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A GENERAL METHOD FOR AUTOMATIC COMPUTATION OF EQUILIBRIUM COMPOSITIONS AND THEORETICAL ROCKET PERFORMANCE OF PROPELLANTS

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Figure 2, page 138: The second term of $\Delta \ln T$ for "Enthalpy" should be $\sum (H_T^0)_i q_i p_i$.

Figure 3, page 139: The terms in the column headings should be (a change in mathematical sign)

$$-\left(\frac{\partial \ln p_Z}{\partial \ln T}\right)_P, \ -\left(\frac{\partial \ln p_Y}{\partial \ln T}\right)_P, \ -\left(\frac{\partial \ln p_X}{\partial \ln T}\right)_P, \ -\left(\frac{\partial n_M}{\partial \ln T}\right)_P, \ -\left(\frac{\partial n_N}{\partial \ln T}\right)_P, \text{ and } +\left(\frac{\partial \ln A}{\partial \ln T}\right)_P.$$

Page 71, cards 464, 470, 471, and 474: TEMPO and 9059 should be TEM 1 and 9049, respectively.

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SUMMARY

A general computer program for chemical equilibrium and rocket performance calculations was written for the IBM 650 computer with 2000 words of drum storage, 60 words of high-speed core storage, indexing registers, and floating point attachments. The program is capable of carrying out combustion and isentropic expansion calculations on a chemical system that may include as many as 10 different chemical elements, 30 reaction products, and 25 pressure ratios. In addition to the equilibrium composition, temperature, and pressure, the program calculates specific impulse, specific impulse in vacuum, characteristic velocity, thrust coefficient, area ratio, molecular weight, Mach number, specific heat, isentropic exponent, enthalpy, entropy, and several thermodynamic first derivatives.

INTRODUCTION

Almost the entire work involved in the calculation of theoretical performance of propellants is in the determination of the equilibrium composition and temperature of the reaction products. The difficulty in determining equilibrium compositions, especially where many reaction products are involved, is due to the fact that the necessary equations for their solution are not simultaneously linear; and hence, in general, a direct solution is not feasible.

In recent years, a number of articles have appeared in the literature dealing with equilibrium calculations for complex mixtures that describe various systematic iterative techniques for obtaining equilibrium compositions (e.g., refs. 1 to 22). With the increasing availability of high-speed digital computers, a number of programs have been prepared to solve for equilibrium compositions automatically (e.g., refs. 13, 16, and 19 to 22).

The present report presents a completely general method programmed for the IBM 650 data processing system with 2000 words of drum storage, 60 words of high-speed core storage, index registers, floating decimal-point attachment, and alphabetic device. This program can handle any chemical system within certain limitations set by the storage capacity of the IBM 650. The program is based essentially on the method described in reference 9; however, some modifications have been made. The program was prepared during 1957 and has been in operation since January 1958.

EQUATIONS DEFINING ADIABATIC COMBUSTION AND ISENTROPIC EXPANSION

The computer program described in this report is primarily concerned with the calculation of theoretical rocket performance of chemical propellants. This calculation is simple and straightforward once the temperature and composition of the reaction products are known at combustion and exit points in the nozzle. The temperature and composition following a process such as adiabatic combustion at constant pressure or isentropic expansion to an assigned pressure can be determined from an appropriate combination of equations describing the conservation of atomic species, chemical equilibrium, Dalton's law of partial pressures, and the conservation of enthalpy or entropy. Since these equations do not constitute a set of linear equations, they must usually be solved by some iterative technique.

Combustion at Constant Pressure

For given initial conditions, the temperature and composition following a combustion process are to be found. The substances entering into the reaction may be represented by an equivalent formula

$$Z_{a_0}Y_{b_0}X_{c_0} \ . \ . \ .$$

where a_0, b_0, c_0, . . . are proportional to the total number of gram atoms of the elements Z, Y, X, . . . in the reaction mixture. (A complete list of symbols is given in appendix A.) For example,

$$N_2H_4 + \frac{3}{2} H_2O_2 \rightarrow H_7N_2O_3 \qquad (1)$$

The reaction at equilibrium may be written as

$$A(Z_{a_0}Y_{b_0}X_{c_0} \ . \ . \ .) \rightarrow \sum_i n_i(Z_{a_i}Y_{b_i}X_{c_i} \ . \ . \ .) \qquad (2)$$

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or

$$Z_{a_0}Y_{b_0}X_{c_0} \ldots \rightarrow \frac{1}{A}\sum_i n_i(Z_{a_i}Y_{b_i}X_{c_i} \ldots) \tag{3}$$

where A is the number of formula weights of the equivalent reactant, and n_i is the number of moles of the i^{th} molecule or atom.

With this representation of the reaction, the equations involving mass conservation, chemical equilibria, pressure, and enthalpy may be written as follows.

<u>Conservation of mass</u>. - Equations defining the relative amounts of each element in the reaction products may be written as follows:

$$\left.\begin{aligned} a &= \frac{1}{A}\sum_i a_i n_i \\ b &= \frac{1}{A}\sum_i b_i n_i \\ c &= \frac{1}{A}\sum_i c_i n_i \\ . &= . \; . \; . \; . \; . \end{aligned}\right\} \tag{4}$$

where $a, b, c, \ldots$ are the number of gram atoms of substance $Z, Y, X, \ldots$ per equivalent formula required to form the reaction products. For the reaction of equation (3), conservation of mass is defined by the following relations:

$$\left.\begin{aligned} a &= a_0 \\ b &= b_0 \\ c &= c_0 \\ \ldots &= \ldots \end{aligned}\right\} \tag{5}$$

<u>Chemical-equilibrium equations</u>. - For convenience in handling the equations, each reaction product can be considered as being formed from the gaseous atoms as follows:

$$a_iZ + b_iY + c_iX + \ldots = Z_{a_i}Y_{b_i}X_{c_i} \ldots \tag{6}$$

The change in free energy across reaction (6), $(\Delta F)_i$, in terms of activities α is given by the relation

$$(\Delta F)_i = (\Delta F^O)_i + RT(\ln \alpha_i - a_i \ln \alpha_Z - b_i \ln \alpha_Y - c_i \ln \alpha_X - \ . \ . \ .) \quad (7)$$

where $(\Delta F^O)_i$ is the standard-state free-energy change across the reaction.

For gaseous reaction products, the standard state, or the state of unit activity, is usually taken to be the ideal gas at 1-atmosphere pressure. This choice of standard state makes the activity and the fugacity numerically equal. If, furthermore, all the gaseous reaction products are assumed to behave ideally, then the fugacity and partial pressure are identical. In this case, dividing by RT and using the symbol δ for $\Delta F/RT$, equation (7) may be written as

$$\delta_i = \left(\frac{\Delta F^O}{RT}\right)_i + \ln p_i - (a_i \ln p_Z + b_i \ln p_Y + c_i \ln p_X + \ . \ . \ .) \quad (8)$$

The criterion for equilibrium for a reaction at constant temperature and pressure is that ΔF (or δ_i) be equal to zero; that is,

$$\left(\frac{\Delta F^O}{RT}\right)_i + \ln p_i - (a_i \ln p_Z + b_i \ln p_Y + c_i \ln p_X + \ . \ . \ .) = 0 \quad (9)$$

In this report, a condensed phase is assumed to be a pure solid or liquid, excluding the possibility of solid or liquid solutions. The activity for a condensed phase is conventionally taken to be unity for the pure solid or liquid at 1-atmosphere pressure. At moderate pressures the activity of the condensed phase is essentially the same as in the standard state, and hence the equilibrium relation for the formation of the condensed product $Z_{a_N}Y_{b_N}X_{c_N}$ . . . from the gaseous atoms may be written as

$$\delta_N = \left(\frac{\Delta F^O}{RT}\right)_N - (a_N \ln p_Z + b_N \ln p_Y + c_N \ln p_X + \ . \ . \ .) \quad (10)$$

Similar expressions may be written for other condensed products, $Z_{a_M}Y_{b_M}X_{c_M}$ . . ., and so forth. At equilibrium conditions δ_N, δ_M, . . . are equal to zero; that is,

$$\left.\begin{aligned} \left(\frac{\Delta F^O}{RT}\right)_N - (a_N \ln p_Z + b_N \ln p_Y + c_N \ln p_X + \ . \ . \ .) &= 0 \\ . &= 0 \end{aligned}\right\} \quad (11)$$

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Dalton's law of partial pressures. - The static pressure of the system is the sum of the partial pressures of the gaseous products:

$$P = \sum_i p_i \tag{12}$$

If a process has an assigned pressure P_0, then

$$P = P_0 \tag{13}$$

In this report, it is assumed that the gases at combustion conditions have zero velocity; and hence, in the combustion chamber, static pressure is equal to the total pressure.

Conservation of enthalpy. - Adiabatic combustion is a constant-enthalpy process; and hence, if chemical energy is included in the enthalpy of each substance, the enthalpy of the products of reactions must equal the enthalpy of the reactants.

Since only differences in enthalpy are involved, an arbitrary base may be adopted for assigning absolute values to the enthalpy of various substances. The molar enthalpy of a substance is defined as

$$(H_T^o)_i = \int_0^T (C_P^o)_i \, dT + (H_0^o)_i \tag{14}$$

where $(C_P^o)_i$ is the molar specific heat at constant pressure, and $(H_0^o)_i$ is the assigned reference enthalpy at 0° K of the i^{th} substance.

If the enthalpy of the reactants per formula weight of the equivalent formula $Z_{a_0}Y_{b_0}X_{c_0}$ . . . is H_0, then

$$H_0 = \sum_i n_{f_i}(H_T^o)_{f_i} + \sum_i n_{x_i}(H_T^o)_{x_i} \tag{15}$$

where n_{f_i} and n_{x_i} are the moles of the i^{th} fuel and i^{th} oxidant corresponding to equivalent formula $Z_{a_0}Y_{b_0}X_{c_0}$ . . ., and $(H_T^o)_{f_i}$ and $(H_T^o)_{x_i}$ are the molar enthalpies of the i^{th} fuel and i^{th} oxidant, respectively.

The enthalpy of the combustion products per equivalent formula of reactants may be written as

$$H = \frac{1}{A} \sum_i (H_T^O)_i \, n_i \tag{16}$$

If the H_0^O values for all substances are consistently assigned (taking into account heats of reaction and transition), then for adiabatic combustion,

$$H = H_0 \tag{17}$$

Isentropic Expansion to Assigned Pressure

The temperature and composition following an isentropic expansion of the combustion gases to an assigned pressure may be determined by equations for (1) conservation of atomic species, (2) chemical equilibrium, (3) the law of partial pressures, and (4) the conservation of entropy. The first three types of equations ((5), (9), (11), and (13)) have been discussed in the previous section and again apply. The fourth type is discussed herein.

The entropy of the reaction products per formula weight of the equivalent reactant is given by

$$S = \frac{1}{A} \sum_i (S_T)_i \, n_i \tag{18}$$

where

$$(S_T)_i = \begin{cases} (S_T^O)_i - R \ln p_i & \text{for gases} \\ (S_T^O)_i & \text{for condensed phases} \end{cases} \tag{19}$$

and $(S_T^O)_i$ is the absolute molar entropy of the i^{th} product at temperature T in the standard state.

For an isentropic expansion following a combustion process, the entropy at any point in the expansion S_e must be equal to the value of entropy at combustion conditions S_c. If S_c is considered to be an assigned value S_0, then

$$S_e = S_c = S_0 \tag{20}$$

Summary of Equations for Adiabatic Combustion and Isentropic Expansion

Equations (5), (9), (11), and (13), together with equation (17) for adiabatic combustion or equation (20) for isentropic expansion, are sufficient to solve the problem of equilibrium calculations completely. However, these equations involve both the moles n_i and the partial pressures p_i. The equations can be expressed in the same variables by letting A be that number of formula weights of equivalent reactant such that, for ideal gases,

$$p_i = n_i \tag{21}$$

This is the same as saying that the reaction takes place in a volume V numerically equal to RT. Each condensed phase is considered to occupy a negligible volume with respect to the volume occupied by the gases, even when finely divided and suspended in the gas. Condensed phases are further discussed in the subsequent section on "Condensation phenomena."

ITERATION TECHNIQUE

The two sets of equations ((5), (9), (11), (13), and (17), and (5), (9), (11), (13), and (20)) are sets of nonlinear equations, and therefore it is usually not feasible to find a direct solution. The Newton-Raphson method for solving nonlinear equations (ref. 23) is well suited to this type of calculation. In this method the finite-difference approximation to the total differential serves as a basis for the iteration procedure. This method will be illustrated by a simple example.

Let Q_1 and Q_2 be two nonlinear functions of x and y:

$$\left.\begin{aligned} Q_1 &= Q_1(x,y) = 0 \\ Q_2 &= Q_2(x,y) = 0 \end{aligned}\right\} \tag{22}$$

and let their simultaneous solution be $\bar{x},\bar{y}$. For any other values of x and y, say x_i,y_i,

$$\left.\begin{aligned} Q_1(x_i,y_i) &\neq Q_1(\bar{x},\bar{y}) \\ Q_2(x_i,y_i) &\neq Q_2(\bar{x},\bar{y}) \end{aligned}\right\} \tag{23}$$

or

$$\left.\begin{aligned} \Delta Q_1 &= Q_1(\bar{x},\bar{y}) - Q_1(x_i,y_i) \\ \Delta Q_2 &= Q_2(\bar{x},\bar{y}) - Q_2(x_i,y_i) \end{aligned}\right\} \tag{24}$$

The total differentials of (22) are

$$\left.\begin{aligned} dQ_1 &= \frac{\partial Q_1}{\partial x}\,dx + \frac{\partial Q_1}{\partial y}\,dy \\ dQ_2 &= \frac{\partial Q_2}{\partial x}\,dx + \frac{\partial Q_2}{\partial y}\,dy \end{aligned}\right\} \qquad (25)$$

In finite-difference form, these become

$$\left.\begin{aligned} \Delta Q_1 &= \left(\frac{\partial Q_1}{\partial x}\right)\Delta x + \left(\frac{\partial Q_1}{\partial y}\right)\Delta y \\ \Delta Q_2 &= \left(\frac{\partial Q_2}{\partial x}\right)\Delta x + \left(\frac{\partial Q_2}{\partial y}\right)\Delta y \end{aligned}\right\} \qquad (26)$$

If the difference terms ΔQ_1 and ΔQ_2 and the analytic expressions for the partial derivatives are evaluated numerically at the point x_i, y_i, the correction variables Δx and Δy can be solved for simply, since equation (26) is a simultaneous linear set of equations in the correction variables.

Because equation (26) is not exact,

$$\left.\begin{aligned} x_{i+1} &= x_i + \Delta x \neq \bar{x} \\ y_{i+1} &= y_i + \Delta y \neq \bar{y} \end{aligned}\right\} \qquad (27)$$

but rather x_{i+1} and y_{i+1} will in general be a closer approximation to $\bar{x}$ and $\bar{y}$ than are x_i and y_i. The process of solving for corrections Δx and Δy is repeated until Δx and Δy (or ΔQ_1 and ΔQ_2) are sufficiently small.

Linear Correction Equations

Equations. - The finite-difference form of the total differential of equations (5), (9), (11), (13), (17), and (20) in terms of logarithmic correction variables is

$$\left.\begin{aligned}
A\,\Delta a &= A(a_0 - a) = \sum_i a_i n_i\,\Delta \ln n_i - \sum_i a_i n_i\,\Delta \ln A \\
A\,\Delta b &= A(b_0 - b) = \sum_i b_i n_i\,\Delta \ln n_i - \sum_i b_i n_i\,\Delta \ln A \\
A\,\Delta c &= A(c_0 - c) = \sum_i c_i n_i\,\Delta \ln n_i - \sum_i c_i n_i\,\Delta \ln A \\
\ldots &= \ldots\ldots = \ldots\ldots\ldots\ldots
\end{aligned}\right\} \quad (28)$$

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$$-\delta_i = \Delta \ln p_i - (a_i\,\Delta \ln p_Z + b_i\,\Delta \ln p_Y + c_i\,\Delta \ln p_X + \ldots) - q_i\,\Delta \ln T \quad (29)$$

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$$\left.\begin{aligned}
-\delta_N &= -(a_N\,\Delta \ln p_Z + b_N\,\Delta \ln p_Y + c_N\,\Delta \ln p_X + \ldots) - q_N\,\Delta \ln T \\
\ldots &= \ldots
\end{aligned}\right\} \quad (30)$$

where $q = \dfrac{\Delta H_T^{\circ}}{RT} = \dfrac{\partial\left(-\dfrac{\Delta F_T^{\circ}}{RT}\right)}{\partial \ln T}$;

$$\Delta P = (P_0 - P) = \sum_i p_i\,\Delta \ln p_i \quad (31)$$

$$A\,\Delta H = A(H_0 - H) = \sum_i (H_T^{\circ})_i n_i\,\Delta \ln n_i - \sum_i (H_T^{\circ})_i n_i\,\Delta \ln A + T\sum_i (C_P^{\circ})_i n_i\,\Delta \ln T \quad (32)$$

$$A\,\Delta S = A(S_0 - S) = \sum_i (S_T)_i n_i\,\Delta \ln n_i - \sum_i (S_T)_i n_i\,\Delta \ln A + \sum_i (C_P^{\circ})_i n_i\,\Delta \ln T \quad (33)$$

where

$$(S_T)'_i \begin{cases} = (S_T^o)_i - R(1 + \ln p_i) = (S_T)_i - R & \text{for gases} \\ = (S_T^o)_i & \text{for condensed phases} \end{cases} \qquad (34)$$

The values for Δa, Δb, Δc, . . ., $(-\delta_i)$, $(-\delta_N)$, . . ., ΔP, ΔH, and ΔS serve to indicate the error still left in the system of equations with the estimates n_i, A, and T.

Relation between δ_i and q_i. - For purposes of machine computation, it was found more convenient to write equations (8) and (10) in a different form. The relation

$$\left(\frac{\Delta F_T^o}{RT}\right)_i = \left(\frac{\Delta H_T^o}{RT}\right)_i - \left(\frac{\Delta S_T^o}{R}\right)_i = q_i - \left(\frac{\Delta S_T^o}{R}\right)_i \qquad (35)$$

is used to eliminate $(\Delta F_T^o/RT)_i$ in equations (8) and (10), which become

$$\delta_i = q_i - \left[\left(\frac{S_T^o}{R}\right)_i - \ln p_i\right] + a_i\left[\left(\frac{S_T^o}{R}\right)_Z - \ln p_Z\right] + b_i\left[\left(\frac{S_T^o}{R}\right)_Y - \ln p_Y\right] + c_i\left[\left(\frac{S_T^o}{R}\right)_X - \ln p_X\right] + \ . \ . \ . \qquad (36)$$

$$\delta_N = q_N - \left[\left(\frac{S_T^o}{R}\right)_N\right] + a_N\left[\left(\frac{S_T^o}{R}\right)_Z - \ln p_Z\right] + b_N\left[\left(\frac{S_T^o}{R}\right)_Y - \ln p_Y\right] + c_N\left[\left(\frac{S_T^o}{R}\right)_X - \ln p_X\right] + \ . \ . \ . \qquad (37)$$

Matrix Representation of Correction Equations

Matrix. - The augmented matrix for the combustion problem (eqs. (28) to (32)) is given in figure 1. The augmented matrix for the expansion problem is identical to that for combustion, except that equation (32) is replaced by equation (33), as indicated in the footnote in figure 1. A direct elimination of the correction variables pertaining to the gaseous molecules gives a new matrix whose order is equal to the sum of the different chemical elements and condensed phases plus 2. This reduced matrix is presented as figure 2, where the correction variables for the condensed phases are linear rather than logarithmic to permit a greater symmetry in the coefficient matrix.

In figure 2 and elsewhere in this report, the symbol p_i is used in summations that include only gaseous reaction products, whereas the symbol n_i is used in summations that include condensed as well as gaseous reaction products.

Condensation phenomena. - In this report, a molecular species which appears in a condensed phase is considered to be independent of the same species in the gaseous phase. The vapor pressure is assigned completely to the gas phase, and a zero vapor pressure is assigned to the condensed phase. Two separate equilibrium equations (eqs. (8) and (10)) are written for this species, one for the gaseous phase and one for the condensed. The vapor-condensed-phase equilibrium is implicit in these two equations.

The present program is capable of considering several situations when the chemical system is such that condensed reaction products are possible. In the first situation, a condensed product is assumed to be present. After the equilibrium compositions have been determined, the assumption is checked. If correct, the program continues; if incorrect (a negative value for the amount of the condensed product), the program automatically restarts the calculations with this condensed phase excluded. In a second situation, a condensed phase is assumed to be not present. After equilibrium compositions have been determined, if the assumption is correct the program continues. If the assumption is incorrect (the partial pressure of the condensable gas exceeds the vapor pressure), the program automatically restarts the calculations with the condensed phase included.

The criterion for condensation is easily obtained from the equilibrium constant. Thus, for the reaction

$$(Z_{a_i} Y_{b_i} X_{c_i} \dots)_g = (Z_{a_N} Y_{b_N} X_{c_N} \dots)_c \tag{38}$$

where $a_i = a_N$, $b_i = b_N$, $c_i = c_N \dots$, the equilibrium constant is

$$K = \frac{K_N}{K_i} = \frac{1}{p_{vap}} = e^{-\left[\frac{(F_T^o)_c - (F_T^o)_g}{RT}\right]} \tag{39}$$

Condensation occurs when

$$p_i \geq p_{vap} = \frac{1}{K}$$

or

$$p_i K \geq 1$$

which can be written as

$$\frac{(F_T^o)_c - (F_T^o)_g}{RT} - \ln p_i \leq 0 \tag{40}$$

THERMODYNAMIC FIRST PARTIAL DERIVATIVES

From the many thermodynamic first partial derivatives, it is possible arbitrarily to select three independent derivatives and then to express all the other possible thermodynamic first partial derivatives in terms of these three. The three thermodynamic derivatives selected for calculation in this report are $(\partial H/\partial T)_P$, $(\partial \ln \mathcal{M}/\partial \ln T)_P$, and $(\partial \ln \mathcal{M}/\partial \ln P)_T$, where $\mathcal{M}$ is the molecular weight of the reaction products as defined in equation (45).

Heat Capacity at Constant Pressure

The enthalpy of the products of reaction per equivalent formula of reactant is given by (16). Since the heat capacity per equivalent formula of reactant is $(\partial H/\partial T)_P$, then the heat capacity of the reaction products per mole of reaction product is

$$\frac{A}{n}\left(\frac{\partial H}{\partial T}\right)_P = C_P^o \tag{41}$$

where

$$n = \sum_i n_i$$

Differentiation of equation (16) gives an expression for $(\partial H/\partial T)_P$ that may be used to obtain C_P^o in equation (41):

$$\left(\frac{\partial H}{\partial T}\right)_P = \frac{1}{AT}\left[\sum_i (H_T^o)_i p_i \left(\frac{\partial \ln p_i}{\partial \ln T}\right)_P + (H_T^o)_N \left(\frac{\partial n_N}{\partial \ln T}\right)_P + (H_T^o)_M \left(\frac{\partial n_N}{\partial \ln T}\right)_P + \right.$$
$$\left. \ldots + T\sum_i (C_P^o)_i n_i - \sum_i (H_T^o)_i n_i \left(\frac{\partial \ln A}{\partial \ln T}\right)_P\right] \tag{42}$$

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Equation (42) may be written in another form that was found more convenient with the calculation method of this report. Differentiation of (9) gives the identity

$$\left(\frac{\partial \ln p_i}{\partial \ln T}\right)_P = a_i\left(\frac{\partial \ln p_Z}{\partial \ln T}\right)_P + b_i\left(\frac{\partial \ln p_Y}{\partial \ln T}\right)_P + \cdot \cdot \cdot + q_i \tag{43}$$

Combining equations (41), (42), and (43) gives the following expression for C_P^O:

$$C_P^O = \frac{1}{nT}\Bigg[\sum_i (H_T^O)_i a_i p_i\left(\frac{\partial \ln p_Z}{\partial \ln T}\right)_P + \sum_i (H_T^O)_i b_i p_i\left(\frac{\partial \ln p_Y}{\partial \ln T}\right)_P + \cdot \cdot \cdot + (H_T^O)_N\left(\frac{\partial n_N}{\partial \ln T}\right)_P + (H_T^O)_M\left(\frac{\partial n_M}{\partial \ln T}\right)_P + \cdot \cdot \cdot - \sum_i (H_T^O)_i n_i\left(\frac{\partial \ln A}{\partial \ln T}\right)_P + T\sum_i (C_P^O)_i n_i + (H_T^O)_i q_i p_i\Bigg] \tag{44}$$

A comparison of equation (44) with the last row in figure 2 shows that the coefficients of the derivatives are the elements of the enthalpy row. The solution of the partials $(\partial \ln p_Z/\partial \ln T)_P$, $(\partial \ln p_Y/\partial \ln T)_P$, . . ., is discussed in the section on "Derivative Matrices."

Molecular-Weight Derivatives

Each condensed phase is considered to occupy a negligible volume with respect to the volume occupied by the gases, even when finely divided and suspended in the gas. An average molecular weight is then defined to be the weight of the reaction products divided by the number of moles of gaseous products:

$$\mathscr{M} = \frac{\sum_i n_i \mathscr{M}_i}{\sum_i p_i} = \frac{A\,\mathscr{M}_r}{P} \tag{45}$$

where $\mathscr{M}_r$ is the formula weight of the equivalent formula of equation (3). When only gaseous products are formed in the reaction, this definition is identical to the usual definition of an average molecular weight. With the definition of equation (45), the molecular weight is suitable for use in the ideal gas law even when solids are present:

$$\left.\begin{aligned} P &= \frac{\rho RT}{\mathscr{M}} \\ &\text{or} \\ Pv &= \frac{RT}{\mathscr{M}} \end{aligned}\right\} \tag{46}$$

The density ρ or specific volume v in equation (46) is the average value of the mixture of gases and condensed phases. Taking logarithms of equation (45),

$$\ln \mathcal{M} = \ln A + \ln \mathcal{M}_r - \ln P \tag{47}$$

Differentiation of equation (47) with respect to $\ln T$ at constant P gives

$$\left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P = \left(\frac{\partial \ln A}{\partial \ln T}\right)_P \tag{48}$$

Differentiation of equation (47) with respect to $\ln P$ at constant T gives

$$\left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T = \left(\frac{\partial \ln A}{\partial \ln P}\right)_T - 1 \tag{49}$$

Differentiation of equation (12) with respect to $\ln A$ at constant T gives

$$\left(\frac{\partial \ln P}{\partial \ln A}\right)_T = \frac{1}{\left(\frac{\partial \ln A}{\partial \ln P}\right)_T} = \frac{1}{P}\sum_i p_i\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T \tag{50}$$

which may be used in equation (49) to give

$$\left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T = \left[\frac{P}{\sum_i p_i\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T} - 1\right] \tag{51}$$

Differentiation of equation (9) gives

$$\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T = a_i\left(\frac{\partial \ln p_Z}{\partial \ln A}\right)_T = b_i\left(\frac{\partial \ln p_Y}{\partial \ln A}\right)_T + \cdot \cdot \cdot \tag{52}$$

Equations (51) and (52) may be combined to give

$$\left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T = \left[\frac{P}{\sum_i a_i p_i\left(\frac{\partial \ln p_Z}{\partial \ln A}\right)_T + \sum_i b_i p_i\left(\frac{\partial \ln p_Y}{\partial \ln A}\right)_T + \cdot \cdot \cdot} - 1\right] \tag{53}$$

Comparison of equation (53) and the pressure row in figure 2 shows that the coefficients of the derivatives in equation (53) are the elements of the pressure row.

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Other First Partial Derivatives (γ and C_V^o)

Bridgman (ref. 24) presents a convenient scheme for expressing all first partial derivatives in terms of three first partial derivatives, one of which is the same as selected in this report, $(\partial H/\partial T)_P = C_P^o$, and two of which are different, $(\partial v/\partial T)_P$ and $(\partial v/\partial P)_T$. In order to make use of the tables of reference 24, $(\partial v/\partial T)_P$ and $(\partial v/\partial P)_T$ can be obtained from the derivatives given in this report by means of the following equations, which have been derived from the equation of state for ideal gases with variable molecular weight (eq. (46)):

$$\left(\frac{\partial v}{\partial T}\right)_P = \frac{v}{T}\left[1 - \left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P\right] \tag{54}$$

$$\left(\frac{\partial v}{\partial P}\right)_T = -\frac{v}{P}\left[1 + \left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T\right] \tag{55}$$

With the aid of the tables in reference 24 and equations (46), (54), and (55), other first partial derivatives can be expressed in terms of C_P^o, $(\partial \ln \mathcal{M}/\partial \ln T)_P$, and $(\partial \ln \mathcal{M}/\partial \ln P)_T$. As examples, expressions are derived for the isentropic exponent γ, which is used to calculate velocity of sound, and specific heat at constant volume C_V^o.

By definition,

$$\gamma = \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s = -\left(\frac{\partial \ln P}{\partial \ln v}\right)_s = -\frac{v}{P}\left(\frac{\partial P}{\partial v}\right)_s \tag{56}$$

From Bridgman's tables (ref. 24),

$$\left(\frac{\partial P}{\partial v}\right)_s = \frac{C_P^o/\mathcal{M}}{\left(\frac{C_P^o}{\mathcal{M}}\right)\left(\frac{\partial v}{\partial P}\right)_T + T\left(\frac{\partial v}{\partial T}\right)_P^2} \tag{57}$$

Substituting equations (46), (54), (55), and (57) into equation (56) yields

$$\gamma = \frac{C_P^o/R}{\frac{C_P^o}{R}\left[1 + \left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T\right] - \left[1 - \left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P\right]^2} \tag{58}$$

For nonreacting gases ("frozen" composition), $\mathcal{M}$ is a constant, and equation (58) reduces to

$$\gamma = \frac{C_P^o/R}{\frac{C_P^o}{R} - 1} \tag{59}$$

By definition and from Bridgman's tables (ref. 24),

$$\frac{C_V^o}{\mathcal{M}} = \frac{1}{\mathcal{M}}\left(\frac{\partial E}{\partial T}\right)_V = \frac{\left(\frac{C_P^o}{\mathcal{M}}\right)\left(\frac{\partial v}{\partial P}\right)_T + T\left(\frac{\partial v}{\partial T}\right)_P^2}{\left(\frac{\partial v}{\partial P}\right)_T} \tag{60}$$

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Substituting equations (46), (54), and (55) into equation (60) gives

$$C_V^o = C_P^o - R\frac{\left[1 - \left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P\right]^2}{\left[1 + \left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T\right]} \tag{61}$$

For nonreacting gases, $\mathcal{M}$ is constant, and equation (61) reduces to

$$C_V^o = C_P^o - R \tag{62}$$

Derivative Matrices

The evaluation of the three independent thermodynamic first partial derivatives is possible if the quantities $(\partial \ln p_Z/\partial \ln T)_P$, $(\partial \ln p_Y/\partial \ln T)_P$ . . . $(\partial n_N/\partial \ln T)_P$ . . . $(\partial \ln A/\partial \ln T)_P$ and $(\partial \ln p_Z/\partial \ln A)_T$, $(\partial \ln p_Y/\partial \ln A)_T$, . . . are known. These quantities may be calculated for equilibrium conditions by the solution of a set of simultaneous equations involving the preceding derivatives. The necessary equations for the temperature derivatives may be obtained from equations (5), (9), (11), and (13). Differentiation of these equations with respect to $\ln T$ at constant P gives

$$\left.\begin{aligned}
&\sum_i a_i p_i\left(\frac{\partial \ln p_i}{\partial \ln T}\right)_P + a_N\left(\frac{\partial n_N}{\partial \ln T}\right)_P + \cdots - \sum_i a_i n_i\left(\frac{\partial \ln A}{\partial \ln T}\right)_P = 0\\
&\sum_i b_i p_i\left(\frac{\partial \ln p_i}{\partial \ln T}\right)_P + b_N\left(\frac{\partial n_N}{\partial \ln T}\right)_P + \cdots - \sum_i b_i n_i\left(\frac{\partial \ln A}{\partial \ln T}\right)_P = 0\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots = 0
\end{aligned}\right\} \tag{63}$$

$$\left(\frac{\partial \ln p_i}{\partial \ln T}\right)_P - \left[a_i\left(\frac{\partial \ln p_Z}{\partial \ln T}\right)_P + b_i\left(\frac{\partial \ln p_Y}{\partial \ln T}\right)_P + \cdot \cdot \cdot\right] - q_i = 0 \qquad (64)$$

$$\left.\begin{aligned} a_N\left(\frac{\partial \ln p_Z}{\partial \ln T}\right)_P + b_N\left(\frac{\partial \ln p_Y}{\partial \ln T}\right)_P + \cdot \cdot \cdot + q_N &= 0 \\ \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot &= 0 \end{aligned}\right\} \qquad (65)$$

$$\sum_i p_i\left(\frac{\partial \ln p_i}{\partial \ln T}\right)_P = 0 \qquad (66)$$

If equation (64) is used to eliminate $(\partial \ln p_i/\partial \ln T)_P$ from equations (63) and (66), then the resulting augmented matrix is identical to the matrix of figure 2 with the last row and column deleted, as shown in figure 3.

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The derivatives with respect to $\ln A$ at constant T are obtained in a similar fashion. Differentiation of equations (5), (9), and (11) yields:

$$\left.\begin{aligned} \sum_i a_i p_i\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T + a_N\left(\frac{\partial n_N}{\partial \ln A}\right)_T + \cdot \cdot \cdot - \sum_i a_i n_i &= 0 \\ \sum_i b_i p_i\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T + b_N\left(\frac{\partial n_N}{\partial \ln A}\right)_T + \cdot \cdot \cdot - \sum_i b_i n_i &= 0 \\ \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot &= 0 \end{aligned}\right\} \qquad (67)$$

$$\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T - \left[a_i\left(\frac{\partial \ln p_Z}{\partial \ln A}\right)_T + b_i\left(\frac{\partial \ln p_Y}{\partial \ln A}\right)_T + \cdot \cdot \cdot\right] = 0 \qquad (68)$$

$$\left.\begin{aligned} a_N\left(\frac{\partial \ln p_Z}{\partial \ln A}\right)_T + b_N\left(\frac{\partial \ln p_Y}{\partial \ln A}\right)_T + \cdot \cdot \cdot &= 0 \\ \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot &= 0 \end{aligned}\right\} \qquad (69)$$

If equation (68) is used to eliminate $(\partial \ln p_i/\partial \ln A)_T$ from equation (67), then the resulting augmented matrix is identical to the matrix of figure 2 with the last two rows and columns deleted, as shown in figure 4.

ROCKET PERFORMANCE PARAMETERS

Calculation

The evaluation of rocket performance parameters for a propellant is simple once the temperature and composition are known at combustion and exit points of a nozzle. The following formulas used in computing the various performance parameters were derived from the one-dimensional forms of continuity, energy, and momentum equations and the following assumptions: zero velocity in the combustion chamber, perfect gas law, complete combustion, homogeneous mixing, adiabatic combustion, and isentropic expansion. (The units used were h = cal/g, T = °K, P = lb force/sq in., A = sq in., w = lb mass/sec, and g_c = 32.174 (lb mass/lb force)(ft/sec^2).)

Specific impulse with ambient and exit pressures equal, (lb force)(sec)/lb mass:

$$I = 294.98\sqrt{\frac{h_c - h}{1000}} \tag{70}$$

Specific impulse in vacuum (ambient pressure zero), (lb force)(sec)/lb mass:

$$I_{vac} = I + P\left(\frac{A}{w}\right) \tag{71}$$

Nozzle area per unit mass-flow rate, (sq in.)(sec)/lb:

$$\frac{A}{w} = \frac{86.4554\ T}{P\mathcal{M}I} \tag{72}$$

Characteristic velocity, ft/sec:

$$c^* = g_c P_c \frac{A_t}{w} = 32.174\ P_c \frac{A_t}{w} \tag{73}$$

Coefficient of thrust:

$$C_F = \frac{g_c I}{c^*} = 32.174 \frac{I}{c^*} \tag{74}$$

Mach number:

$$M = \frac{U}{a} = \frac{I}{\sqrt{\frac{86.4554\ \gamma T}{\mathcal{M}}}} \tag{75}$$

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Effect of Chamber Pressure on Performance Parameters

For a given pressure ratio P_c/P, the logarithms of the performance parameters given in equations (70) to (74) are very nearly linear in the logarithm of the combustion-chamber pressure P_c. Thus, if any one of the performance parameters is denoted by λ, then, to a good approximation,

$$\left(\frac{\partial \ln \lambda}{\partial \ln P_c}\right)_{P_c/P} = \pi_\lambda \cong \frac{\ln \lambda_2 - \ln \lambda_1}{\ln(P_c)_2 - \ln (P_c)_1} \tag{76}$$

or

$$\frac{\lambda_2}{\lambda_1} \cong \left[\frac{(P_c)_2}{(P_c)_1}\right]^{\pi_\lambda} \tag{77}$$

Analytical expressions are readily obtained for the partial derivatives π_λ by the method indicated in reference 25. Using this technique it is possible to derive the following identities:

$$\pi_I = \frac{RT}{I^2}\left[\frac{1}{\mathcal{M}_c} - \frac{1}{\mathcal{M}}\right] \tag{78}$$

$$\pi_{A/w} = -\left\{\frac{R}{C_P^o \dfrac{\mathcal{M}_c}{\mathcal{M}}}\left[1 - \left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P\right] + \frac{1}{\gamma} + \pi_I\right\} \tag{79}$$

$$\pi_\epsilon = \pi_{A/w} - (\pi_{A/w})_t \tag{80}$$

$$\pi_{c^*} = 1 + (\pi_{A/w})_t \tag{81}$$

$$\pi_T = \frac{R}{C_P^o}\left[1 - \left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P\right] - \frac{R}{C_P^o\left(\dfrac{\mathcal{M}_c}{\mathcal{M}}\right)} \tag{82}$$

$$\pi_{C_F} = \pi_I - \pi_{c^*} \tag{83}$$

$$\pi_{I_{vac}} = \frac{I(\pi_I) + (I_{vac} - I)(\pi_\epsilon + \pi_{c^*})}{I_{vac}} \tag{84}$$

ITERATION TO AN ASSIGNED MACH NUMBER

It may sometimes be desired to calculate conditions following an isentropic expansion to an assigned Mach number rather than to an assigned pressure. For example, one might wish to find the conditions at the throat of a nozzle where the Mach number is 1. The procedure used in this report for calculating conditions at an assigned Mach number is as follows:

(1) An estimate of pressure corresponding to the assigned Mach number is made.

(2) After equilibrium composition and temperature have been obtained in a manner identical to isentropic expansion to assigned pressure, the Mach number is then calculated.

(3) The error between the desired Mach number and the calculated Mach number is used to obtain a new estimate for pressure.

(4) Steps (2) and (3) are repeated until the desired degree of accuracy is obtained.

The correction to the assumed pressure ratio can be obtained by using a parameter h^*, defined as

$$h^* = h + \frac{M_0^2}{2} \frac{\gamma RT}{\mathcal{M}} \qquad (85)$$

where h, γ, T, and $\mathcal{M}$ are values corresponding to the assumed pressure, and M_0 is the assigned Mach number. When the correct pressure (or pressure ratio) is used, h^* will equal the initial enthalpy of the propellants h_c. The estimate for the pressure ratio is corrected on the basis of the difference between h^* and h_c. Since h^* is a function of P,

$$\Delta h^* = \left(\frac{\partial h^*}{\partial \ln P}\right)_s \Delta \ln P \qquad (86)$$

where

$$\Delta h^* = h_c - h_k^*$$

and

$$\Delta \ln P = \frac{P_{k+1} - P_k}{P_k}$$

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with the subscript k referring to the k^{th} estimate. Equation (86) then gives

$$\frac{P_c}{P_{k+1}} = \frac{P_c/P_k}{\left[1 + \dfrac{h_c - h_k^*}{\left(\dfrac{\partial h^*}{\partial \ln P}\right)_s}\right]} \tag{87}$$

The $(k+1)^{th}$ estimate can be obtained from the k^{th} estimate for the pressure ratio by means of equation (87), provided that $(\partial h^*/\partial \ln P)_s$ can be evaluated. Since γ is essentially constant for a small change in pressure ratio, then from equation (85),

$$\left(\frac{\partial h^*}{\partial \ln P}\right)_s \cong P\left\{\left(\frac{\partial h}{\partial P}\right)_s + \frac{\gamma R M_0^2}{2}\left[\frac{\partial(T/\mathcal{M})}{\partial P}\right]_s\right\} \tag{88}$$

From equation (46) for an ideal gas,

$$\left[\frac{\partial(T/\mathcal{M})}{\partial P}\right]_s = \frac{1}{R\rho}\left[1 - \left(\frac{\partial \ln \rho}{\partial \ln P}\right)_s\right] = \frac{1}{R\rho}\left(\frac{\gamma - 1}{\gamma}\right) \tag{89}$$

Using the thermodynamic relation $(\partial h/\partial P)_s = 1/\rho$ and equation (89) in equation (88) yields

$$\left(\frac{\partial h^*}{\partial \ln P}\right)_s \cong \frac{RT}{\mathcal{M}}\left[1 + \frac{M_0^2}{2}(\gamma - 1)\right] \tag{90}$$

In particular, at the throat $M_0 = 1$ and equation (90) becomes

$$\left(\frac{\partial h^*}{\partial \ln P}\right)_s \cong \frac{RT}{2\mathcal{M}}(\gamma + 1) \tag{91}$$

COMPUTER PROGRAM

A computer program for performing the calculations previously discussed has been made for an IBM 650 Magnetic Drum Data-Processing Machine with 2000 words of drum storage, 60 words of high-speed core storage, indexing registers, floating point attachments, and an alphabetic device. When additional attachments such as tapes and RAMAC are available, the program may be modified to make use of these attachments. A wiring diagram for the IBM type 533 Read-Punch Unit is given in appendix I. In the description of the program, a familiarity with the symbolic coding for the IBM 650 computer (SOAP II) is assumed, as described in IBM Form 32-7646-1, "Soap Programmer's Reference Manual." References to storage locations will be made with symbolic addresses given in upper case and enclosed by quotes. For the absolute equivalents of the symbolic addresses, the program listing given in appendixes F, G, and H can be consulted.

Because of computer storage limitations, it was necessary to divide the program into two sections, (1) The "Vector and Propellant Program," which prepares most of the input data and requires an alphabetic device on the IBM 650, and (2) The "Main Calculating Program," which solves for the equilibrium compositions and temperatures and the performance parameters. The Main Calculating Program may be used without using the Vector and Propellant Program if the necessary input data are prepared manually. The primary use of the Vector and Propellant Program is to simplify the preparation of input data and to minimize the possibility of errors. However, since the use of the Vector and Propellant Program is optional, the Main Calculating Program will be described first.

MAIN CALCULATING PROGRAM

General Description

Figure 5 gives a schematic outline of the Main Calculating Program. Individual portions of the program will be discussed in more detail in later sections. A SOAP listing of the Main Program is given in appendix F, and operating instructions are given in appendix C.

The program as written is capable of performing thermodynamic equilibrium calculations for both combustion and isentropic expansion conditions for a chemical system that may include as many as 10 different chemical elements (if no condensed phases appear as reaction products). When condensed phases are present as reaction products, then the sum of the different chemical elements and different condensed phases must not exceed 10. This restriction implies that the size of the reduced augmented matrix (fig. 2) is limited to 12×13. It should be emphasized that this restriction is imposed solely by machine storage limitations.

The program will handle as many as 30 reaction products and 25 pressure ratios including the combustion chamber and the throat. The restriction on the number of products and pressure ratios is also the result of storage limitations. The program calculates the equilibrium composition, temperature, pressure, enthalpy, and entropy of the reaction products, and the following performance parameters: specific impulse, specific impulse in vacuum, thrust coefficient, characteristic velocity, area ratio, specific heat, isentropic exponent γ, and Mach number. The program also calculates the derivatives $\left(\frac{\partial \ln \mathcal{M}}{\partial \ln T}\right)_P$, $\left(\frac{\partial \ln \mathcal{M}}{\partial \ln P}\right)_T$, and the chamber-pressure derivatives π_I, π_ϵ, π_T, and π_{c^*}.

Normally the program calculates combustion conditions ($P_c/P = 1$), then throat conditions, and finally other exit conditions corresponding to assigned pressure ratios. The program is easily modified to operate for assigned temperatures and pressures or to work a series of constant-enthalpy calculations at various pressures. The necessary changes in the program are given in the section "Program Modifications."

The following input data are required by the Main Calculating Program for the solution of equilibrium compositions and temperature following an adiabatic combustion process:

(1) The reaction products to be considered

(2) Gram atoms of elements in 1 gram of fuel and 1 gram of oxidant

(3) Enthalpies of fuel and oxidant per gram of fuel and oxidant

(4) Oxidant to fuel weight ratio O/F (or percent fuel or equivalence ratio r)

(5) Thermodynamic data for products considered

(6) Chamber pressure

(7) Initial estimate of temperature, composition, and number of formula weights A. (A set of estimates is already provided by the program and therefore need not be supplied unless a better set is desired.)

Reaction products (the composition vector). - The composition of any product of reaction in terms of the elements may be represented as a chemical vector whose components are determined by the chemical formula for the reaction product. Thus, the molecule $Z_{a_i}Y_{b_i}X_{c_i}$ . . . may be associated with the vector

$$C = \left\{a_i, b_i, c_i \ldots\right\}$$

The number of components associated with each composition vector is known once it is decided how many chemical elements are to be considered in any particular problem. For example, if hydrogen and oxygen were the only two elements appearing, then any reaction product could be specified with two components. If hydrogen, oxygen, and nitrogen were the elements under consideration, then each reaction product would have three components. This is illustrated in the following table for four possible products of reaction involving hydrogen, oxygen, and nitrogen:

Product	Component		
	H	N	O
N	0	1	0
OH	1	0	1
H_2O	2	0	1
NO	0	1	1

A considerable portion of the matrix of figure 2 may be constructed in a reasonably systematic manner with the aid of the composition vector. This is described in the section "Vector multiplication routine."

Packed chemical vector. - The total number of components of all the chemical vectors is directly related to the size of the chemical system and to the number of possible reaction products. Thus, for a 10-element system in which 30 different products of reaction are to be considered, a total of 300 components requiring 300 storage locations would have to be specified. Since these numbers would be placed in the storage area of a computer with limited storage capacity, the storage area available for programming would be seriously reduced. It has been found that with a few suitable restrictions all the components of a vector may be packed into one 10-digit word, and thus only 30 storages would be required for 30 products. The following restrictions have been set forth:

(1) All the chemical vector components that are not specified are assumed to be zero.

(2) No reaction product may be formed from more than five different chemical elements; that is, the chemical vector may have no more than five nonzero components.

(3) Each subscript in the chemical formula for the reaction product must be less than 10; that is, no vector component may be greater than 9.

The packed chemical vector may now be generated from the chemical formula of a reaction product in the following manner:

(1) Each element in the chemical system is assigned a number equal to one less than its column assignment in the reduced augmented matrix (fig. 2). This number is used to specify the component.

(2) The magnitude of any component is equal to the subscript associated with the chemical element in the chemical formula for the reaction product under consideration.

(3) The packed vector consists of five pairs of numbers. In each pair of numbers (where both numbers are not zero) the number designating the component precedes the number that gives the magnitude of the component.

(4) The nonzero vector components and their associated magnitudes are arranged in the packed vector in the order of their appearance in the chemical formula of the reaction product, the entire packed vector being shifted as far to the right as possible.

(5) The sign of the packed composition vector is positive for a gaseous reaction product and negative for a condensed-phase reaction product.

An example of how components might be designated in an H-N-O system is as follows:

Element	H	N	O
Column of matrix in fig. 2	1	2	3
Number designating component (column number - 1)	0	1	2

The assignment of numbers designating the elements is completely arbitrary. However, once an assignment has been made for some problem, then all product vectors must be consistent with this assignment.

Examples of packed vectors for four reaction products using the numbers designating components given in the previous table are as follows:

Reaction product	Packed vector
N	00 00 00 00 11+
OH	00 00 00 21 01+
H_2O	00 00 00 02 21+
NO	00 00 00 11 21+

To read the preceding packed vectors, proceed as follows:

(1) Pair the digits into groups of two.

(2) The first digit of a pair designates the atom.

(3) The second digit of the pair tells how many of these atoms there are.

(4) The sign is + for gas and - for condensed phases.

For example, the H_2O packed vector may be interpreted as follows:

00 00 00 02 21 +

- 00 00 00 — Ignored because both digits of each pair are zero
- 0 — Number designating element hydrogen
- 2 — Magnitude (number of hydrogen atoms)
- 2 — Number designating element oxygen
- 1 — Magnitude (number of oxygen atoms)
- + — Gaseous product

<u>Calculation of gram atoms of elements in fuel and oxidant or in reactant.</u> - To specify a reactant, the relative proportion of the elements in the reactant is all that is required. That is, the absolute magnitude of the elements $a_0, b_0, c_0, \ldots$ in the equivalent reactant $Z_{a_0}Y_{b_0}X_{c_0} \ldots$ is immaterial if their ratios remain constant. In the IBM 650 program the number of gram atoms of each element in a reactant is calculated to be that number which gives an equivalent formula with a formula weight $\mathcal{M}_r$ of 1.

