.-2)
     2WRITE(6,4)
      GO TO 400
  300 CONTINUE
      IF(MNFR.EQ.0)
     2WRITE(6,5)
      IF(MNFR.EQ.1)
```

```
      2WRITE(6,6)
       IF(MNFR.EQ.-1)
      2WRITE(6,7)
       IF(MNFR.EQ.-2)
      2WRITE(6,8)
       GO TO 400
  200 CONTINUE
       IF(MNFR.EQ.0)
      2WRITE(6,9)
       IF(MNFR.EQ.1)
      2WRITE(6,10)
       IF(MNFR.EQ.-1)
      2WRITE(6,11)
       IF(MNFR.EQ.-2)
      2WRITE(6,12)
  400 CONTINUE
       RETURN
       END
```

```
$IBFTC READ
      SUBROUTINE READ
      COMMON/APE13/SPL(13)
C
C     SORTS WHAT IS ON TAPE 3
C
C
      DIMENSION PAR(13,16),DER(13,13),              ANS(454)
      DIMENSION AMOL(13,90)
      COMMON  C
      COMMON Q000CM(7700)
C     COMMON C
      EQUIVALENCE   (ANS(1),  C(421)),  (ANS(454),    C(874))
      EQUIVALENCE (LEN, C(1766)), (MAY, C(1767))
      EQUIVALENCE (LOOP, C(1770)), (KTAPE, C(8045))
      EQUIVALENCE (IN, C(8046))
      EQUIVALENCE  (NN,   C(2329))
      EQUIVALENCE (PAR(1), C(8370)), (PAR(208), C(8577))
      EQUIVALENCE (AMOL(1),  C(9268)), (AMOL(1170), C(10437))
      EQUIVALENCE (DER(1), C(10438)),  (DER(169), C(10606))
      DO 1 I=1,IN
      DO 2 J=1,16
    2 PAR(I,J)=ANS(J)
      N=1
      DO 3 J=20,32
      DER(I,N)=ANS(J)
    3 N=N+1
      SPL(I)=ANS(33)
      N=1
      J=38
      DO 4 JJ=1,NN
      AMOL(I,N)=ANS(J)
      J=J+4
    4 N=N+1
      IF(KTAPE-LEN)100,1,100
  100 READ  (3)(ANS(K),K=1,454)
      KTAPE=KTAPE+1
    1 CONTINUE
      RETURN
       END
```

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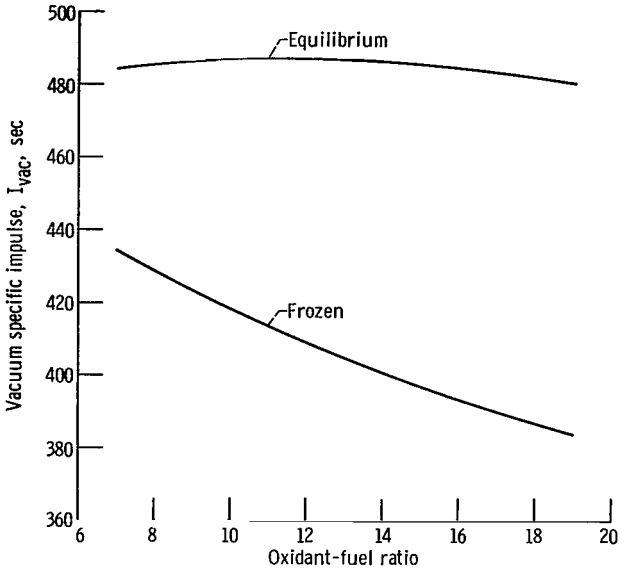

Figure 1. - Comparison of equilibrium and frozen-exhaust-gas expansion for hydrogen fluorine rocket engine. Combustion-chamber pressure, 60 psia (41.37×10^4 N/m^2); nozzle-area ratio, 100.