For example, the equivalent formula in equation (1) $(H_7N_2O_3)$ has a molecular weight of 83.072. In the IBM 650 program the equivalent formula would be $H_{(7/83.072)}\,N_{(2/83.072)}\,O_{(3/83.072)}$ or $H_{0.08426}\,N_{0.02408}\,O_{0.03611}$ $(\mathcal{M}_r = 1)$.

The method selected in this report for the calculation of the gram atoms of element per gram of reactant was based on the assumption that performance data for a particular reactant would be desired for a number of oxidant-fuel ratios. For this reason, the input to the Main Calculating Program consists of the number of gram atoms of each element per gram of fuel and the number of gram atoms of each element per gram of oxidant. The number of gram atoms of each element per gram of reactant can then be calculated from these quantities as soon as the oxidant-fuel ratio (or % fuel or equivalence ratio r) is specified as shown in the following discussion.

The fuels are considered to be those materials undergoing oxidation primarily and the oxidants those materials undergoing reduction primarily. Let 1 gram of equivalent fuel be $Z_{a_f}Y_{b_f}X_{c_f} \ldots$ and 1 gram of equivalent oxidant be $Z_{a_x}Y_{b_x}X_{c_x} \ldots$ where $a_f, b_f, c_f \ldots$ and $a_x, b_x, c_x \ldots$ are the number of gram atoms of elements Z, Y, X . . . in 1 gram of equivalent fuel and 1 gram of equivalent oxidant, respectively. If W_x is the weight of the oxidant and W_f the weight of

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the fuel $(O/F = W_x/W_f)$, then the number of gram atoms of each element in 1 gram of equivalent reactant $Z_{a_0}Y_{b_0}X_{c_0} \ldots$ is

$$\left.\begin{aligned} a_0 &= \frac{W_x a_x + W_f a_f}{W_x + W_f} = \frac{(O/F)a_x + a_f}{(O/F) + 1} \\ b_0 &= \frac{W_x b_x + W_f b_f}{W_x + W_f} = \frac{(O/F)b_x + b_f}{(O/F) + 1} \\ \ldots &= \ldots\ldots\ldots = \ldots\ldots\ldots \end{aligned}\right\} \tag{92}$$

Equation (92) may be illustrated by considering the example of equation (1):

$$N_2H_4 + \frac{3}{2} H_2O_2 \tag{1}$$

The formulas per gram of equivalent fuel and oxidant are

$$\left.\begin{aligned} N_{(2/32.048)}\, H_{(4/32.048)} &= N_{0.062406390}\, H_{0.12481278} \\ H_{(2/34.016)}\, O_{(2/34.016)} &= H_{0.058795860}\, O_{0.058795860} \end{aligned}\right\} \tag{93}$$

(Eight significant figures are kept in this example, since the IBM 650 floating point attachment keeps eight significant figures.) For equation (1),

$$O/F = \frac{1.5(34.016)}{32.048} = 1.5921118 \tag{94}$$

and therefore

$$\left.\begin{aligned} (H)\ a_0 &= \frac{1.5921118(0.058795860) + 0.12481278}{1.5921118 + 1} = 0.084264252 \\ (N)\ b_0 &= \frac{1.5921118(0) + 0.062406390}{1.5921118 + 1} = 0.024075501 \\ (O)\ c_0 &= \frac{1.5921118(0.058795860) + 0}{1.5921118 + 1} = 0.036113250 \end{aligned}\right\} \tag{95}$$

Calculation of enthalpy of fuel and oxidant or of propellant. - Let h_f and h_x be the enthalpy per gram of equivalent fuel and per gram of equivalent oxidant, respectively. Then the enthalpy per gram of equivalent reactant $Z_{a_0}Y_{b_0}X_{c_0} \ldots$ is

$$H_0 = h_0 = \frac{(O/F)h_x + h_f}{(O/F) + 1} \qquad (96)$$

Equation (96) may be illustrated by again considering the reaction of equation (1). Using values similar to those on page 19 of reference 9 and the O/F value from equation (94),

$$\left.\begin{aligned} h_{N_2H_4} &= h_f = \frac{154,702.97}{32.048} = 4827.2269 \text{ cal/g} \\ h_{H_2O_2} &= h_x = \frac{28,681.626}{34.016} = 843.18043 \text{ cal/g} \end{aligned}\right\} \qquad (97)$$

$$h_0 = \frac{1.5921118\ (843.18043) + 4827.2269}{1.5921118 + 1} = 2380.1691 \text{ cal/g} \qquad (98)$$

Optional specification of O/F. - In addition to the oxidant to fuel weight ratio O/F, two other quantities may be used to give the relative amounts of oxidant and fuel. One of these is the weight percent of fuel in the propellant %F and the other is the equivalence ratio r.

(1) %F: The relation between O/F and %F is given by

$$\%F = \frac{100}{(O/F) + 1} \qquad (99)$$

(2) Equivalence ratio r: The equivalence ratio is defined in terms of arbitrary, permanently assigned oxidation states for each element in a compound. This practice produces no difficulty so long as all the elements have the assigned oxidation state in all their compounds (e.g., H = +1, Na = +1, F = -1). Some elements have various oxidation states; for example, sulfur, which has the oxidation numbers -2, +4, +6 in the compounds H_2S, SO_2, and H_2SO_4, respectively. In cases such as this the assigned oxidation states are taken to be those considered as occurring commonly in products. For this reason it is possible that some components of the propellant combination may show a net positive or negative oxidation state, contrary to the usual practice of having the sum of the oxidation numbers of a compound add up to zero.

Let V_Z^+, V_Y^+, V_X^+ . . . be the positive oxidation states and V_Z^-, V_Y^-, V_X^- . . . be the negative oxidation states of the elements Z, Y, X . . in the reactant. Let V_x^+ and V_x^- be the total positive oxidation state and total negative oxidation state, respectively, per gram of equivalent oxidant, and let V_f^+ and V_f^- be the total positive and negative oxidation states, respectively, per gram of equivalent fuel. Then,

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$$\left.\begin{aligned} V_x^+ &= \left[a_x V_Z^+ + b_x V_Y^+ + c_x V_X^+ + \ldots\right] \\ V_x^- &= \left[a_x V_Z^- + b_x V_Y^- + c_x V_X^- + \ldots\right] \\ V_f^+ &= \left[a_f V_Z^+ + b_f V_Y^+ + c_f V_X^+ + \ldots\right] \\ V_f^- &= \left[a_f V_Z^- + b_f V_Y^- + c_f V_X^- + \ldots\right] \end{aligned}\right\} \tag{100}$$

The total positive oxidation state V^+ and total negative oxidation state V^- per gram of propellant are

$$\left.\begin{aligned} V^+ &= \frac{(O/F)V_x^+ + V_f^+}{(O/F) + 1} \\ V^- &= \frac{(O/F)V_x^- + V_f^-}{(O/F) + 1} \end{aligned}\right\} \tag{101}$$

The equivalence ratio may now be defined as

$$r \equiv \left|\frac{V^-}{V^+}\right| = \left|\frac{V_f^- + (O/F)V_x^-}{V_f^+ + (O/F)V_x^+}\right| \tag{102}$$

This definition of r gives $r = 1$ for stoichiometric conditions, $r > 1$ for oxidant-rich conditions, and $r < 1$ for fuel-rich conditions. For those who prefer to consider $r > 1$ for fuel-rich conditions and $r < 1$ for oxidant-rich conditions, the reciprocal of r in equation (102) may be taken as the definition of equivalence ratio, provided that the computing program be correspondingly modified.

The reaction of equation (1) may be again taken to illustrate equations (100) and (102). Let a, b, c refer to H, N, O, respectively. Then, from equation (100),

$$\left.\begin{aligned} H_2O_2 &\begin{cases} V_x^+ = [2(1) + (0)(0) + 2(0)]/34.016 = 0.058795860 \\ V_x^- = [2(0) + (0)(0) + 2(-2)]/34.016 = -0.11759172 \end{cases} \\ N_2H_4 &\begin{cases} V_f^+ = [4(1) + 2(0) + 0(0)]/32.048 = 0.12481278 \\ V_f^- = [4(0) + 2(0) + 0(0)]/32.048 = 0 \end{cases} \end{aligned}\right\} \tag{103}$$

From equation (102), and using the O/F = 1.5921118 of equation (94),

$$r = \left| \frac{(1.5921118)(-0.11759172) + 0}{(1.5921118)(0.058795860) + 0.12481278} \right| = 0.85714286 \qquad (104)$$

For any problem it is sufficient to specify any one of the three quantities O/F, %F, or r, since any two may be expressed in terms of the third. (See eqs. (99) and (102), e.g.)

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Thermodynamic data. - Since the computer program solves for temperature simultaneously with composition, it was found convenient to represent the thermodynamic data for each product as a function of temperature as follows:

$$C_P^o/R = A + BT + CT^2 + DT^3 \qquad (105)$$

$$H_T^o/RT = A + \frac{BT}{2} + \frac{CT^2}{3} + \frac{DT^3}{4} + \frac{E}{T} \qquad (106)$$

$$S_T^o/R = A \ln T + BT + \frac{CT^2}{2} + \frac{DT^3}{3} + F \qquad (107)$$

where T is in degrees Kelvin. The function H_T^o/RT must include H_0^o/RT, where H_0^o is the reference enthalpy at 0^o K (see eq. (14)).

In order to minimize the errors resulting from a functional representation of the thermodynamic data, the six coefficients A, B, C, D, E, and F for each product were obtained from a simultaneous least-squares fit of the thermodynamic functions C_P^o/R, H_T^o/RT, and S_T^o/R for several selected temperature intervals with continuity from one interval to the next. Coefficients for several substances in the C, H, O, N, F, and Cl chemical system are given in table I.

Calculating Routines

The Main Calculating Program consists of ten major routines and several auxiliary routines with suitable connecting links. These routines are described in the following sections.

Packed vector loading routine. - The flow chart for the packed vector loading routine is given in figure 6. This short program permits direct loading of the packed vectors from the Vector and Propellant Program. The packed vectors are in the form of load hub cards on which the second word gives the permanent code number associated with the reaction product, and the fourth word gives the packed vector for the same product. The permanent code and the packed vector are loaded into sequential locations in the P region; that is, the code and packed vector from the first card are placed into "P0001" and "P0002," respectively; the code and vector from the next card are placed into "P0003" and "P0004," and so forth.

When the program encounters a condensed phase, it examines the contents of the word "OASIS" to determine whether or not this product is to be considered in the first iteration. Thereafter, the decision to use or not to use a condensed phase is made internally. All positions of "OASIS" must be either zero or one, a zero indicating use and one indicating nonuse of a condensed phase. Each position of "OASIS" corresponds to a different condensed phase; thus position 1 (right-most position) is associated with the first condensed phase encountered, position 2 with the second, and so forth. For example, if "OASIS" contained

00 0000 1101 +

the program would not initially consider the first, third, and fourth condensed phases encountered. Should only two condensed-phase packed vectors be present, the program will ignore all positions beyond the first two. If the operator does not specify the contents of "OASIS," the program puts ones in all positions, thus initially considering only the gas phase.

The packed vector loading routine requires a transfer card to precede the first packed vector. The transfer card is a load hub card on which the first word is

NOP 0000 V0001 + (or numerical equivalent, 000000 1599+)

The last packed vector must be followed by another load hub card on which the first word is

00 0000 0000+

The packed vectors themselves must be arranged so that all the gaseous atoms enter storage before any gaseous molecules or condensed phases. If this condition is not met, a programmed stop will halt the loading. (The vectors for gaseous atoms may be loaded in any order followed by the remainder of the vectors in any order. However, the thermal data coefficients must be loaded in the same order as the vectors.) As each gaseous atom and each condensed-phase vector considered by "OASIS" is placed into storage, it is counted so that the two constants "ATOM1" and "SYS," used to specify the size of the reduced augmented matrix, may be obtained. Both of these are fixed point numbers in the low-order positions. "ATOM1" gives the number of different elements in the chemical system, and "SYS" gives the number of elements plus the condensed phases currently being considered. During the course of loading packed vectors, any load card with word 2 blank or zero will be bypassed.

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Input data routine. - The flow chart for the input data routine is given in figure 7. The routine converts the input data as specified by the operator into suitable form for use in the computer. Thus, using equations (99) and (102), it calculates any two of the quantities O/F, r, and %F from the one which is supplied by the operator. The numbers a_0, b_0, c_0, . . . h_0 are calculated from a_f, a_x, b_f, b_x, . . . h_x, h_f using equations (92) and (96). Also, the combustion-chamber pressure in pounds per square inch absolute is converted to atmospheres.

The input data for this routine and, hence, for the general program consist of the following:

(1) A 4-digit identification number for the problem (case no.) is loaded into "F0039" as

0000 Case no. 00+

(2) The chamber pressure P_c in pounds per square inch absolute is loaded into "F0000."

(3) The numbers a_x, b_x, . . . j_x; h_x, V_x^+, and V_x^- are loaded into locations 0537, 0538, . . .; 0547, 0548, and 0549, respectively, and the numbers a_f, b_f, . . . j_f; h_f, V_f^+, and V_f^- are loaded into locations 0587, 0588, . . .; 0597, 0598, and 0599, respectively. If the Vector and Propellant Program is used, these numbers will be prepared automatically.

(4) Any one of the three quantities O/F, r, and %F is loaded into "O/F," "EQRAT," or "PCT F," respectively, while the other two are loaded as zero.

(5) A schedule of up to 25 pressure ratios is loaded into the region R(1075-1099).

A set of estimates for $\ln p_i$, n_N, $\ln T$, and $\ln A$ is already provided by the program and need not be supplied unless one wishes to use a better set of estimates. Convergence usually occurs without good estimates.

The output from this routine is seven Bell format cards (see discussion in section on "Auxiliary routines" and also appendix B). The first Bell card contains the following six words: r, O/F, %F, P_c (atm), h_0 (cal/g), and the identification number for the problem. The identification number is a composite of the equivalence ratio, the case number, and the chamber pressure in pounds per square inch absolute. The input data a_f, b_f, . . . j_f; h_f, V_f^+, V_f^-, a_x, b_x, . . . j_x; h_x, V_x^+, and V_x^- are punched out on the next six Bell cards. A console-controlled punch can be used to obtain the calculated numbers a_0, b_0 . . . (h_0/R).

Load thermal data routine. - The thermodynamic data for each reaction product are represented by six coefficients A, B, C, D, E, and F, which were discussed in the section on "Thermodynamic data." The routine requires the coefficients to be on a load hub card in columns 21 through 80 (the last six words). The first word on the card is actually the first instruction in the routine following the read command for a basic load card and is

RAL 9051 RDB

The second word is the identification for the card, being a composite of the permanent code for the molecule and the low temperature (divided by 10) and high temperature (divided by 10) of the interval for which the coefficients were obtained. Thus, if the code for the molecule is 0121 and the temperature range is from 2600° to 3200° K, word 2 would be

Code	T_{low}	T_{high}
0121	260	320

With this scheme no molecule may have a code greater than four digits in length or a temperature interval higher than 9990° K.

The information from a thermodynamic coefficient card appears on the drum in a block of ten consecutive storages in the T region. The first word of the block contains the permanent code for the molecule in the instruction address position. For the previous example this would be

00 0000 0121

The following six storage positions contain the thermal coefficients. The eighth word is reserved for the composition estimate $\ln p_i$ or n_N, while the last two words of the block are reserved for q_i and $-\delta_i$. Since the sequential blocks of ten storages are assigned to reaction products on the basis of their order of appearance, within any temperature interval the order of the thermal data cards must match the order of the packed vectors. If this is not so, a programmed stop will halt the loading of the thermal coefficients.

Each set of basic load cards corresponding to some temperature interval must be followed by a Bell format card that is filled with zeros except for words 1 (columns 11 to 21) and 2 (columns 22 to 32). Word 1 is the floating point number for the low temperature, and word 2 is the floating point number for the high temperature of the interval covered by the preceding cards.

The flow chart for the load thermal data routine is given in figure 8.

Unpacking routine and thermal routine. - The purpose of the unpacking and thermal routines is to construct a "row vector." This row vector is a set of consecutive core storage locations representing a convenient arrangement of quantities that will eventually be used to construct the elements of the reduced augmented matrix. The row vector and its contents are as follows:

Symbolic location	Absolute location	Contents
RV000	9004	$(H_T^o/R)_i$ During expansion, zero during combustion
RV001	9005	a_i
RV002	9006	b_i
RV003	9007	c_i
RV004	9008	d_i
RV005	9009	e_i } Composition vector components as floating point numbers (a_i through j_i)
RV006	9010	f_i
RV007	9011	g_i
RV008	9012	h_i
RV009	9013	i_i
RV010	9014	j_i
RV011	9015	1 For gas, 0 for condensed
RV012	9016	q_i
RV013	9017	δ_i
RV014	9018	$(H_T^o/R)_i$ For combustion, $(S'/R)_i$ for expansion

Storage space has been provided for ten subscripts or ten components of the composition vector. If the chemical system being used does not require ten components, then the first component appears in the location "RV011" minus "SYS" and is followed by the remaining components. The locations from "RV001" to "RV010" minus "SYS" inclusive remain zero. The unpacking routine fills in the locations "RV001" through "RV011" inclusive, the thermal routine completing the remaining quantities. The flow chart for the unpacking routine is given in figure 9, while the thermal routine is given in figure 10.

Vector multiplication routine. - The vector multiplication routine calculates the elements of the reduced augmented matrix by multiplication of vectors. The gaseous-product contributions to the matrix elements of the mass-balance equations in figure 2 are generated by the following operation:

$$\begin{bmatrix} a_i p_i \\ b_i p_i \\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot\ \cdot \\ j_i p_i \end{bmatrix} \qquad \begin{bmatrix} a_i, b_i, \ . \ . \ . \ j_i, 1, q_i, \delta_i \end{bmatrix} \tag{108}$$

Only those terms that are on or to the right of the principal diagonal are filled in. The gaseous-product contributions to the pressure-row elements are obtained from

$$p_i \begin{bmatrix} a_i, b_i, \ . \ . \ . \ j_i, 0, q_i, \delta_i \end{bmatrix} \tag{109}$$

The gaseous-product contributions to the enthalpy-row elements are obtained from

$$\frac{p_i (H_T^O)_i}{R} \begin{bmatrix} a_i, b_i, \ . \ . \ . \ j_i, 1, q_i, \delta_i \end{bmatrix} \tag{110}$$

An entropy row is used in place of the enthalpy row during expansion, and the gaseous-product contributions to the entropy-row elements are given by

$$\frac{p_i S_i'}{R} \begin{bmatrix} a_i, b_i, \ . \ . \ . \ j_i, 1, q_i, \delta_i \end{bmatrix} \tag{111}$$

The condensed products each contribute a row to the reduced augmented matrix, which, for $Z_{a_N} Y_{b_N} X_{c_N}$ . . ., is

$$\begin{bmatrix} a_N, b_N, \ . \ . \ . \ j_N, 0, q_N, \delta_N \end{bmatrix} \tag{112}$$

and, in addition, the contribution of this condensed product to the column $(-\Delta \ln A)$ is

$$\begin{bmatrix} a_N n_N \\ b_N n_N \\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot\ \cdot \\ j_N n_N \\ 0 \\ (H_T^O)_N n_N \end{bmatrix} \tag{113}$$

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The flow chart for this routine is given in figure 11.

Matrix completion routine. - This routine completes the matrix by calculating and adding to the appropriate matrix elements the quantities $A\ \Delta a$, $A\ \Delta b$, . . . ΔP, $A\ \Delta h$, $\sum_i (C_P^o)_i n_i \big/ R$ or $T \sum_i (C_P^o)_i n_i \big/ R$, and reflecting the symmetric portions of the matrix about the diagonal. During expansion, $\sum_i (S_T)_i n_i \big/ R$ replaces the term in the entropy row and $-\Delta \ln A$ column. When this has been completed, the routine examines all the error terms, requiring them to be smaller than some preassigned value before the iteration process is halted. After convergence is complete, the program checks to make sure that the thermal data for the correct temperature interval were used and examines the partial pressures of the condensable materials to ascertain whether or not condensed-phase products should have been considered. The flow chart for this routine is given in figure 12.

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Matrix solution routine. - The correction variables for the gaseous atoms and condensed phases are obtained from the reduced augmented matrix (fig. 2) by the matrix solution routine presented in figure 13. The corrections to the gaseous molecules are obtained from the correction equations for the gaseous atoms using equation (29). When the iteration process has converged to the equilibrium values, this same routine is used to solve the two sets of equations discussed in the section on "Derivative Matrices."

The solution routine carries out a Gauss reduction on the linear set; that is, it eliminates the first variable from all equations following the first equation, the second variable from all equations following the second equation, and so on. The solution routine assumes that the equations appear in consecutive bands of storage, the n^{th} equation in band one, the $(n - 1)^{th}$ equation in band two, and so forth. Thus, the energy equation appears in band one and the pressure equation in band two. Within each band the coefficients of the variables are placed in consecutive storage locations with the constant term appearing in the last storage location of the band.

The number of equations to be solved must appear as an integer in the low-order positions of the upper accumulator when entering the routine. For the correction equations, this is specified by the constant "SYS + 2." The results of the solution appear in the first band with the first variable appearing in location 0049-"(SYS + 1)" as shown in the following table:

Storage location	Variable
0049 - "(SYS + 1)"	$\Delta \ln n_Z$
0049 - "(SYS)"	$\Delta \ln n_Y$
0049 - "(SYS - 1)"	$\Delta \ln n_X$
-----------------	-------
-----------------	-------
0046	Δn_M
0047	Δn_N
0048	$-\Delta \ln A$
0049	$\Delta \ln T$

Two entries to the routine are provided. The first is at location "SOLVE," and the second is at location "BACK." The first entry is used when the Gauss reduction must be performed, while the second is used when the reduction has already been accomplished and only the back solution is needed.

The solution routine can run into difficulty in several situations while carrying out the Gauss reduction. The first happens when the machine attempts to perform a floating multiplication of two numbers that are so small that the resulting product would be less than 10^{-51}, and an underflow occurs. This has been taken care of for several operations by using branch on overflow commands and replacing the result of the multiplication by a zero if underflow occurs.

A second difficulty occurs when the coefficient matrix of figure 2 is singular or nearly singular; that is, its determinant is zero or very nearly so. In this case, because of the way in which the reduction is performed, the machine attempts division by zero. This problem arises when the system is such that within the precision of the calculations only one reaction product exists, as may occur for stoichiometric conditions at low temperatures. For example, in the chemical system hydrogen and oxygen at low temperatures and stoichiometric conditions, gaseous water is the only reaction product of any significance. This type of difficulty may be handled by changing the relative amounts of oxidant and fuel slightly from stoichiometric conditions (perhaps 1 to 10 parts per million) and repeating the calculation.

A third, and perhaps the most difficult, situation occurs when the coefficient matrix is poorly conditioned. For example, if the coefficient of the k^{th} variable in the k^{th} equation is small relative to the coefficients of the $(k + 1)^{th}$, $(k + 2)^{th}$, . . . variables in the same equation, and if the k^{th} equation is then used to eliminate the k^{th}

variable from the $(k + 1)^{th}$, $(k + 2)^{th}$, . . . equations at an early stage of the calculations, then large rounding errors may occur. This situation occurs more often when condensed phases are present in the calculation than when only gaseous products are considered. In particular, if one chemical element appears almost exclusively in the condensed phase, the matrix element for this chemical element, which appears on the diagonal, will be very small. Should the row containing this small element be used to eliminate its variable at an early stage of the solution, then large rounding errors may occur, causing the solution vector obtained to bear little resemblance to the true solution vector.

To take care of this situation, a modified pivot method has been incorporated into the solution routine. This feature may be used at the operator's discretion, since it is console-controlled. An 8 in position one of the console (right-most position) causes pivoting. Prior to each elimination, the program examines the remaining equations and selects the best one for eliminating the next variable. The program selects the best equation to be that equation in which the coefficients differ by the smallest amount after division by the coefficient of the variable to be eliminated.

For the usual problems involving only gaseous products and those for which graphite is the only condensed phase, adequate solutions can be obtained without use of the modified pivoting routine. If no difficulty is expected, it is recommended that the pivot feature not be used, since each iteration will require more time.

Correction routine and performance-parameter routine. - The correction routine (fig. 14) applies the corrections to the estimates during the course of iteration. Once the iteration procedure has converged to a solution, the performance-parameter routine (fig. 15) calculates the performance parameters.

Auxiliary routines. - During the course of calculations it is necessary to use subroutines for exponentiation, taking square roots, and for punching the results of the calculations on Bell format cards. The subroutines that have been incorporated into the program for this purpose were taken from a collection of closed subroutines in reference 26. The three subroutines have been assembled in the locations 1833 to 1999, and a listing is given in appendix F. The arrangement of the words in the punch band by the punching subroutine, just prior to punching, and the corresponding card columns in which they are to appear are given in appendix B.

Because of the iterative nature of the calculation, it is at times desirable to have information on the progress of the calculations. This has been provided in the form of four console-controlled punches that may be used individually or in any combination to give intermediate answers during the iterative process. However, because of storage limitations it was necessary to consider these intermediate answer-punching routines as expendable. For this reason they were assembled in the lower portions of the P and T regions and hence can only be used at the expense of a number of reaction products. The output of the punches is on Bell format cards. The punches are as follows:

(1) Console position 2: To be used only when there are 28 or less reaction products. An 8 in position 2 of the console causes punching, in order, of $(1 - P/P_0)$, $(1 - h/h_0)$, or $(1 - s/s_0)$ depending upon whether it is a combustion or expansion process, $(1 - a/a_0)$, $(1 - b/b_0)$, ... These are followed by the code and $-\delta_i$ for each reaction product.

(2) Console position 3: To be used only when there are 26 or less reaction products. An 8 in position 3 of the console causes punching of P, T, and A, followed by the code and n_i for each reaction product.

(3) Console position 4: To be used only when there are 26 or less reaction products. An 8 in position 4 of the console causes punching of the entire reduced matrix, one equation at a time.

(4) Console sign: To be used only when there are 28 or less reaction products. A minus sign on the console causes punching of the solution to the reduced augmented matrix.

Convergence

Because of the complexity and variability of the problem, no exact analysis can be made of the rate of convergence of the iteration. It is possible, however, to obtain useful information on the rate of convergence by studying a few representative chemical systems. A function E is defined that will be used to indicate the error left in the system by the current estimates:

$$E = \left(1 - \frac{P}{P_0}\right)^2 + \left(1 - \frac{h}{h_0}\right)^2 + \left(1 - \frac{a}{a_0}\right)^2 + \ . \ . \ . + \sum \delta_i^2 \qquad (114)$$

where the summation includes all reaction products. The first group of terms will be called the mass balance errors, and the last group will be referred to as the equilibrium errors. Using identical initial estimates in all cases - namely, $p_i = 1$ atm, $n_N = 1\times10^{-11}$ mole, $T = 3800^\circ$ K, and $A = 148.4$ formula weights - it was possible to construct the curves given in figures 16 to 18.

From figure 16 it is seen that $\ln\sqrt{E}$ decreases linearly in the initial stages of the calculation, the slope increasing quite rapidly once E has been reduced to approximately 1. In other words, as convergence is approached, the rate of convergence increases. The erratic behavior of the curves for small E is due to loss of significance when convergence is essentially complete. Although the total error of the system is exponentially reduced in a rather systematic fashion, no such trend has been observed in the mass balance or equilibrium errors taken separately.

For the three cases shown in figure 16, 10 to 18 iterations were required to reduce the error to an acceptable limit when starting with poor estimates. The number of iterations may be even higher in some cases, in particular, if the temperature interval for the thermodynamic data that was selected on the basis of the initial estimate for the temperature is not the correct interval, or if there are any additions to or subtractions from the list of reaction products when the program checks for condensation of condensable materials.

The number of iterations can usually be significantly reduced if the correct assumption on the existence or nonexistence of condensed phases is made and if a good estimate for the reaction temperature and composition is available. A large number of iterations is unusual for pressure ratios other than the first, because the program uses the answers from the preceding calculation as estimates for the following point. These are generally good estimates, and therefore fewer iterations are required. This is illustrated in figure 17, where $\ln\sqrt{E}$ is plotted as a function of the iteration number. The data in figure 17 were obtained for the reaction of equation (1) using the same initial estimates as for figure 16. As shown by figure 17, convergence to combustion and throat conditions each required 11 iterations, while the following three exit points needed only 8, 6, and 5 iterations, respectively. The performance results of this example are given in table IV.

For the problem shown in figure 17, it was assumed that the iteration procedure had converged to a solution when each of the mass balance errors, such as $(1 - a/a_0)$, had a magnitude less than 5×10^{-7} and each of the equilibrium errors δ_i had a magnitude less than 5×10^{-6}:

$$\left.\begin{matrix} \left|1 - \frac{P}{P_0}\right| \\ \left|1 - \frac{h}{h_0}\right| \\ \left|1 - \frac{a}{a_0}\right| \\ \left|\cdots\cdots\right| \end{matrix}\right\} < 5\times10^{-7}; \quad \left|\delta_i\right| < 5\times10^{-6}$$

These convergence criteria result in more accuracy than may be desired in some cases. For the example in figure 17, relaxing the convergence criteria by a factor of 10 permitted the total number of iterations to be reduced from 41 to 34 while still retaining five or more figures of accuracy in the final result.

When a poor set of estimates is made for the variables, the first iteration usually overcorrects the estimates and results in an increase in the value of E, as may be seen from figure 16. A solution to this problem is to restrict the size of the applied corrections. This technique is often used in iterative calculations; however, an increased number of iterations is generally required to converge. One procedure is to multiply each correction by some constant factor less than 1 (see ref. 19, e.g.). With such a technique it is often possible to induce convergence in what would normally be a divergent case, although an increased number of iterations is required. An alternative procedure has been developed that not only prevents overcorrection and produces convergence in all divergent cases that have occurred so far in this laboratory, but also often decreases the number of iterations required to reach convergence. In this procedure, the magnitude of each component of the solution vector of figure 2 must be less than a specified maximum value. If one or more components are larger than this specified maximum, the largest component is reduced to the specified maximum, and all the other components, including all $\Delta \ln p_i$, are reduced proportionally.

Figure 18 shows the effect of various maximum magnitudes imposed on the solution vector. Restricting the magnitudes of the components to 5 results in the fewest number of iterations for this case. In other cases a maximum component magnitude of 3 appeared to be best, particularly in systems with fewer chemical elements and reaction products.

The restriction of magnitude of the solution vector is given as an optional program and is discussed in the next section.

Program Modifications

The standard program is considered to be the program that first calculates combustion conditions for assigned enthalpy and pressure and then throat and other exit conditions assuming equilibrium composition of the reaction products during isentropic expansion. However, several modifications to the standard program are available.

The limitations to be discussed apply only to the particular assembly given in appendix F. If the program were assembled in some other fashion, then these limitations would no longer apply.

Assigned enthalpy for series of pressures. - The first modification permits the calculation of an assigned enthalpy problem for a series of pressures. This is accomplished by changing one instruction of the program and can be done at no sacrifice in the number of permitted reaction products.

Restriction on magnitude of solution vector. - A second modification places a size restriction on the maximum magnitude of the solution vector of the matrix of figure 2. If any component is larger than this maximum value, then all the corrections, including $\Delta \ln p_i$, are multiplied a number less than 1 so that the maximum component of the solution vector of figure 2 becomes equal to the maximum permitted value. This program modification may be used only if no more than 26 reaction products are being considered. In addition, only the intermediate punches controlled by console position 2 and sign may be used.

Assigned temperature and pressure. - The third program modification permits calculations for an assigned temperature and pressure. This is done at a sacrifice of five reaction products; however, the intermediate punches controlled by console position 2 and sign may be used in addition to the program change that controls the size of the solution vector. The modified program for calculations at assigned temperature and pressure is not very efficient, since the program performs many unnecessary calculations. However, a more efficient program for this type of calculation can be made with more extensive modifications. The modified pivoting routine may not be used for assigned temperature and pressure calculations. To perform calculations at an assigned temperature for a series of pressures, the program modifications for an assigned enthalpy and a series of pressures must also be included.

Calculations for Assumption of Frozen Composition During Expansion

Rocket performance parameters are generally calculated either with the assumption of complete chemical equilibrium among the combustion products during the expansion process (equilibrium expansion) or with composition remaining fixed at combustion-chamber composition during the expansion process (frozen composition). The method for calculating performance for the first assumption has been described in the previous sections. Performance calculations for the second assumption are the same with respect to determining combustion conditions; however, determination of exit conditions, which is described in the next section, is far simpler, since the composition of reaction products is already known.

Equations for frozen-composition isentropic expansion to assigned pressure. - Since composition during expansion is fixed as the combustion-chamber composition, the following relations are obtained:

$$\frac{(p_i)_c}{(p_i)_e} = \frac{(n_i)_c}{(n_i)_e} = \frac{A_c}{A_e} = \frac{P_c}{P_e} \tag{115}$$

Substituting equation (115) into equations (18), (19), and (20) and rearranging terms give, as the condition for frozen isentropic expansion,

$$\sum_i (n_i)_c (S_T^o)_{i_e} + RP_c \ln \frac{P_c}{P_e} = \left[\sum_i n_i (S_T^o)_i\right]_c \tag{116}$$

Equation (116) can be written in a form analogous to equation (20) if the following definitions are used:

$$S_e^f = \sum_i (n_i)_c (S_T^o)_{i_e} + RP_c \ln \frac{P_c}{P_e} \tag{117}$$

$$S_c^f = \left[\sum_i n_i (S_T^o)_i\right]_c \tag{118}$$

for then,

$$S_e^f = S_c^f \tag{119}$$

For an assigned exit pressure, equation (117) is a function of temperature only. For any guess of exit temperature T, equation (119) will not be satisfied identically, and hence an iteration scheme again is employed to converge to correct temperature. The total differential of equation (119) in finite-difference form is

$$\Delta S^f = (S_c^f - S_e^f) = \sum_i (n_i)_c (C_P^o)_i \, \Delta \ln T \tag{120}$$

or

$$\Delta \ln T = \frac{\Delta S^f}{\sum_i (n_i)_c (C_P^o)_i} \tag{121}$$

Equation (121) may be used to obtain new values of T until the value of ΔS^f is less than some assigned small value.

After convergence has been reached, the calculation of the rocket performance parameters is similar to that described for equilibrium composition during expansion.

Description of program. - Because of storage limitations, the program for the calculation of rocket performance assuming frozen composition during expansion could not be incorporated as part of the standard program for equilibrium-composition calculations. Equilibrium composition in the combustion chamber is first calculated with the standard deck. The program for frozen-composition calculations is then read into storage and calculations for frozen composition are begun. Operating instructions for this program are given in appendix D, a flow diagram in figure 19, and a SOAP listing in appendix G.

VECTOR AND PROPELLANT PROGRAM

The Vector and Propellant Program was prepared in order to have a simple and almost automatic method of preparing the packed vectors and the quantities (henceforth referred to as packed propellants) a_f, b_f, c_f, . . ., a_x, b_x, c_x, . . ., V_f^+, V_f^-, V_x^+, V_x^-, h_f, and h_x. The output of this program serves as part of the input data for the Main Calculating Program (see input data routine). The storage locations for the packed propellants are a_x, b_x, c_x, . . ., 537 to 546; h_x, V_x^+, V_x^-, 547, 548, 549; a_f, b_f, c_f, . . ., 587 to 596; h_f, V_f^+, V_f^-, 597, 598, 599.

The flow diagrams for this program are given in figures 20 to 25 and are discussed in the section on "Calculating Routines." Operating instructions are given in appendix E, and a SOAP listing is given in appendix H. Included in the SOAP listing are two punch subroutines taken from reference 26. The format of the output of these two routines (Bell and Random) is given in appendix B. Also given in appendix B is the output format of the packed vectors.

There are ten types of input cards to the Vector and Propellant Program. The type of card is indicated by a symbol of two or three alphabetic or numerical characters appearing in columns 48, 49, and 50 of the IBM card. The data (if any) corresponding to the type of card follow in columns 51 through 72 of the card. The ten types and their functions are listed in the following table and will be discussed more fully in the following sections:

Symbol for type of input	Function	Comment
ATM	Specifies an alphabetic chemical vector for the gaseous atom; e.g., H, AL, or CL	No subscripts permitted for chemical symbol
BOP	Begins program by clearing and initializing	
END	Begins calculations (end of input data)	Begins calculation of a_f, a_x, b_f, b_x, etc.
EFn	Specifies enthalpy of n^{th} fuel in cal/g-mol	$0 \leq n \leq 9$*
EXn	Specifies enthalpy of n^{th} oxidant in cal/g-mol	$0 \leq n \leq 9$*
Fn	Specifies n^{th} fuel	$0 \leq n \leq 9$*
MOL	Specifies all reaction products that are not atoms; e.g., H1F1, N1H3, H1CL1	All subscripts must be given explicitly
PFn	Gives the weight percent or weight fraction of n^{th} fuel in combined fuel	Weight percent or weight fraction in floating point $0 \leq n \leq 9$*
PXn	Gives weight percent or weight fraction of n^{th} oxidant in combined oxidant	Weight percent or weight fraction in floating point $0 \leq n \leq 9$*
Xn	Specifies n^{th} oxidant	$0 \leq n \leq 9$*

*n = 1 through 9 specifies fuel or oxidant 1 through 9, but n = 0 specifies the tenth fuel or oxidant.

Only two types of cards in the preceding table are general for every problem. These are BOP and END.

Transfer Cards

BOP - Initialize card. - The BOP card serves to initialize the program, preparing it to process a new collection of vector and propellant cards. BOP precedes all other input cards:

Input		Output
Card column		
3	+ Sign (12 punch)	
48-50	BOP	No output

END - Start calculations. - The END card follows at the end of all other input cards and serves as a transfer card to begin calculation of the packed propellants:

Input		Output
Card column		
3	+ Sign (12 punch)	
48-50	END	No output

Input for Packed Vectors

The preparation of the packed vectors requires only two types of input cards, ATM and MOL. These two types specify the products of reaction to be considered. For bookkeeping purposes each product of reaction is given a permanent 4-digit numerical code. This permanent code also appears on the thermodynamic data cards for the same product and serves as a check during calculations in the Main Calculating Program.

ATM - Atom cards. - The ATM cards are used to specify which chemical elements will be considered in the equilibrium calculations. They are to be used only for the gaseous atoms. The reduced matrix column assignments are based on the order of appearance of the ATM cards. ATM cards must precede all the other type cards with the exception of BOP cards. The output of an ATM card is a packed vector for the gaseous atom:

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Input		Output	
Card column		Card column	
3	+ Sign (12 punch)	17-20	4-Digit code for gaseous element (same as 44-47 of input)
44-47	4-Digit permanent code for gaseous element	31-40	Packed chemical vector
48-50	ATM	41-80	Input reproduced
51-52	Chemical symbol for element, e.g., AL, CL, H (no numerical subscripts)		
53-80	Blank		

<u>MOL - Molecule cards</u>. - The MOL cards are used for the composition vectors of all reaction products that are not gaseous atoms. Thus, condensed elements such as graphite would be on MOL cards. The output of a MOL card is a packed vector for the corresponding product:

Input		Output	
Card column		Card column	
3	+ Sign (12 punch)	17-20	4-Digit code for reaction product
42	Sign (- for condensed phase, + or blank for gaseous phase)	31-40	Packed chemical vector
44-47	4-Digit permanent code for reaction product	41-80	Input reproduced
48-50	MOL		
51-65	Chemical symbol for reaction product. All subscripts must be explicitly given; e.g., CH_4 is C1H4 H_2O is H2$\bar{0}$1 Al_2O_3 is AL2$\bar{0}$3 ($\bar{0}$ is an alphabetic character)		
66-80	Blank		

Input for Packed Propellants

A number of propellants consist of more than one fuel or one oxidant. The Vector and Propellant Program can accommodate a propellant consisting of a mixture of up to 10 fuels and up to 10 oxidants. Each fuel and each oxidant in the propellant is characterized by three cards. For the fuel, the three cards are Fn, PFn, and EFn; and for the oxidant, Xn, PXn, and EXn.

Fn - Fuel cards. - The Fn cards are used to specify the chemical formula of the n^{th} fuel, where n is any one of the integers 1, 2, 3, 4, 5, 6, 7, 8, 9, 0 (0 is used for the tenth fuel). The subscripts for elements on the fuel cards may either be integers less than 9 digits in length or floating point numbers. Either one or both forms may be used in the same Fn card. Should the chemical formula for the n^{th} fuel be too long to fit on one card (more than 22 columns) it may be continued on the next card providing that (1) the same Fn symbol is used, and (2) the complete numerical subscript for an element is on the same card as the alphabetic symbol for the element:

Input		Output	
Card column		Card column	
3	+ Sign (12 punch)	0-80	Input reproduced
43-47	Anything - never used in program		
48-49	Fn where n = 1,2,3,4,5,6,7,8,9,0		
50	Blank		
51-72	Chemical formula for the fuel		

Three examples are given to illustrate Fn cards:

Fuel	Columns 48-49	Columns 51-72
N_2H_4	F1	N2H4
C_8H_{18}	F1	C8H18 (or C8H1800000052)
Mixture of NH_3 and H_2	F1 F2	N1H3 H2

Xn - Oxidant cards. - The Xn cards are identical to the fuel cards except that these cards are used for the n^{th} oxidant, and Fn in card columns 48 and 49 is replaced by Xn. Two examples are given to illustrate Xn cards:

Oxidant	Columns 48-49	*Columns 51-72
H_2O_2	X1	H2Ō2
$HN_{1.0529061}O_{3.0344255}$ (Red fuming nitric acid)	X1 X1	H1N1052906151 Ō3034425551

*Ō is an alphabetic character.

PFn - Percent fuel cards. - The percent fuel card PFn gives the weight percent of the n^{th} fuel in the fuel mixture. The percent or weight fractions must be expressed as floating point numbers. There must be a PFn card corresponding to each Fn card:

Input		Output	
Card column		Card column	
3	+ Sign (12 punch)	0-80	Input reproduced
48-50	PFn (n = 1,2,3,4,5,6,7,8,9,0)		
51-60	Weight percent of n^{th} fuel in fuel mixture (a floating point number)		

Two examples are given to illustrate PFn cards:

	Columns 48-50	Columns 51-60
One fuel only	PF1	1000000053
Mixture of fuels (20 percent fuel 1, 80 percent fuel 2 by weight)	PF1 PF2	2000000052 8000000052

PXn - Percent oxidant cards. - The PXn cards are identical to the PFn cards except that they refer to the n^{th} oxidant.

EFn - Fuel enthalpy cards. - The EFn card format is identical to that of PFn and PXn, except that instead of weight percentages this type of card gives the enthalpy of the n^{th} fuel in calories per formula weight as a floating point number. An example is given to illustrate an EFn card:

	Columns 48-50	Columns 51-72
Enthalpy of N_2H_4 (*l*) at 298.16° K (see eq. (97))	EF1	1547029756

EXn - Oxidant enthalpy cards. - The EXn cards are the same as the EFn card except that they refer to oxidant rather than fuel.

Calculating Routines

Flow charts and tables. - Figure 20 gives a general flow chart for the Vector and Propellant Program and includes the BOP routine. Flow charts for the other routines are given in figures 21 to 25.

For the calculation of the packed propellants, the program requires a table of atomic weights and assigned oxidation states. The atomic weight table for 101 elements is located in the M region, while the corresponding table for the oxidation states is in the V region. The atomic weight table is complete, while oxidation-state assignments have been made only for several elements. Additions or alterations to the tables of atomic weights and oxidations states may be made as needed.

Formulas for propellants containing several fuels or several oxidants. - The program can prepare "packed propellant cards" for propellants containing as many as 10 fuels and 10 oxidants. The combination of all fuels is referred to as the equivalent fuel, while the combination of all oxidants is referred to as the equivalent oxidant. The necessary equations are given as follows:

According to the definitions given in previous sections, $Z_{a_f}Y_{b_f}X_{c_f}$ . . . and $Z_{a_x}Y_{b_x}X_{c_x}$ . . . refer to 1 gram of equivalent fuel and 1 gram of equivalent oxidant having enthalpies h_f and h_x, respectively, where a_f, b_f, c_f . . . and a_x, b_x, c_x . . . are the number of gram atoms of elements Z, Y, X, . . . in the gram of equivalent fuel and the gram of equivalent oxidant, respectively. Let the i^{th} oxidant have the formula $Z_{a_{x_i}}Y_{b_{x_i}}X_{c_{x_i}}$ . . ., its mass W_{x_i}, and its

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enthalpy $(H_T^{\circ})_{x_i}$, while the i^{th} fuel has the formula $Z_{a_{f_i}} Y_{b_{f_i}} X_{c_{f_i}} \ldots$, its mass W_{f_i}, and its enthalpy $(H_T^{\circ})_{f_i}$. The total weight of oxidant is W_x and the total weight of fuel is W_f:

$$\left.\begin{aligned} W_f &= \sum_i W_{f_i} \\ W_x &= \sum_i W_{x_i} \end{aligned}\right\} \tag{122}$$

Therefore, the oxidant-to-fuel weight ratio is

$$\frac{O}{F} = \frac{W_x}{W_f} \tag{123}$$

The gram atoms of elements per gram of equivalent oxidant or fuel are

$$\left.\begin{aligned} a_x &= \frac{1}{W_x}\sum \frac{a_{x_i} W_{x_i}}{\mathscr{M}_{x_i}}, \quad b_x = \frac{1}{W_x}\sum \frac{b_{x_i} W_{x_i}}{\mathscr{M}_{x_i}}, \quad \ldots \\ a_f &= \frac{1}{W_f}\sum \frac{a_{f_i} W_{f_i}}{\mathscr{M}_{f_i}}, \quad b_f = \frac{1}{W_f}\sum \frac{b_{f_i} W_{f_i}}{\mathscr{M}_{f_i}}, \quad \ldots \end{aligned}\right\} \tag{124}$$

and the enthalpies are

$$\left.\begin{aligned} h_x &= \frac{1}{W_x}\sum \frac{(H_T^{\circ})_{x_i} W_{x_i}}{\mathscr{M}_{x_i}} \\ h_f &= \frac{1}{W_f}\sum \frac{(H_T^{\circ})_{f_i} W_{f_i}}{\mathscr{M}_{f_i}} \end{aligned}\right\} \tag{125}$$

Equation (124) may be used in equations (92) and (100) to obtain a_0, b_0, c_0, . . . and V_x^+, V_x^-, V_f^+, and V_f^-, while equation (125) may be used in equation (96) to obtain h_0.

Example

The propellant $N_2H_4 + \frac{3}{2} H_2O_2$ has been used in this report for purposes of illustration (see eqs. (1), (93), (94), (95), (97), and (98)). This same problem will be used to illustrate the input and output of the Vector and Propellant Program and the Main Calculating Program.

The products considered, which are all gaseous, are H, N, O, H_2, H_2O, N_2, NO, O_2, and OH. The values of enthalpy for the propellants are similar to those on page 19 of reference 9:

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$$(H^{O}_{298.16})_{N_2H_4(l)} = 154{,}702.97 \text{ cal/mol}$$

$$(H^{O}_{298.16})_{H_2O_2(l)} = 28{,}681.626 \text{ cal/mol}$$

The input and output of the Vector and Propellant Deck and the Main Operating Deck are given in tables II to V.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, July 2, 1959

APPENDIX A

SYMBOLS

A	number of formula weights of equivalent reactant; also, cross-sectional area of a nozzle, sq in.
a	velocity of sound, $\sqrt{\left(\frac{\partial P}{\partial \rho}\right)_S}$, ft/sec
$a,b,c, \ldots$	number of gram atoms of the elements $Z,Y,X, \ldots$
C_F	thrust coefficient
C_P^O	molar heat capacity at constant pressure, cal/(mole)($^{\circ}$K)
C_V^O	heat capacity at constant volume, cal/(mole)($^{\circ}$K)
c^*	characteristic velocity, ft/sec
E	internal energy per unit mass, cal/mole; also error function defined by eq. (114)
F	free energy per mole of formula weight of material, cal/mole
$\%F$	weight or mass percent fuel
g_c	gravitational conversion factor, 32.174 (lb mass/lb force)(ft/sec^2)
H	sum of sensible enthalpy and chemical energy per mole or formula weight of material, cal/mole
h	sum of sensible enthalpy and chemical energy per unit mass of material, cal/g
h^*	iteration parameter defined by eq. (85)
I	specific impulse with ambient and exit pressures equal, (lb force)(sec)/(lb mass)
I_{vac}	specific impulse in vacuum (ambient pressure equal to zero), (lb force)(sec)/(lb mass)

K	thermodynamic equilibrium constant
M	Mach number
$\mathcal{M}$	molecular weight, formula weight or atomic weight
N	number
n	number of moles or formula weights of material
O/F	oxidant-to-fuel weight or mass ratio
P	static pressure (sum of partial pressures), consistent units
p	partial pressure, consistent units
p_{vap}	equilibrium vapor pressure of gas
Q	any function
q	symbol for $\partial(-\Delta F_T^O/RT)/\partial \ln T = \Delta H_T^O/RT$
R	universal gas constant, consistent units
r	equivalence ratio defined by eq. (102)
S	entropy per mole or formula weight of material
s	entropy per unit mass of material, cal/(g)(^{O}K)
T	temperature, ^{O}K
U	velocity
V	oxidation state or volume
v	volume per unit mass
W	mass
w	mass-flow rate, (lb mass)/sec; also, weight or mass fraction
x,y	independent variables
Z,Y,X, . . .	symbols for the chemical elements

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α	activity of a material
γ	isentropic exponent, $(\partial \ln P/\partial \ln \rho)_s$
δ	error in equilibrium equation, $\Delta F/RT$
ϵ	area ratio
π	with a subscript, a chamber-pressure exponent defined by eq. (76)
ρ	mass density, consistent units

Subscripts:

c	combustion chamber or condensed phase
e	exit points of a nozzle
f_i	i^{th} fuel
g	gaseous phase
i	i^{th} product of reaction, i^{th} function, i^{th} variable
M,N	M^{th}, N^{th}, . . . condensed reaction products
P	constant pressure
r	equivalent reactant
s	constant entropy
T	at temperature T; also, constant temperature
t	throat of a nozzle
V	constant volume
x_i	i^{th} oxidant
Z,Y,X, . . .	refers to chemical elements
0	an assigned value, equivalent reactant, or absolute zero of temperature

Superscripts:

f	frozen composition during expansion
o	thermodynamic standard state
+	positive oxidation state
-	negative oxidation state

APPENDIX B

CARD FORMATS

Following are word arrangements for Bell, Random, and SOAP II output cards:

Word arrangement for Bell card:

Punch band	Card column
Word 1	11-21 (sign in 11)
Word 2	22-32 (sign in 22)
Word 3	33-43 (sign in 33)
Word 4	44-54 (sign in 44)
Word 5	55-65 (sign in 55)
Word 6	66-76 (sign in 66)
Word 7 (positions 8-5)	6-9 (location of word 1)
Word 8 (positions 8-5)	5, 77-79 (prob. no.)
Word 9 (position 5)	10 (word count)
Word 10 (positions 9-5)	80 (tab. space control)
	1-4 (card number)

Word arrangement for Random card:

Punch band	Card column
Word 1	5-15 (sign in 15)
Word 2	20-30 (sign in 30)
Word 3	35-45 (sign in 45)
Word 4	50-60 (sign in 60)
Word 5	65-75 (sign in 75)
Word 6 (positions 8-5)	1-4 (location of word 1)
Word 7 (positions 8-5)	16-19 (location of word 2)
Word 8 (positions 8-5)	31-34 (location of word 3)
Word 9 (positions 8-5)	46-49 (location of word 4)
Word 10 (positions 8-5)	61-64 (location of word 5)
	76-80 (not used)

Word arrangement for SOAP II output (packed vectors):

Punch band	Card column	Comments
	1-10 (sign in 10), emitted	Not used in program
Word 9	11-20 (sign in 20)	Columns 17-20 are product code
	21-30 (sign in 30), emitted	Not used in program
Word 7	31-40 (sign in 40)	Packed vectors
Word 8 (position 1)	41	Reproduce input ↓
Sign of word 7	42	
Word 1 (positions 5 to 1)	43-47	
Word 4 (positions 5 to 3)	48-50	
Word 1 (positions 5 to 1)	51-55	
Word 4 (position 2)	56	
Word 3 (positions 5 to 1)	57-61	
Word 4 (position 1)	62	
Word 5 (positions 5 to 1)	63-67	
Word 6 (positions 5 to 1)	68-72	

APPENDIX C

OPERATING INSTRUCTIONS FOR MAIN CALCULATING PROGRAM

Normally the computer program will not be loaded as one instruction per card, SOAP cards, but will be subjected to some shrinking procedure that will permit loading of five or six instructions per card. (See appendix B for formats of Bell and Random cards.) Assuming this to be the case and also assuming that all input data which must be loaded are in the same card format, the following operating instructions apply for the Main Calculating Program:

(1) Set console:

(a) Storage entry switches (70 1951 9/8 9/8 9/8 9/8±):
An 8 in position 1 - pivoting during solution
An 8 in position 2 - punching of current errors
An 8 in position 3 - punching of current values for variables
An 8 in position 4 - punching of reduced augmented matrix
Minus sign - punching of solution vector for reduced augmented matrix

When the program has been loaded, the 9 in the position 7 of the console may be changed to an 8 if the operator does not wish the program to check for condensation.

(b) Set programmed switch to STOP.

(c) Set half-cycle switch to RUN.

(d) Set control switch to RUN.

(e) Set display switch to PROGRAM REGISTER.

(f) Set overflow switch to SENSE.

(g) Set error switch to STOP.

(2) Place cards in the read feed so that they will be read in the following order:

(a) Loading routine for program

(b) Computer program
Equilibrium program
Rocket package excerpt

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(c) Input data to be loaded:

Case card
r card: O/F, %F, or r (any one of the three may be used)
Chamber-pressure card in lb/sq in. abs
Pressure-ratio schedule, as many as 25 pressure ratios
Atoms cards ($a_f, b_f, c_f, \ldots j_f$; $h_f, V_f^+, V_f^-, a_x, b_x, c_x, \ldots j_x$; h_x, V_x^+, V_x^-)

(d) Packed vectors

(e) Thermodynamic data as coefficients

Items (a), (b), and (c) are loaded by a loading routine, while (d) and (e) are read into storage by program read commands.

(3) Ready the punch feed with blank cards.

(4) Press computer reset key.

(5) Press program start key.

To aid in detecting errors, programmed stops have been incorporated into the program. The following list gives the card number of the instruction, in the SOAP listing, which produced the stop; the contents of the program register at the time of the stop; and the significance of the stop:

Card number	Instruction	Significance
198	HLT 0000 7766	Thermal data out of order
229	HLT 0000 7777	Elements plus condensed phases greater than 10
325	HLT 0000 8855	Trying to process a molecule or condensed phase before all atoms done
378	HLT 0000 8866	Picked up wrong thermal data for the product
635	NZU XXXX 8877	Trying to process too many condensed phases
1702	HLT 0000 9955	Overflow occurred during construction of matrix
1740	HLT 0000 9966	Overflow occurred in back solution
1827	HLT 0000 9988	Some molecules ahead of some atoms
1570	NZU XXXX 9999	End of program

APPENDIX D

OPERATING INSTRUCTIONS FOR FROZEN COMPOSITION

To carry out frozen-composition calculations it is necessary first to perform an equilibrium-combustion calculation. Thus, the initial operating instructions are identical to those of the Main Calculating Program (appendix C), with the exception that an additional instruction is included (with the input data (2)(c)) that causes the program to stop when combustion calculations are complete. The instruction loads into storage location "FROZ" (1362) and is HLT 9999 9999 (01 9999 9999).

The following instructions apply after combustion calculations are complete:

(1) Run out any cards remaining in the read hopper.

(2) Place cards in the read feed hopper so that they will be read in the following order:

(a) Loading routine for program

(b) Frozen-composition program

(c) A transfer card to start program at "START"

(d) Thermodynamic data as coefficients

(3) Press computer reset key.

(4) Press program start key.

APPENDIX E

OPERATING INSTRUCTIONS FOR VECTOR AND PROPELLANT PROGRAM

The following operating instructions are for the Vector and Propellant Program, which may be used to prepare input data for the Main Calculating Program:

(1) Prepare the appropriate alphabetic ATM and MOL cards. There must be one ATM card for each chemical element and one MOL card for each other product of reaction.

(2) Prepare Fn, PFn, and EFn cards for each fuel, and Xn, Pxn, and EXn cards for each oxidant in the equivalent reactant.

(3) Set console:

(a) Storage entry switches (70 1951 19 9/8 8±); an 8 in position 2 - punching of fuels, oxidants, and percents and enthalpies of fuels and oxidants.

(b) Set programmed switch to STOP.

(c) Set half-cycle switch to RUN.

(d) Set control switch to RUN.

(e) Set display switch to PROGRAM REGISTER.

(f) Set overflow switch to STOP.

(g) Set error switch to STOP.

(4) Place cards in read feed so that they will be read in the following order:

(a) Loading routine for program

(b) Vector and Propellant Program

(c) Input data to be read:
BOP card (if desired)
ATM cards
MOL cards
Fn, PFn, EFn, Xn, PXn, EXn in any order
END card

(5) Ready punch feed with blank cards.

(6) Press computer reset key.

(7) Press program start key.

As an aid in the detection of errors, the following programmed stops have been included in the program:

Card number	Instruction	Significance
337	HLT 9999 1111	Wrong symbol in ATM program
342	HLT 9999 2222	Wrong symbol in BOP program
351	HLT 9999 3333	Wrong symbol in EFn program
364	HLT 9999 4444	Wrong symbol in END program
378	HLT 9999 5555	Wrong symbol in EXn program
388	HLT 9999 6666	Wrong symbol in Fn program
395	HLT 9999 7777	Wrong symbol in MOL program
404	HLT 9999 8888	Wrong symbol in PFn program
414	HLT 9999 9999	Wrong symbol in PXn program
424	HLT 9999 0000	Wrong symbol in Xn program
460	HLT 2222 8888	Trying to process ATM card after MOL, Fn, or Xn cards
466	HLT 3333 7777	Symbol for atom has more than two letters
491	HLT 4444 6666	More than 10 atoms processed
500	HLT 5555 5555	Trying to process more condensed phases than are permitted
506	HLT 6666 4444	Formula for reaction product has more than 15 letters and digits
509	HLT 7777 3333	No chemical formula on MOL card
551	HLT 8888 2222	An element on a MOL card that did not appear on an ATM card
616	HLT 9988 9988	More than 10 ATM cards
665	HLT 4321 4321	Column equivalent for element not in table
680	HLT 2233 4455	Subscript for element greater than 10 digits
684	HLT 5544 3322	Subscript for element is 9 digits
713	HLT 8888 1111	Enthalpy or percent greater than 10 digits
784	HLT 1111 1111	Sum of percents not close enough to 100

APPENDIX F

MAIN OPERATING PROGRAM (CHEMICAL EQUILIBRIUM)

CHEMICAL EQUILIBRIUM PROGRAM

```
1        PROTECT ROCKET PACKAGE EXCERPT
1        BY LOADING AVAILABILITY TABLE
1
1
1
      SYN FROZ       1362
      SYN CHEK       0499
      SYN PROB       1904
      SYN EXP E      1850
      SYN SQRT       1900
      SYN PUNCH      1950
      SYN CARDN      1852
      SYN LINK       1855
      SYN TEMP1      1048      LOW TEMP
      SYN TEMP2      1049      HIGH TEMP
      REG A0961      0980      ATOM DATA
      REG B1247      1249      TWO 3 FOU?
      REG C9050      9050
      REG D0001      0001
      BLA  0001      0001
      BLR  0037      0049
      BLR  0087      0099
      BLR  0137      0149
      BLR  0187      0199
      BLR  0237      0249
      BLR  0287      0299
      BLR  0337      0349
      BLR  0387      0399
      BLR  0437      0449
      BLR  0487      0499
      BLR  0537      0549
      BLR  0587      0599
      REG F1110      1149
      REG G0001      0015
      REG H0987      0999      EXTRA H E)
      REG I1001      1005
      REG J1006      1012
      REG K1013      1019
      REG M9000      9000
      REG N9015      9015
      REG P1599      1659      PROD DATA
      REG Q1020      1027
      REG R1075      1099      PRES RATIO
      REG T0660      0959      HEAT DATA
      REG U0050      0058
      REG Y0059      0065
      REG Z1340      1349      PRESS ROW
      EQU PCP        F0001
      EQU TEE        F0002
      EQU P          F0003
      EQU H          F0004
      EQU I          F0005
      EQU M          F0006
      EQU CF         F0007
      EQU EPSIL      F0008
      EQU MACH       F0009
      EQU I VAC      F0010
      EQU CP         F0011
      EQU GAMMA      F0012
      EQU LMPT       F0013
      EQU LMTP       F0014
      EQU S          F0015
      EQU NI         F0016
      EQU NT         F0017
      EQU NEPS       F0018
      EQU NCSTR      F0019
      EQU CSTAR      F0020
      EQU AW         F0021
      EQU NAW        F0022
      EQU HSTR       F0023
      EQU AAY        F0024
      EQU HC         F0025
      EQU RECMC      F0026
      EQU NAWT       F0027
      EQU AWT        F0028
      EQU HSTR2      F0029
      EQU P1         F0030
      EQU CONS1      F0031
      EQU CONS2      F0032
      EQU CONS3      F0033
      EQU CONS4      F0034
      EQU CONS5      F0035
      EQU S2         F0036
      EQU R          F0037
      EQU GC         F0038
      EQU IDENT      F0039
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```
            EQU ONE       F0040
            EQU LNAAY     G0001
            EQU LNT       G0002
            EQU S0/R      G0003
            EQU H0/R      G0004
            EQU AOMOL     G0005
            EQU BOMOL     G0006
            EQU COMOL     G0007
            EQU DOMOL     G0008
            EQU EOMOL     G0009
            EQU FOMOL     G0010
            EQU GOMOL     G0011
            EQU HOMOL     G0012
            EQU IOMOL     G0013
            EQU JOMOL     G0014
            EQU PO        G0015
            EQU CODE       9000
            EQU SIR        9001
            EQU ATOM2      9002
            EQU T          9003
            EQU RV000      9004
            EQU RV001      9005
            EQU RV002      9006
            EQU RV003      9007       ROW VECTOR
            EQU RV004      9008       EXTENDS
            EQU RV005      9009       FROM 9005
            EQU RV006      9010       TO 9018
            EQU RV007      9011
            EQU RV008      9012
            EQU RV009      9013
            EQU RV010      9014
            EQU RV011      9015
            EQU RV012      9016
            EQU RV013      9017
            EQU RV014      9018
            EQU NI         9019
            EQU A          9021
            EQU B          9022
            EQU C          9023
            EQU D          9024
            EQU E          9025
            EQU F          9026
            EQU LN NI      9027
            EQU 1A         9011
            EQU 1B         9012
            EQU 1C         9013
            EQU 1D         9014
            EQU 1E         9015
            EQU 1F         9016
            EQU LNNI       9017
            EQU TWO        9028
            EQU THREE      9029
            EQU FOUR       9030
            EQU CPR        9031
            EQU S CPR      9032
            EQU HRT        9033
            EQU S HRT      9034
            EQU SR         9035
            EQU S  SR      9036
            EQU MINEX      9045
            EQU MINCO      9046
            EQU MAXCO      9047
            EQU VARBL      9048
            EQU TEM 1      9049
            EQU TEMPO      9059
            EQU MOVE1      9058
            EQU MOVE2      9059
            EQU BASIC      9050
            EQU INDXA     THREE
            EQU INDXC     FOUR
            EQU S1        C0001
            EQU ELMIN     C0001
            EQU NOROW     C0000
            SYN RDR        1193
            SYN PC        F0000
 1
 1
     BEGIN  RAU LNT                    SET TO        0000  60 0002 0107
            STL COMEX                  COMBUSTION    0107  20 0111 0114
            STD PCPCT                  FIRST PC      0114  24 0017 0020
            LDD           EXP E        OVER P        0020  69 0023 1850
            STU T                      T FROM LNT    0023  21 9003 0031
            LDD TDATA     PCP 1                      0031  69 0034 0637
 1
 1             IF COMEX IS ZERO WE ARE DOING
 1             COMBUSTION OTHERWISE EXPANSION
 1             COMEX EQUALS MINUS UNITY FOR
 1             THROAT AND PLUS UNITY FOR
 1             EXPANSION
 1
 1
```

```
                     READ THERMAL DATA ROUTINE FOR
                     GENERAL ROCKET PERFORMANCE
                               CALCULATION
      TDATA   RAA  0000                                 0034  80 0000 0640
              RAC  0000      TD001                      0640  88 0000 0646
      TD001   RCD BASIC      BELL       READ CARD       0646  70 9050 1046
      BASIC   RAL  9051      RDB        ARE WE          9050  65 9051 1193
      RDB     SLT  0004                 GOING TO        1193  35 0004 0103
              STU  9051                 STORE IN        0103  21 9051 0161
              RAU P0001 A               COPRECT         0161  60 3599 0153
              SLT  0001                 PLACE           0153  35 0001 0109
              SRT  0001                                 0109  30 0001 0115
              SUP  9051                                 0115  11 9051 0073
              NZU TD005                                 0073  44 0027 0028
              LDD T0008 C               YES STORE       0028  69 6667 0070
              STD  9058                 THERMAL         0070  24 9058 0026
              SET  9051                 DATA            0026  27 9051 0081
              SBB T0001 C                               0081  28 6660 0113
              AXA  0002                                 0113  50 0002 0019
              AXC  0010      TD001                      0019  58 0010 0646
      TD005   HLT  0000      7766                       0027  01 0000 7766
      BELL    RAU  9051                 WAS THE         1046  60 9051 0203
              FSB T                     DATA JUST       0203  33 9003 0033
              BMI TDATA                 READ IN         0033  46 0034 1037
              RAU T                     FOR THE         1037  60 9003 0645
              FSB  9050                 CORRECT         0645  33 9050 0025
              BMI TDATA                 INTERVAL        0025  46 0034 0029
              SET  9050                                 0029  27 9050 0084
              SBB TEMP1      UNPAK                      0084  28 1048 0101

                     UNPACKING ROUTINE FOR GENERAL
                     ROCKET PERFORMANCE CALCULATION

                     ATOM1 IS THE NUMBER OF THE
                     ELEMENTS IN THE SYSTEM AND IS
                     IN THE I ADDRESS POSITION

                     SYS IS THE SUM OF ELEMENTS
                     AND CONDENSED PHASES IN THE
                     I ADDRESS POSITION AND MUST
                     BE LESS THAN OR EQUAL TO TEN

                     SYSTM IS GENERATED FROM SYS
                     BY SHIFTING TO THE D ADDRESS
                     POSITION

      UNPAK   RAU UNITY                 IS  SYS         0101  60 0104 0159
              SLT  0001                 GREATER         0159  35 0001 0165
              SUP SYS                   THAN TEN        0165  11 0018 0123
              BMI            UP000                      0123  46 0076 0077
              HLT  0000      7777                       0076  01 0000 7777
      UP000   RAU SYS                   GENERATE        0077  60 0018 0173
              SLT  0004                 I ADDRESS       0173  35 0004 0083
                                        CONSTANTS
              STU SYSTM                 SYS+1 AND       0083  21 0638 0641
              RAL SYS                   SYS+2 AND       0641  65 0018 0223
              ALO UNITY                 ATM-1 ALSO      0223  15 0104 0209
              AUP  8001                 D ADDRESS       0209  10 8001 0067
              AUP  8002                 CONSTANT        0067  10 8002 0075
              STL SYS+1                 SYSTM FROM      0075  20 0079 0032
              STU SYS+2                 SYS AND         0032  21 0036 0639
              RAU ATOM1                 ATOM1           0639  60 0642 0647
              SUP UNITY                                 0647  11 0104 0259
              STU ATM-1                                 0259  21 0164 0117
              STL S CPR                 CLEAR THE       0117  20 9032 0024
              STD S HRT                 SUMMATION       0024  24 9034 0030
              STD S  SR                 STORAGES        0030  24 9036 0086
              STD P                                     0036  24 1112 0215
              RAL STORE                 SET STORE       0215  65 0068 0273
              SLO SYSTM                 ORDER FOR       0273  16 0638 0643
              LDD UP033                 SUBSCRIPT       0643  69 1196 0649
              SDA UP033                                 0649  22 1196 1199
              LDD TH024                 SET DATA        1199  69 0102 0105
              SDA TH024                 ADDRESS OF      0105  22 0102 0155
              LDD TH035                 TH024 AND       0155  69 0108 0211
              SDA TH035                 TH035           0211  22 0108 0261
              RAU SYS                   SET SOLIDS      0261  60 0018 0323
              SUP ATOM1                 COUNTER         0323  11 0642 1047
              STU COUNT                                 1047  21 0152 0205
              STD SOLID                                 0205  24 0158 0311
              SLT  0004                 SET             0311  35 0004 0021
              RSL  8003                 DATA            0021  66 8003 0129
              ALO STORE                 ADDRESS OF      0129  15 0068 0373
              LDD VM007                 VM007 AND       0373  69 0126 0179
              SDA VM007                 VM048 TO        0179  22 0126 0229
              LDD VM048                 RV011B          0229  69 0082 0035
              SDA VM048                 LESS SOLID      0035  22 0082 0085
              RAU LNT                   GET T FROM      0085  60 0002 0157
              LDD UP001      EXP E      LNT             0157  69 0110 1850
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  UP001    STU T                                 0110  21 9003 0167
           LDD ATOM1               SET ATOM      0167  69 0642 1045
           STD ATOM2                COUNTER      1045  24 9002 0151
1
               INDEX ACCUMULATOR C WILL BE
               USED FOR PICKING UP THE
               THERMAL DATA IN THE FUTURE
1
           RAC  0000                             0151  88 0000 0207
           RAA  0012                             0207  80 0012 0163
           RAU WIPE1      8003                   0163  60 0016 8003
   8003    STL  9007 A UP003       CLEAR THE     8003  20 9207 0078
  UP003    NZA UP005    UP007      LAST 13       0078  40 0131 0132
  UP005    SXA  0001     8003      POSITIONS     0131  51 0001 8003
  UP007    RAB  0011    UP009      OF FIRST      0132  82 0011 1038
  UP009    SET  9007               12 BANDS      1038  27 9007 1043
           STB  0037 A             FOR MATRIX    1043  29 2037 1040
           NZB          UP012                    1040  42 1243 0644
           SXB  0001                             1243  53 0001 1299
           AXA  0050    UP009                    1299  50 0050 1038
  UP012    SET  9007               CLEAR THE     0644  27 9007 1399
           STB H0001               H REGION      1399  29 0987 1190
           RAA  0000    UP013                    1190  80 0000 1246
  UP013    RAB  0013               CLEAR 14      1246  82 0013 0202
           RAU WIPE2      8003     CORE LOCA     0202  60 0255 8003
   8003    STL RV001 B UP015       FOR ROW       8003  20 9405 0066
  UP015    NZB UP017    UP019      VECTOR        0066  42 0069 0120
  UP017    SXB  0001      8003                   0069  53 0001 8003
1
               INDEX ACCUMULATOR A WILL BE
               USED FOR PICKING UP THE
               CURRENT PRODUCT CODE IN FUTURE
1
               DATA ADDRESS OF UP033 HAS BEEN
               SET TO RV011B MINUS SYSTM AT
               START OF UNPAK ROUTINE
1
  UP019    RAL P0001 A             STORE PROD    0120  65 3599 0253
           NZE          MATRX      CODE IF       0253  45 0106 0257
           SLT  0001               HERE IF NO    0106  35 0001 0213
           NZU UP021               GO CLEAN      0213  44 0217 0118
           SRT  0001               UP MATRIX     0118  30 0001 0125
           STL CODE     UP024                    0125  20 9000 0182
  UP021    SRT  0001               PASS UP       0217  30 0001 0423
           STU T0008 C             SOLID AND     0423  21 6667 0170
           STD T0010 C             SET NI AND    0170  24 6669 0022
           AXA  0002               DELTAI TO     0022  50 0002 0128
           AXC  0010    UP019      ZERO          0128  58 0010 0120
  UP024    RAU P0002 A             GAS OR        0182  60 3600 0305
           STL CHECK               CONDENSED     0305  20 0309 0112
           BMI          UP037      SET ONE OR    0112  46 0265 0116
           RSU  8003    UP029      LEAVE ZERO    0265  61 8003 0473
  UP029    SRT  0002    UP030      IN RV011      0473  30 0002 0279
  UP030    SUP  8003                             0279  11 8003 1187
           STD TEMPO                             1187  24 9059 1293
           AUP ATOM2               CHECK ATOM    1293  10 9002 0201
           NZU          UP031                    0201  44 0355 0156
           HLT  0000     8855                    0355  01 0000 8855
  UP031    SLT  0001                             0156  35 0001 0263
           ALO 51                  FLOAT AND     0263  15 0166 0071
           RAB  8003    UP033      STORE THE     0071  82 8003 1196
  UP033    STL RV011 B             SUBSCRIPT     1196  20 9415 0154
           RAU TEMPO               GET NEXT      0154  60 9059 0361
           NZU UP029               SUBSCRIPT     0361  44 0473 0216
           AXA  0002    THERM                    0216  50 0002 0072
1
               PREPARE FOR NEXT PRODUCT THEN
               GO TO THE THERMAL ROUTINE
1
  UP037    LDD ONE                 SET ONE IN    0116  69 1149 0252
           STD RV011               RV011         0252  24 9015 0208
           SRT  0002               IS IT ONE     0208  30 0002 0315
           NZU UP030               ELEMENT       0315  44 0279 0220
           STL TEMPO               YES IT WAS    0220  20 9059 0178
           SLT  0001               IS IT AN      0178  35 0001 0135
           RAU  8002               ATOM          0135  60 8002 1393
           SUP UNE                               1393  11 1296 0251
           NZU          UP038      IT WAS A      0251  44 0405 0206
           RAL TEMPO    UP030      MOLECULE      0405  65 9059 0279
  UP038    RAU ATOM2               IT WAS AN     0206  60 9002 0313
           SUP UNITY               ATOM          0313  11 0104 0359
           STD CHECK                             0359  24 0309 0162
           STU ATOM2                             0162  21 9002 0119
           RAL TEMPO                             0119  65 9059 0127
           STU TEMPO    UP031                    0127  21 9059 0156
1
               CONSTANTS FOR UNPACKING
  STORE     00 RV011 B  0000                     0068  00 9415 0000
  WIPE1    STL  9007 A UP003                     0016  20 9207 0078
  WIPE2    STL RV001 B UP015                     0255  20 9405 0066
  ONE       10  0000      0051                   1149  10 0000 0051
```

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UNITY   00  0000      0001                          0104   00 0000 0001
51      00  0000      0051                          0156   00 0000 0051
UNE     10  0000      0000                          1296   10 0000 0000
1
1
1          THERMAL ROUTINE FOR GENERAL
1          ROCKET PERFORMANCE CALCULATION
1
1          THE DATA ADDRESSES OF TH024
1          AND TH035 SHOULD BE SET TO
1          RV011B MINUS SYSTM AT START OF
1                UNPACKING ROUTINE
1
THERM   SET  9020                   PICK UP         0072   27 9020 0177
        LBB T0001 C                 THERMAL         0177   08 6660 0363
1                                   DATA
        RAU  9020                   IS THIS         0353   60 9020 0121
        SUP CODE                    THE RIGHT       0121   11 9000 0329
        NZU             TH003       DATA            0329   44 0133 0134
        HLT  0000       8866                        0133   01 0000 8866
TH003   RAU P0000 A                                 0134   30 3598 0303
        BMI             TH007                       0303   46 0256 0307
1
1          IF DEALING WITH CONDENSED
1          PRODUCT SET LN NI TO ZERO
1
        RAU LN NI                   LN NI IS        0256   60 9027 0413
        STL LN NI                   REALLY NI       0413   20 9027 0270
        STU NI          TH009                       0270   21 9019 0227
TH007   RAU LN NI                   GET NI          0307   60 9027 0365
        LDD             EXP E       FROM LN NI      0365   69 0168 1850
        STU NI          TH009                       0158   21 9019 0227
TH009   SET TWO                     TWO 3 FOUR      0227   27 9028 0232
        LDB B0001                   ON CORE         0232   09 1247 0100
        RAU D                       CALCULATE       0100   60 9024 0357
        FMP T                       CPR             0357   39 9003 0160
        FAD C                                       0160   32 9023 1039
        FMP T                                       1039   39 9003 1042
        FAD B                                       1042   32 9022 0171
        FMP T                                       0171   39 9003 0074
        FAD A                                       0074   32 9021 0353
1
1          S CPR  S HRT  S  SR MUST BE
1          CLEARED AT MATRIX CLEARING
1
        STU CPR                                     0353   21 9031 0411
        FMP NI                      SUM CPRXNI      0411   39 9019 0214
        FAD S CPR                   IN CORE         0214   32 9032 1443
        STU S CPR                                   1443   21 9032 0301
        RAU D                       CALCULATE       0301   60 9024 0409
        FDV FOUR                    HRT             0409   34 9030 0212
        FMP T                                       0212   39 9003 0415
        STU TEMPO                                   0415   21 9059 0523
        RAU C                                       0523   60 9023 0181
        FDV THREE                                   0181   34 9029 0184
        FAD TEMPO                                   0184   32 9059 0463
        FMP T                                       0463   39 9003 0266
        STU TEMPO                                   0266   21 9059 0573
        RAU B                                       0573   60 9022 0231
        FDV TWO                                     0231   34 9028 0234
        FAD TEMPO                                   0234   32 9059 0513
        FMP T                                       0513   39 9003 0316
        STU TEMPO                                   0316   21 9059 0623
        RAU F                                       0623   60 9025 0281
        FDV T                                       0281   34 9003 0284
        FAD TEMPO                                   0284   32 9059 0563
        FAD A                                       0563   32 9021 1493
        STU HRT                                     1493   21 9033 0351
        FMP NI                      SUM HRTXNI      0351   39 9019 0204
        FAD S HRT                   IN CORE         0204   32 9034 0183
        STU S HRT                                   0183   21 9034 1041
        RAU D                       CALCULATE       1041   60 9024 1449
        FDV THREE                   SR              1449   34 9029 0302
        FMP T                                       0302   39 9003 0455
        STU TEMPO                                   0455   21 9059 0613
        RAU C                                       0613   60 9023 0221
        FDV TWO                                     0221   34 9028 0124
        FAD TEMPO                                   0124   32 9059 0403
        FMP T                                       0403   39 9003 0306
        FAD B                                       0306   32 9022 0185
        FMP T                                       0185   39 9003 1188
        STU TEMPO                                   1188   21 9059 1195
        RAU A                                       1195   60 9021 0453
        FMP LNT                                     0453   39 0002 0352
        FAD TEMPO                                   0352   32 9059 0331
        FAD F                                       0331   32 9026 0461
        FSB LN NI                   SR MINUS        0461   33 9027 1191
        STU SR                      LN PI           1191   21 9035 1499
        FMP NI                      SUM SR          1499   39 9019 0402
        FAD S  SR                   LESS LN PI      0402   32 9036 0381
        STU S  SR                   X NI  CORE      0381   21 9036 1189
        RAU CHECK                   IS IT ATOM      1189   60 0309 1063
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          NZU         TH023                         1063   44 0267 0218

              REGION A IS PERMANENT STORAGE
              OF ATOM GAS THERMAL PROPERTIES

          RAU HRT                    PERMANENT   0267   60 9033 0175
          STU A0001 B                STORAGE OF  0175   21 4961 0264
          RAL SR                     HRT AND SR  0264   65 9035 0271
          STL A0011 B                LESS LN PI  0271   20 4971 0174
          STU T0009 C                OF GASEOUS  0174   21 6668 0321
          STD T0010 C TH044          ATOMS       0321   24 6669 0122
  TH023   RAU ATM-1                  SET MULT    0218   60 0164 0169
          RAB  8003                  FREQUENCY   0169   82 8003 0228
          STL TEMPO                  FOR QI      0228   20 9059 0136
          SET  9050                              0136   27 9050 1241
          LRB A0001     TH024                    1241   08 0961 0102
  TH024   RAU RV011 B                            0102   60 9415 0459
          NZU           TH027                    0459   44 1163 0314
          FMP  9050 B                            1163   39 9450 0366
          FAD TEMPO                              0366   32 9059 1245
          STU TEMPO     TH027                    1245   21 9059 0314
  TH027   NZB           TH031                    0314   42 0317 0268
          SXB  0001     TH024                    0317   53 0001 0102
  TH031   RSU TEMPO                              0268   61 9059 0225
          FAD HRT                                0225   32 9033 0505
          STU RV012                  QI IN 9016  0505   21 9016 1213
          STD TEM 1                  AND TEM 1   1213   24 9049 0219
          STD T0009 C                AND T REGN  0219   24 6669 0371
          RAU ATM-1                  SET MULT    0371   60 0164 0269
          RAB  8003                  FREQUENCY   0269   82 8003 0278
          SET  9050                              0278   27 9050 0233
          LRB A0011     TH035                    0233   08 0971 0108
  TH035   RAU RV011 B                            0108   60 9415 0465
          NZU           TH039                    0465   44 0319 0320
          FMP  9050 B                            0319   39 9450 0172
          FAD TEM 1                              0172   32 9049 0401
          STU TEM 1     TH039                    0401   21 9049 0320
  TH039   NZB           TH043                    0320   42 1073 0224
          SXB  0001     TH035                    1073   53 0001 0108
  TH043   RAU TEM 1                              0224   60 9049 0431
          FSB SR                     DELTA I IN  0431   33 9035 0511
          STU RV013                   9017       0511   21 9017 0369
          RSU  8003                  STORE NEG   0369   61 8003 0277
          STU T0010 C TH044          DELTAI IN   0277   21 6669 0122
  TH044   AXC  0010                  T REGION    0122   58 0010 0328
          RAU HRT                    H OVER R    0328   60 9033 0235
          FMP T                      IN HR       0235   39 9003 1238
          STU HR                                 1238   21 1192 1295
          RAU P0000 A                            1295   60 3598 0503
          BMI TH045                              0503   46 0356 0407
          RAU SR                     S PRIMED    0407   60 9035 0515
          FSB ONE       TH050        OVER R      0515   33 1149 0275
  TH045   RAU SP        TH050                    0356   60 9035 0275
  TH050   STU S1R       TH051        IN S1R      0275   21 9001 0283
  TH051   RAU COMEX                              0283   60 0111 0565
          NZU EXPAN     COMB                     0565   44 0419 0370
  COMB    RAU HR                                 0370   60 1192 1197
          STL RV000     TH047                    1197   20 9004 0254
  EXPAN   RAU S1R                                0419   60 9001 0327
          LDD HR                                 0327   69 1192 1395
          STD RV000     TH047                    1395   24 9004 0254
  TH047   STU RV014     MULT                     0254   21 9018 0561

          CONSTANTS FOR THERMAL ROUTINE
  ONE     10  0000      0051                     1149   10 0000 0051
  UNITY   00  0000      0001                     0104   00 0000 0001
  B0001   20  0000      0051         TWO         1247   20 0000 0051
  B0002   30  0000      0051         THREE       1248   30 0000 0051
  B0003   40  0000      0051         FOUR        1249   40 0000 0051


          VECTOR MULTIPLICATION ROUTINE
          FOR GENERAL ROCKET PERFORMANCE
                 CALCULATION

          WHEN THERE ARE N EQUATIONS THE
          NTH APPEARS IN BAND 1 AND THE
          1ST APPEARS IN BAND N

          IN THIS ROUTINE INDEX A WILL
          TRACK THE CURRENT EQUATION  B
          WILL  TRACK  THE CURRENT
          SUBSCRIPT   C WILL TRACK THE
          NUMBER OF MULTIPLICATIONS

          THE SOLIDS COUNTER SHOULD BE
          SET TO ITS MAXIMUM VALUE PRIOR
          TO CLEARING MATRIX LOCATIONS
```

```
                THE DATA ADDRESSES OF VM007
                AND VM048 SHOULD BE SET TO
                RV011B MINUS SOLID AT THE
                START OF THE UNPACKING ROUTINE
MULT    LDD  8005     VM001      STORE INDX  0561  69 8005 0367
VM001   STD  INDXA               A  AND  C   0367  24 9029 1173
        LDD  8007                FOP THE     1173  69 8007 0379
        STD  INDXC               TIME BEING  0379  24 9030 0285
        RAU  P0000 A             IS PRODUCT  0285  60 3598 0553
        BMI  VM042               CONDENSED   0553  46 0406 0457

                GASEOUS PRODUCT PROCESSING

        RAU  SYS+1               SET INDXA   0457  60 0079 0333
        MPY  50                  TO SYS+1    0333  19 0186 0456
        RAA  8002                TIMES 50    0456  80 8002 0615
        RSU  ATOM1               SET INDEXB  0615  61 0642 1297
        RAB  8003     VM002      TO ATOM     1297  82 8003 0506
                                 NEGATIVED
VM002   RAC  8003                SET INDEXC  0506  88 8003 0364
        LDD  SOLID               TO INDEXB   0364  69 0158 0611
        SXC  8001                LESS SOLID  0611  59 8001 0417
        SXC  0002     VM007      LESS TWO    0417  59 0002 0126
VM007   RAU  RV011 B             IS IT ZERO  0126  60 9415 0383
        NZU           VM023      SUBSCRIPT   0383  44 1237 1288
        FMP  NI                  SUBSCRIPT   1237  39 9019 1240
        STU  TEMPO               TIMES NI    1240  21 9059 1397
        SET  9037                BRING IN    1397  27 9037 0452
        LDB  0037 A   VM013      EQUATION    0452  09 2037 1290
VM013   RAU  RV013 C                         1290  60 9617 1447
        NZU           VM017                  1447  44 0451 0502
        FMP  TEMPO               PERFORM A   0451  39 9059 0304
        FAD  9049 C              MULTIPLY    0304  32 9649 0433
        STU  9049 C   VM017      AND ADD     0433  21 9649 0502
VM017   NZC           VM021      ANY MORE    0502  48 0555 0556
        AXC  0001     VM013      TO MULTPLY  0555  58 0001 1290
VM021   SET  9037                            0556  27 9037 1061
        STB  0037 A   VM023                  1061  29 2037 1288
VM023   AXB  0001                ANY MORE    1288  52 0001 1044
        NZB           VM027      EQUATIONS   1044  42 1497 0648
        RAU  8006                            1497  60 8006 0605
        SXA  0050     VM002                  0605  51 0050 0506
VM027   RAA  0000                COMPLETE    0648  80 0000 0354
        RAB  0001                BOTH THE    0354  82 0001 0210
        RAU  RV014    VM101      ENTROPY     0210  60 9018 0467
VM101   NZU           VM104      AND THE     0467  44 0421 0222
        FMP  NI                  ENTHALPY    0421  39 9019 0274
        STU  TEMPO               DURING THE  0274  21 9059 0481
        RAU  SYS+2               EXPANSION   0481  60 0036 1291
        RSC  8003                SET INDXC   1291  89 8003 0150
        SET  9037                            0150  27 9037 0655
        LDB  0037 A   VM028                  0655  09 2037 1390
VM028   RAU  RV013 C             DO THE      1390  60 9617 1547
        NZU           VM031      LAST        1547  44 0501 0552
        FMP  TEMPO               EQUATION    0501  39 9059 0404
        FAD  9049 C              WHICH IS    0404  32 9649 0483
        STU  9049 C   VM031      ENTHALPY    0483  21 9649 0552
VM031   NZC           VM035      OR ENTROPY  0552  48 1055 0606
        AXC  0001     VM028                  1055  58 0001 1390
VM035   SET  9037                            0606  27 9037 1161
        STB  0037 A   VM104                  1161  29 2037 0222
VM104   NZB           VM036                  0222  42 0325 0176
        SXB  0001                DURING      0325  53 0001 0531
        RAA  0950                EXPANSION   0531  80 0950 1287
        RAU  RV000    VM101      ENTHALPY    1287  60 9004 0467
                                 EQUATION
                                 IS IN 0950
                                 BAND
                                 ALSO FILL
VM036   RAU  SYS+2               IN THE      0176  60 0036 1391
        STL  RV011               PRESSURE    1391  20 9015 1198
        RSC  8003                EQUATION    1198  89 8003 0656
        SET  9037                            0656  27 9037 1211
        LDB  0087     VM037                  1211  09 0087 1440
VM037   RAU  RV013 C                         1440  60 9617 1597
        NZU           VM039                  1597  44 0551 0602
        FMP  NI                              0551  39 9019 0454
        FAD  9049 C                          0454  32 9649 0533
        STU  9049 C   VM039                  0533  21 9649 0602
VM039   NZC           VM041                  0602  48 1105 1056
        AXC  0001     VM037                  1105  58 0001 1440
VM041   SET  9037                            1056  27 9037 1261
        STB  0087                            1261  29 0087 1490
        RAU  NI                  SUM PI      1490  60 9019 1697
        FAD  P                               1697  32 1112 1239
        STU  P        VM061                  1239  21 1112 1065
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                CONDENSED PRODUCT PROCESSING


                COUNT IS NUMBER OF UNPROCESSED
                         CONDENSED PRODUCTS

      VM042   RAU COUNT                                   0406  60 0152 0507
              NZU          8877                           0507  44 1311 8877


                ARE WE TRYING TO PROCESS TOO
                MANY CONDENSED PHASES

              RSB   8003                  SET THE         1311  83 8003 0420
              ALO   8003                  INDICES TO      0420  15 8003 0377
              SUP  UNITY                  STORE           0377  11 0104 0509
              ALO   8001                  CONDENSED       0509  15 8001 0517
              STU  COUNT                  PHASE           0517  21 0152 1155
              RAU   8002                  EQUATION        1155  60 8002 1263
              MPY  50                     AND ITS         1263  19 0186 1106
              RAA   8002                  ENTHALPY        1106  80 8002 1165
                                          OR ENTROPY
              SET  RV001                  STORE THE       1165  27 9005 0470
              STB   0037 A                EQUATION        0470  29 2037 1540
              RAU  RV014                  STORE THE       1540  60 9018 1747
              STU   0047 B                ENTHALPY        1747  21 4047 0200
                                          OR ENTROPY
              FMP  NI                     COMPLETE        0200  39 9019 0603
              FAD   0047                  ENTHALPY        0603  32 0047 1223
              STU   0047                  ROW             1223  21 0047 0250
              RAU  COMEX                                  0250  60 0111 1215
              NZU               VM111                     1215  44 0469 0520
              RAU  RV000                                  0469  60 9004 0427
              STU  H0011 B                                0427  21 4997 0300
              FMP  NI                                     0300  39 9019 0653
              FAD  H0011                                  0653  32 0997 1273
              STU  H0011        VM111                     1273  21 0997 0520
      VM111   RAU  SYS+1                  COMPLETE        0520  60 0079 0583
              MPY  50                     THE COLUMN      0583  19 0186 1156
              RAA   8002                  FOR AAY         1156  80 8002 1265
              RAU  ATOM1                                  1265  60 0642 1797
              RSB   8003        VM048                     1797  83 8003 0082
      VM048   RAU  RV011 B                                0082  60 9415 1289
              NZU               VM051                     1289  44 1543 1194
              FMP  NI                                     1543  39 9019 1396
              FAD   0047 A                                1396  32 2047 1323
              STU   0047 A      VM051                     1323  21 2047 1194
      VM051   AXB   0001                                  1194  52 0001 0350
              NZB               VM061                     0350  42 1053 1065
              SXA   0050        VM048                     1053  51 0050 0082
      VM061   RAA  INDXA                  GO TO NEXT      1065  80 9029 1373
              RAC  INDXC        UP013     PRODUCT         1373  88 9030 1246

                CONSTANTS FOR VECTOR MULTIPLY
                          ROUTINE
      50      00   0000         0050                      0186  00 0000 0050



                MATRIX CLEAN UP ROUTINE FOR
                GENERAL ROCKET PERFORMANCE
                          CALCULATION

      MATRX   RAU  LNAAY                  GET AAY         0257  60 0001 1205
              LDD  MC003        EXP E     FROM            1205  69 0258 1850
      MC003   STU  AAY                    LNAAY           0258  21 1133 0236
              LDD  ATM-1                  SET INDXB       0236  69 0164 0567
              RAB   8001                  TO ATM-1        0567  82 8001 1423
              RAU  SOLID                                  1423  60 0158 1313
              AUP  UNITY                  SET INDXA       1313  10 0104 0559
              AUP   8001                  TO SOLID        0559  10 8001 0617
              MPY  50                     PLUS TWO        0617  19 0186 1206
              RAA   8002        MC007     TIMES 50        1206  80 8002 1315

      MC007   RAU  AOMOL B      MC009     ADD MASS        1315  60 4005 0609
      MC009   FMP  AAY                    BALANCE         0609  39 1133 0633
              STU  TEMPO                  AND             0633  21 9059 1441
              FSB   0047 A                ENTHALPY        1441  33 2047 1473
              FAD   0049 A                OR ENTROPY      1473  32 2049 0375
              STU   0049 A                DELTAS TO       0375  21 2049 0652
                                          MATRIX
              RAU  TEMPO                  STORE           0652  60 9059 0659
              FSB   0047 A                ERRORS          0659  33 2047 1523
              FDV  TEMPO                                  1523  34 9059 0226
              STU  RV002 B                                0226  21 9406 0983
              BMB  MC031                                  0983  43 0286 1337
              NZB  MC015        MC017                     1337  42 1590 1491
      MC015   SXB   0001                                  1590  53 0001 1446
              AXA   0050        MC007                     1446  50 0050 1315
      MC017   RAA   0000                                  1491  80 0000 1298
              RSB   0001                                  1298  83 0001 0504
              RAU  COMEX                                  0504  60 0111 1365
              NZU  MC019        MC021                     1365  44 0519 0570
      MC019   LDD  S   SR                 PLACE S/R       0519  69 9036 0425
              STD   0047                  IN ENTROPY      0425  24 0047 0400
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         RAU SQ/R    MC009    ROW AND     0400  60 0003 0609
                              COLUMN A
                                          0570  60 0004 0609
MC021    RAU HQ/R    MC009    ADD         0286  60 0015 0569
MC031    RAU PO               PRESSURE    0569  33 1112 1339
         FSB P                DELTA TO    1339  21 9059 1398
         STU TEMPO            MATRIX      1398  32 0099 0475
         FAD  0099                        0475  21 0099 1052
         STU  0099            STORE       1052  60 9059 1059
         RAU TEMPO            ERROR       1059  34 0015 1415
         FDV PO                           1415  21 9004 1573
         STU RV000   MC103    COMPLETE    1573  60 0111 1465
MC103    RAU COMEX            ENTROPY     1465  44 0619 0620
         NZU MC109   MC105    AND THE     1620  60 9032 0477
MC105    RAU S CPR            ENTHALPY    0477  39 9003 0080
         FMP T                EQUATIONS   0080  32 0048 0525
         FAD  0048                        0525  21 0048 0601
         STU  0048                        0601  27 9037 1256
         SET  9037                        1256  09 0037 1690
         LDB  0037                        1690  27 9037 1445
         SET  9037                        1445  29 0987 1740
         STB H0001   MC115                0619  60 9032 0527
MC109    RAU S CPR                        0527  32 0048 0575
         FAD  0048                        0575  21 0048 0651
         STU  0048                        0651  60 9032 1159
         RAU S CPR                        1159  39 9003 0262
         FMP T                            0262  32 0998 0625
         FAD  0998                        0625  21 0998 1740
         STU  0998   MC115

             DURING COMPLETION OF SYMMETRIC
             PORTIONS OF MATRIX    FOR GAS
             PHASE  INDXA WILL TRACK THE
             EQUATION BEING USED   INDXB
             WILL TRACK THE DIAGONAL
             POSITION AND INDXC WILL TRACK
             THE CURRENT MOVE OPERATION