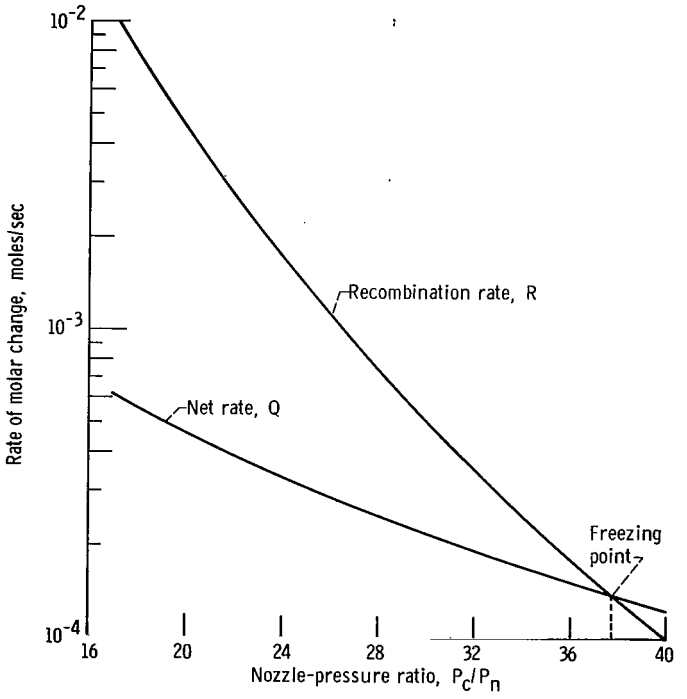

Figure 2. - Graphical solution of sudden freezing analysis for hydrogen-fueled ramjet with 15°-conical nozzle and 15.24-centimeter throat radius. Nozzle area ratio at freezing point, 6.0.

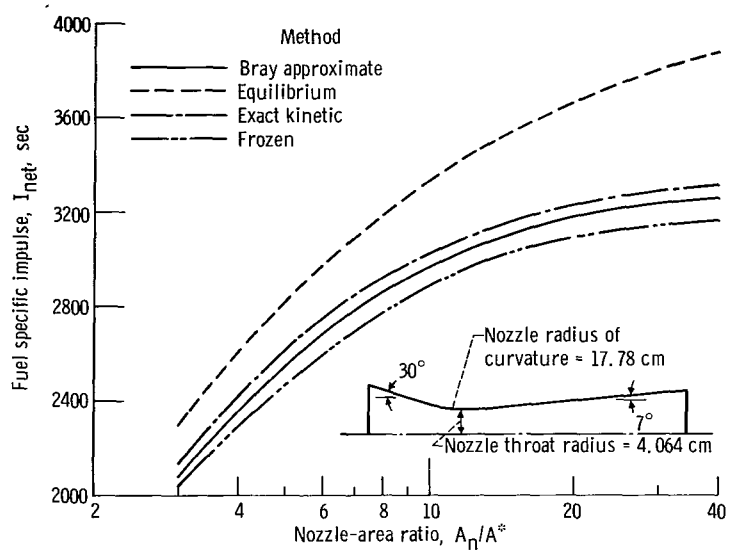

Figure 3. - Comparison of calculated specific impulse using Bray approximate method with results from exact kinetic method for hydrogen-air system. Simulated Mach 6 at 36 120 meters; combustion-chamber static pressure, 36.54×10^4 N/m^2; equivalence ratio, 1.0.

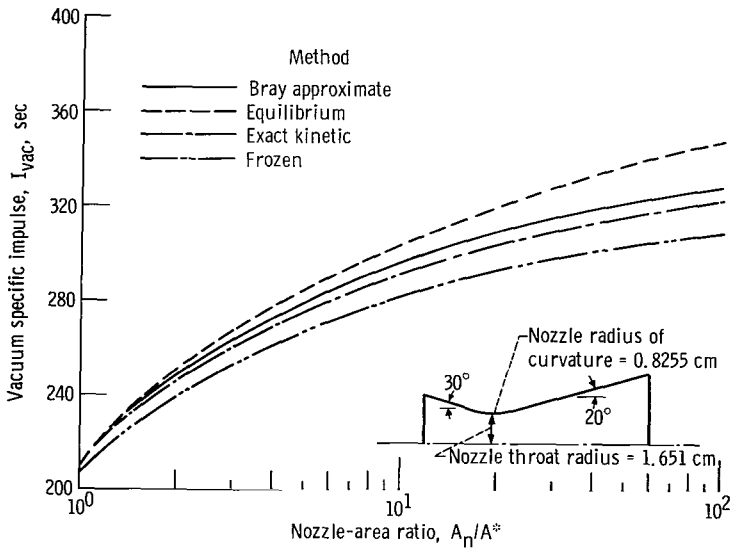

Figure 4. - Comparison of calculated specific impulse using Bray approximate method with results from exact kinetic method for nitrogen tetroxide - 50-percent hydrazine - 50-percent UDMH system. Combustion-chamber pressure, 41.37×10^4 N/m^2; oxidant-fuel ratio, 2.25.