             THE PHASE TEST WORD CHECK IS
             ZERO FOR GAS REFLECTION AND
             UNITY FOR SOLID REFLECTION
                                          1740  61 0158 1363
MC115    RSU SOLID            SET CHECK   1363  35 0004 1673
         SLT  0004            TO GAS      1673  20 0309 0312
         STL CHECK                        0312  10 1515 1069
         AUP LDD              GENERATE    1069  21 9058 0577
         STU MOVE1            MOVE1 AND   0577  61 0638 1593
         RSU SYSTM            MOVE2       1593  10 1496 1051
         AUP STD              ORDERS      1051  21 9059 1209
         STU MOVE2            SET INDXB   1209  60 0164 1169
         RAU ATM-1            TO ATM-1    1169  44 1723 0324
         NZU         MC151    NEGATIVED   1723  83 8003 0282
         RSB  8003   MC117    SET INDXC   0282  69 8006 1338
MC117    LDD  8006            TO INDXB    1338  88 8001 1244
         RAC  8001            INDXA IS    1244  61 8001 1101
         RSU  8001            SOLID PLUS  1101  10 0158 1413
         AUP SOLID            TWO MINUS   1413  10 0104 1259
         AUP UNITY            INDXB ALL   1259  10 8001 1067
         AUP  8001            TIMES 50    1067  19 0186 1306
         MPY 50                           1306  80 8002 1565
         RAA  8002            GAS         1565  69 8005 0471
         LDD  8005                        0471  24 9029 0627
         STD INDXA   MC123    CONDENSED   0450  69 8005 1356
MC121    LDD  8005                        1356  24 9029 0362
         STD INDXA                        0362  61 8006 1219
         RSU  8006                        1219  10 0104 1309
         AUP UNITY                        1309  19 0186 1406
         MPY 50                           1406  80 8002 0627
         RAA  8002   MC123                0627  27 9037 0332
MC123    SET  9037                        0332  09 2037 1790
         LDB  0037 A                      1790  80 9029 1448
         RAA INDXA                        1448  60 9058 1255
         RAU MOVE1            REFLECT     1255  15 9059 8003
         ALO MOVE2   8003     ONE         8003  69 9646 8002
8003     LDD  9046 C 8002     EQUATION    8002  24 2047 0500
8002     STD  0047 A MC133    AT A TIME   0500  48 1103 0554
MC133    NZC MC135   MC139                1103  58 0001 1359
MC135    AXC  0001                        1359  51 0050 8003
         SXA  0050   8003                 0554  52 0001 0260
MC139    AXB  0001                        0260  42 1463 0324
         NZB         MC151                1463  15 0416 0521
         ALO UNO                          0521  20 9059 0378
         STL MOVE2   MC143    GAS OR      0378  60 0309 1513
MC143    RAU CHECK                        1513  44 1167 0282
         NZU MC160   MC117    ANY SOLIDS  0324  60 0158 1563
MC151    RAU SOLID            IN SYSTEM   1563  44 1217 0318
         NZU MC153   MC041                1217  60 0309 1663
MC153    RAU CHECK                        1663  44 0318 0368
         NZU MC041   MC159    SET CHECK   0368  15 0104 1409
MC159    ALO UNITY            TO SOLID    1409  20 0309 0412
         STL CHECK                        0412  61 0158 1713
         RSU SOLID            GENERATE    1713  35 0004 1773
         SLT  0004
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          STU TEMPO                 MOVE1 AND    1773   21 9059 0581
          AUP LDD                   MOVE2 FOR    0581   10 1515 1269
          STU MOVE1                 CONDENSED    1269   21 9058 1177
          RAU TEMPO                 PHASE        1177   60 9059 0335
          AUP STD                                0335   10 1496 1151
          STU MOVE2                              1151   21 9059 1459
          RAU SOLID                 INDXB IS     1459   60 0158 1763
          RSB  8003   MC160         NEG SOLID    1763   83 8003 1167
MC160     LDD ATY-1                 INDEXC IS    1167   69 0164 1267
          RSC  8001                 ATM-1        1267   89 8001 1823
                                    NEGATIVED
          RAU SYS+1                 INDXA IS     1823   60 0079 1033
          MPY 50                    SYS+1        1033   19 0186 1456
          RAA  8002   MC121         TIMES 50     1456   30 8002 0450

             AT THIS POINT DECIDE IF
             ITERATION WILL BE NEEDED
             BY TESTING ON EXPONENT EACH
             DELTA MUST BE LESS THAN
             SOME SPECIFIED VALUE

MC041     RAB  0052   MC042         EXP TEST     0318   82 0052 0374
                                    ITERATION
MC042     RAU ATOM1                 CONTINUED    0374   60 0642 1498
          AUP UNITY                 UNTIL THE    1498   10 0104 1509
          RAC  8003   MC043         EXPONENT     1509   88 8003 0418
MC043     RAU RV000 C               OF DELTAS    0418   60 9604 1175
          FAD  8006                 IS EIGHT     1175   32 8006 1305
          NZU MC053                 LESS THAN    1305   44 1559 0310
          NZC         MC049         THAT GIVEN   0310   48 1813 0414
          SXC  0001   MC043         BY WORD      1813   59 0001 0418
MC049     RAB  0054   MC050         IN INDEXB    0414   82 0054 1070
MC050     RAA  0000                              1070   80 0000 0276
          RAC  0000   MC051                      0276   88 0000 0382
MC051     RAU P0001 A                            0382   60 3599 1153
          NZU         MC052                      1153   44 0557 0308
          RAU T0010 C               DEL SUB I    0557   60 6669 0424
          AXA  0002                              0424   50 0002 0130
          AXC  0010                              0130   58 0010 0336
          FAD  8006                              0336   32 8006 1665
          NZU MC053   MC051                      1665   44 1559 0382
MC052     RAU TESTX                 CONVERGED    0308   60 1361 1715
          NZU MC054                 IF ERROR     1715   44 1319 1170
          LDD UNITY                 LESS THAN    1170   69 0104 0607
          STD TESTX                 EXPON 45     0607   24 1361 0464
          RAB  0053   MC050         ONCE OR      0464   82 0053 1070
                                    EXPON 46
                                    TWICE

             WHEN CONVERGED GO TO MC054

MC054     LDD T                     SAVE TEMP    1319   69 9003 1225
          STD TEE                   ON DRUM      1225   24 1111 0514
          SET  9050                 WAS THE      0514   27 9050 1369
          LBB TEMP1                 ITERATION    1369   08 1048 1201
          RAU  9051                 DONE WITH    1201   60 9051 1709
          FSB T                     THE RIGHT    1709   33 9003 1389
          BMI MC058                 THERMAL      1389   46 1242 1693
          RAU T                     DATA         1693   60 9003 1251
          FSB  9050                              1251   33 9050 0631
          BMI MC058                              0631   46 1242 0385

             ROUTINE TO CHECK ON TRANSITION
             FROM GAS TO CONDENSED PHASE

             IF POSITION 7 ON THE CONSOLE
             IS  AN EIGHT CONDENSING
             PROGRAM IS PASSED BY

             THE PROGRAM ASSUMES THAT BOTH
             GAS AND CONDENSED VECTOR ARE
             IN STORAGE

          LDD  8000                              0385   69 8000 1541
          BD7 DONE                               1541   97 1294 1546
          STL SW1                   INITIALIZE   1546   20 1301 0604
          RAA  0000                 SWITCH SW1   0604   80 0000 0360
          RAC  0000   MC201                      0360   88 0000 0466
MC201     RAU P0001 A               ANY MORE     0466   60 3599 1203
          NZU         MC230         PRODUCTS     1203   44 0657 0358
          RAU P0002 A               YES IS IT    0657   60 3600 1355
          BMI         MC227         GASEOUS      1355   46 0408 1759
          RAL P0001 A               NO           0408   65 3599 1253
          SLT  0001                 WAS THE      1253   35 0001 1809
          NZU MC205                 SOLID USED   1809   44 0564 0614
          RAL T0008 C               YES IS NI    0614   65 6667 0571
          BMI         MC227         NEGATIVE     0571   46 0474 1759
          RAU UNITY                 YES IGNORE   0474   60 0104 0410
          SRT  0001                 THIS SOLID   0410   30 0001 1317
          ALO P0001 A               NEXT TIME    1317   15 3599 1303
          STL P0001 A                            1303   20 3599 1102
          RSU UNITY   MC219                      1102   61 0104 0460
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MC205   RAB  0000                NO LOCATE    0564  82 0000 1220
        RAU P0002 A MC207        THE GAS      1220  60 3600 1405
MC207   AUP P0002 B              PHASE        1405  10 5600 1455
        NZU          MC211       VECTOR       1455  44 0510 0560
        SUP  8001                             0510  11 8001 1367
        AXB  0002    MC207                    1367  52 0002 1405
MC211   RAU  8006                FOUND IT     0560  60 8006 1417
        MPY FUNF                              1417  19 1270 1591
        RAB  8002                             1591  82 8002 1549

             INDEX C LOCATES SOLID AND
             INDEX B THE GAS PHASE DATA

        LDD  8007                STORE        1549  69 8007 1505
        STD INDXC                INDEX C      1505  24 9030 1411
        LDD TEE                  GET T TWO    1411  69 1111 1064
        STD T                    AND THREE    1064  24 9003 1320
        SET TWO                  FOR CORE     1320  27 9028 1275
        LBB B0001                             1275  08 1247 0550
        LDD MC215    F/RT                     0550  69 1353 1506
F/RT    STD LINK                 CALCULATES   1506  24 1855 0458
        SET  9010                F/RT FOR     0458  27 9010 1164
        LBB T0001 C              SOLID AND    1164  08 6660 1214
        RAU 1E                   GAS          1214  60 9015 0621
        FDV T                                 0621  34 9003 0524
        STU TEM1                              0524  21 0428 0981
        RAU 1D                                0981  60 9014 1439
        FDV TWO                               1439  34 9028 1292
        FMP T                                 1292  39 9003 1495
        FAD 1C                                1495  32 9013 1325
        FDV THREE                             1325  34 9029 0478
        FMP T                                 0478  39 9003 1031
        FAD 1B                                1031  32 9012 1461
        FDV TWO                               1461  34 9028 1264
        FMP T                                 1264  39 9003 1467
        FAD 1F                                1467  32 9016 1548
        FSB TEM1                              1548  33 0428 1555
        STU TEM 1                             1555  21 9049 1314
        RAU ONE                               1314  60 1149 1403
        FSB LNT                               1403  33 0002 0429
        FMP 1A                                0429  39 9011 0432
        FSB TEM 1    LINK                     0432  33 9049 1855
MC215   STU TEMPO                STORE F/RT   1253  21 9059 1511
        LDD  8006                             1511  69 8006 1517
        RAC  8001                             1517  88 8001 0574
        LDD MC217    F/RT                     0574  69 1227 1506
MC217   RSU  8003                CHECK FOR    1227  61 8003 0435
        FAD TEMPO                CONDENSING   0435  32 9059 1765
        FSB LNNI                              1765  33 9017 1545
        BMI          MC225                    1545  46 1598 1699
        RAU P0001 A              IT SHOULD    1598  60 3599 1453
        SLT  0001                HAVE BEEN    1453  35 0001 0610
        SRT  0001                CONDENSED    0610  30 0001 1567
        STU P0001 A              FIX IT       1567  21 3599 1152
        RAU UNITY    MC219                    1152  60 0104 0460
MC219   AUP SYS                  MODIFY       0460  10 0018 0624
        STU SYS                  SYS          0624  21 0018 1071
        LDD UNITY                SET SWITCH   1071  69 0104 1057
        STD SW1      MC225       SW1          1057  24 1301 1699
MC225   RAC INDXC    MC227       ADVANCE TO   1699  88 9030 1759
MC227   AXA  0002                THE NEXT     1759  50 0002 1815
        AXC  0010    MC201       PRODUCT      1815  58 0010 0466
MC230   STL TESTX                             0358  20 1361 1364
        RAU SW1                  ANY WRONG    1364  60 1301 1705
        NZU UNPAK    DONE        PRODUCTS     1705  44 0101 1294
DONE    LDD S   SR               SUMMATIONS   1294  69 9036 0600
        STD S                    OF S/P AND   0600  24 1124 1277
        LDD S HRT                H/RT ON      1277  69 9034 1183
        STD H                    DRUM         1183  24 1113 0516
        LDD ATM-1                INDXC IS     0516  69 0164 1667
        RSC  8001                ATM-1 NEG    1667  89 8001 1074
        LDD SYS+2                INDXA IS     1074  69 0036 1489
        RSA  8001                SYS+2 NEG    1489  81 8001 1595
        SET  9059 C              STORE        1595  27 9659 0650
        LBB  0099 A              PRESSURE     0650  08 2099 1202
        SET  9059 C              ROW IN       1202  27 9659 1107
        SBB Z0010 C MC057        Z REGION     1107  28 7349 1252
MC058   STL TESTX    MC059                    1242  20 1361 1414

             TEST CONSOLE FOR PUNCHING
             INTERMEDIATE ANSWERS

MC053   LDD ITERA    TEST1                    1559  69 0462 0566
MC057   LDD DERIV    TEST1                    1252  69 1755 0566
MC059   LDD MC060    TEST1                    1414  69 1717 0566
MC060   LDD TEE                               1717  69 1111 1464
        STD T        TDATA                    1464  24 9003 0034
TEST1   STD LINK1                             0566  24 1419 0272
        LDD  8000                             0272  69 8000 0528
        RD2 DELS     NEXT1       TEMPORARY    0528  92 1181 1233
NEXT1   LDD  8000                PUNCHES      1233  69 8000 1539
        RD3 VARIA    NEXT2       FOR          1539  93 1392 1394
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E-417

E-417

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NEXT2   LDD  8000                  PROGRAM       1394  69 8000 1000
        RD4 MTRIX    LINK1         CHECKING      1000  94 1503 1419

                CONSTANTS FOR MATRIX
                CLEAN UP ROUTINE
LDD     LDD  9046 C  8002                        1515  69 9646 8002
STD     STD  0047 A MC133                        1496  24 2047 0500
UNO     00   0001     0000                       0416  00 0001 0000
FUNF    00   0000     0005                       1270  00 0000 0005


                ROUTINE FOR CALCULATING THE
                CORRECTIONS TO THE CURRENT
                COMPOSITIONS  AAY AND THE
                TEMPERATURE

ITERA   RAU SYS+2    NEW00         SOLVE  FOR    0462  60 0036 1691
NEW00   LDD NEW01    SOLVE         CORECTIONS    1691  69 1444 1698
NEW01   LDD SYS+2                  LOAD          1444  69 0036 1589
        RSB  8001                  VARIABLES     1589  83 8001 1695
        SET M0001                  IN            1695  27 9000 1050
        LDB D0050 B NEW02          M-REGION      1050  09 4050 1553

                INDXA WILL TRACK THE PRODUCT
                CODE AND INDXC WILL TRACK
                THE LN NI

NEW02   RSA  0002                                1553  81 0002 0960
        RSC  0010                                0960  89 0010 0616
        LDD SOLID                                0616  69 0158 1561
        STD COUNT    NEW03                       1561  24 0152 1805

NEW03   LDD ATOM1                                1805  69 0642 1745
        RAB  0010                  CLEAR 11      1745  82 0010 1351
        RAU WIPE9     8003         CORE          1351  60 0654 8003
 8003   STL N0001 B NEW04          LOCATIONS     8003  20 9415 1066
NEW04   NZB          NEW06         FOR ROW       1066  42 1469 1370
        SXB  0001     8003         VECTOR        1469  53 0001 8003
WIPE9   STL N0001 B NEW04                        0654  20 9415 1066

NEW06   AXA  0002                                1370  50 0002 0326
        AXC  0010                                0326  58 0010 0482
        RAL P0001 A                DO WE HAVE    0482  65 3599 1703
        NZE NEW07    NEW18         A PRODUCT     1703  45 1556 1157
NEW07   SLT  0001                  YES   USE     1556  35 0001 1514
        NZU NEW06    NEW08         OR BYPASS     1514  44 1370 0468

NEW08   RAU P0002 A                TEST FOR      0468  60 3600 1706
        BMI NEW20    NEW10         CONDENSED     1706  46 1060 1160

NEW10   SRT  0002                  GET THE       1160  30 0002 1767
        SUP  8003                  MOLECULE      1767  11 8003 1375
        STD TEMPO                  SUBSCRIPTS    1375  24 9059 1231
        SLT  0001                  AND LOCATE    1231  35 0001 1387
        ALO 51                     POSITION      1387  15 0166 1171
        RAB  8003                  TO STORE      1171  82 8003 0180
        STL N0001 B                STORE         0180  20 9415 1388
        RAU TEMPO                  SUBSCRIPTS    1388  60 9059 1795
        NZU NEW10                  IN CORE       1795  44 1160 1100
        LDD SYS+2                  LOAD          1100  69 0036 1689
        RAB  8001                  QI AND        1689  82 8001 1596
        SET N0000 B                DELTAI        1596  27 9414 1401
        LDB T0009 C NEW15          ON CORE       1401  09 6668 1221

NEW15   SET C0001                  ROUTINE       1221  27 9050 0376
        LBB 00001    C0001         FOR           0376  08 1020 9050
00001   SXB  0001    C0002         DEL LN PI     1020  53 0001 9051
00002   RAU M0001 B C0003                        1021  60 9400 9052
00003   FMP N0001 B C0004                        1022  39 9415 9053
00004   FAD N0002 B C0005                        1023  32 9416 9054
00005   STU N0001 B C0006                        1024  21 9415 9055
00006   NZB C0001    C0007                       1025  42 9050 9056
00007   FAD T0008 C C0008          NEW LN NI     1026  32 6667 9057
00008   STU T0008 C NEW03          FOR GAS       1027  21 6667 1805

NEW20   LDD COUNT                  NEW NI        1060  69 0152 1756
        RSB  8001    NEW21         FOR           1756  83 8001 0512
NEW21   RAU D0048 B NEW22          CONDENSED     0512  60 4048 1753
NEW22   FAD T0008 C                              1753  32 6667 1743
        STU T0008 C                              1743  21 6667 1420
        RAU COUNT                  DECREASE      1420  60 0152 1207
        SUP UNITY                  COUNT         1207  11 0104 1210
        STU COUNT    NEW06         FOR SOLIDS    1210  21 0152 1370

NEW18   RAU D0049    NEW19         NEW LNT       1157  60 0049 1803
NEW19   FAD LNT                                  1803  32 0002 0479
        STU LNT      NEW60                       0479  21 0002 1806
NEW60   RSU D0048    NEW61         NEW LNA       1806  61 0048 1104
NEW61   FAD LNAAY                                1104  32 0001 1327
        STU LNAAY                                1327  21 0001 1154
        RAU  8000                  PUNCH THE     1154  60 8000 1661
        BMI DELX     UNPAK         CORRECTION    1661  46 1564 0101
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                  START NEW ITERATION AT UNPAK


                  PERFORMANCE PARAMETER ROUTINE

                  WHEN ITERATION IS COMPLETED
                  ENTER AT DERIV

      DERIV    RAU SYS+2    D1         SOLVE FOR     1755  60 0036 1741
      D1       LDD 1LESS    REDUC      DLNPI/        1741  69 1494 1748
      1LESS    RAU SYS+1               DLNT AT       1494  60 0079 1283
               LDD CP   1   SOLVE      CONSTANT P    1283  69 0386 1698
      CP   1   LDD SYS+1               LOAD          0386  69 0079 0532
               RSA  8001               PARTIALS      0532  81 8001 1438
               RAB  8001                DLNPI/       1438  82 8001 1544
               SET M0001               DLNT AT       1544  27 9000 1749
               LDB D0050 A             CONSTANT P    1749  09 2050 1204
                                       ON CORE

               SET N0001               ENTHALPY      1204  27 9015 1260
               LDB H0012 A CP   2      ROW MOVED     1260  09 2998 1451
                                       TO CORE

      CP   2   SXB  0001               CALCULATE     1451  53 0001 1257
               RSU M0001 B             SPECIFIC      1257  61 9400 1166
               FMP N0001 B             HEAT TIMES    1166  39 9415 1519
               FAD N0002 B             MOLECULAR     1519  32 9416 1799
               STU N0001 B             WEIGHT        1799  21 9415 1307
               NZB CP   2              DIVIDED       1307  42 1451 1711
               FDV P                   BY R          1711  34 1112 0562
               FDV TEE                               0562  34 1111 1761
               STU CPMR                              1761  21 1216 1569
               RAU D0049 -             STORE         1569  60 0049 1254
               STU LMTP                DLNM/DLNT     1254  21 1123 0426
               LDD  8000               AT CONST P    0426  69 8000 0582
               RD1          CP   3     CHANGES       0582  91 0485 1437
               LDD NOOP                MADE          0485  69 1488 1791
               STD MC041    UNPAK      NECESSARY     1791  24 0318 0101
      ONCE     LDD NORM                BY            1150  69 1304 1357
               STD MC041               EQUATION      1357  24 0318 1271
               RAU SYS+2               SHIFTING      1271  60 0036 1442
               LDD          REDUC                    1442  69 1696 1748
               RAU SYS+1                             1696  60 0079 1333
               LDD          REDUC                    1333  69 0436 1748
               RAU SYS                               0436  60 0018 1174
               LDD DLMPT    SOLVE                    1174  69 1377 1698
      NOOP     NOP  0000    ONCE                     1488  00 0000 1150
      NORM     RAB  0052    MC042                    1304  82 0052 0374
      CP   3   RAU SYS+1                             1437  60 0079 1383
               LDD 2LESS    REDUC                    1383  69 0486 1748

      2LESS    RAU SYS                               0486  60 0018 1224
               LDD DLMPT    BACK                     1224  69 1377 0230


                  CONSTANTS FOR USE IN PARAMETER
                  CALCULATIONS

      CONS1     14  6960    0652       PSI/ATM       1140  14 6960 0652
      CONS2     86  4554    0052                     1141  86 4554 0052
      CONS3     10  0000    0054                     1142  10 0000 0054
      CONS4     29  4980    0053                     1143  29 4980 0053
      CONS5     57  0000    0050                     1144  57 0000 0050
      52        00  0000    0052                     1145  00 0000 0052
      R         19  8718    0051       CAL/MOL K     1146  19 8718 0051
      GC        32  1740    0052       GRAVITY       1147  32 1740 0052
      ONE       10  0000    0051                     1149  10 0000 0051

                  SET CORE LOCATIONS EQUIVALENT
                  TO PARAMETERS AND CONSTANTS
                  OF THE E REGION

               EQU PCP      M0001      9000
               EQU TEE      M0002
               EQU P        M0003
               EQU H        M0004
               EQU I        M0005
               EQU M        M0006
               EQU CF       M0007
               EQU EPSIL    M0008
               EQU MACH     M0009
               EQU I VAC    M0010
               EQU CP       M0011
               EQU GAMMA    M0012
               EQU LMPT     M0013
               EQU LMTP     M0014
               EQU S        M0015
               EQU NI       M0016
               EQU NT       M0017
               EQU NEPS     M0018
               EQU NCSTR    M0019
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          EQU CSTAR    M0020
          EQU AW       M0021
          EQU NAW      M0022
          EQU HSTR     M0023
          EQU AAY      M0024
          EQU HC       M0025
          EQU RECMC    M0026
          EQU NAWT     M0027
          EQU AWT      M0028
          EQU HSTR2    M0029
          EQU P1       M0030
          EQU CONS1    M0031
          EQU CONS2    M0032
          EQU CONS3    M0033
          EQU CONS4    M0034
          EQU CONS5    M0035
          EQU 52       M0036
          EQU R        M0037
          EQU GC       M0038
          EQU IDENT    M0039
          EQU ONE      M0040       9039
1
1             CALCULATE THE PARTIAL DERIV
1             OF THE LOG OF MOLEC WEIGHT
1             WITH RESPECT TO THE LOG OF
1             PRESSURE AT CONSTANT TEMPERTUR
1
   DLMPT  SET M0001                                1377  27 9000 0632
          LDB F0001                                0632  09 1110 1664
          LDD SYS                  LOAD            1664  69 0018 1321
          RSA  8001                DLNPT/DLNA      1321  81 8001 1427
          SET M0041                IN CORE         1427  27 9040 0982
          LDB D0050 A                              0982  09 2050 1354
          LDD ATM-1                                1354  69 0164 1817
          RSA  8001                                1817  81 8001 1274
          RAB  8001                                1274  82 8001 0280
          SET M0051                                0280  27 9050 0535
          LDB Z0010 A LMPT1        BRING AAY       0535  09 3349 1302
   LMPT1  RAU M0041 B              COLUMN          1302  60 9440 1310
          FMP M0051 B              TO CORE         1310  39 9450 1714
          FAD LMPT                                 1714  32 9012 1793
          STU LMPT                                 1793  21 9012 1501
          NZB          LMPT2                       1501  42 1404 1407
          SXB  0001    LMPT1                       1404  53 0001 1302
   LMPT2  RAU P                                    1407  60 9002 1266
          FDV LMPT                                 1266  34 9012 1669
          FSB ONE                                  1669  33 9039 1200
          STU LMPT                                 1200  21 9012 1457
1
1             CALCULATE SEVERAL OTHER
1             PARAMETERS
1
          RAU AAY                  CALCULATE       1457  60 9023 1316
          FDV P                    MOLECULAR       1316  34 9002 1719
          STU M                    WEIGHT          1719  21 9005 1477
1
          RAU CPMR                 SPECIFIC        1477  60 1216 1371
          FMP R                    HEAT            1371  39 9036 1324
          FDV M                    CAL/G           1324  34 9005 1527
          STU CP                                   1527  21 9010 0585
1
          RAU ONE                  GAMMA           0585  60 9039 1594
          FSB LMTP                 EQUALS          1594  33 9013 1374
          FMP  8003                PARTIAL OF      1374  39 8003 1577
          STU TEMPO                LN PRESSUR      1577  21 9059 0635
          RAU ONE                  WITH RESP       0635  60 9039 1694
          FAD LMPT                 TO              1694  32 9012 1424
          FMP CPMR                 LN DENSITY      1424  39 1216 1366
          FSB TEMPO                AT CONSTNT      1366  33 9059 1746
          STU TEMPO                ENTROPY         1746  21 9059 1454
          RAU CPMR                                 1454  60 1216 1421
          FDV TEMPO                                1421  34 9059 1474
          STU GAMMA                                1474  21 9011 1281
1
          RAU H                    CALCULATE       1281  60 9003 1739
          FDV AAY                  ENTHALPY        1739  34 9023 1492
          FMP TEE                  CAL/G           1492  39 9001 1796
          FMP R                                    1796  39 9036 1250
          STU H                                    1250  21 9003 1507
1
          RAU S                    CALCULATE       1507  60 9014 1416
          FDV AAY                  ENTROPY         1416  34 9023 1769
          STU TEMPO                                1769  21 9059 1677
          FMP R                                    1677  39 9036 0330
          STU S                                    0330  21 9014 1487
1
1             TEST IF COMBUSTION  THROAT  OR
1             EXIT
1
          RAU COMEX                                1487  60 0111 1466
          NZU TOREX                                1466  44 1819 1470
1
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                 RAU ONE                   STORE          1470   60 9039 1727
                 FDV M                     1/MC           1727   34 9005 0380
                 STU RECMC                                0380   21 9025 1537

                 FMP R                     CALCULATE      1537   39 9036 1542
                 FDV CP                    N SUB T        1542   34 9010 1798
                 FMP LMTP                                 1798   39 9013 1551
                 RSU  8003                                1551   61 8003 1360
                 STU NT                                   1360   21 9016 0518

                 LDD H                     SAVE HC        0518   69 9003 1524
                 STD HC                                   1524   24 9024 0430
                 LDD TEMPO                                0430   69 9059 0536
                 STD SO/R                  SAVE SO/R      0536   24 0003 1557
                 RSU UNITY    FIX H        SET COMEX      1557   61 0104 1410
       FIX H     STU COMEX    H FIX        FOR THROAT     1410   21 0111 1764
       H FIX     STL CSTAR    PNCH         CLEAR CSTR     1764   20 9019 0322

                    TEST IF THROAT OR EXIT IS
                    BEING PROCESSED


       TOREX     BMI THROT    EXIT                        1819   46 0372 1574
       EXIT      LDD REMAN    SEVRL                       1574   69 1777 0480


                 EQU TWO      80001

       THROT     RAU TEE                   CALCULATE      0372   60 9001 0529
                 FDV M                     HSTR AS        0529   34 9005 1032
                 FMP R                     H PLUS         1032   39 9036 0985
                 FDV TWO                   VELOCITY       0985   34 1247 1300
                 STU RT/2M                 OF SOUND       1300   21 1504 1707
                 FMP GAMMA                 SQUARED        1707   39 9011 1460
                 FAD H                     OVER TWO       1460   32 9003 1789
                 STU HSTR                                 1789   21 9022 1350
                 FDV HC                    THROAT IS      1350   34 9024 1554
                 FSB FINS                  GOOD WHEN      1554   33 1757 1433
                 NZU          CSTR1        HSTR EQUAL     1433   44 1587 1538
                                           HC
                 RAU GAMMA                 THROAT NOT     1587   60 9011 1400
                 FAD ONE                   DONE YET       1400   32 9039 0579
                 FMP RT/2M                                0579   39 1504 1704
                 STU TEMPO                 CALCULATE      1704   21 9059 1811
                 RAU HC                    THE NEXT       1811   60 9024 1520
                 FSB HSTR                  PRESSURE       1520   33 9022 1450
                 FDV TEMPO                 ESTIMATE       1450   34 9059 1754
                 FAD ONE                   FOR THROAT     1754   32 9039 1483
                 FMP P                                    1483   39 9002 0586
                 STU PO                                   0586   21 0015 0568
                 RAU PC                                   0568   60 1109 1814
                 STL TESTX                                1814   20 1361 1516
                 FDV PO                                   1516   34 0015 1566
                 STU R0002                                1566   21 1076 0629
                 STU F0001    UNPAK        STOR PC/PT     0629   21 1110 0101

                     START REITERATING WITH THE NEW
                     THROAT PRESSURE ESTIMATE

                     CONSTANT FOR TESTING THROAT
                              FOR CONVERGENCE

       FINS       00  1000     0053        THROT TEST     1757   00 1000 0053


       CSTR1     LDD CSTR2    SEVRL                       1538   69 1592 0480

       CSTR2     STU NAWT                  CALCULATE      1592   21 9026 1500
                 FAD ONE                   C STAR         1500   32 9039 1029
                 STU NCSTR                 EXPONENT       1029   21 9018 1687

                 RAU AW                    STORE          1687   60 9020 1550
                 STD AWT                   THROAT A/W     1550   24 9027 1807

                 FMP PC                                   1807   39 1109 1510
                 FMP GC                    CALCULATE      1510   39 9037 1666
                 FMP CONS1                 CSTAR          1666   39 9030 1570
                 STU CSTAR                                1570   21 9019 1827

                 LDD UNITY                 SET COMEX      1827  .69 0104 0508
                 STD COMEX    REMAN        FOR EXIT       0508   24 0111 1777


                      SUBROUTINE TO
                      CALCULATE SEVERAL PERFORMANCE
                      PARAMETERS WHICH ARE NEEDED
                      AFTER BOTH THROAT AND EXIT ARE
                      CONVERGED BUT ARE ALSO USED TO
                      OBTAIN SEVERAL SPECIAL THROAT
                      PARAMETERS AFTER THROAT IS
                      CONVERGED

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SEVRL   STD LINK1                   CALCULATE   0480  24 1419 0422
        RAU HC                      SPECIFIC    0422  60 9024 1179
        FSB H                       IMPULSE     1179  33 9003 1560
        FDV CONS3                               1560  34 9032 1716
        LDD IMPUL     SQRT                      1716  69 1670 1900
IMPUL   FMP CONS4                               1670  39 9033 1674
        STU I                                   1674  21 9004 1331

        RSU ONE                     CALCULATE   1331  61 9039 1692
        FDV M                       SPECIFIC    1692  34 9005 1700
        FAD RECMC                   IMPULSE     1700  32 9025 1229
        FMP TEE                     EXPONENT    1229  39 9001 1182
        FMP CONS2                               1182  39 9031 1035
        FDV I                                   1035  34 9004 1588
        FDV I                                   1588  34 9004 1742
        STU NI                                  1742  21 9015 1750

        RAU TEE                     CALCULATE   1750  60 9001 0558
        FDV AAY                     AREA PER    0558  34 9023 0612
        FDV I                       UNIT FLOW   0612  34 9004 1766
        FMP CONS2                   RATE        1766  39 9031 1720
        FDV CONS1                               1720  34 9030 1724
        STU AW                                  1724  21 9020 1381

        RAU R                       CALCULATE   1381  60 9036 1792
        FDV CP                      R OVER      1792  34 9010 1800
        FMP RECMC                   CP TIMES    1800  39 9025 1804
        STU RCPMC                   MC          1804  21 0608 1062

        RAU ONE                     CALCULATE   1062  60 9039 1770
        FDV GAMMA                   AREA PER    1770  34 9011 1774
        STU TEMPO                   UNIT FLOW   1774  21 9059 1431
        RAU LMTP                    RATE        1431  60 9013 1744
        FSB ONE                     EXPONENT    1744  33 9039 1824
        FMP RCPMC                               1824  39 0608 0658
        FSB TEMPO                               0658  33 9059 1737
        FSB NI                                  1737  33 9015 0618
        STU NAW       LINK1                     0618  21 9021 1419



           CALCULATE THOSE PERFORMANCE
           PARAMETERS WHICH HAVE NOT YET
           BEEN CALCULATED


REMAN   RAU I                       CALCULATE   1777  60 9004 1185
        FMP GC                      THRUST      1185  39 9037 1688
        FDV CSTAR                   COEFFICIEN  1688  34 9019 1794
        STU CF                      C SUB F     1794  21 9006 1701

        RAU AW                      CALCULATE   1701  60 9020 1660
        FDV AWT                     AREA RATIO  1660  34 9027 1816
        STU EPSIL                               1816  21 9007 1425

        RAU AW                      CALCULATE   1425  60 9020 1533
        FMP P                       SPEC IMPLS  1533  39 9002 0636
        FMP CONS1                   ASSUMING    0636  39 9030 1751
        FAD I                       AMBIENT     1751  32 9004 1481
        STU I VAC                   PRESS ZERO  1481  21 9009 1801

        RAU GAMMA                   CALCULATE   1801  60 9011 1710
        FMP TEE                     MACH        1710  39 9001 1068
        FMP CONS2                   NUMBER      1068  39 9031 1471
        FDV M                                   1471  34 9005 1475
        LDD MACH1     SQRT                      1475  69 0578 1900
MACH1   STU TEMPO                               0578  21 9059 1235
        RAU I                                   1235  60 9004 1352
        FDV TEMPO                               1352  34 9059 1058
        STU MACH                                1058  21 9008 1168

        RAU ONE                     CALCULATE   1168  60 9039 1525
        FSB LMTP                    TEMPERATUR  1525  33 9013 1108
        FDV CPMR                    EXPONENT    1108  34 1216 1218
        FSB RCPMC                   N SUB T     1218  33 0608 1285
        STU NT                                  1285  21 9016 1402

        RAU NAW                     CALCULATE   1402  60 9021 1760
        FSB NAWT                    AREA RATIO  1760  33 9026 1452
        STU NEPS      PNCH          EXPONENT    1452  21 9017 0322


           ROUTINE FOR PUNCHING ROCKET
           PERFORMANCE PARAMETERS AND
           COMPOSITION OF COMBUSTION
           PRODUCTS

PNCH    RAU  8003                   SET CARD    0322  60 8003 1279
        STL CARDN                   NUMBR ZERO  1279  20 1852 1158
        SET M0001                               1158  27 9000 1268
        STB F0001                               1268  29 1110 1318
        RSA  0005                   PUNCHES 2   1318  81 0005 1575
        RAB  0004                   PERFORMANC  1575  82 0004 1531
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                LDD IDENT               PARAMETERS   531   69 9038 1787
                STD M0011    PNCH1      ON 4 CARDS   787   24 9010 1502

        PNCH1   NZB          COMP1      EACH CARD    502   42 1208 1258
                SXB  0001               HAS 5        208   53 0001 1368
                AXA  0005               PARAMETERS   368   50 0005 1675
                SET M0005               PLUS         675   27 9005 0530
                LBB F0001 A             IDENTIFI-    530   08 3110 1418
                NZA SPEC                CATION AS    1418  40 1521 0472
                RAL SPEC1    PNCH2      6TH WORD     1472  65 1725 1329
        PNCH2   LDD PNCH1    PUNCH                   1329  69 1502 1950

        SPEC    RAL SPEC2    PNCH2                   1521  65 1775 1329
        COMP1   RAA  0000                            1258  80 0000 1468
                RAB  0000    COMP2                   1468  82 0000 1825

        COMP2   RSC  0005               CLEAR        1825  89 0005 1581
                RAU  8003    COMP3      POSITIONS    1581  60 8003 1552
        COMP3   STL M0011 C             FOR          1552  20 9610 1810
                AXC  0001               PRODUCTS     1810  58 0001 1518
                BMC COMP3               AND CODES    1518  49 1552 0522

                RSC  0004    COMP4                   0522  89 0004 0628
        COMP4   RAU P0001 A             DO WE HAVE   0628  60 3599 1308
                NZU          COMP5      A PRODUCT    1308  44 1162 1212

                STU M0010 C             LOAD CODE    1162  21 9609 1820
                AXC  0001                            1820  58 0001 0476

                RAU P0002 A             TEST FOR     0476  60 3600 1358
                BMI COMP6               CONDENSED    1358  46 1262 1312

                RAU T0008 B             CALC PI      1312  60 4667 1571
                LDD COMP7    EXP E      FROM LN PI   1571  69 0526 1850
        COMP7   STU M0010 C             AND LOAD     0526  21 9609 1583
                AXA  0002                            1583  50 0002 1702
                AXB  0010                            1702  52 0010 1408
                AXC  0001                            1408  58 0001 1568
                BMC COMP4    COMP5                   1568  49 0628 1212

        COMP5   NZA          SPACE                   1212  40 1668 1718
                RAL SPEC2    COMP8                   1668  65 1775 1379
        SPACE   RAL SPEC3    COMP8                   1718  65 1671 1379
        COMP8   LDD          PUNCH      PRODUCTS     1379  69 1232 1950
                RAU P0001 A             AND CODES    1232  60 3599 1458
                NZU COMP2    FROZ                    1458  44 1825 1362
        FROZ    LDD UNPAK    PCP 1                   1362  69 0101 0637

        COMP6   RAU T0008 B COMP7       COND IS NI   1262  60 4667 0526



                  CONSTANTS FOR PUNCH ROUTINE

        SPEC1    07 M0006     0006                   1725  07 9005 0006
        SPEC2    00 M0006     0006                   1775  00 9005 0006
        SPEC3    06 M0006     0006                   1671  06 9005 0006


                EQU PCP      F0001
                EQU TEE      F0002
                EQU P        F0003
                EQU H        F0004
                EQU I        F0005
                EQU M        F0006
                EQU CF       F0007
                EQU EPSIL    F0008
                EQU MACH     F0009
                EQU I VAC    F0010
                EQU CP       F0011
                EQU GAMMA    F0012
                EQU LMPT     F0013
                EQU LMTP     F0014
                EQU S        F0015
                EQU NI       F0016
                EQU NT       F0017
                EQU NEPS     F0018
                EQU NCSTR    F0019
                EQU CSTAR    F0020
                EQU AW       F0021
                EQU NAW      F0022
                EQU HSTR     F0023
                EQU AAY      F0024
                EQU HC       F0025
                EQU RECMC    F0026
                EQU NAWT     F0027
                EQU AWT      F0028
                EQU HSTR2    F0029
                EQU P1       F0030
                EQU CONS1    F0031
                EQU CONS2    F0032
                EQU CONS3    F0033
                EQU CONS4    F0034
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                EQU CONS5     F0035
                EQU 52        F0036
                EQU R         F0037
                EQU GC        F0038
                EQU IDENT     F0039
 1
 1
 1                  SUBROUTINE TO SET ASSIGNED
 1                  PRESSURE
 1
      PCP 1     STD LINK                                0637  24 1855 1508
                RAL PCPCT                 ADVANCE       1508  65 0017 1721
                ALO UNITY                 PRESSURE      1721  15 0104 1412
                STL PCPCT                 RATIO         1412  20 0017 1771
 1                                        COUNTER
                RAA  8001                               1771  80 8001 1028
                SLT  0004                               1028  35 0004 1752
                STL PROB                                1752  20 1904 1558
                RAU R0000 A                             1558  60 3074 1429
                STL TESTX                               1429  20 1361 1768
                STU PCP                   NEW PC/PE     1768  21 1110 1818
                NZU           9999        TEST FOR      1818  44 1821 9999
 1                                        LAST PC/PE
                RAU PC                                  1821  60 1109 0572
                FDV PCP                                 0572  34 1110 1462
                STU PO        CLER1                     1462  21 0015 0622
 1
      CLER1     RAB  0018                 CLEAR 18      0622  82 0018 1178
                RAU WIPE7     8003        PARAMETER     1178  60 1681 8003
       8003     STL F0001 B CL  1         STORAGES      8003  20 5110 1072
      CL  1     SXB  0001                               1072■ 53 0001 1228
                NZB  8003     LINK                      1228  42 8003 1855
 1
 1                 CONSTANTS FOR ASSIGNED
 1                 PRESSURE SUBROUTINE
 1
      UNITY      00  0000     0001                      0104  00 0000 0001
      WIPE7     STL F0001 B CL  1                       1681  20 5110 1072
 1
 1
 1                 SUBROUTINE FOR SOLUTION OF
 1                 N SIMULTANEOUS EQUATIONS
 1
      SOLVE     STD LINK                                1698  24 1855 1708
                STU EQUAT                               1708  21 1512 1172
                SUP UNITY                               1172  11 0104 1562
                NZU OKEH                                1562  44 1222 1272
                RAU D0049                               1272  60 0049 1758
                FDV D0048                               1758  34 0048 1802
                STU D0049     LINK                      1802  21 0049 1855
      OKEH      AUP UNITY     START                     1222  10 0104 1662
 1
 1
      BACK      STD LINK                  BACK          0230  24 1855 1808
                STU NOROW                 SOLUTION      1808  21 9049 1322
                RAU D0049     BACK1       ONLY          1322  60 0049 1712
      START     STU NOROW                 STORE EQUA    1662  21 9049 1372
                STD MINEX                 NUMBER        1372  24 9045 1278
                STL MINCO                               1278  20 9046 0986
                LDD  8000                 MUST EQUA     0986  69 8000 1762
                BD1 AGAIN     STRT1       BE SHIFTED    1762  91 1422 1472
      AGAIN     STU VARBL                               1422  21 9048 1479
                SUP UNITY                               1479  11 0104 1812
                BMI SHOVE                               1812  46 1522 1572
                MPY 50                    INDXB         1572  19 0186 1672
                RAB  8002                 FOLLOWS       1672  82 8002 1731
                SXB NOROW                 EQUATIONS     1731  53 9049 1722
                RAU NOROW                 INDXA THE     1722  60 9049 1529
                SUP UNITY                 VARIABLES     1529  11 0104 1772
                NZU           BACKS                     1772  44 0576 0626
                RAA  8003                               0576  80 8003 0334
                RAC  8003                               0334  88 8003 1822
                SET M0001                 BRING EQUA    1822  27 9000 1328
                LDB D0049 B               TO CORE       1328  09 4049 1176
                SET C0001                               1176  27 9050 1781
                LDB U0001     C0001                     1781  09 0050 9050
      U0001     RAU M0001     C0002       DIVIDE THE    0050  60 9000 9051
      U0002     NZU C0003     LEAVE       EQUATION      0051  44 9052 1226
      U0003     RAU M0001 A C0004         BY THE        0052  60 9200 9053
      U0004     FDV M0001     C0005       LEADING       0053  34 9000 9054
      U0005     RAM  8003     C0006       COEFICIENT    0054  67 8003 9055
      U0006     STL M0001 A C0007                       0055  20 9200 9056
      U0007     SXA  0001     C0008                     0056  51 0001 9057
      U0008     NZA C0003     C0009                     0057  40 9052 9058
      U0009     STU MAXCO                               0058  21 9047 1326
                RAA NOROW                 TO ZERO       1326  30 9049 0384
                SXA  0001                               0384  51 0001 1376
                SET C0001                               1376  27 9050 1831
                LDB Y0001     C0001                     1831  09 0059 9050
      Y0001     RAU MAXCO     C0002       SEARCH FOR    0059  60 9047 9051
      Y0002     FSB M0001 A C0003         MAXIMUM       0060  33 9200 9052
      Y0003     BMI C0004     C0006       COEFICIENT    0061  46 9053 9055
```

```
        Y0004   LDD M0001 A C0005
        Y0005   STD MAXCO   C0006
        Y0006   SXA  0001   C0007
        Y0007   NZA C0001
                RSU MINCO
                NZU         BOOK
                FAD MAXCO
                BMI BOOK    LEAVE
        BOOK    LDD MAXCO
                STD MINCO
                LDD VARBL
                STD MINEX   LEAVE
        LEAVE   RAU VARBL
                SUP UNITY   AGAIN
        SHOVE   RAU NOROW
                SUP MINEX
                NZU         STRTO
                RAU NOROW
                SUP UNITY
                MPY 50
                RAA  8002
                RAU MINEX
                SUP UNITY
                MPY 50
                RAB  8002
                SET M0001
                LDB D0037 A
                LDB D0037 B
                SET M0001
                STB D0037 B
                STB D0037 A STRTO
        STRTO   RAU NOROW   STRT1
        STRT1   SUP UNITY
                NZE         BACKS
                MPY 50
                RAB  8002
                SXB NOROW
                SET M0001
                LDB D0049 B
                RAA NOROW   DIV
        DIV     SET C0001
                LBB I0001   C0001
        I0001   RAU M0001 A C0002
        I0002   FDV M0001   C0003
        I0003   STU M0001 A C0004
        I0004   SXA  0001   C0005
        I0005   NZA C0001   NEXTR
1
        NEXTR   SET M0002
                STB D0050 B
                SET C0001
                LBB J0001   NEW R
1
        NEW R   SXB  0050
                AXB NOROW
                BOV OFLO1
                BMB OUT 1
                SXB NOROW
                SET N0001
                LDB D0049 B
                RAA NOROW   ELMIN
        OFLO1   HLT  0000   9955
        OUT 1   RAU NOROW
                SUP UNITY   START
        J0001   RSU N0001   C0002
        J0002   FMP M0001 A C0003
        J0003   BOV ZEROU   C0004
        J0004   FAD N0001 A C0005
        J0005   STU N0001 A C0006
        J0006   SXA  0001   C0007
        J0007   NZA ELMIN
                SET N0002
                STB D0050 B NEW R
        ZEROU   RAU  8002   C0004
1
        BACKS   RAU N0003   B1
        B1      FDV N0002
                LDD EQUAT
1
                STD NOROW   BACK1
        BACK1   RAB  0000
                RAC  0001
                SET C0001
                LBB K0001   S7
1
        S7      SXC  0001
                STU D0049 C
                BOV OFLO2
                RSL  8007
                RAA  8002
                AXA  0001
```

```
               0062  69 9200 9054
               0063  24 9047 9055
               0064  51 0001 9056
               0065  40 9050 1426
PLACE          1426  61 9046 1683
SMALLEST       1683  44 1738 1788
COEFFICIENT    1738  32 9047 1476
IN MINCO       1476  46 1788 1226
AND EQUAT      1788  69 9047 1526
NUMBER IN      1526  24 9046 1282
MINEX          1282  69 9048 1576
               1576  24 9045 1226
GO TO NEXT     1226  60 9048 1733
EQUATION       1733  11 0104 1422
               1522  60 9049 1579
               1579  11 9045 1676
               1676  44 1679 0580
               1679  60 9049 1726
               1726  11 0104 1776
               1776  19 0186 1826
               1826  80 8002 1335
               1335  60 9045 1378
               1378  11 0104 1428
               1428  19 0186 1478
               1478  82 8002 1528
SHIFT THE      1528  27 9000 1783
EQUATIONS      1783  09 2037 1578
               1578  09 4037 1678
               1678  27 9000 0434
               0434  29 4037 1728
               1728  29 2037 0580
               0580  60 9049 1472
               1472  11 0104 1778
               1778  45 1332 0626
               1332  19 0186 1828
               1828  82 8002 1729
               1729  53 9049 1779
TRANSFER       1779  27 9000 0484
EQ TO CORE     0484  09 4049 1829
               1829  80 9049 0630
               0630  27 9050 1385
DIVIDE         1385  08 1001 9050
ELEMENTS       1001  60 9200 9051
OF FIRST       1002  34 9000 9052
EQUATION       1003  21 9200 9053
BY LEADING     1004  51 0001 9054
COEFFIC        1005  40 9050 1030

AND STORE      1030  27 9001 1435
BACK ON        1435  29 4050 1180
DRUM           1180  27 9050 1485
               1485  08 1006 1230

ANY MORE       1230  53 0050 1036
EQUATIONS      1036  52 9049 1280
CHK OVRFLO     1280  47 0534 1535
               1535  43 1330 1380
YES            1380  53 9049 1430
               1430  27 9015 1585
               1585  09 4049 1480
               1480  80 9049 9050
               0534  01 0000 9955
NO             1330  60 9049 1530
               1530  11 0104 1662
ELIMINATE      1006  61 9015 9051
A VARIABLE     1007  39 9200 9052
CHK OVRFLO     1008  47 1580 9053
               1009  32 9215 9054
               1010  21 9215 9055
               1011  51 0001 9056
               1012  40 9050 1680
               1680  27 9016 1685
               1685  29 4050 1230
OVERFLOW       1580  60 8002 9053

LEAVES THE     0626  60 9017 0584
LAST           0584  34 9016 1730
VARIABLE       1730  69 1512 1780
IN UPPER
               1780  24 9049 1712
               1712  82 0000 1830
               1830  88 0001 1186
               1186  27 9050 1382
               1382  08 1013 1432

               1432  59 0001 1482
               1482  21 6049 1532
CHK OVRFLO     1532  47 1735 1582
               1582  66 8007 1682
               1682  80 8002 1732
               1732  50 0001 1782
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```
         AXB  0049                                 1782  52 0049 1832
         SXA  NOROW                                1832  51 9049 0634
         BMA            LINK                       0634  41 0984 1855
         AXA  NOROW                                0984  50 9049 1034
         SET  M0001                   VARIABLES    1034  27 9000 1184
         LDB  D0049 C                 IN M0001     1184  09 6049 1234
         SET  N0001                   COEFFICNTS   1234  27 9015 1284
         LDB  D0049 B S1              IN N0001     1284  09 4049 9050
OFLO2    HLT  0000      9966                       1735  01 0000 9966
49        49  0000      0000                       1334  49 0000 0000


              CALCULATE AND LEAVE NEXT
              VARIABLE IN UPPER

K0001    SXA  0001      C0002                      1013  51 0001 9051
K0002    RSU  M0001 A   C0003                      1014  61 9200 9052
K0003    FMP  N0001 A   C0004                      1015  39 9215 9053
K0004    BOV  ZERUP     C0005         CHK OVRFLO   1016  47 1384 9054
K0005    FAD  N0002 A   C0006                      1017  32 9216 9055
K0006    STU  N0001 A   C0007                      1018  21 9215 9056
K0007    NZA  S1        S7                         1019  40 9050 1432
ZERUP    RAU  8002      C0005                      1384  60 8002 9054


              SUBROUTINE TO REDUCE MATRIX BY
              ONE COLUMN AND ONE ROW

REDUC    STD  LINK                    REDUCE       1748  24 1855 1434
         RSB  8003                    MATRIX       1434  83 8003 1484
         RAA  8003                    BY           1484  80 8003 1534
         SXA  0001      SHIFT         ONE          1534  51 0001 1584
SHIFT    AXB  0050                    COLUMN       1584  52 0050 1684
         SET  M0001                   AND          1684  27 9000 1734
         LDB  D0049 B                 ONE          1734  09 4049 1784
         SET  M0001                   ROW          1784  27 9000 1785
         STB  D0000 B                              1785  29 4000 1236
         SXA  0001                                 1236  51 0001 1286
         NZA  SHIFT     LINK                       1286  40 1584 1855


              ROUTINE TO LOAD PACKED VECTORS
              AND GENERATE ATOM1 AND SYS THE
              PROGRAM DEFINING CONSTANTS

              PRECEED PACKED VECTORS WITH
              A LOAD HUB TRANSFER CARD WHICH
              IS  NOP GO TO V0001

              FOLLOW PACKED VECTORS WITH A
              LOAD HUB CARD WORD1 EQUAL ZERO

              THE PROGRAM BYPASSES THE
              PROPELLANT IDENTIFICATION CARD

              INDEXB TOTALS GASEOUS ATOMS
              INDEXC TOTALS CONDENSED PHASES

              OASIS SPECIFIES WHICH OF THE
              CONDENSED PHASES ARE USED

         REG  R1951     1960          READ BAND
         REG  V1599     1659          IN PREGION
         REG  C9000     9000
         EQU  PCH10     1986          WRD 10 PCH
         EQU  ODIN      C0048
         EQU  OASIS     C0049
         EQU  RELAY     C0050

8000     RCD  R0001     1998          CONSOLE      8000  70 1951 1998
R0001     00  0000      V0001         TRANSFR CD   1951  00 0000 1599
V0001    SET  C0003     V0002                      1599  27 9002 1600
V0002    LDB  V0003     C0003                      1600  09 1601 9002
V0003    RAA  0000      C0004         CLEAR        1601  80 0000 9003
V0004    RAB  0000      C0005         INDEX A B    1602  82 0000 9004
V0005    RAC  0000      C0006         AND C        1603  88 0000 9005
V0006    SUP  8003      C0007                      1604  11 8003 9006
V0007    STU  RELAY     C0008                      1605  21 9049 9007
V0008    RCD  PCH10     9977                       1606  70 1986 9977
PCH10    NOP  0000      C0009                      1986  00 0000 9008
V0009    RAU  R0001     C0010         ARE ALL      1607  60 1951 9009
V0010    NZU  C0011     C0042         VECTORS IN   1608  44 9010 9041
V0011    RAU  R0002     C0012         NO BYPASS    1609  60 1952 9011
V0012    NZU  C0013     C0008         NONVECTORS   1610  44 9012 9007
V0013    RAU  R0004     C0014                      1611  60 1954 9013
V0014    BMI  C0025     C0015         IS THIS      1612  46 9024 9014
V0015    SRT  0002      C0016         AN ATOM OR   1613  30 0002 9015
V0016    NZU  C0025     C0017         MOLECULE     1614  44 9024 9016
V0017    SLT  0001      C0018                      1615  35 0001 9017
V0018    SLO  ODIN      C0019                      1616  16 9047 9018
V0019    RAL  8002      C0020                      1617  65 8002 9019
```

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V0020    NZE C0025    C0021                       1618  45 9024 9020
V0021    AXR  0001    C0022      GAS ATOM         1619  52 0001 9021
V0022    RAU RELAY    C0023      ARE ALL          1620  60 9049 9022
V0023    NZU C0024    C0037      ATMS AHEAD       1621  44 9023 9036
V0024    HLT  0000     9988                       1622  01 0000 9988
V0025    LDD ODIN     C0026      IT IS A          1623  69 9047 9025
V0026    STD RELAY    C0027      MOLECULE         1624  24 9049 9026
V0027    RAU R0004    C0028      IS PRODUCT       1625  60 1954 9027
V0028    BMI C0029    C0037      CONDENSED        1626  46 9028 9036
V0029    RAU OASIS    C0030      YES              1627  60 9048 9029
V0030    SRT  0001    C0031                       1628  30 0001 9030
V0031    STU OASIS    C0032                    /  1629  21 9048 9031
V0032    RAL  8002    C0033      IS IT TO      /  1630  65 8002 9032
V0033    NZE C0036    C0034      BE USED          1631  45 9035 9033
V0034    RAL R0002    C0035      YES              1632  65 1952 9034
V0035    AXC  0001    C0038                       1633  58 0001 9037
V0036    ALO R0002    C0038      NO               1634  15 1952 9037
V0037    RAL R0002    C0038                       1635  65 1952 9037
V0038    STL P0001 A  C0039      STORE CODE       1636  20 3599 9038
V0039    LDD R0004    C0040      AND VECTOR       1637  69 1954 9039
V0040    STD P0002 A  C0041                       1638  24 3600 9040
V0041    AXA  0002    C0008                       1639  50 0002 9007
V0042    RAU  8007    C0043                       1640  60 8007 9042
V0043    STL P0001 A  C0044                       1641  20 3599 9043
V0044    LDD  8006    C0045                       1642  69 8006 9044
V0045    STD ATOM1    C0046      STORE SYS        1643  24 0642 9045
V0046    AUP  8001    C0047      AND ATOM1        1644  10 8001 9046
V0047    STU SYS      CHEK                        1645  21 0018 0499
1
1                CONSTANTS
1
V0048     10  0000     0000      ODIN             1646  10 0000 0000
V0049     11  1111     1111      OASIS            1647  11 1111 1111
1
1                BUILT IN ESTIMATES FOR
1                ALL THE VARIABLES
1
T0008     10  0000     0040      ESTIMATES        0667  10 0000 0040
T0018     10  0000     0040      FOR LN OF        0677  10 0000 0040
T0028     10  0000     0040      COMPOSITON       0687  10 0000 0040
T0038     10  0000     0040      EQUIVALENT       0697  10 0000 0040
T0048     10  0000     0040      TO PARTIAL       0707  10 0000 0040
T0058     10  0000     0040      PRESSURES        0717  10 0000 0040
T0068     10  0000     0040      OF I             0727  10 0000 0040
T0078     10  0000     0040      ATMOSPHERE       0737  10 0000 0040
T0088     10  0000     0040      FOR ALL          0747  10 0000 0040
T0098     10  0000     0040      GASEOUS          0757  10 0000 0040
T0108     10  0000     0040      PRODUCTS         0767  10 0000 0040
T0118     10  0000     0040                       0777  10 0000 0040
T0128     10  0000     0040                       0787  10 0000 0040
T0138     10  0000     0040                       0797  10 0000 0040
T0148     10  0000     0040                       0807  10 0000 0040
T0158     10  0000     0040                       0817  10 0000 0040
T0168     10  0000     0040                       0827  10 0000 0040
T0178     10  0000     0040                       0837  10 0000 0040
T0188     10  0000     0040                       0847  10 0000 0040
T0198     10  0000     0040                       0857  10 0000 0040
T0208     10  0000     0040                       0867  10 0000 0040
T0218     10  0000     0040                       0877  10 0000 0040
T0228     10  0000     0040                       0887  10 0000 0040
T0238     10  0000     0040                       0897  10 0000 0040
T0248     10  0000     0040                       0907  10 0000 0040
T0258     10  0000     0040                       0917  10 0000 0040
T0268     10  0000     0040                       0927  10 0000 0040
T0278     10  0000     0040                       0937  10 0000 0040
T0288     10  0000     0040                       0947  10 0000 0040
T0298     10  0000     0040                       0957  10 0000 0040
G0001     50  0000     0051      LNA ESTM T       0001  50 0000 0051
G0002     82  4300     0051      LNT ESTM T       0002  82 4300 0051
1
1
1                TO RUN AT CONSTANT ENTHALPY
1                AT VARIOUS PRESSURE RATIOS
1                LOAD THE FOLLOWING CARD
1
 FIX H    STL COMEX    H FIX     CONST H          1410  20 0111 1764
1
1                TO RUN FROZEN COMPOSITION
1                CALCULATIONS LOAD THE
1                FOLLOWING CARD
1
 FROZ     HLT  9999    9999                       1362  01 9999 9999
1
1
          PAT
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```
              PUNCH ROUTINE FOR TESTING
              GENERAL ROCKET PERFORMANCE
                      CALCULATION

              PUNCHING IS CONSOLE CONTROLLED
              BY POSITIONS 2 3 4 AND SIGN
              THESE POSITIONS MUST BE EITHER
              EIGHT OR NINE PUNCHING ON 8

              POSITION 2 PUNCHES ONE MINUS
              P/PO ETC  AND NEGATIVE DELTAI

              POSITION 3 PUNCHES P   T   AAY
              AND THE COMPOSITIONS NI

              POSITION 4 PUNCHES THE
              REDUCED MATRIX

              A MINUS ON CONSOLE PUNCHES
              CORRECTION VARIABLES

              ANY COMBINATION OF THE FOUR
              PUNCHES MAY BE USED TOGETHER

           BLA  1656     1659
           BLA  0940     0959


              PUNCH THE DELS AT THIS TIME

   DELS    RAL PCH01                PUNCH ONE    1181   65 1336 0941
           ALO ATOM1                MINUS A      0941   15 0642 0947
           LDD DELS1     PUNCH      OVER AO      0947   69 0950 1950
   DELS1   RAA  0000                ETC          0950   80 0000 0956
           RAC  0000     DELS2                   0956   88 0000 1386
   DELS2   RAU P0001 A              PUNCH THE    1386   60 3599 0953
           NZU           DELS3      PRODUCT      0953   44 0957 0958
           STU  9000 A              CODES AND    0957   21 9200 1436
           LDD T0010 C              THE DELTAI   1436   69 6669 1486
           STD  9001 A                           1486   24 9201 0942
           AXA  0002                             0942   50 0002 0948
           AXC  0010     DELS2                   0948   58 0010 1386
   DELS3   RAL  8005                             0958   65 8005 1536
           ALO PCH02                             1536   15 0940 0945
           LDD NEXT1     PUNCH                   0945   69 1233 1950


              PUNCH THE SOLUTION TO THE
                    CURRENT MATRIX

   DELX    LDD SYS+1                PUNCH THE    1564   69 0079 1586
           RSA  8001                SOLUTION     1586   81 8001 0943
           SET  9000                TO THE       0943   27 9000 0949
           LDB D0049 A              CORRECTION   0949   09 2049 0952
           RAL PCH02                MATRIX       0952   65 0940 0946
           ALO SYS+2                             0946   15 0036 0944
           LDD UNPAK     PUNCH                   0944   69 0101 1950

              CONSTANTS FOR THE PUNCH
                        ROUTINE

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```
        PCH01     06 RV000     0002                            1336   06 9004 0002
        PCH02     06  9000     0000                            0940   06 9000 0000
      1
                  PAT



                  BLA  1652    1655
                  BLA  0920    0939
      1
      1              PUNCH THE CURRENT VARIABLES
      1
        VARIA     RAU LNT                  PUNCH TEMP          1392   60 0002 1657
                  LDD VAR01    EXP E       PRESSURE            1657   69 0920 1850
        VAR01     STU  9000                AND AAY             0920   21 9000 0927
                  LDD P                                        0927   69 1112 0921
                  STD  9001                                    0921   24 9001 0928
                  LDD AAY                                      0928   69 1133 0936
                  STD  9002                                    0936   24 9002 0951
                  RAL PCH03                                    0951   65 0954 0959
                  LDD VAR02    PUNCH                           0959   69 0922 1950
        VAR02     RAA  0000                PUNCH THE           0922   80 0000 0929
                  RAC  0000    VAR03       PRODUCT             0929   88 0000 0935
        VAR03     RAU P0001 A              CODE AND            0935   60 3599 1653
                  NZU          VAR11       MOLES OF            1653   44 1658 1659
                  STD  9000 A              EACH                1658   24 9200 0923
                  RAU P0002 A              COMBUSTION          0923   60 3600 0955
                  BMI VAR07                PRODUCT             0955   46 0924 0925
                  RAU T0008 C                                  0925   60 6667 0926
                  LDD VAR05    EXP E                           0926   69 0930 1850
        VAR05     STU  9001 A VAR09                            0930   21 9201 0937
        VAR07     LDD T0008 C                                  0924   69 6667 0931
                  STD  9001 A VAR09                            0931   24 9201 0937
        VAR09     AXA  0002                                    0937   50 0002 1652
                  AXC  0010    VAR03                           1652   58 0010 0935
        VAR11     RAL PCH02                                    1659   65 0940 1654
                  ALO  8005                                    1654   15 8005 0932
                  LDD NEXT2    PUNCH                           0932   69 1394 1950
      1
      1
      1              PUNCH OUT THE MATRIX
      1
        MTRIX     RAU SYS+1                                    1503   60 0079 0933
                  MPY 50                                       0933   19 0186 1656
                  RAA  8002    MTR01                           1656   80 8002 0934
        MTR01     SET  9000                                    0934   27 9000 0939
                  LDB  0037 A                                  0939   09 2037 1655
                  RAL PCH04                                    1655   65 1686 1736
                  LDD MTR03    PUNCH                           1736   69 1786 1950
        MTR03     NZA          LINK1                           1786   40 0938 1419
                  SXA  0050    MTR01                           0938   51 0050 0934
      1
      1
      1              CONSTANTS FOR THE PUNCH
      1                          ROUTINE
      1
        PCH03     06  9000     0003                            0954   06 9000 0003
        PCH04     06  9000     0013                            1686   06 9000 0013
                  PAT
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                PROGRAM CHANGE TO CONTROL SIZE
                OF APPLIED CORRECTION

             BLA  1652     1655
             BLA  0920     0939
             REG C9050     9050
                LOAD AVAILABILITY TABLE GIVEN
                BY CARD NUMBER 1967

    NEW00    LDD MAG00    SOLVE                        1691   69 0951 1698
    MAG00    LDD SYS+1                                 0951   69 0079 0932
             RSA  8001                                 0932   81 8001 0938
             RAB  8001                   BRING         0938   82 8001 1652
             RAC  8001                   SOLUTION      1652   88 3001 1658
             SET M0001                   VECTOR TO     1658   27 9000 0920
             LDB D0049 A MAG01           CORE          0920   09 2049 1653
    MAG01    RAM M0001 B                 MAKE ALL      1653   67 9400 0921
             STL N0001 B                 COMPONENTS    0921   20 9415 0928
             NZB          MAG03          POSITIVE      0928   42 0931 0933
             SXB  0001    MAG01                        0931   53 0001 1653
    MAG03    RAU N0001 C MAG05           FIND THE      0933   60 9615 0954
    MAG05    FSB N0000 C                 LARGEST       0954   33 9614 0934
             BMI          TOP            COMPONENT     0934   46 0937 0939
             RAU N0000 C MAG07                         0937   60 9614 1654
    TOP      FAD N0000 C MAG07                         0939   32 9614 1654
    MAG07    SXC  0001                   IF THE        1654   59 0001 0922
             NZC MAG05                   COMPONENT     0922   48 0954 0926
             FSB MAXMA                   IS LARGER     0926   33 0929 0955
             BMI          MAG09          THAN MAXMA    0955   46 0959 1659
             LDD F0040                   STORE THE     0959   69 1149 1655
             STD RATIO    NEW01          RATIO OF      1655   24 0923 1444
    MAG09    FAD MAXMA                   COMPONENT     1659   32 0929 1656
             FDV MAXMA                   TO MAXMA      1656   34 0929 0930
             STU RATIO    NEW01                        0930   21 0923 1444
    MAXMA     50  0000    0051           MAX RATIO     0929   50 0000 0051
    Q0006    NZB C0001                                 1025   42 9050 0935
             FDV RATIO    Q0007                        0935   34 0923 1026
    NEW21    RAU D0048 B                               0512   60 4048 1657
             FDV RATIO    NEW22                        1657   34 0923 1753
    NEW18    RAU D0049                                 1157   60 0049 0924
             FDV RATIO    NEW19                        0924   34 0923 1803
    NEW60    RSU D0048                                 1806   61 0048 0925
  •          FDV RATIO    NEW61                        0925   34 0923 1104


                PROGRAM MAY BE MODIFIED TO
                CONVERGE FOR ASSIGNED
                TEMPERATURE AND PRESSURE BY
                INCLUDING THE FOLLOWING STEPS

             BLA  0910     0919
             BLA  1650     1651

    MC021    RAU HO/R                                  0570   60 0004 0910
             STL RV001    MC031                        0910   20 9005 0286
    ITERA    LDD HOLD1                                 0462   69 0915 0918
             STD BACKS                                 0918   24 0626 0936
             RAU SYS+2    NEW00                        0936   60 0036 1691
    HOLD1    SUP  8003    B1                           0915   11 8003 0584
    DERIV    LDD HOLD2                                 1755   69 0911 0914
             STD BACKS•                                0914   24 0626 1686
             RAU SYS+2    D1                           1686   60 0036 1741
    HOLD2    RAU N0003    B1                           0911   60 9017 0584
             PAT
```

```
 1              INPUT DATA ROUTINE
 1
                BLR  0000     0036
                BLR  0050     0086
                BLR  0100     0136
                BLR  0150     0186
                BLR  0200     0236
                BLR  0250     0286
                BLR  0300     0336
                BLR  0350     0386
                BLR  0400     0436
                BLR  0450     0486
                BLR  0500     1999
                BLA  0987     0999
                BLA  1340     1349
                REG G0001     0015
                REG I0040     0045
                REG F1110     1110
                REG M9000     9000
                SYN VFPLS     0598       +FUEL VALN
                SYN VFMIN     0599       -FUEL VALN
                SYN VXPLS     0548       +OXID VALN
                SYN VXMIN     0549       -OXID VALN
                SYN O/F       0199
                SYN PCT F     0299
                SYN EQRAT     0399       EQUIVLENCE
 1                                       RATIO
                SYN CHEK      0499
                SYN BEGIN     0000
                SYN PUNCH     1950
                SYN PC       F0000
                SYN IDENT    F0039
                SYN R        F0037
                SYN TEMPO     9011
                SYN CONS1     1140
                SYN PROB      1904
 1
 1                CALCULATE NUMBER OF MOLES OF
 1                OXIDANT PER MOLE OF FUEL
 1
 1                                                 0499   60 0199 0037
      CHEK      RAU O/F                            0037   44 0091 0092
                NZU OXFUL                          0092   60 0299 0087
                RAU PCT F                          0087   44 0141 0142
                NZU PRCNT                          0142   60 0399 0137
                RAU EQRAT                          0137   44 0191 0192
                NZU EQUIV                          0192   01 9999 9999
                HLT  9999     9999
 1                                                 0091   60 0199 0187
      OXFUL     RAU O/F                            0187   32 0090 0237
                FAD 10051                          0237   21 9011 0095
                STU TEMPO                          0095   60 0048 0287
                RAU 10053                          0287   34 9011 0140
                FDV TEMPO                          0140   21 0299 0337
                STU PCT F     EQU                  0337   60 0548 0387
      EQU       RAU VXPLS                          0387   39 0199 0049
                FMP O/F                            0049   32 0598 0437
                FAD VFPLS                          0437   21 9011 0145
                STU TEMPO                          0145   61 0549 0487
                RSU VXMIN                          0487   39 0199 0099
                FMP O/F                            0099   33 0599 0987
                FSB VFMIN                          0987   34 9011 0190
                FDV TEMPO                          0190   21 0399 0038
                STU EQRAT     ATM 1
 1                                                 0141   60 0048 0088
      PRCNT     RAU 10053                          0088   33 0299 0138
                FSB PCT F                          0138   34 0299 0149
                FDV PCT F                          0149   21 0199 0337
                STU O/F       EQU
 1                                                 0191   60 0548 0188
      EQUIV     RAU VXPLS                          0188   39 0399 0249
                FMP EQRAT                          0249   32 0549 0238
                FAD VXMIN                          0238   21 9011 0195
                STU TEMPO                          0195   61 0598 0288
                RSU VFPLS                          0288   39 0399 0349
                FMP EQRAT                          0349   33 0599 0338
                FSB VFMIN                          0338   34 9011 0241
                FDV TEMPO                          0241   21 0199 0388
                STU O/F                            0388   32 0090 0438
                FAD 10051                          0438   21 9011 0245
                STU TEMPO                          0245   60 0048 0488
                RAU 10053                          0488   34 9011 0291
                FDV TEMPO                          0291   21 0299 0038
                STU PCT F     ATM 1
 1                                                 0038   60 0199 0988
      ATM 1     RAU O/F                            0988   32 0090 0039
                FAD 10051                1 PLUS O/F 0039  21 0094 0047
                STU 1 O/F                          0047   82 0010 0089
                RAB  0010                          0089   80 0000 0295
                RAA  0000     ATM 2
 1                                       CALCULATE 0295   60 2537 0341
      ATM 2     RAU  0537 A              ATOMS PER 0341   39 0199 0449
                FMP O/F                  GRAM OF   0449   32 2587 0139
                FAD  0587 A              PROPELLANT 0139  34 0094 0144
                FDV 1 O/F                          0144   21 2005 0189
                STU G0005 A                        0189   53 0001 0345
                SXB  0001
```

```
        NZB          ATM 3                    0345  42 0098 0999
        AXA  0001    ATM 2                    0098  50 0001 0295
1
 ATM 3  RAU  0547                CALCULATE    0999  60 0547 0239
        FMP O/F                  ENTHALPY     0239  39 0199 1349
        FAD  0597                OVER R       1349  32 0597 0289
        FDV 1 O/F                PER GRAM     0289  34 0094 0194
        FDV R                    OF           0194  34 1146 0046
        STU G0004    DIST2       PROPELLANT   0046  21 0004 0339
1
1            AN EIGHT IN POSITION TWO OF
1            CONSOLE CAUSES PUNCHING OF
1            A0  B0    ETC
1
 DIST2  RAU  8000                             0339  60 8000 0097
        BD2          IDEN                     0097  92 0389 0439
        RAL SPEC1                             0389  65 0242 0147
        LDD          PUNCH                    0147  69 0489 1950
        RAL SPEC2                             0489  65 0292 0197
        LDD IDEN     PUNCH                    0197  69 0439 1950
1
 IDEN   RAU EQRAT                EQUIV RATO   0439  60 0399 0989
        STD M0006                             0989  24 9005 0395
        UFA 55  I                             0395  02 0148 0240
        SRT  0002                             0240  30 0002 0247
        SLO  8002                             0247  16 8002 0290
        SLT  0006                             0290  35 0006 0340
        AUP F0039                             0340  10 1148 0390
        STU M0011                IDNTFICATN   0390  21 9010 0297
        SLT  0008                             0297  35 0008 0440
        NZU          IDEN2                    0440  44 0093 0244
        RAU M0011                             0093  60 9010 0490
        STU F0039    IDEN3                    0490  21 1148 0990
 IDEN2  RAU F0000                             0244  60 1109 1340
        SRT  0001                             1340  30 0001 0347
        SLO  8002                             0347  16 8002 0391
        STD TEMPO                             0391  24 9011 0397
        SRT  0008                             0397  30 0008 0441
        SLO  8002                             0441  16 8002 0491
        ALO TEMPO                             0491  15 9011 0991
        SLT  0001                             0991  35 0001 0447
        AUP M0011                             0447  10 9010 1341
        STU M0011                             1341  21 9010 0342
        STD F0039    IDEN3                    0342  24 1148 0990
 IDEN3  RAU F0000                CONVERT      0990  60 1109 0392
        STD M0009                             0392  24 9008 0198
        FDV CONS1                CHAM PRESS   0198  34 1140 0442
        STU F0000                TO ATMOSPH   0442  21 1109 0492
        LDD O/F                  OXID/FUEL    0492  69 0199 0992
        STD M0007                WT RATIO     0992  24 9006 0248
        LDD PCT F                PERCENT      0248  69 0299 1342
        STD M0008                FUEL BY WT   1342  24 9007 0193
        RAU G0004                ENTHALPY     0193  60 0004 0243
        FMP R                                 0243  39 1146 0096
        STU M0010                             0096  21 9009 0293
        RAL SPEC3                             0293  65 0146 0343
        STU PROB                 CLEAR PROB   0343  21 1904 0393
        LDD          PUNCH                    0393  69 0196 1950
        RAA  0050    IDEN1                    0196  80 0050 0443
 IDEN1  SET  9005                             0443  27 9005 0348
        LBB  0537 A                           0348  08 2537 0493
        RAL SPEC3                             0493  65 0146 0993
        LDD          PUNCH                    0993  69 0246 1950
        SET  9005                             0246  27 9005 1343
        LBB  0542 A                           1343  08 2542 0445
        RAL SPEC3                             0445  65 0146 0294
        LDD          PUNCH                    0294  69 0497 1950
        SET  9005                             0497  27 9005 0344
        LBB  0547 A                           0344  08 2547 0394
        RAL SPEC3                             0394  65 0146 0444
        STU M0009                CLEAR        0444  21 9008 0494
        STD M0010                CLEAR        0494  24 9009 0994
        LDD          PUNCH                    0994  69 0997 1950
        NZA          BEGIN                    0997  40 1344 0000
        RAA  0000    IDEN1                    1344  80 0000 0443
1
1             CONSTANTS
1
 10051   10  0000     0051                    0090  10 0000 0051
 10053   10  0000     0053                    0048  10 0000 0053
 55  I   00  0000     0055                    0148  00 0000 0055
 R       19  8718     0051                    1146  19 8718 0051
 CONS1   14  6960     0652                    1140  14 6960 0652
 SPEC1   00 G0005     0010                    0242  00 0005 0010
 SPEC2   00 G0004     0001                    0292  00 0004 0001
 SPEC3   00 M0006     0006                    0146  00 9005 0006
 SPEC4   00  9005     0006                    0495  00 9005 0006
        PAT
```

```
1          ROCKET PACKAGE EXCERPT FOR
1          FOR GENERAL ROCKET PERFORMANCE
1
1
        SYN PROB     1904
        SYN EXP E    1850
        SYN SQRT     1900
        SYN PUNCH    1950
        SYN LINK     1855
        SYN CARDN    1852
        SYN J000N    1961
        REG X1883    1899
        REG C9050    9050
        REG R1951    1960         READ BAND
        REG J1962    1967
        REG K1968    1973
        REG P1977    1986
        REG S1987    1995
        BLR  0000    1832
1
1
1          EXPONENTIAL
1
        REG X1883    1899         17 WORDS
1
EXP E   STD LINK                  EXPO     7   1850  24 1855 1858
        FMP EX1      EXB1         NENTIAL  7    858  39 1861 1911
EX1      43  4294     4850        ENTRY    7    861  43 4294 4850
EXB1    SET  9043                               911  27 9043 1866
        SET  9043                          72   866  27 9043 1871
        LDB X0001                          72  1871  09 1883 1836
        STU  9040                          72  1836  21 9040 1843
        FSB  9043                              1843  33 9043 1873
        BMI          EXB2                      1873 .46 1876 1877
        FAD  9043                              1876  32 9043 1905
        NZU          EXB61                     1905  44 1859 1860
        FAD  9043                              1859  32 9043 1839
        BMI EXB3                               1839  46 1842 1943
        RAU  9040                 EXPONENT72   1943  60 9040 1851
        BMI          EXB4         MINUS    72   851  46 1854 1856
        LDD EX2      EXB5         YES      72   854  69 1857 1910
X0001    40  0000     0052                 72  1883  40 0000 0052
EXB2    LDD  8666    EXB3         ALARM    73   877  69 8666 1842
EXB3    RAU  8002    LINK         ZERO          842  60 8002 1855
EXB61   RAU  9040                               860  60 9040 1867
        FDV EX1                                 867  34 1861 1862
        FAD  9058    LINK                       862  32 9058 1855
EXB4    RSU  8003                 NO       73   856  61 8003 1863
        STU  9040                          73   863  21 9040 1921
        LDD EX3      EXB5                  73  1921  69 1874 1910
EXB5    STD  9041                 FIND     74  1910  24 9041 1916
        FAD HALF                               1916  32 1869 1845
        UFA EXP58     9049        LAMBDA   74  1045  02 1848 9049
X0007   STU  9042                          74  1689  21 9042 1847
        FAD  8002     9050                 74  1847  32 8002 9050
X0008   FAM  9040                          74   890  37 9040 1919
        STU  9040                          74   919  21 9040 1927
        LDD  8005                 SAVE     74   927  69 8005 1833
        STD  9043                 A        74   833  24 9043 1939
        RSA  0007                          74   939  81 0007 1945
        RAU  8002     9059                 74   945  60 8002 9059
X0017   FMP  9040     9044                 74   899  39 9040 9044
X0002   FAD  9258     9045                 74   884  32 9258 9045
X0003   NZA  9046     9047                      885  40 9046 9047
X0004   AXA  0001     9059                      886  50 0001 9059
X0005   FMP  8003     9048                 74   887  39 8003 9048
X0006   STU  9040    EXB6                  74   888  21 9040 1846
EXB6    RAA  9043                          75   846  80 9043 1906
        RSU  9042                          75   906  61 9042 1913
        SRT  0002                          75   913  30 0002 1870
        RAU  8003                               870  60 8003 1878
        AUP  9040                          75   878  10 9040 1835
        STU  9040     9041                 75   835  21 9040 9041
EX2     RAU  9058                          75   857  60 9058 1865
        FDV  9040    LINK                       865  34 9040 1855
EX3     RAU  8001    LINK                       874  60 8001 1855
HALF     50  0000     0050                      869  50 0000 0050
X0009    93  2642     6747                 76   891  93 2642 6747
X0010    25  5491     8048                 76   892  25 5491 8048
X0011    17  4211     2049                 76   893  17 4211 2049
X0012    72  9517     3749                 76   894  72 9517 3749
X0013    25  4393     5750                 76   895  25 4393 5750
X0014    66  2730     8850                 76   896  66 2730 8850
X0015    11  5129     2851                 76   897  11 5129 2851
X0016    10  0000     0051                 76   898  10 0000 0051
EXP58    00  0000     0058                     1848  00 0000 0058
1
1
1          SQUARE ROOT ROUTINE
1
        REG C9050     9050
        REG S1987     1995        NINE WORDS
1
SQRT    STD LINK                               1900  24 1855 1908
        BMI STOP                               1908  46 1912 1864
        NZE          LINK                      1864  45 1868 1855
        STU C0000                              1868  21 9049 1875
        SET C0001                              1875  27 9050 1880
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```
                LBR S0001                          1880  08 1987 1840
                SRT  0002             CUTOFF EXP   1840  30 0002 1947
                RAU  8002                          1947  60 8002 1907
                MPY 00050             HALF EXP     1907  19 1914 1834
                SUP  8002             SAVE DEC     1834  11 8002 1844
                AUP 1ST E                          1844  10 1997 1901
                ALO  8002    C0001                 1901  15 8002 9050
      S0001     STU C0010    C0002                 1987  21 9059 9051
      S0002     RAU C0000    C0003    GET N        1988  60 9049 9052
      S0003     FDV C0010    C0004    DIV BY R     1989  34 9059 9053
      S0004     FAD C0010    C0005    ADD R TO Q   1990  32 9059 9054
      S0005     FMP C0009    C0006    DIV BY 2     1991  39 9058 9055
      S0006     SUP C0010    C0007    TEST FOR     1992  11 9059 9056
      S0007     NZE C0008              END         1993  45 9057 1948
                RAU C0010    LINK                  1948  60 9059 1855
      S0008     AUP C0010    C0001                 1994  10 9059 9050
      S0009      50  0000     0050    ONE HALF     1995  50 0000 0050
    1
         50      00  0000     0050                 1914  00 0000 0050
      1ST E      70  0000     0025                 1997  70 0000 0025
      STOP       99  9999     9999    SORT NEG X   1912  99 9999 9999
    1
    1
    1               PUNCH BELL CARDS
    1
                REG C9050     9050
                SYN J000N     1961
                REG J1962     1967    SIX WORDS
                REG K1968     1973    SIX WORDS
                REG P1977     1986    PUNCH BAND
    1
      PUNCH     STD LINK              START HERE   1950  24 1855 1909
                LDD  8003                          1909  69 8003 1917
                SDA C0005             1ST WORD     1917  22 9054 1924
                SLT  0004                          1924  35 0004 1935
                SDA C0006             NUMBER WDS   1935  22 9055 1942
                SRT  0002                          1942  30 0002 1849
                RAU  8003                          1849  60 8003 1915
                SRT  0002                          1915  30 0002 1872
                SET C0007                          1872  27 9056 1928
                LDD WDCT6                          1928  69 1881 1934
                STD P0009                          1934  24 1985 1838
                LDD PROB                           1838  69 1904 1918
                STD P0008                          1918  24 1984 1837
                LDD C0005    PCH3                  1837  69 9054 1944
      PCH3      STD P0007                          1944  24 1983 1936
                ALO CARDN                          1936  15 1852 1920
                ALO ONE D                          1920  15 1923 1879
                SDA CARDN                          1879  22 1852 1922
                STL P0010    NZERO                 1922  20 1986 1940
      NZERO     RAU C0006             IS NO OF     1940  60 9055 1998
                SUP WDCT6             WORDS LESS   1998  11 1881 1937
                BMI LESS6    PCH4                  1937  46 1841 1941
      PCH4      STU C0006                          1941  21 9055 1949
                RAU P0009                          1949  60 1985 1946
                SRT  0004                          1946  30 0004 1974
              . AUP XMOVE             SET TO MOV   1974  10 1929 1933
                ALO XLOC               N WORDS     1933  15 1938 1996
                ALO C0005    MOVEW                 1996  15 9054 1853
      MOVEW     AUP 09999     8002                 1853  10 1925 8002
       8002     LDD LOC       8003                 8002  69 1999 8003
       8003     STD P0007    J000N                 8003  24 1983 1961
      J0000     RAU C0006    PCH2                  1961  60 9055 1975
      J0001     RAU C0006    PCH2                  1962  60 9055 1975
      J0002     ALO ONE D    MOVEW                 1963  15 1923 1853
      J0003     ALO ONE D    MOVEW                 1964  15 1923 1853
      J0004     ALO ONE D    MOVEW                 1965  15 1923 1853
      J0005     ALO ONE D    MOVEW                 1966  15 1923 1853
      J0006     ALO ONE D    MOVEW                 1967  15 1923 1853
      PCH2      PCH P0001                          1975  71 1977 1930
                NZE          LINK                  1930  45 1902 1855
                RAU P0007                          1902  60 1983 1903
                AUP P0009                          1903  10 1985 1926
                STU C0005    PCH3                  1926  21 9054 1944
    1
      LESS6     RAL C0006                          1841  65 9055 1976
                STD P0009                          1976  24 1985 1931
                SRT  0004             CLEAR ZERO   1931  30 0004 1882
                ALO XCLER     8002                 1882  15 1932 8002
       8002      00  0000    K0001                 8002  00 0000 1968
      K0001     STU P0001    K0002                 1968  21 1977 1969
      K0002     STU P0002    K0003                 1969  21 1978 1970
      K0003     STU P0003    K0004                 1970  21 1979 1971
      K0004     STU P0004    K0005                 1971  21 1980 1972
      K0005     STU P0005    K0006                 1972  21 1981 1973
      K0006     STU P0006    PCH4                  1973  21 1982 1941
    1
      XCLER      00  0000    K0001                 1932  00 0000 1968
      WDCT6      00  0006     0000                 1881  00 0006 0000
       9999      00  0000     9999                 1925  00 0000 9999
      XLOC      LDD  0000     8003                 1938  69 0000 8003
      XMOVE     STD P0000    J0001                 1929  24 1976 1962
      CARDN      00  0000     0000                 1852  00 0000 0000
      ONE D      00  0001     0000                 1923  00 0001 0000
                PLA  0000     1832
                PAT
```

APPENDIX G

FROZEN-COMPOSITION PROGRAM

```
          GENERAL FROZEN COMPOSITION
            PERFORMANCE PROGRAM



          THIS PROGRAM ASSUMES THAT
          LN OF COMBUSTION COMPOSITION
          TEMPERATURE PRESSURE ENTHALPY
          MOLECULAR WEIGHT FACTOR A AND
          ALL NECESSARY THERMODYNAMIC
          COEFFICIENTS ARE ALREADY IN
          STORAGE


       SYN LNX       1700
       SYN EXP E     1850
       SYN SQRT      1900
       SYN PUNCH     1950
       SYN PCPCT     0017
       SYN COMEX     0061
       SYN START     0500
       SYN TEMP1     1048
       SYN TEMP2     1049
       SYN PC        1109
       SYN RDB       1193
       SYN LINK      1855
       SYN CARDN     1852
       SYN PROB      1904
       REG A1347     1349
       REG B1247     1249
       REG C9050     9050
       REG F1110     1149
       REG G0001     0015
       REG M9000     9000
       REG P1599     1659
       REG R1075     1099
       REG T0660     0959
       BLR  1832     1999
       EQU PCP      F0001
       EQU TEE      F0002
       EQU P        F0003
       EQU H        F0004
       EQU I        F0005
       EQU M        F0006
       EQU CF       F0007
       EQU EPSIL    F0008
       EQU MACH     F0009
       EQU I VAC    F0010
       EQU CP       F0011
       EQU GAMMA    F0012
       EQU S        F0015
       EQU CSTAR    F0020
       EQU AW       F0021
       EQU HSTR     F0023
       EQU AAY      F0024
       EQU HC       F0025
       EQU PLNP     F0026
       EQU SC       F0027
       EQU AWT      F0028
       EQU RA       F0029
       EQU RM       F0030
       EQU CONS1    F0031
       EQU CONS2    F0032
       EQU CONS3    F0033
       EQU CONS4    F0034
       EQU CONS5    F0035
       EQU R        F0037
       EQU GC       F0038
       EQU IDENT    F0039
       EQU ONE      F0040
       EQU LNT      G0002
       EQU PO       G0015
       EQU S CPR     1347
       EQU S HRT     1348
       EQU S  SR     1349
       EQU CODE      9000
       EQU T         9003
       EQU A         9021
       EQU B         9022
       EQU C         9023
       EQU D         9024
       EQU E         9025
       EQU F         9026
       EQU NI        9027
       EQU TWO       9028
       EQU THREE     9029
       EQU FOUR      9030
       EQU TEM 1     9049
       EQU BASIC     9050
       EQU TEMPO     9059
```

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```
1
     START   RSM IDENT                                      0500  68 1148 0053
             STL IDENT    X1          REVRS SIGN            0053  20 1148 0051
1
1               CONVERT LNNI TO NI
      X1     RAA  0000                                      0051  80 0000 0057
             RAC  0000    X2                                0057  88 0000 0063
      X2     RAL P0001 A                                    0063  65 3599 0103
             NZE          X5                                0103  45 0056 0107
             RAU P0002 A                                    0056  60 3600 0055
             BMI X3       X4                                0055  46 0058 0059
      X4     RAU T0008 C                                    0059  60 6667 0021
             LDD          EXP E                             0021  69 0024 1850
             STU T0008 C X3                                 0024  21 6667 0058
      X3     AXA  0002                                      0058  50 0002 0064
             AXC  0010    X2                                0064  58 0010 0063
1               CLEAR F REGION
      X5     SET M0004                                      0107  27 9003 0062
             LDB F0004                                      0062  09 1113 0016
             RSA  0026                                      0016  81 0026 0022
             RAU  8003    X6                                0022  60 8003 0029
      X6     STL F0030 A                                    0029  20 3139 0042
             NZA          X7                                0042  40 0045 0046
             AXA  0001    X6                                0045  50 0001 0029
1
1               SAVE TEE HC M AND AAY
1                 OF COMBUSTION
      X7     LDD M0024                AAY                   0046  69 9023 0052
             STD F0024                                      0052  24 1133 0036
             LDD M0025                HC                    0036  69 9024 0092
             STD F0025                                      0092  24 1134 0037
             LDD TEE                                        0037  69 1111 0114
             STD T                                          0114  24 9003 0020
             LDD M0006                M                     0020  69 9005 0026
             STD F0006                                      0026  24 1115 0018
1
1               COMPUTE R/AAY AND STORE IN RA
             RAU R                                          0018  60 1146 0101
             FDV AAY                                        0101  34 1133 0033
             STU RA                                         0033  21 1138 0041
1
1               COMPUTE R/M AND STORE IN RM
             RAU R                                          0041  60 1146 0151
             FDV M                                          0151  34 1115 0065
             STU RM                                         0065  21 1139 0142
             RAU  8003                                      0142  60 8003 0049
             STL COMEX                                      0049  20 0061 0164
1
1               FOR COMBUSTION OUT IS Z1
             LDD Z1                                         0164  69 0067 0070
             STD OUT      Y1                                0070  24 0023 0076
1
1               LOOP TO COMPUTE
1                    SUM NI CPR
1                    SUM NI HRT
1                    SUM NI  SR
1
1               LOOP IS COMPLETED WHEN ZERO
1                 APPEARS IN P REGION
1                 THEN GO TO OUT
1               OUT FOR COMB IS Z1
1               OUT FOR THROAT AND EXIT IS
1                 FROZN
1
      Y1     RAU  8003                                      0076  60 8003 0083
             STL S CPR                CLER S CPR            0083  20 1347 0000
             STL S HRT                CLER S HRT            0000  20 1348 0201
             STL S  SR                CLER S  SR            0201  20 1349 0102
             RAA  0000                                      0102  80 0000 0108
             RAC  0000    Y2                                0108  88 0000 0214
      Y2     RAL P0001 A                                    0214  65 3599 0153
             NZE          OUT                               0153  45 0106 0023
             STL CODE     THERM                             0106  20 9000 0264
     THERM   SET  9020                                      0264  27 9020 0019
             LBB T0001 C                                    0019  08 6660 0113
             RAU  9020                                      0113  60 9020 0071
             SUP CODE                                       0071  11 9000 0079
             NZU          TH009                             0079  44 0133 0034
             HLT  0000    8866                              0133  01 0000 8866
```

```
TH009   SET TWO                          0034  27 9028 0039
        LDB 80001                        0039  09 1247 0050
        RAU D                            0050  60 9024 0157
        FMP T                            0157  39 9003 0060
        FAD C                            0060  32 9023 0089
        FMP T                            0089  39 9003 0192
        FAD B                            0192  32 9022 0121
        FMP T                            0121  39 9003 0074
        FAD A                            0074  32 9021 0203
        FMP NI                           0203  39 9027 0156
        FAD S CPR                        0156  32 1347 0073
        STU S CPR                        0073  21 1347 0100
        RAU D                            0100  60 9024 0207
        FDV FOUR                         0207  34 9030 0110
        FMP T                            0110  39 9003 0163
        STU TEMPO                        0163  21 9059 0171
        RAU C                            0171  60 9023 0129
        FDV THREE                        0129  34 9029 0032
        FAD TEMPO                        0032  32 9059 0111
        FMP T                            0111  39 9003 0314
        STU TEMPO                        0314  21 9059 0221
        RAU B                            0221  60 9022 0179
        FDV TWO                          0179  34 9028 0082
        FAD TEMPO                        0082  32 9059 0161
        FMP T                            0161  39 9003 0364
        STU TEMPO                        0364  21 9059 0271
        RAU E                            0271  60 9025 0229
        FDV T                            0229  34 9003 0132
        FAD TEMPO                        0132  32 9059 0211
        FAD A                            0211  32 9021 0091
        FMP NI                           0091  39 9027 0044
        FAD S HRT                        0044  32 1348 0025
        STU S HRT                        0025  21 1348 0251
        RAU D                            0251  60 9024 0109
        FDV THREE                        0109  34 9029 0112
        FMP T                            0112  39 9003 0115
        STU TEMPO                        0115  21 9059 0123
        RAU C                            0123  60 9023 0031
        FDV TWO                          0031  34 9028 0084
        FAD TEMPO                        0084  32 9059 0213
        FMP T                            0213  39 9003 0066
        FAD B                            0066  32 9022 0095
        FMP T                            0095  39 9003 0048
        STU TEMPO                        0048  21 9059 0105
        RAU A                            0105  60 9021 0263
        FMP LNT                          0263  39 0002 0152
        FAD TEMPO                        0152  32 9059 0081
        FAD F                            0081  32 9026 0261
        FMP NI                           0261  39 9027 0414
        FAD S  SR                        0414  32 1349 0075
        STU S  SR                        0075  21 1349 0202
        AXA  0002                        0202  50 0002 0158
        AXC  0010      Y2                0158  58 0010 0214
1
1             TEST FOR CONVERGENCE
1             IS DEL S ZERO
1
1             YES MEANS CONVERGENCE
1               GO TO BTHER
1
1             NO MEANS NO CONVERGENCE
1               CORRECT T AND THEN GO TO Y1
1
FROZN   RAU PLNP                         0150  60 1135 0139
        FAD S  SR                        0139  32 1349 0125
        STU TEM 1                        0125  21 9049 0183
        FDV SC                           0183  34 1136 0086
        FSB EINSS                        0086  33 0189 0165
        NZU            BTHER             0165  44 0069 0120
        RSU TEM 1                        0069  61 9049 0027
        FAD SC                           0027  32 1136 0313
        FDV S CPR                        0313  34 1347 0047
        FAD LNT                          0047  32 0002 0279
        STU LNT                          0279  21 0002 0155
        LDD            EXP E             0155  69 0208 1850
        STU T                            0208  21 9003 0215
        LDD FROZN                        0215  69 0150 0253
        STD OUT        Y1                0253  24 0023 0076
```

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```
1
1            AFTER CONVERGENCE TEST IF
1            CORRECT TDATA IS IN STORAGE
1            YES GO TO FIX
1            NO GO TO TDATA
1
   BTHER   SET  9050                          0120  27 9050 0175
           LBB TEMP1                          0175  08 1048 0301
           RAU  9051                          0301  60 9051 0159
           FSB T                              0159  33 9003 0239
           BMI TDATA                          0239  46 0242 0043
           RAU T                              0043  60 9003 0351
           FSB  9050                          0351  33 9050 0131
           BMI TDATA    FIX                   0131  46 0242 0035
1
1            READ THERMAL DATA
1            WHEN CORRECT TDATA IS FOUND
1               GO TO Y1
   TDATA   RAA  0000                          0242  80 0000 0098
           RAC  0000    TD001                 0098  88 0000 0054
   TD001   RCD BASIC    BELL                  0054  70 9050 0104
   BASIC   RAL  9051    RDB                   9050  65 9051 1193
   RDB     SLT  0004                          1193  35 0004 0303
           STU  9051                          0303  21 9051 0311
           SUP P0001 A                        0311  11 3599 0353
           NZU TD005                          0353  44 0257 0258
           LDD T0008 C                        0258  69 6667 0170
           STD  9058                          0170  24 9058 0126
           SET  9051                          0126  27 9051 0181
           SBB T0001 C                        0181  28 6660 0363
           AXA  0002                          0363  50 0002 0119
           AXC  0010    TD001                 0119  58 0010 0054
   TD005   HLT  0000     7766                 0257  01 0000 7766
   BELL    RAU  9051                          0104  60 9051 0361
           FSB T                              0361  33 9003 0141
           BMI TDATA                          0141  46 0242 0145
           RAU T                              0145  60 9003 0403
           FSB  9050                          0403  33 9050 0233
           BMI TDATA                          0233  46 0242 0087
           SET  9050                          0087  27 9050 0292
           SBB TEMP1    Y1                    0292  28 1048 0076
1
   FIX     LDD T                              0035  69 9003 0191
           STD TEE                            0191  24 1111 0464
           LDD PO                             0464  69 0015 0068
           STD P        Z1                    0068  24 1112 0067
1
           EQU PCP      M0001
           EQU TEE      M0002
           EQU P        M0003
           EQU H        M0004
           EQU I        M0005
           EQU M        M0006
           EQU CF       M0007
           EQU EPSIL    M0008
           EQU MACH     M0009
           EQU I VAC    M0010
           EQU CP       M0011
           EQU GAMMA    M0012
           EQU S        M0015
           EQU CSTAR    M0020
           EQU AW       M0021
           EQU HSTR     M0023
           EQU AAY      M0024
           EQU HC       M0025
           EQU PLNP     M0026
           EQU SC       M0027
           EQU AWT      M0028
           EQU RA       M0029
           EQU RM       M0030
           EQU CONS1    M0031
           EQU CONS2    M0032
           EQU CONS3    M0033
           EQU CONS4    M0034
           EQU CONS5    M0035
           EQU R        M0037
           EQU GC       M0038
           EQU IDENT    M0039
           EQU ONE      M0040
1
```