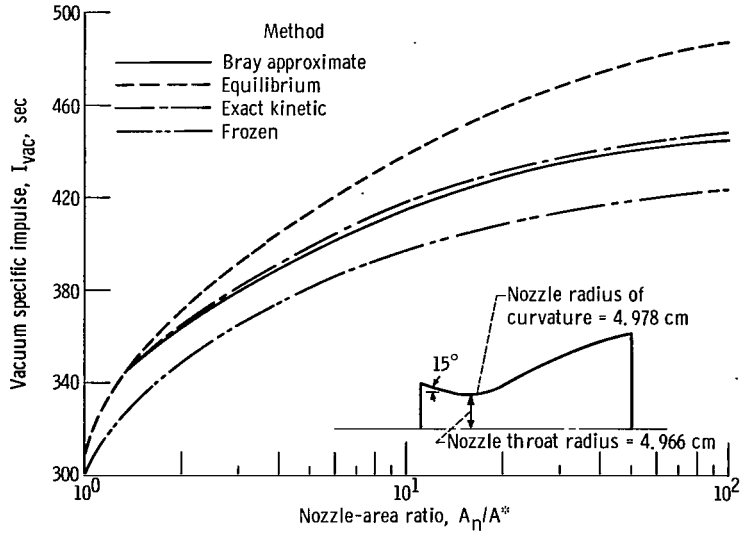

Figure 5. - Comparison of calculated specific impulse using Bray approximate method with results from exact kinetic method for hydrogen-fluorine rocket engine. Combustion-chamber pressure, 41.37×10^4 N/m^2; oxidant-fuel ratio, 9.0.

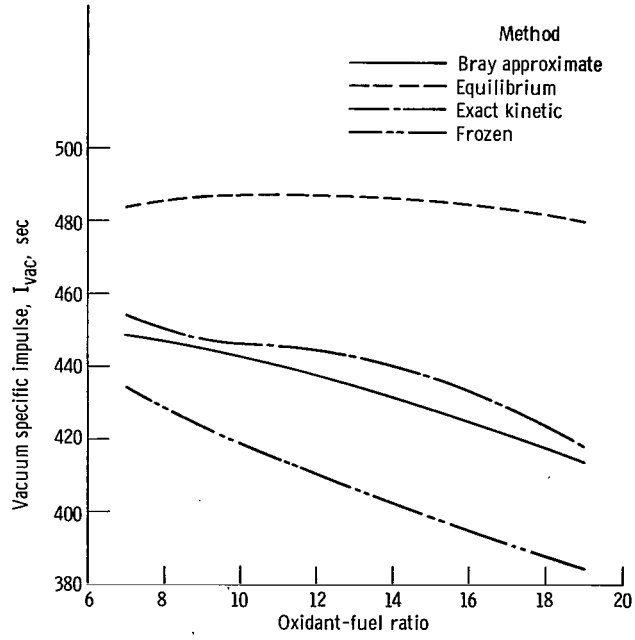

Figure 6. - Comparison of calculated specific impulse using Bray approximate method with results from exact kinetic method for hydrogen-fluorine rocket engine with contoured bell nozzle. Combustion-chamber static pressure, 41.37×10^4 N/m^2; nozzle-area ratio, 100.

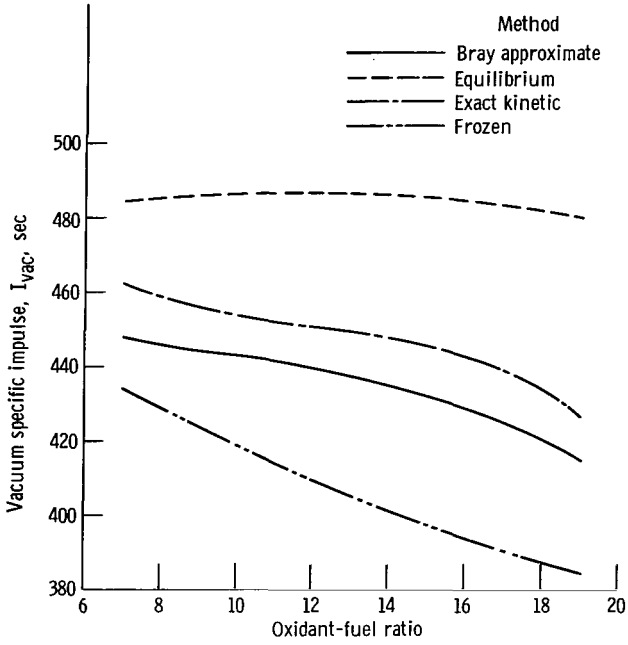

Figure 7. - Comparison of calculated specific impulse using Bray approximate method with results from exact kinetic method for hydrogen-fluorine rocket engine with 15°-conical nozzle. Combustion-chamber, 41.37×10^4 N/m^2; nozzle-area ratio, 100.

NASA-Langley, 1967 —— 28 E-3745

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