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```
                  CALCULATE ROCKET PERFORMANCE
                    PARAMETERS

      Z1     SET M0001                                0067  27 9000 0072
             LDB F0001                                0072  09 1110 0413

                  COMPUTE CP
             RAU S CPR                                0413  60 1347 0401
             FMP RA                                   0401  39 9028 0154
             STU CP                                   0154  21 9010 0411

                  COMPUTE GAMMA
             FSB RM                                   0411  33 9029 0241
             STU TEM 1                                0241  21 9049 0099
             RAU CP                                   0099  60 9010 0307
             FDV TEM 1                                0307  34 9049 0160
             STU GAMMA                                0160  21 9011 0117

                  COMPUTE ENTHALPY
             RAU S HRT                                0117  60 1348 0453
             FMP TEE                                  0453  39 9001 0206
             FMP RA                                   0206  39 9028 0209
             STU H                                    0209  21 9003 0167

                  TEST COMEX
                    ZERO MEANS COMBUSTION
                    NONZERO MEANS THROAT OR EXIT

             RAU COMEX                                0167  60 0061 0265
             NZU TOREX                                0265  44 0169 0220

                  COMPUTE PSEUDO ENTROPY FOR
                    COMBUSTION
             RAU S  SR                                0220  60 1349 0503
             STU SC                                   0503  21 9026 0461
             FMP RA                                   0461  39 9028 0514
             STU S                                    0514  21 9014 0321
             RSU UNITY                    SET COMEX   0321  61 0124 0329
             STU COMEX    PNCH            FOR THROAT  0329  21 0061 0564

                  COMPUTE PSEUDO ENTROPY FOR
                    THROAT AND EXIT
      TOREX  RAU S  SR                                0169  60 1349 0553
             FAD PLNP                                 0553  32 9025 0283
             FMP RA                                   0283  39 9028 0136
             STU S                                    0136  21 9014 0093
             RAU COMEX                                0093  60 0061 0315
             BMI THROT    EXIT                        0315  46 0118 0219
             EQU TWO      B0001

                  CONVERGENCE TEST FOR THROAT
                  IS HC EQUAL TO HSTR
                  IF YES GO TO CSTR1
                  IF NO THEN CORRECT P AND GO
                  TO FROZN

      THROT  RAU TEE                                  0118  60 9001 0225
             FDV M                                    0225  34 9005 0028
             FMP R                                    0028  39 9036 0231
             FDV TWO                                  0231  34 1247 0097
             STU RT/2M                                0097  21 0252 0205
             FMP GAMMA                                0205  39 9011 0308
             FAD H                                    0308  32 9003 0137
             STU HSTR                                 0137  21 9022 0195
             FDV HC                                   0195  34 9024 0148
             FSB EINS                                 0148  33 0451 0077
             NZU          CSTR1                       0077  44 0281 0182
             RAU GAMMA                                0281  60 9011 0289
             FAD ONE                                  0289  32 9039 0269
             FMP RT/2M                                0269  39 0252 0302
             STU TEMPO                                0302  21 9059 0259
             RAU HC                                   0259  60 9024 0217
             FSB HSTR                                 0217  33 9022 0147
             FDV TEMPO                                0147  34 9059 0200
             FAD ONE                                  0200  32 9039 0379
             FMP P                                    0379  39 9002 0232
             STU PO                                   0232  21 0015 0168
             RAU PC                                   0168  60 1109 0463
             FDV PO                                   0463  34 0015 0365
             STU R0002                                0365  21 1076 0429
             STU F0001                                0429  21 1110 0513
             LDD          LNX                         0513  69 0116 1700
             FMP PC                                   0116  39 1109 0309
             STU F0026    FROZN                       0309  21 1135 0150
      CSTR1  LDD CSTR2    SEVRL                       0182  69 0085 0038
```

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```
 1               STORE A/W FOR THROAT
    CSTR2   RAU AW                                  0085  60 9020 0143
            STD AWT                                 0143  24 9027 0149
 1
 1               COMPUTE CSTAR
            FMP PC                                  0149  39 1109 0359
            FMP GC                                  0359  39 9037 0162
            FMP CONS1                               0162  39 9030 0415
            STU CSTAR                               0415  21 9019 0173
            LDD UNITY                   SET COMEX   0173  69 0124 0127
            STD COMEX     REMAN         FOR EXIT    0127  24 0061 0614
 1
    EXIT    LDD REMAN     SEVRL                     0219  69 0614 0038
 1
 1               COMPUTE THRUST COEFFICIENT CF
    REMAN   RAU I                                   0614  60 9004 0371
            FMP GC                                  0371  39 9037 0174
            FDV CSTAR                               0174  34 9019 0177
            STU CF                                  0177  21 9006 0135
 1
 1               COMPUTE AREA RATIO
            RAU AW                                  0135  60 9020 0193
            FDV AWT                                 0193  34 9027 0096
            STU EPSIL                               0096  21 9007 0603
 1
 1               COMPUTE SP IMP IN VACUUM IVAC
            RAU AW                                  0603  60 9020 0511
            FMP P                                   0511  39 9002 0964
            FMP CONS1                               0964  39 9030 0267
            FAD I                                   0267  32 9004 0197
            STU I VAC                               0197  21 9009 0255
 1
 1               COMPUTE MACH NUMBER
            RAU GAMMA                               0255  60 9011 0563
            FMP TEE                                 0563  39 9001 0166
            FMP CONS2                               0166  39 9031 0319
            FDV M                                   0319  34 9005 0122
            LDD MACH1     SQRT                      0122  69 0275 1900
    MACH1   STU TEMPO                               0275  21 9059 0333
            RAU I                                   0333  60 9004 0291
            FDV TEMPO                               0291  34 9059 0094
            STU MACH      PNCH                      0094  21 9008 0564
    SEVRL   STD LINK1                               0038  24 0341 0144
 1
 1               COMPUTE SPECIFIC IMPULSE I
            RAU HC                                  0144  60 9024 0501
            FSB H                                   0501  33 9003 0331
            FDV CONS3                               0331  34 9032 0134
            LDD IMPUL     SQRT                      0134  69 0187 1900
    IMPUL   FMP CONS4                               0187  39 9033 0040
            STU I                                   0040  21 9004 0247
 1
 1               COMPUTE A/W
            RAU TEE                                 0247  60 9001 0305
            FDV P                                   0305  34 9002 0358
            FDV M                                   0358  34 9005 0561
            FDV I                                   0561  34 9004 1014
            FMP CONS2                               1014  39 9031 0317
            FDV CONS1                               0317  34 9030 0270
            STU AW        LINK1                     0270  21 9020 0341
 1
 1               PUNCH RESULTS THEN GO TO PCP 1
    PNCH    RAU  8003                               0564  60 8003 0421
            STL CARDN                               0421  20 1852 0355
            SET M0001                               0355  27 9000 0210
            STB F0001                               0210  29 1110 0613
            RSA  0005                               0613  81 0005 0369
            RAB  0004                               0369  82 0004 0325
            LDD IDENT                               0325  69 9038 0381
            STD M0011     PNCH1                     0381  24 9010 0237
    PNCH1   NZB           PCP 1                     0237  42 0090 0391
            SXB  0001                               0090  53 0001 0146
            AXA  0005                               0146  50 0005 0352
            SET M0006                               0352  27 9005 0357
            LBB F0001 A                             0357  08 3110 0963
            NZA SPEC                                0963  40 0216 0367
            RAL SPEC1     PNCH2                     0367  65 0320 0375
    PNCH2   LDD PNCH1     PUNCH                     0375  69 0237 1950
    SPEC    RAL SPEC2     PNCH2                     0216  65 0419 0375
    COMP1   LDD FROZN     PCP 1                     0250  69 0150 0391
 1
```

```
              EQU PCP       F0001
              EQU TEE       F0002
              EQU P         F0003
              EQU H         F0004
              EQU I         F0005
              EQU M         F0006
              EQU CF        F0007
              EQU EPSIL     F0008
              EQU MACH      F0009
              EQU I VAC     F0010
              EQU CP        F0011
              EQU GAMMA     F0012
              EQU S         F0015
              EQU CSTAR     F0020
              EQU AW        F0021
              EQU HSTR      F0023
              EQU AAY       F0024
              EQU HC        F0025
              EQU PLNP      F0026
              EQU SC        F0027
              EQU AWT       F0028
              EQU RA        F0029
              EQU RM        F0030
              EQU CONS1     F0031
              EQU CONS2     F0032
              EQU CONS3     F0033
              EQU CONS4     F0034
              EQU CONS5     F0035
              EQU R         F0037
              EQU GC        F0038
              EQU IDENT     F0039
              EQU ONE       F0040

                 ADVANCE PRESSURE RATIO PCP
                 COMPUTE PC LN PC/PE
                 AND STORE IN PLNP

      PCP 1   RAL PCPCT                                  0391  65 0017 0471
              ALO UNITY                                  0471  15 0124 0479
              STL PCPCT                                  0479  20 0017 0370
              RAA  8001                                  0370  80 8001 0176
              SLT  0004                                  0176  35 0004 0287
              STL PROB                                   0287  20 1904 0407
              RAU R0000 A                                0407  60 3074 0529
              STU PCP                                    0529  21 1110 1013
              NZU           9999       FINISHED          1013  44 0417 9999
              LDD          LNX                           0417  69 0420 1700
              FMP PC                                     0420  39 1109 0409
              STU PLNP                                   0409  21 1135 0088
              RAU PC                                     0088  60 1109 1063
              FDV PCP                                    1063  34 1110 0260
              STU PO       FROZN                         0260  21 0015 0150

                 CONSTANTS FOR PROGRAM
      ONE     10  0000     0051                          1149  10 0000 0051
      B0001   20  0000     0051                          1247  20 0000 0051
      B0002   30  0000     0051                          1248  30 0000 0051
      B0003   40  0000     0051                          1249  40 0000 0051
      CONS1   14  6960     0652                          1140  14 6960 0652
      CONS2   86  4554     0052                          1141  86 4554 0052
      CONS3   10  0000     0054                          1142  10 0000 0054
      CONS4   29  4980     0053                          1143  29 4980 0053
      CONS5   57  0000     0050                          1144  57 0000 0050
      R       19  8718     0051                          1146  19 8718 0051
      GC      32  1740     0052                          1147  32 1740 0052
      EINS    00  1000     0053                          0451  00 1000 0053
      EINSS   01  0000     0052                          0189  01 0000 0052
      UNITY   00  0000     0001                          0124  00 0000 0001
      SPEC1   07 M0006     0006                          0320  07 9005 0006
      SPEC2   00 M0006     0006                          0419  00 9005 0006
```

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```
1
1             LNX ROUTINE EXCERPT FROM
1             THE ROCKET PACKAGE
1
1
          REG C9050      9050
1
   LNX    STD LINK                                     1700  24 1355 0408
          LDD OP1                                      0408  69 0611 1064
          STD C0005                                    1064  24 9054 0470
          NZU            HLT                           0470  44 0223 0224
          BMI HLT                                      0223  46 0224 0227
          SRT  0002                   EXPON IN         0227  30 0002 0383
          ALO EXP52                   LO PUT IN        0383  15 0186 0441
          STL C0001                   FLT NOTATN       0441  20 9050 0198
          SLO  8001                   CLEAR LO         0198  16 8001 0405
          ALO 51EXP                   NUM IN UPR       0405  15 0458 1163
          SLT  0002                   ADD 51 EXP       1163  35 0002 0469
          STU C0002                                    0469  21 9051 0277
          RAU C0001                   SUB 51 FRM       0277  60 9050 0185
          FSB 51LNK                   EXPONENT         0185  33 0138 0465
          FMP LN10                    MUL LN 10        0465  39 0218 0268
          FAD LN3                     ADD LN  3        0268  32 0521 0297
          STU C0001                                    0297  21 9050 0455
          RAU C0002                                    0455  60 9051 1213
          FAD K                       X MINUS 3        1213  32 0266 0243
          STU C0003                   OVER             0243  21 9052 0551
          RAU C0002                   X PLUS  3        0551  60 9051 0459
          FSB K                                        0459  33 0266 0293
          FDV C0003                   EQUALS Y         0293  34 9052 0196
          FAD  8003                   FORM 2Y          0196  32 8003 0425
          ALO  8001                   Y IN LOWER       0425  15 8001 0433
          STU C0003                   2Y IN 9003       0433  21 9052 0491
          RSU  8002                   MINUS Y IN       0491  61 8002 0199
          FMP  8001                   Y SQUARED        0199  39 8001 0402
          STU C0002                                    0402  21 9051 0509
          FMP K1                                       0509  39 0212 0262
          FAD K2                                       0262  32 0515 0541
          FMP C0002                                    0541  39 9051 0194
          FAD K3                      FORM             0194  32 0347 0273
          FMP C0002                   NUMERATOR        0273  39 9051 0226
          FAD K4                                       0226  32 0579 0505
          STU C0004                                    0505  21 9053 1263
          RAU C0002                                    1263  60 9051 0571
          FMP K5                                       0571  39 0274 0324
          FAD K6                                       0324  32 0327 0653
          FMP C0002                                    0653  39 9051 0256
          FAD K7                      FORM             0256  32 0559 0235
          FMP C0002                   DENOMNATOR       0235  39 9051 0188
          FAD K4                                       0188  32 0579 0555
          FDV C0004                   QUOTIENT         0555  34 9053 0508
          FMP C0003                   MULT BY 2Y       0508  39 9052 0961
          FAD C0001                                    0961  32 9050 0591
          FMP C0005      LINK                          0591  39 9054 1855
   HLT    HLT  1111      1111                          0224  01 1111 1111
1
1           LN X ROUTINE CONSTANTS
   EXP52  00  0000     0052                            0186  00 0000 0052
   51EXP  51  0000     0000                            0458  51 0000 0000
   51LNK  51  0000     0052                            0138  51 0000 0052
   K      30  0000     0051                            0266  30 0000 0051
   LN10   23  0258     5151                            0218  23 0258 5151
   LN3    10  9861     2351                            0521  10 9861 2351
   OP1    10  0000     0051                            0611  10 0000 0051
   K1     81  5850     8249           DENOM 4  •       0212  81 5850 8249
   K2     73  4265     7350           DENOM 3          0515  73 4265 7350
   K3     16  1538     4651           DENOM 2          0347  16 1538 4651
   K4     99  9999     9950                            0579  99 9999 9950
   K5     17  0496     1749           NUM    4         0274  17 0496 1749
   K6     39  5804     2050           NUM    3         0327  39 5804 2050
   K7     12  8205     1351           NUM    2         0559  12 8205 1351
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		PAT										
		1111	0450	050	111000000	950	1000	1111111111	1450	1500	1100011000	1950
1	000	000	0451	0501	11000000	951	1001	1111111111	1451	1501	1100111000	1951
2	000	001	0452	0502	1111000000	952	1002	1111111111	1452	1502	1100111000	1952
3	000	000	0453	0503		953	1003	1111111111	1453	1503	1100111000	1953
4*	000	111111	0454	0504	1111000000	954	1004	0011111111	1454	1504	1100111000	1954
5	000	000	0455	0505	11000000	955	1005	1111111111	1455	1505	1100111000	1955
6	000	1111	0456	0506	1111000000	956	1006	1111111111	1456	1506	1100111000	1956
7	000	001	0457	0507	1111000000	957	1007	1111111111	1457	1507	1100111000	1957
8	000	000	0458	0508	111000000	958	1008	1111111111	1458	1508	1100111000	1958
9	000	000	0459	0509	11000000	959	1009	1101111111	1459	1509	1100111000	1959
1		1111	0460	051	1110000001	960	1010	1101111111	1460	1510	1101111000	1960
11	000	000	0461	0511		961	1011	1101111111	1461	1511	1101111000	1961
12	000	1111	0462	0512	1110000001	962	1012	1101111111	1462	1512	1101111000	1962
13	000	000	0463	0513		963	1013	0000001111	1463	1513	1101111000	1963
14	000	000	0464	0514		964	1014	0001111111	1464	1514	1101111000	1964
15	000	000	0465	0515	110000001	965	1015	1101111111	1465	1515	1101111000	1965
16	000	1111	0466	0516	1110000001	966	1016	1101111111	1466	1516	1101111000	1966
17	000	001	0467	0517	1110000001	967	1017	1101111111	1467	1517	1101111000	1967
18	000	1111	0468	0518	1110000001	968	1018	1101111111	1468	1518	1101111000	1968
19	000	000	0469	0519	1110000001	969	1019	1101111111	1469	1519	1101111000	1969
2		000	0470	052	1110000001	970	1020	1101111111	1470	1520	1101111000	1970
21	000	000	0471	0521	10000001	971	1021	1101111111	1471	1521	1101111000	1971
22*	0001111111		0472	0522	1110000001	972	1022	1101111111	1472	1522	1101111000	1972
23	000	1111	0473	0523	1110000001	973	1023	1101111111	1473	1523	1101111000	1973
24	000	111	0474	0524	1110000001	974	1024	1101111111	1474	1524	1101111000	1974
25	000	001	0475	0525	1110000001	975	1025	1001111111	1475	1525	1101111000	1975
26	000	11111	0476	0526	1110000001	976	1026	1001111111	1476	1526	1101111000	1976
27	000	111	0477	0527	1110000001	977	1027	1001111111	1477	1527	1101111000	1977
28*	111111111		0478	0528	1110000001	978	1028	1001111111	1478	1528	1101111000	1978
29	000	000	0479	0529	10000001	979	1029	1001111111	1479	1529	1101111000	1979
30*	1111111111		0480	053	1110000001	980	1030	1001111111	1480	1530	1101111000	1980
31	000	011	0481	0531	1110000001	981	1031	1001111111	1481	1531	1101111000	1981
32	000	'1111	0482	0532	1110000001	982	1032	1001111111	1482	1532	1101110000	1982
33	000	001	0483	0533	1110000001	983	1033	1001111111	1483	1533	1101110000	1983
34*	0001111111		0484	0534	1110000001	984	1034	1001111111	1484	1534	1101110000	1984
35	000	11111	0485	0535	1110000001	985	1035	1001111111	1485	1535	1101110000	1985
36*	000	111111	0486	0536	1110000001	986	1036	1001111111	1486	1536	1101110000	1986
37	000	1111	0487	0537	1110000001	987	1037	1001111111	1487	1537	1101110000	1987
38*	000	111111	0488	0538	1110000001	988	1038	1001111111	1488	1538	1101110000	1988
39	000	1111	0489	0539	1110000001	989	1039	1001111111	1489	1539	1101110000	1989
40*	11111111		0490	054	1110000001	990	1040	1001111111	1490	1540	1101110000	1990
41	000	000	0491	0541	10000001	991	1041	1001111111	1491	1541	1101110000	1991
42	000	1111	0492	0542	1110000001	992	1042	1001111111	1492	1542	1101110000	1992
43	000	1111	0493	0543	1110000001	993	1043	1000111111	1493	1543	1101110000	1993
44*	000	111111	0494	0544	1110000001	994	1044	1001111111	1494	1544	1101110000	1994
45*	000	111111	0495	0545	1110000001	995	1045	1001111111	1495	1545	1101110000	1995
46*	000	111111	0496	0546	1110000001	996	1046	1001111111	1496	1546	1101110000	1996
47	000	111	0497	0547	1110000001	997	1047	1001110111	1497	1547	1101110000	1997
48*	000	111111	0498	0548	1110000001	998	1048	0001110111	1498	1548	1101110000	1998
49*	000	111111	0499	0549	1110000001	999	1049	0001110111	1499	1549	1001110000	1999

APPENDIX H

VECTOR AND PROPELLANT PROGRAM

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 1 1           PROGRAM FOR ASSEMBLING
 2 1           COMBUSTION PRODUCT PACKED
 3 1           VECTORS AND FUEL AND OXIDANT
 4 1           GRAM ATOM RATIOS ENTHALPIES
 5 1           AND OXIDATION NUMBERS
 6 1
 7          REG A0001      0011        ATOM TABLE
 8          REG F0100      0199        FUELS
 9          REG X0200      0299        OXIDANTS
10          REG L0300      0309        PCTS FUEL
11          REG D0310      0319        PCTS OXID
12          REG H0320      0329        FUEL ENTH
13          REG E0330      0339        OXID ENTH
14          REG W0340      0349        ATOMIC WTS
15          REG S0350      0359        OXID NUMBR
16          REG N0360      0379        MOLES
17          REG G0380      0399        GRAM ATOMS
18 1                                   PER GRAM
19          REG M0400      0510        ATOMIC WTS
20          REG V0600      0710        SYMBOL AND
21 1                                   OXID TABLE
22          REG U0800      0809
23          REG R1951      1960        READ BAND
24          REG P1977      1986        PUNCH BAND
25          REG C9000      9000
26          BLR  0000      0000
27          BLR  0090      0099        ZEROS
28          BLR  0360      0379        SPARE
29          BLR  0537      0549        OXIDANT
30          BLR  0587      0599        FUEL
31          BLR  0900      0909
32          BLR  1500      1999
33          SYN PUNCH      1930
34          SYN RMPCH      1940
35          EQU TEMPO     C0001        TEMPORARY
36          EQU TEMP1     C0002        TEMPORARY
37          EQU TEMP2     C0003        TEMPORARY
38          EQU R000X     R0001
39 1
40          EQU U01XX     U0101
41          EQU V00XX     V0001
42          EQU M00XX     M0001
43          EQU XXXXX      0000
44 1
45 1             TABLE OF ATOMIC WEIGHTS
46    M0001    39  9440    0052        ARGON        0400   39 9440 0052
47    M0002    22  7000    0053        ACTINIUM     0401   22 7000 0053
48    M0003    10  7880    0053        SILVER       0402   10 7880 0053
49    M0004    26  9800    0052        ALUMINUM     0403   26 9800 0052
50    M0005    24  3000    0053        AMERICIUM    0404   24 3000 0053
51    M0006    74  9100    0052        ARSENIC      0405   74 9100 0052
52    M0007    21  1000    0053        ASTATINE     0406   21 1000 0053
53    M0008    19  7000    0053        GOLD         0407   19 7000 0053
54    M0009    10  8200    0052        BORON        0408   10 8200 0052
56    M0011    90  1300    0051        BERYLLIUM    0410   90 1300 0051
57    M0012    20  9000    0053        BISMUTH      0411   20 9000 0053
58    M0013    24  5000    0053        BERKELIUM    0412   24 5000 0053
55    M0010    13  7360    0053        BARIUM       0409   13 7360 0053
59    M0014    79  9160    0052        BROMINE      0413   79 9160 0052
60    M0015    12  0110    0052        CARBON       0414   12 0110 0052
61    M0016    40  0800    0052        CALCIUM      0415   40 0800 0052
62    M0017    11  2410    0053        CADMIUM      0416   11 2410 0053
63    M0018    14  0130    0053        CERIUM       0417   14 0130 0053
64    M0019    24  8000    0053        CALIFORNUM   0418   24 8000 0053
65    M0020    35  4570    0052        CHLORINE     0419   35 4570 0052
66    M0021    24  5000    0053        CURIUM       0420   24 5000 0053
67    M0022    58  9400    0052        COBALT       0421   58 9400 0052
68    M0023    52  0100    0052        CHROMIUM     0422   52 0100 0052
69    M0024    13  2910    0053        CESIUM       0423   13 2910 0053
70    M0025    63  5400    0052        COPPER       0424   63 5400 0052
71    M0026    16  2510    0053        DYSPROSIUM   0425   16 2510 0053
72    M0027    25  5000    0053        EINSTEINUM   0426   25 5000 0053
73    M0028    16  7270    0053        ERBIUM       0427   16 7270 0053
74    M0029    15  2000    0053        EUROPIUM     0428   15 2000 0053
75    M0030    19  0000    0052        FLUORINE     0429   19 0000 0052
76    M0031    55  8500    0052        IRON         0430   55 8500 0052
77    M0032    25  2000    0053        FERMIUM      0431   25 2000 0053
78    M0033    22  3000    0053        FRANCIUM     0432   22 3000 0053
79    M0034    69  7200    0052        GALLIUM      0433   69 7200 0052
80    M0035    15  7260    0053        GADOLINIUM   0434   15 7260 0053
81    M0036    72  6000    0052        GERMANIUM    0435   72 6000 0052
82    M0037    10  0800    0051        HYDROGEN     0436   10 0800 0051
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83	M0038	40	0300	0051	HELIUM	0437	40	0300	0051
84	M0039	17	8580	0053	HAFNIUM	0438	17	8580	0053
85	M0040	20	0610	0053	MERCURY	0439	20	0610	0053
86	M0041	16	4940	0053	HOLMIUM	0440	16	4940	0053
87	M0042	12	6910	0053	IODINE	0441	12	6910	0053
88	M0043	11	4820	0053	INDIUM	0442	11	4820	0053
89	M0044	19	2200	0053	IRIDIUM	0443	19	2200	0053
90	M0045	39	1000	0052	POTASSIUM	0444	39	1000	0052
91	M0046	83	8000	0052	KRYPTON	0445	83	8000	0052
92	M0047	13	8920	0053	LANTHANUM	0446	13	8920	0053
93	M0048	69	4000	0051	LITHIUM	0447	69	4000	0051
94	M0051	17	4990	0053	LUTETIUM	0450	17	4990	0053
95	M0052	24	3200	0052	MAGNESIUM	0451	24	3200	0052
96	M0053	54	9400	0052	MANGANESE	0452	54	9400	0052
97	M0054	95	9500	0052	MOLYBDENUM	0453	95	9500	0052
98	M0055	25	6000	0053	MENDELEVUM	0454	25	6000	0053
99	M0056	14	0080	0052	NITROGEN	0455	14	0080	0052
100	M0057	22	9910	0052	SODIUM	0456	22	9910	0052
101	M0058	92	9100	0052	NIOBIUM	0457	92	9100	0052
102	M0059	14	4270	0053	NEODYMIUM	0458	14	4270	0053
103	M0060	20	1830	0052	NEON	0459	20	1830	0052
104	M0061	58	7100	0052	NICKEL	0460	58	7100	0052
105	M0062	23	7000	0053	NEPTUNIUM	0461	23	7000	0053
106	M0063	16	0000	0052	OXYGEN	0462	16	0000	0052
107	M0064	19	0200	0053	OSMIUM	0463	19	0200	0053
108	M0065	30	9750	0052	PHOSPHORUS	0464	30	9750	0052
109	M0066	23	1000	0053	PROTACTINM	0465	23	1000	0053
110	M0067	20	7210	0053	LEAD	0466	20	7210	0053
111	M0068	10	6700	0053	PALLADIUM	0467	10	6700	0053
112	M0069	14	5000	0053	PROMETHIUM	0468	14	5000	0053
113	M0070	21	0000	0053	POLONIUM	0469	21	0000	0053
114	M0071	14	0920	0053	PRASEODYMM	0470	14	0920	0053
115	M0072	19	5090	0053	PLATINUM	0471	19	5090	0053
116	M0073	24	2000	0053	PLUTONIUM	0472	24	2000	0053
117	M0074	22	6050	0053	RADIUM	0473	22	6050	0053
118	M0075	85	4800	0052	RUBIDIUM	0474	85	4800	0052
119	M0076	18	6220	0053	RHENIUM	0475	18	6220	0053
120	M0077	10	2910	0053	RHODIUM	0476	10	2910	0053
121	M0078	22	2000	0053	RADON	0477	22	2000	0053
122	M0079	10	1100	0053	RUTHENIUM	0478	10	1100	0053
123	M0080	32	0660	0052	SULFUR	0479	32	0660	0052
124	M0081	12	1760	0053	ANTIMONY	0480	12	1760	0053
125	M0082	44	9600	0052	SCANDIUM	0481	44	9600	0052
126	M0083	78	9600	0052	SELENIUM	0482	78	9600	0052
127	M0084	28	0900	0052	SILICON	0483	28	0900	0052
128	M0085	15	0350	0053	SAMARIUM	0484	15	0350	0053
129	M0086	11	8700	0053	TIN	0485	11	8700	0053
130	M0087	87	6300	0052	STRONTIUM	0486	87	6300	0052
131	M0088	18	0950	0053	TANTALUM	0487	18	0950	0053
132	M0089	15	8930	0053	TERBIUM	0488	15	8930	0053
133	M0090	99	0000	0052	TECHNETIUM	0489	99	0000	0052
134	M0091	12	7610	0053	TELLURIUM	0490	12	7610	0053
135	M0092	23	2050	0053	THORIUM	0491	23	2050	0053
136	M0093	47	9000	0052	TITANIUM	0492	47	9000	0052
137	M0094	20	4390	0053	THALLIUM	0493	20	4390	0053
138	M0095	16	8940	0053	THULIUM	0494	16	8940	0053
139	M0096	23	8070	0053	URANIUM	0495	23	8070	0053
140	M0097	50	9500	0052	VANADIUM	0496	50	9500	0052
141	M0098	18	3860	0053	TUNGSTEN	0497	18	3860	0053
142	M0101	13	1300	0053	XENON	0500	13	1300	0053
143	M0102	88	9200	0052	YTTRIUM	0501	88	9200	0052
144	M0103	17	3040	0053	YTTERBIUM	0502	17	3040	0053
145	M0104	65	3800	0052	ZINC	0503	65	3800	0052
146	M0105	91	2200	0052	ZIRCONIUM	0504	91	2200	0052
147 1									
148 1				TABLE OF	VALENCES				
149	V0001	61	0000	0000	ARGON	0500	61	0000	0000
150	V0002	61	6300	0000	ACTINIUM	0501	61	6300	0000
151	V0003	61	6700	0000	SILVER	0502	61	6700	0000
152	V0004	61	7300	0003	ALUMINUM	0503	61	7300	0003
153	V0005	61	7400	0000	AMERICIUM	0504	61	7400	0000
154	V0006	61	8200	0000	ARSENIC	0505	61	8200	0000
155	V0007	61	8300	0000	ASTATINE	0506	61	8300	0000
156	V0008	61	8400	0000	GOLD	0507	61	8400	0000
157	V0009	62	0000	0003	BORON	0508	62	0000	0003
158	V0010	62	6100	0000	BARIUM	0509	62	6100	0000
159	V0011	62	6500	0002	BERYLLIUM	0510	62	6500	0002
160	V0012	62	6900	0000	BISMUTH	0611	62	6900	0000
161	V0013	62	7200	0000	BERKELIUM	0612	62	7200	0000
162	V0014	62	7900	0001	BROMINE	0613	-62	7900	0001
163	V0015	63	0000	0004	CARBON	0614	63	0000	0004
164	V0016	63	6100	0002	CALCIUM	0615	63	6100	0002
165	V0017	63	6400	0000	CADMIUM	0616	63	6400	0000
166	V0018	63	6500	0000	CERIUM	0617	63	6500	0000

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167	V0019		63	6600	0000	CALIFORNUM	0618	63	6600	0000
168	V0020	–	63	7300	0001	CHLORINE	0619	-63	7300	0001
169	V0021		63	7400	0000	CURIUM	0620	63	7400	0000
170	V0022		63	7600	0000	COBALT	0621	63	7600	0000
171	V0023		63	7900	0000	CHROMIUM	0622	63	7900	0000
172	V0024		63	8200	0000	CESIUM	0623	63	8200	0000
173	V0025		63	8400	0000	COPPER	0624	63	8400	0000
174	V0026		64	8800	0000	DYSPROSIUM	0625	64	8800	0000
175	V0027		65	0000	0000	EINSTEINUM	0626	65	0000	0000
176	V0028		65	7900	0000	ERBIUM	0627	65	7900	0000
177	V0029		65	8400	0000	EUROPIUM	0628	65	8400	0000
178	V0030	–	66	0000	0001	FLUORINE	0629	-66	0000	0001
179	V0031		66	6500	0000	IRON	0630	66	6500	0000
180	V0032		66	7400	0000	FERMIUM	0631	66	7400	0000
181	V0033		66	7900	0000	FRANCIUM	0632	66	7900	0000
182	V0034		67	6100	0000	GALLIUM	0633	67	6100	0000
183	V0035		67	6400	0000	GADOLINIUM	0634	67	6400	0000
184	V0036		67	6500	0000	GERMANIUM	0635	67	6500	0000
185	V0037		68	0000	0001	HYDROGEN	0636	68	0000	0001
186	V0038		68	6500	0000	HELIUM	0637	68	6500	0000
187	V0039		68	6600	0000	HAFNIUM	0638	68	6600	0000
188	V0040		68	6700	0000	MERCURY	0639	68	6700	0000
189	V0041		68	7600	0000	HOLMIUM	0640	68	7600	0000
190	V0042	–	69	0000	0001	IODINE	0641	-69	0000	0001
191	V0043		69	7500	0000	INDIUM	0642	69	7500	0000
192	V0044		69	7900	0000	IRIDIUM	0643	69	7900	0000
193	V0045		72	0000	0001	POTASSIUM	0644	72	0000	0001
194	V0046		72	7900	0000	KRYPTON	0645	72	7900	0000
195	V0047		73	6100	0000	LANTHANUM	0646	73	6100	0000
196	V0048		73	6900	0001	LITHIUM	0647	73	6900	0001
197	V0051		73	8400	0000	LUTETIUM	0650	73	8400	0000
198	V0052		74	6700	0002	MAGNESIUM	0651	74	6700	0002
199	V0053		74	7500	0000	MANGANESE	0652	74	7500	0000
200	V0054		74	7600	0000	MOLYBDENUM	0653	74	7600	0000
201	V0055		74	8500	0000	MENDELEVUM	0654	74	8500	0000
202	V0056		75	0000	0000	NITROGEN	0655	75	0000	0000
203	V0057		75	6100	0001	SODIUM	0656	75	6100	0001
204	V0058		75	6200	0000	NIOBIUM	0657	75	6200	0000
205	V0059		75	6400	0000	NEODYMIUM	0658	75	6400	0000
206	V0060		75	6500	0000	NEON	0659	75	6500	0000
207	V0061		75	6900	0000	NICKEL	0660	75	6900	0000
208	V0062		75	7700	0000	NEPTUNIUM	0661	75	7700	0000
209	V0063	–	76	0000	0002	OXYGEN	0662	-76	0000	0002
210	V0064		76	8200	0000	OSMIUM	0663	76	8200	0000
211	V0065		77	0000	0000	PHOSPHORUS	0664	77	0000	0000
212	V0066		77	6100	0000	PROTACTIUM	0665	77	6100	0000
213	V0067		77	6200	0000	LEAD	0666	77	6200	0000
214	V0068		77	6400	0000	PALLADIUM	0667	77	6400	0000
215	V0069		77	7400	0000	PROMETHIUM	0668	77	7400	0000
216	V0070		77	7600	0000	POLONIUM	0669	77	7600	0000
217	V0071		77	7900	0000	PRASEODYMM	0670	77	7900	0000
218	V0072		77	8300	0000	PLATINUM	0671	77	8300	0000
219	V0073		77	8400	0000	PLUTONIUM	0672	77	8400	0000
220	V0074		79	6100	0000	RADIUM	0673	79	6100	0000
221	V0075		79	6200	0000	RUBIDIUM	0674	79	6200	0000
222	V0076		79	6500	0000	RHENIUM	0675	79	6500	0000
223	V0077		79	6800	0000	RHODIUM	0676	79	6800	0000
224	V0078		79	7500	0000	RADON	0677	79	7500	0000
225	V0079		79	8400	0000	RUTHENIUM	0678	79	8400	0000
226	V0080		82	0000	0004	SULFUR	0679	82	0000	0004
227	V0081		82	6200	0000	ANTIMONY	0680	82	6200	0000
228	V0082		82	6300	0000	SCANDIUM	0681	82	6300	0000
229	V0083		82	6500	0000	SELENIUM	0682	82	6500	0000
230	V0084		82	6900	0004	SILICON	0683	82	6900	0004
231	V0085		82	7400	0000	SAMARIUM	0684	82	7400	0000
232	V0086		82	7500	0000	TIN	0685	82	7500	0000
233	V0087		82	7900	0000	STRONTIUM	0686	82	7900	0000
234	V0088		83	6100	0000	TANTALUM	0687	83	6100	0000
235	V0089		83	6200	0000	TERBIUM	0688	83	6200	0000
236	V0090		83	6300	0000	TECHNETIUM	0689	83	6300	0000
237	V0091		83	6500	0000	TELLURIUM	0690	83	6500	0000
238	V0092		83	6800	0000	THORIUM	0691	83	6800	0000
239	V0093		83	6900	0000	TITANIUM	0692	83	6900	0000
240	V0094		83	7300	0000	THALLIUM	0693	83	7300	0000
241	V0095		83	7400	0000	THULIUM	0694	83	7400	0000
242	V0096		84	0000	0000	URANIUM	0695	84	0000	0000
243	V0097		85	0000	0000	VANADIUM	0696	85	0000	0000
244	V0098		86	0000	0000	TUNGSTEN	0697	86	0000	0000
245	V0101		87	6500	0000	XENON	0700	87	6500	0000
246	V0102		88	0000	0000	YTTRIUM	0701	88	0000	0000
247	V0103		88	6100	0000	YTTERBIUM	0702	88	6100	0000
248	V0104		89	7500	0000	ZINC	0703	89	7500	0000
249	V0105		89	7900	0000	ZIRCONIUM	0704	89	7900	0000

250 1

```
1          CLEAR ROUTINE
1
  CLEAR   RAA  0010                         0050  80 0010 0056
          RAM  8002    CLR 1                0056  67 8002 0015
  CLR 1   STU  9049 A                       0015  21 9049 0023
          NZA          CLR 2                0023  40 0026 0027
          SXA  0001    CLR 1                0026  51 0001 0015
  CLR 2   SET  9049                         0027  27 9049 0032
          STB A0001                         0032  29 0001 0054
          RAA  0300    CLR 3                0054  80 0300 0060
  CLR 3   SET  9050                         0060  27 9050 0065
          SBB  0090 A                       0065  28 2090 0043
          NZA          SET01                0043  40 0046 0047
          SXA  0010    CLR 3                0046  51 0010 0060
  SET01   RSU UNITY            SET ATOM     0047  61 0550 0055
          STU ATMCT            COUNTER      0055  21 0560 0013
          STD RELAY    READ    SET SWITCH   0013  24 0016 0019
1                              TO ATOMS
1
1          READ ROUTINE
  READ    RCD R0001            READ CARD    0019  70 1951 0051
          LDD R0001            TRANSFER     0051  69 1951 0554
          STD P0001            IMPUT FROM   0554  24 1977 0030
          LDD R0002            READ BAND    0030  69 1952 0555
          STD P0002            TO PUNCH     0555  24 1978 0031
          LDD R0003            BAND         0031  69 1953 0556
          STD P0003                         0556  24 1979 0082
          LDD R0004                         0082  69 1954 0057
          STD P0004                         0057  24 1980 0033
          LDD R0005                         0033  69 1955 0058
          STD P0005                         0058  24 1981 0034
          LDD R0006                         0034  69 1956 0059
          STD P0006                         0059  24 1982 0035
          RAU R0010                         0035  60 1960 0515
          STL P0007            CLER P0007   0515  20 1983 0036
          STD P0009            CLER P0009   0036  24 1985 0038
          SRT  0002                         0038  30 0002 0045
          STU P0008                         0045  21 1984 0037
          NZU          PV007   SET P0010    0037  44 0041 0042
          ALO 823RD            TO PUNCH     0041  15 0044 0049
          STL P0010    PNCH    TYPE1 CARD   0049  20 1986 0039
  PV007   RAU R0004            REARRANGE    0042  60 1954 0559
          SRT  0004            VECTOR IN    0559  30 0004 0069
          SLO  8002            WORDS 2 3    0069  16 8002 0077
          STD R0004            4 5 AND 6    0077  24 1954 0557
          SLT  0004                         0557  35 0004 0017
          STU SYMBL            SAVE SYMBL   0017  21 0022 0025
          RAL R0004                         0025  65 1954 0759
          SLT  0002                         0759  35 0002 0565
          SLO  8002                         0565  16 8002 0073
          STD TEMP0                         0073  24 9000 0029
          ALO R0003                         0029  15 1953 0757
          SLT  0008                         0757  35 0008 0075
          STU R0003                         0075  21 1953 0756
          STL TEMP1                         0756  20 9001 0014
          RAU R0006                         0014  60 1956 0061
          SRT  0004                         0061  30 0004 0021
          STL R0006                         0021  20 1956 0859
          RAL  8003                         0859  65 8003 0067
          SLT  0004                         0067  35 0004 0527
          AUP R0005                         0527  10 1955 0959
          SRT  0004                         0959  30 0004 0519
          STL R0005                         0519  20 1955 0558
          AUP TEMP1                         0558  10 9001 0715
          STU R0004                         0715  21 1954 0857
          RAU TEMP0                         0857  60 9000 0765
          SRT  0002                         0765  30 0002 0071
          AUP R0004                         0071  10 1954 1009
          STU R0004    LOOK                 1009  21 1954 0957
1          CONSTANTS FOR READ ROUTINE
  823RD    00  0000     0880                0044  00 0000 0880
1
1          TABLE LOOKUP ROUTINE TO FIND
1          CORRECT ROUTINE FOR SYMBOL
1          BEING PROCESSED
1
  LOOK    LDD SYMBL                         0957  69 0022 0525
          TLU U0001                         0525  84 0800 0755
          SUP  8003                         0755  11 8003 0063
          SRT  0004                         0063  30 0004 0523
          ALO 100 I     8002                0523  15 0076 8002
   8002    00  0000    U01XX                8002  00 0000 0900
1
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        U0101   RAU SYMBL               ATM PROGRM   0900  60 0022 0577
                SUP ATM                              0577  11 0080 0085
                NZU         PV009                    0085  44 0089 0040
                HLT  9999    1111       WRONG SMBL   0089  01 9999 1111
1
        U0102   RAU SYMBL               BOP PROGRM   0901  60 0022 0727
                SUP BOP                              0727  11 0530 0535
                NZU         CLEAR                    0535  44 0739 0050
                HLT  9999    2222       WRONG SMBL   0739  01 9999 2222
1
        U0103   RAU SYMBL               FUEL         0902  60 0022 0777
                SRT  0006               ENTHALPY     0777  30 0006 0741
                SLO  8002               PROGRAM      0741  16 8002 0749
                STD CODE                             0749  24 0052 0855
                SLT  0006                            0855  35 0006 0569
                SUP EF                               0569  11 0072 0827
                NZU         OK  3                    0827  44 0081 0532
                HLT  9999    3333       WRONG SMBL   0081  01 9999 3333
        OK  3   RAA  0319   PAR 1                    0532  80 0319 0088
1
1
1            CONSOLE POSITION 2 IS SET TO 8
1            IF IT IS DESIRED TO PUNCH OUT
1            FUELS OXIDANTS PERCENTS AND
1            ENTHALPIES
1
1
        U0104   RAU SYMBL               PROPELLANT   0903  60 0022 0877
                SUP END                 READY TO     0877  11 0580 0585
                NZU         DIST2       PROCESS      0585  44 0789 0740
                HLT  9999    4444       WRONG SMBL   0789  01 9999 4444
        DIST2   LDD  8000                            0740  69 8^00 0746
                BD2         END 1                    0746  92 0799 0551
                RAL SPEC5                            0799  65 0552 1007
                LDD END 1   PUNCH                    1007  69 0551 1930
        SPEC5    00  0100    0240                    0552  00 0100 0240
1
        U0105   RAU SYMBL               OXIDANT      0904  60 0022 0927
                SRT  0006               ENTHALPY     0927  30 0006 0791
                SLO  8002               PROGRAM      0791  16 8002 0849
                STD CODE                             0849  24 0052 0955
                SLT  0006                            0955  35 0006 0719
                SUP EX                               0719  11 0522 0977
                NZU         OK  5                    0977  44 0531 0582
                HLT  9999    5555       WRONG SMBL   0531  01 9999 5555
        OK  5   RAA  0329   PAR 1                    0582  80 0329 0088
1
        U0106   RAU SYMBL               FUEL         0905  60 0022 1027
                SRT  0008               PROGRAM      1027  30 0008 0745
                SLO  8002                            0745  16 8002 0053
                STD CODE                             0053  24 0052 1005
                SLT  0008                            1005  35 0008 0573
                SUP F                                0573  11 0526 0581
                NZU         OK  6                    0581  44 0735 0086
                HLT  9999    6666       WRONG SMBL   0735  01 9999 6666
        OK  6   RAA  0099                            0086  80 0099 0742
                STL R0007   PV180       CLER R0007   0742  20 1957 0760
1
        U0107   RAU SYMBL               MOLECULE     0906  60 0022 1077
                SUP MOL                 PROGRAM      1077  11 0730 0785
                NZU         PV015                    0785  44 0839 0790
                HLT  9999    7777       WRONG SMBL   0839  01 9999 7777
1
        U0108   RAU SYMBL               PERCENT      0907  60 0022 1127
                SRT  0006               FUEL         1127  30 0006 0841
                SLO  8002               PROGRAM      0841  16 8002 0899
                STD CODE                             0899  24 0052 1055
                SLT  0006                            1055  35 0006 0769
                SUP PF                               0769  11 0572 1177
                NZU         OK  8                    1177  44 0731 0732
                HLT  9999    8888                    0731  01 9999 8888
        OK  8   RAA  0299   PAR 1                    0732  80 0299 0088
1
        U0109   RAU SYMBL               PERCENT      0908  60 0022 1227
                SRT  0006               OXIDANT      1227  30 0006 0891
                SLO  8002               PROGRAM      0891  16 8002 0949
                STD CODE                             0949  24 0052 1105
                SLT  0006                            1105  35 0006 0819
                SUP PX                               0819  11 0722 1277
                NZU         OK  9                    1277  44 0781 0782
                HLT  9999    9999                    0781  01 9999 9999
        OK  9   RAA  0309   PAR 1                    0782  80 0309 0088
1
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      U0110   RAU SYMBL             OXIDANT      0909  60 0022 1327
              SRT  0008             PROGRAM      1327  30 0008 0795
              SLO  8002                          0795  16 8002 0553
              STD CODE                           0553  24 0052 1155
              SLT  0008                          1155  35 0008 0723
              SUP X                              0723  11 0576 0831
              NZU          OK 10                 0831  44 0835 0536
              HLT  9999    0000     WRONG SMBL   0835  01 9999 0000
      OK 10   RAA  0199                          0536  80 0199 0792
              STL R0007    PV180    CLER R0007   0792  20 1957 0760
1
1              CONSTANTS FOR TABLE LOOKUP
                           ROUTINE
1
      ATM     61  8374     0000                  0080  61 8374 0000
      BOP     62  7677     0000                  0530  62 7677 0000
      EF      65  6600     0000                  0072  65 6600 0000
      END     65  7564     0000                  0580  65 7564 0000
      EX      65  8700     0000                  0522  65 8700 0000
      F       66  0000     0000                  0526  66 0000 0000
      MOL     74  7673     0000                  0730  74 7673 0000
      PF      77  6600     0000                  0572  77 6600 0000
      PX      77  8700     0000                  0722  77 8700 0000
      X       87  0000     0000                  0576  87 0000 0000
      U0001   61  8374     0000     ATM          0800  61 8374 0000
      U0002   62  7677     0000     BOP          0801  62 7677 0000
      U0003   65  6699     0000     EF9          0802  65 6699 0000
      U0004   65  7564     0000     END          0803  65 7564 0000
      U0005   65  8799     0000     EX9          0804  65 8799 0000
      U0006   66  9900     0000     F9           0805  66 9900 0000
      U0007   74  7673     0000     MOL          0806  74 7673 0000
      U0008   77  6699     0000     PF9          0807  77 6699 0000
      U0009   77  8799     0000     PX9          0808  77 8799 0000
      U0010   87  9900     0000     X9           0809  87 9900 0000
      100 I   00  0000     0100                  0076  00 0000 0100
1
1              ROUTINE FOR PACKED VECTORS
1              ATOMS START AT PV009 AND
1              MOLECULES START AT PV015
1                                   PLACE CODE   0040  69 1957 0810
      PV009   LDD R0007             IN OUTPUT    0810  24 1985 0738
              STD P0009             ITS ATOM     0738  60 0016 0521
              RAU RELAY                          0521  44 0575 0726
              NZU PV011             SWITCH NOT   0726  01 2222 8888
              HLT  2222    8888     INITIALIZE
1                                   IS ATOM      0575  65 1952 1057
      PV011   RAL R0002             MORE THAN    1057  35 0004 0517
              SLT  0004             2 LETTERS    0517  11 8003 0725
              SUP  8003                          0725  45 0028 0079
              NZE          PV013    YES STOP     0028  01 3333 7777
              HLT  3333    7777     NO           0079  65 0560 0815
      PV013   RAL ATMCT             ADVANCE      0815  15 0550 1205
              ALO UNITY             ATOM COUNT   1205  20 0560 0513
              STL ATMCT             STORE ATOM   0513  15 1952 1107
              ALO R0002             COLUMN       1107  10 0560 0865
              AUP ATMCT             EQUIVALENT   0865  16 8002 0773
              SLO  8002             IN TABLE     0773  35 0004 0083
              SLT  0004                          0083  15 8001 0941
              ALO  8001                          0941  10 0744 8003
              AUP STORE    8003                  8003  20 0001 0754
       8003   STL A0001    PACKA    FORM ATOM    0754  60 0560 0915
      PACKA   RAU ATMCT             VECTOR       0915  35 0001 0571
              SLT  0001             STORE IN     0571  10 0550 1255
              AUP UNITY             PUNCH BAND   1255  21 1983 0586
              STU P0007    PV116    PLACE CODE   0790  69 1957 0860
      PV015   LDD R0007             IN OUTPUT    0860  24 1985 0788
              STD P0009             IS THIS      0788  60 0016 0721
              RAU RELAY             FIRST MOL    0721  44 0775 0776
              NZU          PV019    YES          0775  20 0016 0869
              STL RELAY             DID WE       0869  60 0550 1305
              RAU UNITY             PROCESS      1305  35 0001 0511
              SLT  0001             MORE THAN    0511  11 8001 0919
              SUP  8001             TEN ATOMS    0919  11 0560 0965
              SUP ATMCT                          0965  46 0018 0969
              BMI          PV017    TOO MANY     0018  01 4444 6666
              HLT  4444    6666     SET SOLIDS   0969  21 0024 0776
      PV017   STU COUNT    PV019    COUNTER
1                                   NO IS THIS   0776  60 1960 1015
      PV019   RAU R0010             MOLECULE     1015  30 0001 0771
              SRT  0001             CONDENSED    0771  65 8002 0529
              RAL  8002                          0529  45 0832 0533
              NZE          PV023    YES MAY WE   0832  60 0024 0579
              RAU COUNT             PROCESS IT   0579  44 0583 0084
              NZU PV024             NO           0084  01 5555 5555
              HLT  5555    5555
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   PV024   SUP UNITY              YES          0583  11 0550 1355
           STU COUNT    PV023                  1355  21 0024 0533
   PV023   RAU R0005              IS MOLCULE   0533  60 1955 1059
           NZU          PV025     MORE THAN    1059  44 0563 0064
 1                                15 PLACES
           HLT  6666     4444     YES          0563  01 6666 4444
   PV025   RAL R0002                           0064  65 1952 1157
           NZE PV031                           1157  45 0910 0561
           HLT  7777     3333     NO MOLCULE   0561  01 7777 3333
   PV031   RAU CNTR1              CLEAR DATA   0910  60 0713 0567
           STU CNTRX              ADDRESS      0567  21 0772 0825
           STL TEMP1    PV032     SET ZERO     0825  20 9001 0882
   PV032   RAL R0002              IS PRODUCT   0882  65 1952 1207
           NZE          PV115     FINISHED     1207  45 0960 0711
           SLT  0001              NO           0960  35 0001 0717
           SUP NINE1                           0717  11 0020 0875
           NZU LETTR    NUMBR                  0875  44 0729 0780
   LETTR   LDD PV032    PV033                  0729  69 0882 0885
   PV033   STD LINK                            0885  24 0838 0991
           RAL R0002                           0991  65 1952 1257
           AUP TEMP1                           1257  10 9001 1065
           SLT  0002                           1065  35 0002 0821
           STU TEMP1                           0821  21 9001 0779
           STL R0002                           0779  20 1952 1405
           RAU CNTRX                           1405  60 0772 1377
           AUP TWO D                           1377  10 0830 0935
           STU CNTRX    LINK                   0935  21 0772 0838
 1
   NUMBR   LDD PV034    PV033                  0780  69 0733 0885
   PV034   RAU TEMP1                           0733  60 9001 1041
           SRT  0002    PV087                  1041  30 0002 0747
   PV087   SLO NINE               STORE        0747  16 0750 1455
           SLO  8002              MAGNITUDE    1455  16 8002 0763
           STD MAGNI              OF THE       0763  24 0066 1019
           SCT  0000              COMPONENT    1019  36 0000 1091
           STU COMPO    PV089                  1091  21 0796 0999
   PV089   RAL A000X              SEARCH       0999  65 1550 0856
           LDD PV091              SYMBOL       0856  69 1109 0012
           SDA PV091     8001     TABLE FOR    0012  22 1109 8001
 1                                COMPONENT
   PV091   RAL A0001    PV093                  1109  65 0001 0956
   PV093   NZE          PV095                  0956  45 1010 0761
           SRT  0001                           1010  30 0001 0767
           SLT  0001                           0767  35 0001 0823
           SLO COMPO                           0823  16 0796 0751
           NZE          PV097                  0751  45 0854 1006
           RAL PV091              ADVANCE      0854  65 1109 0813
           ALO ONE D              ONE PLACE    0813  15 0516 0871
           STL PV091     8001     ALONG        0871  20 1109 8001
 1                                TABLE
   PV095   HLT  8888     2222     NOT IN       0761  01 8888 2222
 1                                TABLE
   PV097   RAL PV091              GOT THE      1006  65 1109 0863
           LDD PV099              RIGHT ONE    0863  69 0566 1069
           SDA PV099     8001                  1069  22 0566 8001
   PV099   RAU A0001    PV100     ADD IT TO    0566  60 0001 1056
   PV100   SRT  0001              REST OF      1056  30 0001 0913
           ALO MAGNI              PACKED       0913  15 0066 0921
           SUP  8003              VECTOR IN    0921  11 8003 0829
           AUP P0007              P0007        0829  10 1983 0087
           SLT  0002                           0087  35 0002 0743
           STU P0007                           0743  21 1983 0736
           RAL R0003    CNTRX     SHIFT        0736  65 1953 0772
   CNTRX   SLT XXXXX    PV101     WORD 3       0772  35 0000 0845
 1
   PV101   AUP R0002                           0845  10 1952 1307
           STU R0002                           1307  21 1952 1106
           STL R0003                           1106  20 1953 1156
 1
           RAL CNTRX              CNTRY DATA   1156  65 0772 1427
           LDD CNTR2              ADRES SAME   1427  69 0880 0783
           SDA CNTRY              AS CNTRX     0783  22 0737 0840
 1
           RAL R0004    CNTRY     SHIFT        0840  65 1954 0737
   CNTRY   SLT XXXXX    PV102     WORD 4       0737  35 0000 1159
   PV102   AUP R0003                           1159  10 1953 1357
           STU R0003                           1357  21 1953 1206
           STL R0004    PV031                  1206  20 1954 0910
   PV115   RAU R0010                           0711  60 1960 1115
           SRT  0001                           1115  30 0001 0971
           RAU  8002                           0971  60 8002 0879
           NZU          PV116     A SIGN FOR   0879  44 0833 0586
           RSU P0007              THE PACKED   0833  61 1983 0787
           STU P0007    PV116     VECTOR       0787  21 1983 0586
   PV116   LDD 83RD                            0586  69 0389 0842
           STD P0010    PNCH                   0842  24 1986 0039
   PNCH    PCH P0001    READ      PUNCH CARD   0039  71 1977 0019
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1
1            CONSTANTS FOR PACKED VECTOR
1                      ROUTINE
1
   UNITY    00  0000     0001                      0550  00 0?00 0001
   ONE D    00  0001     0000                      0516  00 0001 0000
   TWO D    00  0002     0000                      0830  00 0002 0000
   NINEI    00  0000     0009                      0020  00 0000 0009
   NINE     90  0000     0000                      0750  90 0000 0000
   STORE   STL A0001    PACKA                      0744  20 0001 0754
   A000X    00 A0001     0000                      1550  00 0001 0000
   CNTR1   SLT  0000    PV101                      0713  35 0000 0845
   CNTR2   SLT  0000    PV102                      0880  35 0000 1159
   83RD     00  0000     0800                      0889  00 0000 0800
1
1
1            ROUTINE FOR STORINGS FUELS AND
1                  OXIDANTS
1
   PV180   RAU RELAY               IF NO           0760  60 0016 1021
           NZU          PV198      MOLECULES       1021  44 0925 0826
1                                  IS THIS
1                                  FIRST FUEL
1                                  OR OXIDANT
           STL RELAY               YES             0925  20 0016 1119
           RAU NINEI               ARE THERE       1119  60 0020 0975
           SUP ATMCT               MORE THAN       0975  11 0560 1165
           BMI          PV198      TEN ATOMS       1165  46 0068 0826
           HLT  9988     9988      YES             0068  01 9988 9988
   PV198   RAU R0002                               0826  60 1952 1407
           NZU PV200               NO LETTERS      1407  44 0811 0062
           HLT  9876     9876      OR NUMBERS      0062  01 9876 9876
   PV200   STL TEMP1               CLER TEMP1      0811  20 9001 0518
           STD TEMP2               CLER TEMP2      0518  24 9002 0074
           STU RELA1               SET NONZRO      0074  21 0078 0881
           RAB  0000    PV201      B IS NUMBR      0881  82 0000 0837
1                                  COUNTER
   PV201   RAL R0002               ANY FUEL        0837  65 1952 1457
           NZE          PV220      OR OX LEFT      1457  45 1060 0861
           SLT  0001               YES             1060  35 0001 0817
           SUP NINEI               IS SYMBOL       0817  11 0020 1025
           BMI LETR     NUMR       LET OR NUM      1025  46 0528 0929
   LETR    RAU RELA1               DO WE STOR      0528  60 0078 0883
           NZU          PV221      PREV COEFF      0883  44 0887 0888
           RAL R0002               NO              0887  65 1952 0758
           AUP TEMP1                               0758  10 9001 1215
           SLT  0002                               1215  35 0002 1071
           STU TEMP1    PV209                      1071  21 9001 0979
1
   PV209   STL R0002                               0979  20 1952 1256
           RSC  0003    PV210      SHIFT           1256  89 0003 0512
   PV210   RAL R0006 C             WORDS 2 3       0512  65 7956 0911
           SLT  0002               4 5 AND 6       0911  35 0002 0867
           AUP R0005 C                             0867  10 7955 1209
           STU R0005 C                             1209  21 7955 0858
           STL R0006 C                             0858  20 7956 1259
           NZC          PV201                      1259  48 0562 0837
           AXC  0001    PV210                      0562  58 0001 0512
   NUMR    STU RELA1               CLER RELA1      0929  21 0078 0931
           AXB  0001               ADD TO CNT      0931  52 0001 0937
           AUP TEMP2                               0937  10 9002 0895
           SLT  0001                               0895  35 0001 0851
           STU TEMP2    PV209                      0851  21 9002 0979
   PV220   LDD PAR 6    PV222                      0861  69 0514 0917
   PV221   LDD PV200    PV222      YES             0888  69 0811 0917
   PV222   STD LINK                                0917  24 0838 1141
           RSC  0009                               1141  89 0009 0797
           RAU TEMP1                               0797  60 9001 1306
           SCT  0000                               1306  36 0000 1029
           STU TEMP1    PV223                      1029  21 9001 0987
   PV223   RAL A0010 C             FIND            0987  65 6010 1265
           SRT  0001               SYMBOL  N       1265  30 0001 1121
           SLT  0001               TABLE           1121  35 0001 1477
           SLO TEMP1                               1477  16 9001 0985
           NZE          PV225                      0985  45 0938 0939
           NZC          PV224                      0938  48 1191 0892
           AXC  0001    PV223                      1191  58 0001 0987
   PV224   HLT  4321     4321      NOT IN          0892  01 4321 4321
1                                  TABLE
   PV225   RAU CODE                GENERATE        0939  60 0052 0958
           SLT  0001               STORAGE         0958  35 0001 1315
           SRT  0008               LOCATION        1315  30 0008 0933
           NZU PV227    PV226                      0933  44 1037 0988
   PV226   RAU 100 I    PV227                      0988  60 0076 1037
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    PV227   AUP  8005                              1037  10 8005 0945
            AUP  8007                              0945  10 8007 0753
            SLT  0004                              0753  35 0004 0963
            AUP MASK1                              0963  10 0716 1171
            STU PV233                              1171  21 0876 1079
            RAU TEN I                 IS NUMBER    1079  60 0932 1087
            SUP  8006                 OVER TEN     1087  11 8006 0995
            BMI           PV230       DIGITS       0995  46 0048 1049
            HLT  2233      4455       YES ERROR    0048  01 2233 4455
    PV230   NZU           PV231       IS IT TEN    1049  44 0853 0954
            SUP ONE I                 NO           0853  11 1356 0961
            NZU PV232                 IS IT NINE   0961  44 1365 0766
            HLT  5544      3322       YES ERROR    0766  01 5544 3322
    PV231   RAU TEMP2     PV233                    0954  60 9002 0876
    PV232   RAU TEMP2                              1365  60 9002 0873
            SCT  0000                              0873  36 0000 1045
            AUP  8006                              1045  10 8006 0953
            RAB  0050                              0953  82 0050 1309
            AUP  8006                              1309  10 8006 0967
            SLO  8002     PV233                    0967  16 8002 0876
    PV233   STU XXXXX     LINK                     0876  21 0000 0838
1
1
1              CONSTANTS FOR FUELS AND
1                   OXIDANTS ROUTINE
1
    ONE I    00  0000     0001                     1356  00 0000 0001
    NINEI    00  0000     0009                     0020  00 0000 0009
    TEN I    00  0000     0010                     0932  00 0000 0010
    100 I    00  0000     0100                     0076  00 0000 0100
    MASK1   STU  0000     LINK                     0716  21 0000 0838
1
1
1
1              ROUTINE FOR STORING ENTHALPIES
1              AND PERCENTS FOR FUELS AND
1              OXIDANTS
1
    PAR 1   RAU R0004                              0088  60 1954 1359
            STL TEMPO                 CLER TEMPO   1359  20 9000 0816
            NZU ERR 1                              0816  44 1169 0070
    ERR 1   HLT  8888      1111       PARAMETER    1169  01 8888 1111
1                                     MORE THAN
1                                     10 FIGURES
            RSB  0001     COLAP                    0070  83 0001 0926
    COLAP   RAC  0005                              0926  88 0005 0982
            RAL R0003 B               COLLAPSE     0982  65 5953 1008
            SLO 90909     PAR 2       NUMBER BY    1008  16 1011 1415
    PAR 2   SLT  0001                 REMOVING     1415  35 0001 1221
            AUP TEMPO                 NINES        1221  10 9000 1129
            SLT  0001                              1129  35 0001 1035
            STU TEMPO                              1035  21 9000 0793
            SUP  8003                              0793  11 8003 0951
            SXC  0001                              0951  59 0001 1058
            NZC PAR 2                              1058  48 1415 0712
            NZB           PAR 3                    0712  42 1465 0866
            AXB  0001     COLAP                    1465  52 0001 0926
    PAR 3   RAU CODE                  GENERATE     0866  60 0052 1108
            SLT  0001                 STORAGE      1108  35 0001 0916
            SRT  0009                 LOCATION     0916  30 0009 1137
            NZU PAR 5     PAR 4                    1137  44 1241 0942
    PAR 4   RAU TEN I     PAR 5                    0942  60 0932 1241
    PAR 5   AUP  8005                              1241  10 8005 1099
            SLT  0004                              1099  35 0004 1409
            AUP MASK5                              1409  10 0762 1017
            ALO TEMPO      8003                    1017  15 9000 8003
     8003   STL XXXXX     PAR 6                    8003  20 0000 0514
    PAR 6   PCH P0001     READ                     0514  71 1977 0019
1
1
1              CONSTANTS FOR ENTHALPIES AND
1                   PERCENTS ROUTINE
1
    TEN I    00  0000     0010                     0932  00 0000 0010
    90909    90  9090     9090                     1011  90 9090 9090
    MASK5   STL  0000     PAR 6                    0762  20 0000 0514
1
1
```

```
 1
 1             ROUTINE TO CALCULATE THE GRAM
 1             ATOMS AND ENTHALPIES AND THE
 1             OXIDATION NUMBERS PER GRAM OF
 1             COMBINED FUEL OR PER GRAM OF
 1             COMBINED OXIDANT
 1
   END 1   RAA  0010                             0551  80 0010 1158
           RAC  0010                             1158  88 0010 0564
           RAB  0001    END 2                    0564  82 0001 0520
   END 2   RAU  8003                             0520  60 8003 0578
           STL TEMPO    END 3    CLER TEMP:      0578  20 9000 0786
   END 3   RAU L0000 C           ADD ALL         0786  60 6299 1003
           FAD TEMPO             THE FUEL        1003  32 9000 0983
           STU TEMPO             OR OXIDANT      0983  21 9000 1291
           RAU L0000 C           PERCENTS        1291  60 6299 1053
           FDV 10053             AND CONVR       1053  34 1406 1456
           STU C0010 C           TO FRACTNS      1456  21 9609 1013
           SXA  0001                             1013  51 0001 1219
           NZA          END 4                    1219  40 0822 0923
           SXC  0001    END 3                    0822  59 0001 0786
   END 4   RAU TEMPO             ARE PERCNT      0923  60 9000 0981
           FSB 11051             REALLY          0981  33 0534 1061
           BMI FRACT    PRCNT    FRACTIONS       1061  46 0714 0966
   FRACT   RAU TEMPO    END 5                    0714  60 9000 1271
   PRCNT   SET C0010 C                           0966  27 9609 1321
           SBB L0000 C                           1321  28 6299 0752
           RAU TEMPO                             0752  60 9000 1459
           FDV 10053    END 5                    1459  34 1406 1271
   END 5   FSB 10051                             1271  33 0524 1001
           RAM  8003                             1001  67 8003 1110
           AUP 47  I                             1110  10 1063 1067
           SUP  8002                             1067  11 8002 1075
           BMI          END 6                    1075  46 0728 1179
           HLT  1111     1111    PERCENTS        0728  01 1111 1111
 1                               OUT OF
 1                               LIMITS
   END 6   NZB          MW  1                    1179  42 1032 1033
           SXB  0001                             1032  53 0001 1038
           RAA  0010                             1038  80 0010 0794
           RAC  0020    END 2                    0794  88 0020 0520
 1
 1
 1             LOCATE AND STORE THE REQUIRED
 1             OXIDATION NUMBERS AND ATOMIC
 1             WEIGHTS
 1
 1             CONSOLE POSITION 3 IS SET TO 8
 1             IF IT IS DESIRED TO PUNCH OUT
 1             ATOMIC WEIGHTS AND OXIDATION
 1             NUMBERS
 1
 1
   MW  1   RAA  0000    MW  2    FIND ATOM       1033  80 0000 0989
   MW  2   RAU A0001 A           WEIGHT AND      0989  60 2001 1208
           NZU          DIST3    OXID NO         1208  44 1111 0812
           SRT  0001             OF COLUMN       1111  30 0001 1117
           SLO  8002             ONE             1117  16 8002 1125
           SLT  0001             ELEMENT         1125  35 0001 1031
           ALO MASK6                             1031  15 0584 1039
           LDD  8003                             1039  69 8003 0846
           TLU V0001    MW  3                    0846  84 0600 1258
   MW  3   STL TEMPO     8001                    1258  20 9000 8001
    8001   RAL V00XX    MW  4                    8001  65 0600 1308
   MW  4   SLT  0009                             1308  35 0009 1229
           SUP  8003                             1229  11 8003 1187
           BMI          MW  5                    1187  46 0890 1341
           SLO 51  I    MW  6                    0890  16 0843 0847
   MW  5   ALO 51  I    MW  6                    1341  15 0843 0847
   MW  6   STL S0001 A  MW  7    OXID NO         0847  20 2350 1103
   MW  7   RAL TEMPO                             1103  65 9000 1161
           SLO 200 D                             1161  16 0764 1269
           LDD MASK7                             1269  69 0872 1175
           SDA TEMPO     8001                    1175  22 9000 8001
    8001   LDD M00XX    MW  8                    8001  69 0400 1153
   MW  8   STD W0001 A           ATOMIC W        1153  24 2340 0893
           AXA  0001    MW  2    NEXT ELM        0893  50 0001 0989
 1
   DIST3   LDD  8000                             0812  69 8000 0568
           BD3          AR  1                    0568  93 1371 0973
           RAL SPEC6                             1371  65 0574 1279
           LDD AR  1    PUNCH                    1279  69 0973 1930
   SPEC6    00 W0001     0020                    0574  00 0340 0020
 1
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     AR  1   RAA  0000                             0973  80 0000 1329
             RAB  0190                             1329  82 0190 1085
             RAC  0020     AR  2                   1085  88 0020 1391
     AR  2   SUP  8003                             1391  11 8003 1149
             STU  TEMPO    AR  3    CLER TEMPO     1149  21 9000 1358
     AR  3   RAU  W0001 A           ATOMIC WT      1358  60 2340 1095
             NZU           AR  4                   1095  44 1199 0850
             FMP  F0001 B           ATOM COEFF     1199  39 4100 0950
             FAD  TEMPO             TEMPO HAS      0950  32 9000 1379
             STU  TEMPO             MOL WT         1379  21 9000 1237
             AXA  0001                             1237  50 0001 0943
             AXB  0001                             0943  52 0001 1249
             SXA  0010                             1249  51 0010 1408
             NZA           AR 29                   1408  40 1211 0862
             AXA  0010     AR  3                   1211  50 0010 1358
     AR 29   AXA  0010     AR  4                   0862  50 0010 0850
     AR  4   RAU  L0000 C           CALCULATE      0850  60 6299 1203
             NZU           AR 30    NUMBER OF      1203  44 1458 1160
             FDV  TEMPO    AR 30    MOLES OF       1458  34 9000 1160
     AR 30   STU  N0000 C           EACH FUEL      1160  21 6359 0912
             SXB  2010              OR OXIDANT     0912  53 2010 1319
             BMB  AR  5             WHICH GIVE     1319  43 0922 1023
             RAA  0000              1 GRAM OF      1023  80 0000 1429
             SXC  0001     AR  2    COMBINED       1429  59 0001 1391
1                             FUEL AND 1 GRAM OF
1                             COMBINED OXIDANT
     AR  5   RAU  10051                            0922  60 0524 1479
             STU  RELAY                            1479  21 0016 1369
             SET  9030                             1369  27 9030 0724
             LBB  H0001             FUEL ENTH      0724  08 0320 1073
             SET  9050                             1073  27 9050 0778
             LDB  N0001             FUEL MOLES     0778  09 0360 1113
             SET  9040              CLEAR 904      1113  27 9040 0718
             LBB  0090              BAND           0718  08 0090 0993
             RSA  0009                             0993  81 0009 1299
             RAB  0000                             1299  82 0000 1210
             RAC  0000     AR  6                   1210  88 0000 1016
     AR  6   SUP  8003                             1016  11 8003 1123
             STU  TEMPO    AR  7    CLER TEMPO     1123  21 9000 1081
     AR  7   RAU  9059 A            MOLES          1081  60 9259 1089
             FMP  F0001 B           ATOM COEFF     1089  39 4100 1000
             FAD  TEMPO                            1000  32 9000 0930
             STU  TEMPO                            0930  21 9000 1287
             BMA           AR  8                   1287  41 0940 1441
             AXA  0001                             0940  50 0001 0896
             AXB  0010     AR  7                   0896  52 0010 1081
     AR  8   STU  9040 C            9040 TO        1441  21 9640 1349
             RAU  A0002 C           9049           1349  60 6002 1260
             NZU           AR  9    CONTAIN        1260  44 1163 0814
             RSA  0009              ATOMS PER      1163  81 0009 1419
             SXB  0089              GRAM OF        1419  53 0089 1225
             AXC  0001     AR  6    FUEL OR        1225  58 0001 1016
1                                   OXIDANT
     AR  9   SUP  8003                             0814  11 8003 1421
             STU  TEMPO             CLER TEMPO     1421  21 9000 0980
             STD  TEMP1             CLER TEMP1     0980  24 9001 0836
             STD  TEMP2             CLER TEMP2     0836  24 9002 0992
             RSA  0009     AR 10                   0992  81 0009 0748
     AR 10   RAU  S0010 A                          0748  60 2359 1213
             FMP  9049 A            PLUS AND       1213  39 9249 1066
             BMI           AR 11    MINUS          1066  46 1469 0570
             FAD  TEMP1             VALENCES       1469  32 9001 1399
             STU  TEMP1    AR 12    PER GRAM       1399  21 9001 1310
     AR 11   FAD  TEMPO             OF FUEL        0570  32 9000 1449
             STU  TEMPO    AR 12    OR OXIDANT     1449  21 9000 1310
     AR 12   BMA           AR 13                   1310  41 1263 0864
             AXA  0001     AR 10                   1263  50 0001 0748
     AR 13   RSA  0009     AR 14                   0864  81 0009 0720
     AR 14   RAU  9059 A            ENTHALPY       0720  60 9259 0828
             FMP  9039 A            PER GRAM       0828  39 9239 1131
             FAD  TEMP2             OF FUEL        1131  32 9002 1261
             STU  TEMP2             OR OXIDANT     1261  21 9002 0770
             BMA           AR 15                   0770  41 1173 0774
             AXA  0001     AR 14                   1173  50 0001 0720
     AR 15   RAU  RELAY                            0774  60 0016 1471
             NZU           PCH 0                   1471  44 1275 0976
             STL  RELAY    PCH F                   1275  20 0016 0820
     PCH F   SET  9040              PUNCH          0820  27 9040 1325
             SBB  0587              ATOMS AND      1325  28 0587 0990
             RAL  SPEC1             ENTHALPY       0990  65 1043 0897
             LDD           RMPCH    AND VALENC     0897  69 1050 1940
             SET  9000              PER GRAM       1050  27 9000 1360
             STB  0598              OF FUEL        1360  29 0598 1051
             LDD  TEMP2                            1051  69 9002 1410
             STD  0597                             1410  24 0597 1100
             RAL  SPEC2                            1100  65 1253 1460
             LDD           RMPCH                   1460  69 1313 1940
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                SET  9030                 OXIDANT       1313  27 9030 0768
                LBB  E0001                ENTHALPIES    0768  08 0330 1083
                SET  9050                 OXIDANT       1083  27 9050 1088
                LDB  N0011                MOLES         1088  09 0370 1223
                SET  9040                 CLEAR 904     1223  27 9040 0878
                LBB  0090                 BAND          0878  08 0090 1093
                RSA  0009                               1093  81 0009 1499
                RAB  0100                               1499  82 0100 1311
                RAC  0000    AR  6                      1311  88 0000 1016
      PCH 0     SET  9040                 PUNCH         0976  27 9040 1181
                SBB  0537                 ATOMS AND     1181  28 0537 1040
                RAL  SPEC3                ENTHALPY      1040  65 1143 0947
                LDD          RMPCH        AND VALENC    0947  69 1150 1940
                SET  9000                 PER GRAM      1150  27 9000 1361
                STB  0548                 OF OXIDANT    1361  29 0548 1101
                LDD  TEMP2                              1101  69 9002 1411
                STD  0547                               1411  24 0547 1200
                RAL  SPEC4                              1200  65 1303 1461
                LDD  FINIS   RMPCH                      1461  69 0914 1940
1                  CONSTANTS FOR CALCULATING
1                         ROUTINE
1
      MASK6     RAL  0000    MW  4                      0584  65 0000 1308
      MASK7     LDD  0000    MW  8                      0872  69 0000 1153
      47   I    00   0000    0047                       1063  00 0000 0047
      51   I    00   0000    0051                       0843  00 0000 0051
      200  D    00   0200    0000                       0764  00 0200 0000
      10053     10   0000    0053                       1406  10 0000 0053
      11051     11   0000    0051                       0534  11 0000 0051
      10051     10   0000    0051                       0524  10 0000 0051
      FINIS     HLT  9999    9999         END PROGRM    0914  01 9999 9999
      SPEC1     00   0587    0010                       1043  00 0587 0010
      SPEC2     00   0597    0003                       1253  00 0597 0003
      SPEC3     00   0537    0010                       1143  00 0537 0010
      SPEC4     00   0547    0003                       1303  00 0547 0003
1
1                  ROCKET PACKAGE EXCERPT FOR
1                  VECTOR AND PROPELLANTS PROGRAM
1
                BLA  1500    1999
                BLR  0000    1499
1
1                  OUTPUT ROUTINE
1                  PUNCH BELL CARDS
1
                REG  C9050   9050
                REG  J1991   1996
                REG  K1965   1970
                REG  P1977   1986
                SYN  JOOON   1990
                SYN  PROB    1864
                EQU  LOC     0000
1
      PUNCH     STD  LINK                 START HERE    1930  24 0838 1541
                LDD  8003                               1541  69 8003 1548
                SDA  C0005                1ST WORD      1548  22 9054 1504
                SLT  0004                               1504  35 0004 1515
                SDA  C0006                NUMBER WDS    1515  22 9055 1522
                SRT  0002                               1522  30 0002 1529
                RAU  8003                               1529  60 8003 1537
                SRT  0002                               1537  30 0002 1543
                SET  C0007                              1543  27 9056 1598
                LDD  WDCT6                              1598  69 1501 1554
                STD  P0009                              1554  24 1985 1538
                LDD  PROB                               1538  69 1864 1517
                STD  P0008                              1517  24 1984 1587
                LDD  C0005   PCH3                       1587  69 9054 1593
      PCH3      STD  P0007                              1593  24 1983 1536
                ALO  CARDN                              1536  15 1539 1643
                ALO  ONE D                              1643  15 0516 1521
                SDA  CARDN                              1521  22 1539 1542
                STL  P0010   NZERO                      1542  20 1986 1589
      NZERO     RAU  C0006                IS NO OF      1589  60 9055 1547
                SUP  WDCT6                WORDS LESS    1547  11 1501 1505
                BMI  LESS6   PCH4                       1505  46 1508 1509
      PCH4      STU  C0006                              1509  21 9055 1567
                RAU  P0009                              1567  60 1985 1639
                SRT  0004                               1639  30 0004 1549
                AUP  XMOVE                SET TO MOV    1549  10 1502 1507
                ALO  XLOC                 N WORDS       1507  15 1510 1565
                ALO  C0005   MOVEW                      1565  15 9054 1523
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MOVEW   AUP 09999   8002                        1523  10 1526 8002
 8002   LDD LOC     8003                        8002  69 0000 8003
 8003   STD P0007   J000N                       8003  24 1983 1990
J0000   RAU C0006   PCH2                        1990  60 9055 1597
J0001   RAU C0006   PCH2                        1991  60 9055 1597
J0002   ALO ONE D   MOVEW                       1992  15 0516 1523
J0003   ALO ONE D   MOVEW                       1993  15 0516 1523
J0004   ALO ONE D   MOVEW                       1994  15 0516 1523
J0005   ALO ONE D   MOVEW                       1995  15 0516 1523
J0006   ALO ONE D   MOVEW                       1996  15 0516 1523
PCH2    PCH P0001                               1597  71 1977 1527
        NZE         LINK      IS IT DONE        1527  45 1530 0838
        RAU P0007                               1530  60 1983 1637
        AUP P0009                               1637  10 1985 1689
        STU C0005   PCH3                        1689  21 9054 1593
1
LESS6   RAL C0006                               1508  65 9055 1615
        STD P0009                               1615  24 1985 1588
        SRT  0004             CLEAR ZERO        1588  30 0004 1599
        ALO XCLER   8002                        1599  15 1552 8002
 8002    00  0000   K0001                       8002  00 0000 1965
K0001   STU P0001   K0002                       1965  21 1977 1966
K0002   STU P0002   K0003                       1966  21 1978 1967
K0003   STU P0003   K0004                       1967  21 1979 1968
K0004   STU P0004   K0005                       1968  21 1980 1969
K0005   STU P0005   K0006                       1969  21 1981 1970
K0006   STU P0006   PCH4                        1970  21 1982 1509
1
XCLER    00  0000   K0001                       1552  00 0000 1965
WDCT6    00  0006    0000                       1501  00 0006 0000
 9999    00  0000    9999                       1526  00 0000 9999
XLOC    LDD  0000    8003                       1510  69 0000 8003
XMOVE   STD P0000   J0001                       1502  24 1976 1991
CARDN    00  0000    0000                       1539  00 0000 0000
ONE D    00  0001    0000                       0516  00 0001 0000
1
1          OUTPUT ROUTINE
1          RANDOM LOCATION CARDS WITH
1          ZERO VALUES OMITTED
1
        REG C9050    9050
        REG L1841    1844
        REG P1977    1986
        REG 01845    1845
        SYN LOC      0000
1
RMPCH   STD LINK                                1940  24 0838 1591
        LDD  8006             SAVE INDEX        1591  69 8006 1647
        STD C0003              ACC B AND        1647  24 9052 1503
        LDD  8007              C                1503  69 8007 1559
        STD C0004                               1559  24 9053 1665
        RAC  8002             NO OF WDS         1665  88 8002 1573
1
        LDD  8003                               1573  69 8003 1580
        SDA C0005             1ST WORD          1580  22 9054 1586
        SLT  0004                               1586  35 0004 1697
        SDA C0006             NUMBER WDS        1697  22 9055 1604
        SRT  0002                               1604  30 0002 1511
        RAU  8003                               1511  60 8003 1519
        SRT  0002                               1519  30 0002 1525
        SET C0007                               1525  27 9056 1630
        LBB L0001             C0004 IS          1630  08 1841 1544
        STL C0006              COL 80           1544  20 9055 1602
        RSB  0004              LOCATION         1602  83 0004 1558
        RAL C0005                               1558  65 9054 1715
        ALO PCHX    ENT1      C0003 IS          1715  15 1518 1623
ENT1    STL C0005              CURRENT          1623  20 9054 1680
1                              LOCATION
        ALO XRAU    8002                        1680  15 1533 8002
 8002   RAU LOC     00001                       8002  60 0000 1845
00001   NZU MOVER   C0007     C0007 HAS         1845  44 1649 9056
1                              L0001
L0001   SXC  0001                               1841  59 0001 1747
        NZC         FINS                        1747  48 1500 1551
        RAL C0005                               1500  65 9054 1557
        ALO ONE D   ENT1                        1557  15 0516 1623
1
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MOVER   STD P0005 B          MOVE WD       1649  24 5981 1534
        RAL C0005                          1534  65 9054 1641
        STD P0010 B                        1641  24 5986 1739
        NZB           PCH5   IS CARD       1739  42 1592 1693
        AXB  0001     C0007   FULL YET     1592  52 0001 9056
PCH5    BMI           PLUS                 1693  46 1546 1797
        SLO C0006     BOTH   FIX COL 8     1546  16 9055 1553
PLUS    ALO C0006     BOTH                 1797  15 9055 1553
BOTH    STL P0010                          1553  20 1986 1789
        RAL RMCDN            NUMBER CDS    1789  65 1642 1847
        ALO ONE I                          1847  15 1356 1561
        STL RMCDN                          1561  20 1642 1545
        LDD P0009                          1545  69 1985 1638
        STA P0009                          1638  23 1985 1688
        PCH P0001            PUNCH CARD    1688  71 1977 1577
        RSB  0004     C0008  C0008 HAS     1577  83 0004 9057
L0002   STU C0006     C0007    L0002       1842  21 9055 9056
1
ONE D   00   0001     0000                 0516  00 0001 0000
ONE I   00   0000     0001   ONE INSTR     1356  00 0000 0001
XRAU    59   9999    02001                 1533  59 9999 3845
PCHX    00   0000     8000                 1518  00 0000 8000
RMCDN   00   0000     0000   RANDOM CD     1642  00 0000 0000
                              NUMBER
1
FINS    SET C0007            CHANGE        1551  27 9056 1506
        LBB L0003             ORDERS       1506  08 1843 1596
        RSL PCHX              FOR FINS     1596  66 1518 1673
        STL C0005     C0007                1673  20 9054 9056
L0003   LDD  8003     MOVER                1843  69 8003 1649
L0004   RAB C0001            RESTOR        1844  82 9050 1652
        RAC C0002     LINK    INDX ACC     1652  88 9051 0838
        PAT
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APPENDIX I

533 CONTROL PANEL ("ROCKET BOARD") WIRING INSTRUCTIONS

I. Read card C is used for reading Bell format cards. The word positions are numbered from the right (see 650 Manual of Operation, p. 10):

Read card C (card column)	Storage entry C	Word size entry C
11	Sign of word 1	
12-21	Word 1, positions 10 to 1	10
22	Sign of word 2	
23-32	Word 2, positions 10 to 1	10
33	Sign of word 3	
34-43	Word 3, positions 10 to 1	10
44	Sign of word 4	
45-54	Word 4, positions 10 to 1	10
55	Sign of word 5	
56-65	Word 5, positions 10 to 1	10
66	Sign of word 6	
67-76	Word 6, positions 10 to 1	10
6-9	Word 7, positions 8 to 5, emit sign +	8
5, 77-79	Word 8, positions 8 to 5, emit sign +	8
80, 1-4	Word 9, positions 9 to 5, emit sign +	9
10	Word 10, position 5, emit sign +; positions 4 to 1 of words 7, 8, 9, and 10 wired to emit zero	5

II. Read card B is used for reading Random location format cards:

Read card B (card column)	Storage entry B	Word size entry B
5-15	Word 1, positions 10 to 1, col. 15 is sign	10
20-30	Word 2, positions 10 to 1, col. 30 is sign	10
35-45	Word 3, positions 10 to 1, col. 45 is sign	10
50-60	Word 4, positions 10 to 1, col. 60 is sign	10
65-75	Word 5, positions 10 to 1, col. 75 is sign	10
1-4	Word 6, positions 8 to 5, emit sign +	8
16-19	Word 7, positions 8 to 5, emit sign +	8
31-34	Word 8, positions 8 to 5, emit sign +	8
46-49	Word 9, positions 8 to 5, emit sign +	8
61-64	Co-selector 1 transferred points (U, 1 to 4)(make col. 61 a split wire, p. 119)	
76-80	Not wired Words 6 to 9 emit zero into positions 4 to 1	

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Selector wiring for determining and entering the word count in word 10 and ensuring that word 10 is a legitimate word is as follows:

Co-selector 1 common (W, 1 to 4) to word 10, positions 8 to 5 storage entry B
Word size of word 10. entry B is 8
Co-selector 1 normal (V, 1 to 4), to (V, 32). (This guarantees a nonzero value on word 10 to preserve the negative sign for a branch on minus test.)
Emit zeros to word 10, positions 4 to 2, storage entry B
Emit sign of word 10 minus (V, 28)
Pilot selector 1 common (K, 23) to word 10, position 1, storage entry B
Pilot selector 1 normal (J, 23) to emit zero
Pilot selector 1 transferred (H, 23) to pilot selector 2 common (K, 24)

Pilot selector 2 transferred (H, 24) to pilot selector 3 common (K, 25)
Pilot selector 3 normal (J, 25) to emit 2 (W, 21)
Pilot selector 3 transferred (H, 25) to pilot selector 4 common (K, 26)
Pilot selector 4 normal (J, 26) to emit 3 (X, 21)
Pilot selector 4 transferred (H, 26) to pilot selector 5 common (K, 27)
Pilot selector 5 normal (J, 27) to emit 4 (Y, 21)
Pilot selector 5 transferred (H, 27) to emit 5 (Z, 21)
Pilot selector 2 normal (J, 24) to emit 1 (V, 21)
First reading col. 1 (A, 23) to load (B, 21) } split wire
First reading col. 1 (A, 23) to common of col. split (Z, 34) } split wire
Col. split 0-9 (Y, 34) to D pick pilot selector 1 (F, 23)

Co-selector 3 pick (R, 25) to col. split 12-X (X, 34)
Co-selector 3 common (W, 11) to emit 9 (W, 34)
Co-selector 3 transfer (U, 11) to entry B (D, 21)

First reading col. 16 (A, 38) to D pick pilot selector 2 (F, 24)
First reading col. 31 (C, 33) to D pick pilot selector 3 (F, 25)
First reading col. 46 (C, 28) to D pick pilot selector 4 (F, 26) (Split wire, p. 120)
First reading col. 61 (D, 23) to D pick pilot selector 5 (F, 27)
Couple pilot selector 5 (G, 27) to co-selector pickup 1 (S, 23)

Digit impulse (Q, 21) to digit selector common (R, 21)
First reading col. 15 (A, 37) to col. split 12-X (X, 33)
Col. split common (Z, 33) to entry B (D, 22)

Hold for pilot selectors 1 to 5 (P, 23 to 27) and co-selectors 1 and 3 (U, 23 and 25) are wired to read hold (T, 39).

III. Read card A is used to read input cards (SOAP II format) for Vector and Propellant Program (requires the alphabetic attachment and pilot selectors 11, 12, 13):

First reading col. 3 (A, 25) to col. split common (Z, 35)
Col. split 12-X (X, 35) to entry A (C, 22)
Entry A (C, 23) to pilot selector 12-X pick (E, 34)
Pilot selector 12 couple exit (G, 34) to alphabetic control WI (AL, 12) and also to W2 to W6.

Storage entry A, word 10, position 3 (J, 19) to pilot selector 13 common (K, 35)
Pilot selector 13 normal (J, 35) to zero read impulse (AN, 20)
Pilot selector 13 transfer (H, 35) to read card A, col. 41 (C, 1)
Pilot selector 13 D pick (F, 35) to first reading col. 41 (C, 23)
Storage entry A, word 10, position 2 (J, 20) to pilot selector 13 common (N, 35)
Pilot selector 13 normal (M, 35) to zero read impulse (AP, 20)
Pilot selector 13 transfer (L, 35) to read impulse 9 (V, 34)
Storage entry A, word 10, position 1 (J, 21) to pilot selector 11 common (N, 33)
Pilot selector 11 normal (M, 33) to zero read impulse (AP, 21)
Pilot selector 11 transfer (L, 33) to read impulse 8 (V, 33)
Pilot selector 11 D pick (F, 33) to first reading, col. 42 (C, 24)
Read card A, col. 43 (C, 3) to storage entry A, word 1, position 5 (E, 6)
Read card A, col. 44 to 47 (C, 4 to 7) split wire to word 1, positions 4 to 1 (E, 7 to 10) and to word 7, positions 4 to 1 (H, 7 to 10)
Read card A, col. 48 to 50 (C, 8 to 10) to word 4, positions 5 to 3 (F, 17 to 19)
Read card A, col. 51 (C, 11) to word 2, position 5 (E, 17)
Read card A, col. 52 to 55 (C, 12 to 15) split wire to word 2, positions 4 to 1 (E, 18 to 21) and to word 8, positions 4 to 1 (H, 18 to 21)
Read card A, col. 56 (C, 16) to word 4, position 2 (F, 20)
Read card A, col. 57 (C, 17) to word 3, position 5 (F, 6)
Read card A, col. 58 to 61 (C, 18 to D, 1) split wire to word 3, positions 4 to 1 (F, 7 to 10) and to word 9, positions 4 to 1 (J, 7 to 10)
Read card A, col. 62 (D, 2) to word 4, position 1 (F, 21)
Read card A, col. 63 to 67 (D, 3 to 7) to word 5, positions 5 to 1 (G, 6 to 10)
Read card A, col. 68 to 72 (D, 8 to 12) to word 6, positions 5 to 1 (G, 17 to 21)
First reading, col. 43 to 47 (C, 25 to 29) to alphabetic first read, word 1, positions 5 to 1 (AK, 13 to 17)
Col. 48 to 50 (C, 30 to 32) to alphabetic first read, word 4, positions 5 to 3 (AL, 18 to 20)
Col. 51 to 55 (C, 33 to 37) to alphabetic first read, word 2, positions 5 to 1 (AK, 18 to 22)
Col. 56 (C, 38) to alphabetic first read, word 4, position 2 (AL, 21)
Col. 57 to 61 (C, 39 to D, 23) to alphabetic first read, word 3, positions 5 to 1 (AL, 13 to 17)
Col. 62 (D, 24) to alphabetic first read, word 4, position 1 (AL, 22)
Col. 63 to 67 (D, 25 to 29) to alphabetic first read, word 5, positions 5 to 1 (AM, 13 to 17)
Col. 68 to 72 (D, 30 to 34) to alphabetic first read, word 6, positions 5 to 1 (AM, 18 to 22)

Read validity check wire off (AR, 43) to (AR, 44)
Chain wire pilot selector hold of pilot selectors 11, 12, and 13 (P, 33 to 35) to read hold (T, 39)
Word size entry A, words 7 to 9 (AL, 7 to 9) to word size emitter 4 (AK, 5)
Word size entry A, word 10 (AL, 10) to word size emitter 3 (AK, 4)

IV. Punch card C is used to punch Bell format cards and Trace format cards:

Punch card C (card column)	Storage exit C
11	Sign of word 1
12-21	Word 1, positions 10 to 1
22	Sign of word 2
23-32	Word 2, positions 10 to 1
33	Sign of word 3
34-43	Word 3, positions 10 to 1
44	Sign of word 4
45-54	Word 4, positions 10 to 1
55	Sign of word 5
56-65	Word 5, positions 10 to 1
66	Co-selector 7 common (W, 59) Co-selector 7 normal (V, 59) to word 6 sign (AG, 64)(Split wire, see Trace cards)
67	Word 6, position 10
68-72	Co-selectors 6 and 7 common (W, 54 to 58) Co-selectors 6 and 7 normal (W, 54 to 58) to word 6, positions 9 to 5
73-76	Word 6, positions 4 to 1
6-9	Co-selector 6 common (W, 50 to 53) Co-selector 6 normal (V, 50 to 53) to word 7, positions 8 to 5
5, 77-79	Word 8, positions 8 to 5
10	Word 9, position 5
80, 1-4	Word 10, positions 9 to 5

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For Trace cards:

Co-selector 6 transfer (U, 50 to 53) to word 7, positions 4 to 1
Co-selectors 6 and 7 transfer (U, 54 to 57) to word 8, positions 4 to 1
Co-selector 7 transfer (U, 58) to word 6, sign position
Co-selector 7 transfer (U, 59) to word 8, sign position

An 8 in position 9 of word 10 causes Trace cards to be punched by means of control information:

Control information (AM, 56) to co-selectors 6 and 7 pick (R, 28, 29)
Co-selectors 6 and 7 hold (T, 28, 29) to punch hold (R, 39)
Jack plug "P+" (V, 42) to (W, 42)

V. Punch card B is used to punch Random location cards:

Punch card B (card column)	Storage exit B
5-15	Word 1, positions 10 to 1, col. 15 is sign
20-30	Word 2, positions 10 to 1, col. 30 is sign
35-45	Word 3, positions 10 to 1, col. 45 is sign
50-60	Word 4, positions 10 to 1, col. 60 is sign
65-75	Word 5, positions 10 to 1, col. 75 is sign
1	Pilot selector 6 common (K, 28) Pilot selector 6 normal (J, 28) to word 6, position 8
2-4	Word 6, positions 7 to 5
16	Pilot selector 7 common (K, 29) Pilot selector 7 normal (J, 29) to word 7, position 8
17-19	Word 7, positions 7 to 5
31	Pilot selector 8 common (K, 30) Pilot selector 8 normal (J, 30) to word 8, position 8
32-34	Word 8, positions 7 to 5
46	Pilot selector 9 common (K, 31) Pilot selector 9 normal (J, 31) to word 9, position 8
47-49	Word 9, positions 7 to 5
61	Pilot selector 10 common (K, 32) Pilot selector 10 normal (J, 32) to word 10, position 8
62-64	Word 10, positions 7 to 5
76-79	Word 9, positions 4 to 1
80	Word 10, position 9

Pilot selector 6 I pick (G, 28) to sign word 6
Pilot selector 7 I pick (G, 29) to sign word 7
Pilot selector 8 I pick (G, 30) to sign word 8
Pilot selector 9 I pick (G, 31) to sign word 9
Pilot selector 10 I pick (G, 32) to sign word 10
Co-selector 2 pick (R, 24) to punch X impulse (A, 43)
Co-selector 2 common (W, 6) to punch hold (R, 39)
Co-selector 2 transferred (U, 6) split wire to transfer of pilot selectors 6 to 10 inclusive (L, 28 to 32)
Pilot selectors 6 to 10 common (N, 28 to 32) to pilot selector hold 6 to 10 (Q, 28 to 32)
Co-selector 2 hold (T, 24) to punch hold (S, 39)
Control information 4 (AK, 61) to punch B (D, 43)

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VI. Punch card A is used to punch SOAP II format cards:

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Punch card A (card column)	Storage exit A
1	Col. split common (AM, 52) Col. split 0-9 (AL, 52) to emit 6 (AA, 43) Col. split 12-X (AK, 52) to emit 12 (S, 43); Wire DI (Q, 43) to common (R, 43)
2-6	Emit 9,1,9,5,4, respectively, from punch emitter
7-10	Co-selector 5 common positions 4 to 1 (W, 46 to 49) Co-selector 5 normal positions 4 to 2 (V, 46 to 48) to emit 1,9,5, respectively, from punch emitter Co-selector 5 normal position 1 (V, 49) to col. split common (AM, 45) Col. split 0-9 (AL, 45) to emit 3 Col. split 12-X (AK, 45) to emit 12 (S, 43) Co-selector 5 transfer positions 4 to 2 (U, 46 to 48) to emit 8,0,0, respectively Co-selector 5 transfer position 1 (U, 49) to col. split common (AM, 46) Col. split 0-9 (AL, 46) to emit 3 Col. split 12-X (AK, 46) to emit 12 (S, 43)
11-20	Word 9, positions 10 to 1, wire sign of word 9 to col. 20 with col. split (AM, 47)
21	Emit 2
22	Emit 4
23-26	Word 8, positions 8 to 5
27-29	Emit 8,0,0, respectively
30	Col. split common (AM, 48) Col. split 0-9 (AM, 48) to emit 0 Col. split 12-X (AM, 48) to emit 12
31-40	Word 7, positions 10 to 1, wire sign through col. split to col. 40 and 42
41	Word 8, position 1
42	Sign of word 7
43-47	Word 1, positions 5 to 1
48-50	Word 4, positions 5 to 3
51-55	Word 2, positions 5 to 1
56	Word 4, position 2
57-61	Word 3, positions 5 to 1
62	Word 4, position 1
63-67	Word 5, positions 5 to 1
68-72	Word 6, positions 5 to 1

Control information 2 (AK, 63) to co-selector 5 pick (R, 27)
Control information 3 (AK, 62) to Alpha cut W1 and also chain wire to W2, W3, W4, W5, and W6
3 (AL, 62) to Punch A (C, 43)
Co-selector 5 hold (T, 27) to punch hold (R, 40)

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TABLE I. - COEFFICIENTS FOR OBTAINING THERMODYNAMIC DATA FOR SEVERAL SUBSTANCES

[Coefficients for use in equations (105) to (107).]

Substance (a)	Temperature interval, °K	Coefficients					
		A	B	C	D	E	F
C	150 - 300	+2527 8238 51	+1867 6400 47	-2011 9997 45	+3832 8460 42	+1318 3612 56	+4598 3693 51
	300 - 500	+2511 0512 51	+2341 2431 46	-2064 1813 44	+2504 6361 41	+1318 3951 56	+4694 0319 51
	500 - 700	+2505 9144 51	+1127 9624 46	-6304 0443 43	+5333 3424 40	+1318 4070 56	+4722 3131 51
	700 - 1000	+2503 4230 51	+5325 3290 45	-2160 0382 43	+1354 8725 40	+1318 4156 56	+4737 1984 51
	1000 - 1300	+2503 2775 51	+5521 0150 45	-1695 7438 43	+8855 6245 39	+1318 4123 56	+4737 2493 51
	1300 - 1700	+2504 6546 51	+9314 6910 45	-2465 5314 43	+1190 5488 40	+1318 3969 56	+4726 7149 51
	1700 - 2100	+2501 5285 51	+5907 5500 45	-1820 8474 43	+9928 4700 39	+1318 4349 56	+4749 6818 51
	2100 - 2600	+2488 4570 51	-1345 7700 46	+8780 3410 42	+2879 3181 39	+1318 6460 56	+4852 5918 51
	2600 - 3200	+2472 3653 51	-4335 7912 46	+3975 0497 43	-3693 6212 39	+1319 0115 56	+4990 6948 51
	3200 - 3800	+2476 2539 51	-6493 0882 46	+5315 2588 43	-5893 7109 39	+1319 1045 56	+4983 7555 51
	3800 - 4400	+2504 1340 51	-7041 0160 46	+5063 4142 43	-5359 6037 39	+1318 6229 56	+4783 1816 51
	4400 - 5000	+2546 5888 51	-6519 6370 46	+4155 2568 43	-4063 3061 39	+1317 6142 56	+4455 1751 51
	5000 - 6000	+2610 4540 51	-4741 7690 46	+2664 8172 43	-2304 4960 39	+1315 6607 56	+3935 3511 51
Graphite	300 - 500	+5673 0710 50	-2106 2241 48	+1744 0045 46	-1691 9439 43	+4619 0744 55	-2545 1750 51
	500 - 700	+1058 3269 51	-2064 1842 48	+1091 7536 46	-7970 7376 42	+4607 1927 55	-5175 2399 51
	700 - 1000	+1628 3807 51	-1307 2653 48	+5023 1415 45	-2756 8704 42	+4584 8409 55	-8591 5430 51
	1000 - 1300	+2289 3860 51	-3947 4982 47	+9829 2657 44	-2901 7625 41	+4546 1211 55	-1287 2246 52
	1300 - 1700	+2407 1476 51	-4784 1780 47	+1008 1106 45	-3136 4202 41	+4537 7132 55	-1361 1939 52
	1700 - 2100	+2709 5422 51	-2313 1973 47	+3670 0610 44	-8357 2671 40	+4507 5530 55	-1573 1714 52
	2100 - 2600	+2841 4329 51	-1619 7368 47	+2059 3854 44	-3684 0068 40	+4491 5653 55	-1667 5373 52
	2600 - 3200	+2958 2033 51	-1146 5505 47	+1154 2930 44	-1567 2361 40	+4474 0549 55	-1753 4691 52
	3200 - 3800	+3040 3247 51	-9509 5628 46	+7614 5316 43	-7812 3581 39	+4460 0657 55	-1814 4793 52
	3800 - 4400	+3097 3807 51	-9187 9709 46	+6184 4345 43	-5311 4558 39	+4449 1831 55	-1856 9802 52
	4400 - 5000	+3152 7766 51	-8885 2831 46	+5138 2079 43	-3740 3250 39	+4436 8642 55	-1899 1194 52
CCl	150 - 300	+3820 3364 51	+4255 4820 47	-7410 0490 45	+2285 0707 43	+1092 3347 56	+5349 2058 51
	300 - 500	+3693 1871 51	-9241 6910 47	+7775 5823 45	-8061 9700 42	+1092 5828 56	+6074 2136 51
	500 - 700	+3912 5706 51	-7820 0920 47	+4222 7425 45	-3279 9984 42	+1092 0413 56	+4884 6073 51
	700 - 1000	+4115 6696 51	-4342 0958 47	+1693 0522 45	-9680 7557 41	+1091 2721 56	+3666 0743 51
	1000 - 1300	+4271 6614 51	-2203 0847 47	+6118 7076 44	-2567 8708 41	+1090 4684 56	+2678 1140 51
	1300 - 1700	+4378 2291 51	-9382 1810 46	+1978 6630 44	-6167 2272 40	+1089 6529 56	+1956 5236 51
	1700 - 2100	+4428 6744 51	-5606 4340 46	+9129 2970 43	-2231 4653 40	+1089 1732 56	+1606 6487 51
	2100 - 2600	+4461 6643 51	-3393 9946 46	+4422 3777 43	-8479 8548 39	+1088 7729 56	+1368 9058 51
	2600 - 3200	+4484 6128 51	-2289 1842 46	+2381 7346 43	-3571 2362 39	+1088 4376 56	+1199 9462 51
	3200 - 3800	+4500 7379 51	-1781 1588 46	+1497 8228 43	-1797 2303 39	+1088 1620 56	+1079 4739 51
	3800 - 4400	+4513 7299 51	-1439 6338 46	+1005 6037 43	-9752 0000 38	+1087 8935 56	+9798 5788 50
	4400 - 5000	+4522 5949 51	-1319 2912 46	+7941 9120 42	-6609 4577 38	+1087 6927 56	+9117 3280 50
	5000 - 6000	+4532 7490 51	-1122 4142 46	+5808 8556 42	-3943 1880 38	+1087 4110 56	+8309 5849 50
CCl_4	150 - 300	+6883 4230 51	-2183 6856 49	+2209 0207 47	-3765 2673 44	+4132 9670 55	-2005 0830 51
	300 - 500	+8534 3172 51	-7160 8000 48	+6201 5460 46	-7111 6167 43	+4098 5503 55	-1142 3036 52
	500 - 700	+1008 7133 52	-4760 2740 48	+2629 9117 46	-2170 8108 43	+4062 5210 55	-1986 7563 52
	700 - 1000	+1120 9988 52	-2287 4085 48	+9077 1820 45	-5425 6390 42	+4022 5045 55	-2659 6737 52
	1000 - 1300	+1195 6348 52	-1043 2162 48	+2943 6828 45	-1282 6918 42	+3986 5351 55	-3131 0836 52
	1300 - 1700	+1248 4721 52	-3391 1184 47	+7258 7051 44	-2338 0965 41	+3945 8748 55	-3490 8748 52
	1700 - 2100	+1268 0666 52	-1729 2303 47	+2873 9710 44	-7327 1794 40	+3926 8367 55	-3627 8096 52
	2100 - 2600	+1279 3339 52	-8857 1920 46	+1192 5272 44	-2449 6562 40	+3912 7677 55	-3709 6952 52
	2600 - 3200	+1286 1578 52	-4880 6790 46	+5345 6302 43	-8955 1435 39	+3902 3779 55	-3760 5577 52
	3200 - 3800	+1290 2043 52	-3013 4232 46	+2724 8863 43	-3823 6766 39	+3895 0427 55	-3791 3780 52
	3800 - 4400	+1292 8751 52	-1886 0004 46	+1451 7234 43	-1740 7449 39	+3889 1827 55	-3812 2942 52
	4400 - 5000	+1294 5807 52	-1253 5153 46	+8422 0090 42	-8823 9152 38	+3884 8198 55	-3825 9243 52
	5000 - 6000	+1296 2205 52	-6498 6420 45	+3820 8266 42	-3347 9564 38	+3879 6914 55	-3839 4390 52
CF	150 - 300	+3640 0200 51	+8085 8640 47	-1026 9011 46	+2438 4900 43	+1950 6783 56	+4867 6076 51
	300 - 500	+3498 5413 51	-4528 6370 47	+3399 6376 45	-1921 1982 42	+1950 9729 56	+5674 6721 51
	500 - 700	+3597 7497 51	-8040 8130 47	+4156 7731 45	-2824 2658 42	+1950 7415 56	+5176 7255 51
	700 - 1000	+3810 1072 51	-6268 2490 47	+2385 5288 45	-1274 7825 42	+1949 9158 56	+3918 2736 51
	1000 - 1300	+4048 2657 51	-3885 1238 47	+1061 8631 45	-4275 8782 41	+1948 6368 56	+2414 2551 51
	1300 - 1700	+4225 0270 51	-2089 1357 47	+4374 3033 44	-1339 8215 41	+1947 2978 56	+1226 0050 51
	1700 - 2100	+4334 2200 51	-1335 8403 47	+2161 7485 44	-5212 2758 40	+1946 2672 56	+4713 8170 50
	2100 - 2600	+4411 7942 51	-8377 6910 46	+1084 3361 44	-2048 7978 40	+1945 3278 56	-8671 8950 49
	2600 - 3200	+4467 8185 51	-5822 8670 46	+6020 0162 43	-8903 5200 39	+1944 5100 56	-4985 2010 50
	3200 - 3800	+4508 2460 51	-4630 6640 46	+3870 6023 43	-4584 6109 39	+1943 8215 56	-8000 8070 50
	3800 - 4400	+4541 0295 51	-3813 2379 46	+2644 8087 43	-2522 3761 39	+1943 1526 56	-1050 5867 51
	4400 - 5000	+4569 6116 51	-3184 7846 46	+1851 2604 43	-1379 0052 39	+1942 4685 56	-1273 6745 51
	5000 - 6000	+4608 1204 51	-2076 7807 46	+9178 6561 42	-2634 8774 38	+1941 3042 56	-1586 8660 51
CF_2	150 - 300	+4048 5275 51	-2616 5412 48	+2155 8933 46	-2058 6114 43	+6584 7865 55	+5829 4252 51
	300 - 500	+4074 4857 51	-2499 6320 48	+2064 8571 46	-1981 1983 43	+6584 1442 55	+5680 2914 51
	500 - 700	+4691 9175 51	-2394 9638 48	+1263 9499 46	-9151 9648 42	+6568 6792 55	+2347 8274 51
	700 - 1000	+5409 6786 51	-1408 4350 48	+5348 7413 45	-2842 5180 42	+6539 7513 55	-1979 9985 51
	1000 - 1300	+6025 9535 51	-7504 6540 47	+2030 6869 45	-7987 0809 41	+6504 7319 55	-5917 2859 51
	1300 - 1700	+6398 7799 51	-3929 7130 47	+8155 2021 44	-2451 9736 41	+6475 5249 55	-8433 7760 51
	1700 - 2100	+6642 6054 51	-2224 2198 47	+3543 7494 44	-8257 7665 40	+6450 9950 55	-1013 7338 52
	2100 - 2600	+6788 3007 51	-1372 2122 47	+1756 5186 44	-3252 3470 40	+6432 4476 55	-1119 1218 52
	2600 - 3200	+6891 2452 51	-9243 3170 46	+9493 4160 43	-1396 0756 40	+6416 6267 55	-1195 3073 52
	3200 - 3800	+6967 1014 51	-6796 6480 46	+5630 0065 43	-6591 8731 39	+6402 7074 55	-1252 6276 52
	3800 - 4400	+7021 0652 51	-5466 6732 46	+3777 3931 43	-3621 0579 39	+6390 9978 55	-1294 2206 52
	4400 - 5000	+7058 0449 51	-4920 3790 46	+2933 2725 43	-2418 8941 39	+6382 1426 55	-1322 8904 52
	5000 - 6000	+7097 4438 51	-4178 3006 46	+2148 5733 43	-1461 5182 39	+6370 9039 55	-1354 3379 52
CF_3	150 - 300	+4415 9046 51	-1079 2001 49	+1028 9803 47	-1547 4411 44	+3294 5442 55	+6322 6310 51
	300 - 500	+6995 4769 51	+6890 2840 48	-6064 6113 46	+9838 4060 43	+3233 5181 55	-8614 0409 51
	500 - 700	-1340 4500 50	-2596 2896 49	+1511 2585 47	-1367 1095 44	+3485 6118 55	+3544 3864 52
	700 - 1000	+6412 2822 51	-5167 3100 48	+2151 1245 46	-1307 2694 43	+3257 6653 55	-4378 9560 51
	1000 - 1300	+7725 6912 51	-2967 7290 48	+8838 4890 45	-3912 9278 42	+3209 7765 55	-1236 8123 52
	1300 - 1700	+9068 6613 51	-1109 7817 48	+2576 9457 45	-8070 0746 41	+3114 9770 55	-2139 6277 52
	1700 - 2100	+9682 7034 51	-6851 8810 47	+1229 5950 45	-2863 4956 41	+3061 1725 55	-2559 1310 52
	2100 - 2600	+1013 8660 52	-4418 4184 47	+6387 7821 44	-1094 2288 41	+3008 1267 55	-2883 3689 52
	2600 - 3200	+1047 7649 52	-3606 9383 47	+4132 9340 44	-5398 9138 40	+2961 3360 55	-3127 2861 52
	3200 - 3800	+1076 8882 52	-3381 4409 47	+3076 1815 44	-3205 5453 40	+2914 5240 55	-3339 4045 52
	3800 - 4400	+1102 5318 52	-3277 2624 47	+2461 8412 44	-2128 3409 40	+2865 7705 55	-3530 0856 52
	4400 - 5000	+1125 0822 52	-3285 3329 47	+2101 1199 44	-1569 0770 40	+2817 3513 55	-3699 8762 52
	5000 - 6000	+1150 6199 52	-3117 8637 47	+1722 3104 44	-1082 7473 40	+2750 5776 55	-3898 6721 52
CF_4	150 - 300	+4643 8961 51	-1683 7831 49	+1601 9450 47	-2396 9562 44	-1014 9484 54	+5178 0680 51
	300 - 500	+5623 0578 51	-8719 8704 48	+7316 1903 46	-7605 1763 43	-1222 0906 54	-3985 7300 50
	500 - 700	+7960 4636 51	-6242 2794 48	+3262 8202 46	-2359 3972 43	-1831 2412 54	-1328 2457 52
	700 - 1000	+9906 5230 51	-3434 1001 48	+1267 5804 46	-6495 1661 42	-2626 6184 54	-2506 3601 52
	1000 - 1300	+1147 9388 52	-1815 3256 48	+4641 2069 45	-1652 2082 42	-3541 4110 54	-3514 4361 52
	1300 - 1700	+1233 7867 52	-1186 3523 48	+2313 9431 45	-6249 2947 41	-4218 0861 54	-4090 3195 52
	1700 - 2100	+1298 6542 52	-8631 0470 47	+1280 2308 45	-2607 4621 41	-4855 4757 54	-4538 0510 52
	2100 - 2600	+1342 9488 52	-7049 5815 47	+8401 4548 44	-1348 7181 41	-5387 8368 54	-4851 9210 52
	2600 - 3200	+1383 6480 52	-6127 0088 47	+5871 1932 44	-7435 7727 40	-5966 7885 54	-5145 8668 52
	3200 - 3800	+1421 5792 52	-5686 3751 47	+4435 9055 44	-4538 3719 40	-6598 0089 54	-5424 2675 52
	3800 - 4400	+1455 3027 52	-5438 3782 47	+3578 3524 44	-3067 9795 40	-7256 5240 54	-5676 6439 52
	4400 - 5000	+1485 3135 52	-5353 0332 47	+3054 5903 44	-2273 9993 40	-7916 3830 54	-5904 0139 52
	5000 - 6000	+1520 3418 52	-5012 9280 47	+2490 5609 44	-1562 2083 40	-8854 9760 54	-6178 5165 52

[a]All substances in gaseous phase except graphite.

TABLE I. - Continued. COEFFICIENTS FOR OBTAINING THERMODYNAMIC DATA FOR SEVERAL SUBSTANCES

[Coefficients for use in equations (105) to (107)]

Substance (a)	Temperature interval, °K	Coefficients					
		A	B	C	D	E	F
CH	150 - 300	+3512 7827 51	+4636 0810 46	-5378 9030 44	+1146 7347 42	+1344 6458 56	+1985 4362 51
	300 - 500	+3518 9332 51	+8459 4710 46	-9090 7610 44	+1731 4444 42	+1344 6317 56	+1950 3265 51
	500 - 700	+3488 5177 51	-4341 9700 46	-1474 4120 44	+9635 7572 41	+1344 7464 56	+2140 1459 51
	700 - 1000	+3400 5554 51	-5633 2938 47	+1934 0930 45	-6925 5361 41	+1345 2502 56	+2759 7067 51
	1000 - 1300	+3525 5707 51	-8199 6840 47	+2173 4717 45	-8003 0457 41	+1344 7547 56	+2069 0007 51
	1300 - 1700	+3837 6747 51	-6520 0620 47	+1371 1096 45	-4245 5702 41	+1342 4710 56	+1564 3000 49
	1700 - 2100	+4192 6268 51	-4067 2700 47	+6710 9154 44	-1698 9591 41	+1339 0392 56	-2447 1172 51
	2100 - 2600	+4465 9529 51	-2009 4469 47	+2655 2706 44	-5294 6286 40	+1335 5954 56	-4436 8745 51
	2600 - 3200	+4632 7107 51	-9757 7450 46	+9834 5740 43	-1342 4602 40	+1333 0453 56	-5683 3608 51
	3200 - 3800	+4698 1775 51	-7731 9680 46	+5967 1047 43	-5314 9447 39	+1332 0116 56	-6167 1269 51
	3800 - 4400	+4702 1190 51	-1030 5653 47	+7078 9557 43	-6530 3692 39	+1332 3200 56	-6159 8616 51
	4400 - 5000	+4683 7437 51	-1461 5449 47	+9345 2350 43	-9239 1545 39	+1333 4036 56	-5958 5943 51
	5000 - 6000	+4705 6474 51	-1610 6331 47	+9697 4750 43	-9522 5104 39	+1333 1471 56	-6102 7716 51
CH_4	150 - 300	+4041 7634 51	+2256 4400 47	-8630 3440 45	+3562 5920 43	+1060 6422 56	-6347 7250 50
	300 - 500	+3771 6119 51	-1914 0720 48	+1386 0780 46	-5564 2687 42	+1061 2254 56	+9066 3870 50
	500 - 700	+4137 3746 51	-3824 2483 48	+1900 8319 46	-1114 4742 43	+1060 5115 56	-8222 6700 50
	700 - 1000	+4960 9077 51	-3993 5554 48	+1469 0695 46	-7032 1539 42	+1057 6295 56	-5511 1720 51
	1000 - 1300	+6265 1238 51	-3554 3046 48	+9493 8230 45	-3578 7489 42	+1051 0805 56	-1351 2328 52
	1300 - 1700	+7669 4643 51	-2559 0212 48	+5320 7298 45	-1596 8105 42	+1040 8233 56	-2280 0662 52
	1700 - 2100	+8940 9968 51	-1821 1267 48	+2963 0253 45	-7240 8212 41	+1028 9329 56	-3153 5615 52
	2100 - 2600	+9999 5267 51	-1151 4294 48	+1522 5193 45	-3042 6540 41	+1015 9947 56	-3915 9002 52
	2600 - 3200	+1082 7726 52	-7167 4950 47	+7704 7857 44	-1264 4178 41	+1003 5136 56	-4530 1437 52
	3200 - 3800	+1139 5575 52	-4744 1100 47	+4200 8572 44	-5795 9231 40	+9932 4942 55	-4961 4187 52
	3800 - 4400	+1178 8522 52	-3183 3398 47	+2393 0379 44	-2833 4861 40	+9846 8258 55	-5268 2486 52
	4400 - 5000	+1205 5418 52	-2229 3658 47	+1456 2454 44	-1510 4845 40	+9779 0774 55	-5481 0163 52
	5000 - 6000	+1232 4498 52	-1249 1856 47	+7039 3966 43	-6132 3844 39	+9695 2767 55	-5702 5529 52
CO	150 - 300	+3501 4842 51	+1087 8922 46	-2132 6547 44	+7176 7187 41	+3308 4242 55	+3809 0776 51
	300 - 500	+3504 8282 51	+5717 3880 46	-7717 9140 44	+1948 0969 42	+3308 3690 55	+3790 2032 51
	500 - 700	+3457 2625 51	-2833 6849 47	+1252 0307 45	-3568 5188 41	+3310 1729 55	+4099 1393 51
	700 - 1000	+3478 1473 51	-5369 0403 47	+1958 1791 45	-9091 0461 41	+3310 1638 55	+4029 9306 51
	1000 - 1300	+3651 5834 51	-5144 8902 47	+1380 4870 45	-5272 6366 41	+3301 4098 55	+2971 0270 51
	1300 - 1700	+3860 8374 51	-3546 9532 47	+7404 9426 44	-2247 5935 41	+3285 9734 55	+1582 1786 51
	1700 - 2100	+4040 9776 51	-2413 3244 47	+3930 0638 44	-9624 6665 40	+3269 0418 55	+3411 6830 50
	2100 - 2600	+4182 5494 51	-1491 5448 47	+1963 8756 44	-3880 7574 40	+3251 7557 55	-6791 5710 50
	2600 - 3200	+4288 4419 51	-9428 1210 46	+1001 4612 44	-1599 3818 40	+3235 9292 55	-1463 2026 51
	3200 - 3800	+4364 4008 31	-6326 1270 46	+5453 3767 43	-7027 3322 39	+3222 2132 55	-2039 2716 51
	3800 - 4400	+4419 2221 51	-4399 2938 46	+3153 4215 43	-3308 2674 39	+3210 1502 55	-2466 3384 51
	4400 - 5000	+4455 6250 51	-3418 0326 46	+2087 5301 43	-1819 9816 39	+3200 9544 55	-2753 9920 51
	5000 - 6000	+4489 0699 51	-2554 6512 46	+1323 6630 43	-9051 5936 38	+3190 9734 55	-3024 6520 51
CO_2	150 - 300	+3563 7140 51	-4925 8570 48	+4540 0397 46	-6280 3430 43	+5747 4400 51	+5400 7202 51
	300 - 500	+3816 8846 51	-2963 9146 48	+2490 7914 46	-2567 1204 43	-4925 1570 52	+3956 0791 51
	500 - 700	+4442 4313 51	-2696 4402 48	+1430 5622 46	-1054 0891 43	-1901 0823 53	+6296 7070 50
	700 - 1000	+5077 4390 51	-1862 6330 48	+7097 4891 45	-3796 5406 42	-4195 9603 53	-3119 0925 51
	1000 - 1300	+5616 2514 51	-1446 4518 48	+3992 8769 45	-1646 9220 42	-6690 3300 53	-6421 4910 51
	1300 - 1700	+6233 4300 51	-7697 8330 47	+1624 9078 45	-5067 2175 41	-1123 1388 54	-1056 0477 52
	1700 - 2100	+6653 7149 51	-4526 7290 47	+7359 4847 44	-1790 7679 41	-1524 1600 54	-1347 7832 52
	2100 - 2600	+6946 1749 51	-2588 8848 47	+3382 8632 44	-6523 5648 40	-1891 5354 54	-1559 6591 52
	2600 - 3200	+7139 6491 51	-1643 2337 47	+1725 5138 44	-2650 3605 40	-2185 9376 54	-1703 0668 52
	3200 - 3800	+7296 9835 51	-1012 4495 47	+8494 4890 43	-1007 5545 40	-2485 6878 54	-1823 3039 52
	3800 - 4400	+7355 3715 51	-9492 3200 46	+6828 6345 43	-7193 5879 39	-2598 7416 54	-1867 0777 52
	4400 - 5000	+7412 7505 51	-8253 2950 46	+5117 7600 43	-4618 8168 39	-2726 6119 54	-1911 4164 52
	5000 - 6000	+7871 5782 51	+9909 4290 46	-6572 2870 43	+7825 5668 39	-4364 6730 54	-2298 7484 52
COF_2	150 - 300	+4131 1379 51	-8226 1920 48	+7478 2778 46	-9970 6473 43	+2401 0874 54	+7645 9612 51
	300 - 500	+4500 8690 51	-5432 1224 48	+4581 6857 46	-4789 2357 43	+2320 2046 54	+5535 4142 51
	500 - 700	+5678 2507 51	-4772 8328 48	+2562 2417 46	-1955 9689 43	+2047 8396 54	-7674 1900 50
	700 - 1000	+6831 6009 51	-2985 8582 48	+1156 0805 46	-6481 0941 42	+1625 3541 54	-7624 2150 51
	1000 - 1300	+7879 7798 51	-1693 2846 48	+4684 2722 45	-1945 3137 42	+1089 1210 54	-1429 1012 52
	1300 - 1700	+8678 4190 51	-7904 5080 47	+1673 8397 45	-5273 3114 41	+4801 6047 53	-1962 5655 52
	1700 - 2100	+9108 8118 51	-4627 0080 47	+7630 8454 44	-1926 0389 41	+6748 8280 52	-2261 6387 52
	2100 - 2600	+9396 9763 51	-2546 8965 47	+3401 2225 44	-6947 7252 40	-2892 8132 53	-2470 5039 52
	2600 - 3200	+9587 4023 51	-1454 6465 47	+1576 5317 44	-2628 8817 40	-5779 4560 53	-2612 2675 52
	3200 - 3800	+9704 5646 51	-9199 5550 46	+8210 7660 43	-1147 7945 40	-7897 2630 53	-2701 4363 52
	3800 - 4400	+9781 4824 51	-5987 9330 46	+4538 2056 43	-5439 1950 39	-9569 4820 53	-2761 5713 52
	4400 - 5000	+9832 8204 51	-4061 2490 46	+2673 6624 43	-2799 4552 39	-1087 2569 54	-2802 5647 52
	5000 - 6000	+9883 3737 51	-2174 6468 46	+1235 8455 43	-1082 8883 39	-1244 9725 54	-2844 2347 52
Cl	150 - 300	+2499 7173 51	-5624 1480 47	+4632 7803 45	-4415 2433 42	+1633 2049 55	+5612 5486 51
	300 - 500	+2506 4788 51	-5929 6416 47	+5200 7614 45	-6223 5033 42	+1632 9938 55	+5573 8263 51
	500 - 700	+2656 4730 51	-2859 9690 47	+1686 3535 45	-1622 5100 42	+1629 1113 55	+4735 7792 51
	700 - 1000	+2743 3927 51	+6972 4500 45	+3294 7080 43	-1118 0739 41	+1625 6851 55	+4193 6441 51
	1000 - 1300	+2741 6558 51	+9775 6604 46	-2503 7621 44	+8244 8597 40	+1625 9067 55	+4191 7610 51
	1300 - 1700	+2710 4271 51	+9894 5320 46	-2052 2334 44	+6124 6450 40	+1628 0747 55	+4391 5167 51
	1700 - 2100	+2662 2371 31	+7245 6250 46	-1178 8354 44	+2884 4541 40	+1632 5570 55	+4721 8621 51
	2100 - 2600	+2620 4236 51	+4588 0250 46	-6064 0807 43	+1213 7404 40	+1637 6549 55	+5022 9170 51
	2600 - 3200	+2587 6175 51	+2858 2904 46	-3068 8116 43	+5033 4423 39	+1642 5883 55	+5266 1807 51
	3200 - 3800	+2565 1467 51	+1900 4820 46	-1679 7858 43	+2313 8500 39	+1646 6403 55	+5436 7772 51
	3800 - 4400	+2549 4787 51	+1280 0393 46	-9597 3450 42	+1133 1857 39	+1650 0529 55	+5559 0897 51
	4400 - 5000	+2539 0046 51	+9115 8820 45	-5941 3944 42	+6153 6189 38	+1652 6975 55	+5642 4806 51
	5000 - 6000	+2528 1946 51	+5179 8450 45	-2909 6748 42	+253 4032 38	+1656 0533 55	+5731 4370 51
Cl_2	150 - 300	+3448 0294 51	-1658 5658 48	+2692 6483 46	-478 5249 43	+3934 6532 54	+6890 4000 51
	300 - 500	+3835 3499 51	-1188 8256 48	+1031 7245 46	-119 1520 43	+3873 9265 54	+4963 9378 51
	500 - 700	+4091 1205 51	-7711 9500 47	+4259 4980 45	-351 7128 42	+3815 0122 54	+3572 8781 51
	700 - 1000	+4269 0209 51	-3765 4088 47	+1485 0640 45	-873 1259 41	+3752 5719 54	+2509 1450 51
	1000 - 1300	+4388 1534 51	-1876 4198 47	+5195 4893 44	-215 2894 41	+3696 4574 54	+1760 9050 51
	1300 - 1700	+4478 1904 51	-7895 4060 46	+1610 3315 44	-453 1719 40	+3628 3890 54	+1152 1280 51
	1700 - 2100	+4529 1124 51	-4114 9154 46	+5753 0589 43	-790 8876 39	+3578 5248 54	+7973 3350 50
	2100 - 2600	+4610 0199 51	+3446 6630 46	-7130 3870 43	+275 3050 40	+3467 1576 54	+1942 1652 50
	2600 - 3200	+4760 6830 51	+1734 0760 47	-2492 1302 44	+668 4165 40	+3199 1333 54	-9806 5385 50
	3200 - 3800	+4874 2401 51	+2677 9490 47	-3503 0664 44	+857 2934 40	+2961 0183 54	-1888 1367 51
	3800 - 4400	+4707 9090 51	+1249 2260 47	-2466 4155 44	+714 8116 40	+3476 8067 54	-4600 9460 50
	4400 - 5000	+3900 2910 51	-4688 6050 47	+1508 8757 44	+212 2074 40	+6193 9315 54	+6505 1700 51
	5000 - 6000	+1847 5100 51	-1749 7481 48	+9091 4226 44	-627 1116 40	+1399 8920 55	+2441 5074 52
ClF	150 - 300	+3451 8575 51	-6195 0380 47	+8977 4934 45	-7666 4753 42	+1049 7334 55	+6384 2088 51
	300 - 500	+3579 0533 51	-1315 6216 48	+1125 5565 46	-1238 9078 43	+1047 9573 55	+5807 3032 51
	500 - 700	+3875 6488 51	-9742 9350 47	+5316 9799 45	-4249 9844 42	+1040 8878 55	+4196 6080 51
	700 - 1000	+4115 2891 51	-5105 3400 47	+1999 4981 45	-1155 8321 42	+1032 1081 55	+2761 0926 51
	1000 - 1300	+4288 6764 51	-2591 5310 47	+7178 9728 44	-2989 9947 41	+1023 4995 55	+1667 1854 51
	1300 - 1700	+4412 8578 51	-1117 8049 47	+2318 1580 44	-6881 6527 40	+1014 0647 55	+8273 7321 50
	1700 - 2100	+4477 2114 51	-6520 2695 46	+1001 7884 44	-2059 8553 40	+1007 8838 55	+3807 5405 50
	2100 - 2600	+4547 1461 51	-7415 5100 45	-5651 6910 42	+9141 7438 39	+9986 6554 54	-1340 3011 50
	2600 - 3200	+4645 6835 51	+7474 1360 46	-1161 9276 44	+3369 7793 40	+9817 5674 54	-8938 7220 50
	3200 - 3800	+4702 7409 51	+1144 8060 47	-1631 2277 44	+4294 1388 40	+9707 0473 54	-1340 0407 51
	3800 - 4400	+4616 7451 51	+2967 7500 46	-1034 9624 44	+3467 4400 40	+9985 3475 54	-5886 7590 50
	4400 - 5000	+4293 3670 51	-2350 0980 47	+6853 7890 43	+1305 7477 40	+1111 2799 55	+2237 9870 51
	5000 - 6000	+3523 3574 51	-7547 9324 47	+3686 1299 44	-2000 6130 40	+1412 3199 55	+9021 9350 51

[a]All substances in gaseous phase except graphite.

TABLE I. - Continued. COEFFICIENTS FOR OBTAINING THERMODYNAMIC DATA FOR SEVERAL SUBSTANCES

[Coefficients for use in equations (105) to (107).]

Substance (a)	Temperature interval, °K	Coefficients					
		A	B	C	D	E	F
ClF_3	150 - 300	+5127 0429 51	-1749 4520 49	+1761 6464 47	-2976 1208 44	+2856 0159 55	+4659 5420 51
	300 - 500	+6457 5624 51	-5893 7083 48	+5115 6181 46	-5909 3643 43	+2828 1043 55	-2930 9810 51
	500 - 700	+7730 3861 51	-3819 8758 48	+2115 3958 46	-1756 7111 43	+2798 6643 55	-9857 9920 51
	700 - 1000	+8622 9749 51	-1802 3217 48	+7167 0960 45	-4305 6373 42	+2767 0675 55	-1520 7148 52
	1000 - 1300	+9203 6441 51	-8107 5540 47	+2291 6450 45	-1002 4218 42	+2739 3569 55	-1887 3181 52
	1300 - 1700	+9616 4642 51	-2539 0922 47	+5440 6701 44	-1755 2752 41	+2707 5754 55	-2168 5910 52
	1700 - 2100	+9764 0535 51	-1278 0686 47	+2126 0319 44	-5422 3408 40	+2693 2176 55	-2271 7800 52
	2100 - 2600	+9847 6403 51	-6517 8960 46	+8787 1110 43	-1805 4192 40	+2682 7742 55	-2332 5352 52
	2600 - 3200	+9897 9694 51	-3586 5496 46	+3936 3035 43	-6597 0677 39	+2675 1109 55	-2370 0484 52
	3200 - 3800	+9927 8564 51	-2207 8365 46	+2001 7247 43	-2809 9884 39	+2669 6912 55	-2392 8132 52
	3800 - 4400	+9946 9377 51	-1412 0292 46	+1092 2948 43	-1315 6062 39	+2665 5387 55	-2407 7328 52
	4400 - 5000	+9959 2224 51	-9559 0740 45	+6462 9910 42	-6817 9250 38	+2662 4430 55	-2417 5282 52
	5000 - 6000	+9971 6836 51	-4900 9530 45	+2907 6060 42	-2567 3024 38	+2658 5622 55	-2427 7976 52
F	300 - 500	+2774 1677 51	+1569 7918 47	-1219 8418 45	+8817 6073 41	+2448 1175 55	+3274 3817 51
	500 - 700	+2741 1306 51	+2447 1894 47	-1290 5400 45	+9364 9496 41	+2448 8816 55	+3442 3810 51
	700 - 1000	+2668 2300 51	+1435 7079 47	-5466 0762 44	+2926 9741 41	+2451 8215 55	+3882 1075 51
	1000 - 1300	+2606 1647 51	+7594 5950 46	-2066 6151 44	+8244 1470 40	+2455 3341 55	+4278 5777 51
	1300 - 1700	+2568 8565 51	+3901 3852 46	-8171 2274 43	+2516 1409 40	+2458 2444 55	+4530 4593 51
	1700 - 2100	+2543 7180 51	+1989 4083 46	-3203 1108 43	+7669 7618 39	+2460 7969 55	+4706 8085 51
	2100 - 2600	+2530 2137 51	+1158 2342 46	-1516 1332 43	+2979 4828 39	+2462 5383 55	+4804 8492 51
	2600 - 3200	+2520 8123 51	+6763 1070 45	-7187 4217 42	+1160 3995 39	+2464 0181 55	+4875 0108 51
	3200 - 3800	+2514 3282 51	+3904 6228 45	-3373 8858 42	+4456 9788 38	+2465 2647 55	+4924 7717 51
	3800 - 4400	+2510 0138 51	+2262 4946 45	-1637 1748 42	+1810 1580 38	+2466 2929 55	+4958 8764 51
	4400 - 5000	+2507 8249 51	+1625 4622 45	-1023 3196 42	+1001 0333 38	+2466 8878 55	+4976 3975 51
F_2	150 - 300	+3474 8807 51	-2479 3670 47	+2808 0384 45	+4516 8609 42	+3067 9524 55	+4488 2780 51
	300 - 500	+3499 3010 51	-1230 4361 48	+1038 9229 46	-1091 0390 43	+3067 9438 55	+4441 2399 51
	500 - 700	+3781 3514 51	-1031 1322 48	+5565 7851 45	-4317 1200 42	+3061 1457 55	+2916 9669 51
	700 - 1000	+4041 7357 51	-5868 2000 47	+2277 7137 45	-1285 7726 42	+3051 4311 55	+1359 1435 51
	1000 - 1300	+4247 3596 51	-3180 6992 47	+8736 8100 44	-3561 1383 41	+3040 9909 55	+6212 3900 49
	1300 - 1700	+4395 0680 51	-1548 4066 47	+3194 9833 44	-9363 6692 40	+3029 8390 55	-9330 9680 50
	1700 - 2100	+4473 0713 51	-1083 0146 47	+1705 8185 44	-3801 9221 40	+3022 6281 55	-1468 3319 51
	2100 - 2600	+4530 1221 51	-8004 6210 46	+1001 6324 44	-1705 3955 40	+3015 9621 55	-1873 5356 51
	2600 - 3200	+4577 2369 51	-6669 1418 46	+6657 4614 43	-8791 4462 39	+3009 4373 55	-2213 6134 51
	3200 - 3800	+4617 9447 51	-6168 3545 46	+4992 [illegible]151 43	-5319 2178 39	+3002 9324 55	-2510 8582 51
	3800 - 4400	+4654 6023 51	-5845 5975 46	+3970 3472 43	-3521 4000 39	+2995 9930 55	-2784 3785 51
	4400 - 5000	+4686 8046 51	-5734 8144 46	+3364 9472 43	-2580 7455 39	+2989 1276 55	-3027 5170 51
	5000 - 6000	+4726 7301 51	-5239 8070 46	+2658 8548 43	-1685 9673 39	+2978 4168 55	-3341 3410 51
H	150 - 300	+2500 3116 51	+4852 8250 45	-6211 4920 43	+1415 8863 41	+4294 5264 55	-4609 6828 50
	300 - 500	+2499 6710 51	-2385 2015 45	+2047 2396 43	-2955 4273 40	+4294 5386 55	-4573 1922 50
	500 - 700	+2499 0717 51	-3432 3430 45	+1896 0083 43	-1754 6524 40	+4294 5692 55	-4533 8129 50
	700 - 1000	+2499 5465 51	-1261 8040 45	+4772 2317 42	-3092 1566 39	+4294 5582 55	-4561 8786 50
	1000 - 1300	+2498 9933 51	-2095 0920 45	+6015 1654 42	-2948 5802 39	+4294 6101 55	-4522 0179 50
	1300 - 1700	+2499 9803 51	-1102 0773 44	+6488 9065 40	+4834 1707 36	+4294 5389 55	-4589 9392 50
	1700 - 2100	+2499 2764 51	-1021 2900 45	+1742 6965 42	-5235 9488 38	+4294 6258 55	-4537 6904 50
	2100 - 2600	+2499 9862 51	-4814 9770 43	+2852 3330 39	+7596 2533 36	+4294 5410 55	-4590 4575 50
	2600 - 3200	+2500 3308 51	+1682 7689 44	-2310 5728 41	+4594 2012 37	+4294 4715 55	-4617 5197 50
	3200 - 3800	+2500 2231 51	+6871 4240 43	-8940 1590 40	+1468 3878 37	+4294 4842 55	-4609 4814 50
	3800 - 4400	+2499 6156 51	-2770 3100 44	+2094 2038 41	-2893 9034 37	+4294 6455 55	-4559 8696 50
	4400 - 5000	+2498 9665 51	-5593 0080 44	+3785 6331 41	-4517 9884 37	+4294 8763 55	-4504 7409 50
H_2	150 - 300	+2989 2484 51	-4103 4770 48	+4407 7218 46	-8356 1287 43	+3401 1138 55	-1324 4021 51
	300 - 500	+3383 2407 51	-4324 5294 47	+3912 7728 45	-5061 2747 42	+3393 0261 55	-3572 0562 51
	500 - 700	+3459 0074 51	-1656 0656 47	+9153 4690 44	-7399 4236 41	+3391 6394 55	-3981 7170 51
	700 - 1000	+3480 7949 51	-8057 9160 46	+2316 5682 44	-2880 5124 38	+3391 4081 55	-4101 0320 51
	1000 - 1300	+3471 9964 51	-1811 4833 47	+4046 6752 44	-6393 1054 40	+3393 1405 55	-4004 9763 51
	1300 - 1700	+3478 9902 51	-3159 4629 47	+6167 8657 44	-15[illegible]5 2076 41	+3394 2702 55	-3995 7133 51
	1700 - 2100	+3584 4555 51	-3452 5690 47	+5352 7626 44	-11[illegible]8 9801 41	+3386 2783 55	-4672 5704 51
	2100 - 2600	+3759 4391 51	-2880 8338 47	+3648 3990 44	-6459 7043 40	+3365 5684 55	-5907 5858 51
	2600 - 3200	+3950 4861 51	-2214 0298 47	+2252 3788 44	-3163 7688 40	+3337 4923 55	-7304 4520 51
	3200 - 3800	+4015 1762 51	-2473 1652 47	+2122 [illegible]369 44	-2701 7443 40	+3332 1516 55	-7727 5210 51
	3800 - 4400	+4253 9189 51	-1542 7069 47	+1065 7981 44	-1000 8309 40	+3278 8324 55	-9597 2790 51
	4400 - 5000	+4316 8247 51	-1611 9098 47	+9809 8240 43	-8461 6973 39	+3267 4437 55	-1005 6383 52
	5000 - 6000	+4613 8660 51	-6368 8580 46	+2766 2305 43	-6509 3656 38	+3168 4849 55	-1251 8853 52
HCl	300 - 500	+3507 7834 51	+3434 8560 46	-3783 9075 44	+7488 3407 41	+7840 0952 54	+2478 6303 51
	500 - 700	+3496 6325 51	-8772 1500 45	-1483 8166 44	+5505 0572 41	+7844 5758 54	+2549 0010 51
	700 - 1000	+3455 5431 51	-2524 1094 47	+8256 9265 44	-2240 1276 41	+7868 1516 54	+2838 6335 51
	1000 - 1300	+3497 7739 51	-4336 2524 47	+1120 6186 45	-3799 5512 41	+7857 2051 54	+2632 6456 51
	1300 - 1700	+3637 7472 51	-4092 2196 47	+8387 1455 44	-2412 5676 41	+7762 0326 54	+1733 9321 51
	1700 - 2100	+3828 5869 51	-3262 2034 47	+5240 1857 44	-1237 0559 41	+7587 5851 54	+4355 1680 50
	2100 - 2600	+4008 0692 51	-2269 0376 47	+2958 7010 44	-5696 4676 40	+7371 4782 54	-8489 9400 50
	2600 - 3200	+4163 1444 51	-1552 5681 47	+1637 9704 44	-2558 9129 40	+7141 4411 54	-1992 0853 51
	3200 - 3800	+4279 2700 51	-1136 3225 47	+9795 8780 43	-1262 3444 40	+6935 9632 54	-2867 0492 51
	3800 - 4400	+4365 4707 51	-8607 3540 46	+6238 6255 43	-6741 6929 39	+6753 4656 54	-3533 0504 51
	4400 - 5000	+4428 6165 51	-6932 3370 46	+4323 4380 43	-3995 4750 39	+6599 9666 54	-4029 0913 51
	5000 - 6000	+4496 5332 51	-4983 7368 46	+2652 7672 43	-1976 9074 39	+6397 5200 54	-4580 2542 51
HF	150 - 300	+3502 9862 51	-5341 4090 45	+3907 3861 43	-1722 7617 40	-1026 8292 52	+9285 0538 50
	300 - 500	+3503 7414 51	-7163 1600 44	-5447 6980 42	+5181 9187 40	-1044 2091 52	+9241 9270 50
	500 - 700	+3510 6273 51	+3178 3340 46	-2370 2806 44	+3298 9392 41	-1264 3243 52	+8825 1182 50
	700 - 1000	+3497 5136 51	-1383 0680 46	-5305 0300 43	+1983 9089 41	-5429 5120 51	+9703 1135 50
	1000 - 1300	+3459 5106 51	-2005 0034 47	+4630 1579 44	-9300 2525 40	+2673 4630 52	+1258 5941 51
	1300 - 1700	+3477 7106 51	-3196 6027 47	+6293 8357 44	-1587 5290 41	+2887 5590 52	+1190 5757 51
	1700 - 2100	+3595 2253 51	-3334 3110 47	+5229 6762 44	-1153 0942 41	-6743 7760 52	+4224 9140 50
	2100 - 2600	+3754 7551 51	-2772 2634 47	+3563 5125 44	-6593 9114 40	-2520 7695 53	-7009 1120 50
	2600 - 3200	+3932 3426 51	-2104 1015 47	+2197 0853 44	-3337 2252 40	-5111 5610 53	-1999 9964 51
	3200 - 3800	+4086 7884 51	-1614 8342 47	+1377 0946 44	-1723 8858 40	-7831 6590 53	-3159 4638 51
	3800 - 4400	+4209 3672 51	-1252 4527 47	+8941 3920 43	-9272 9771 39	-1042 4966 54	-4104 5633 51
	4400 - 5000	+4301 3524 51	-1027 8717 47	+6265 6581 43	-5431 6307 39	-1264 8039 54	-4825 1389 51
	5000 - 6000	+4402 9214 51	-7489 6732 46	+3816 7579 43	-2461 9992 39	-1564 9097 54	-5647 2957 51
H_2O	150 - 300	+4012 7997 51	+4448 8300 46	-1184 6208 45	+4440 3590 42	+5696 5839 54	-1658 1832 50
	300 - 500	+3984 3281 51	-1560 3100 47	+8521 9880 44	+9334 5693 41	+5702 9188 54	-3361 4200 48
	500 - 700	+3995 7858 51	-5866 2548 47	+2772 9813 45	-1277 3920 42	+5705 5261 54	-7248 4000 48
	700 - 1000	+4103 2581 51	-7272 2748 47	+2513 6379 45	-93[illegible]2 8919 41	+5673 7398 54	-5886 8940 50
	1000 - 1300	+4273 7895 51	-9457 9644 47	+2418 4150 45	-7900 2882 41	+5608 4188 54	-1548 2509 51
	1300 - 1700	+4561 3587 51	-9361 2130 47	+1893 3359 45	-5227 3842 41	+5420 0843 54	-3374 7881 51
	1700 - 2100	+4985 3551 51	-8042 8280 47	+1277 9848 45	-2926 8695 41	+5036 1704 54	-6240 3270 51
	2100 - 2600	+5419 7867 51	-5975 1330 47	+7745 7137 44	-1467 6260 41	+4512 4857 54	-9338 2540 51
	2600 - 3200	+5838 4391 51	-4173 6144 47	+4396 9203 44	-6843 2077 40	+3882 1430 54	-1242 5644 52
	3200 - 3800	+6196 8101 51	-2837 1462 47	+2441 1367 44	-3130 1900 40	+3213 9760 54	-1514 9891 52
	3800 - 4400	+6449 0690 51	-2024 8380 47	+1471 0187 44	-1599 5108 40	+2645 3976 54	-1711 7423 52
	4400 - 5000	+6624 7105 51	-1547 9092 47	+9747 8790 43	-9242 5186 39	+2187 2059 54	-1851 2177 52

[a]All substances in gaseous phase except graphite.

TABLE I. - Concluded. COEFFICIENTS FOR OBTAINING THERMODYNAMIC DATA FOR SEVERAL SUBSTANCES

[Coefficients for use in equations (105) to (107).]

Substance (a)	Temperature interval, °K	Coefficients A	B	C	D	E	F
N	300 - 500	+2499 6710 51	-2385 2015 45	+2047 2396 43	-2955 4273 40	+5707 9313 55	+4183 1808 51
	500 - 700	+2499 1148 51	-3267 4440 45	+1798 0743 43	-1659 2209 40	+5707 9603 55	+4186 8511 51
	700 - 1000	+2499 6036 51	-1131 0429 45	+4232 2090 42	-2736 5544 39	+5707 9478 55	+4183 9375 51
	1000 - 1300	+2499 0940 51	-1901 1726 45	+5442 2129 42	-2666 8173 39	+5707 9952 55	+4187 5999 51
	1300 - 1700	+2500 2204 51	+3456 2550 44	-9655 6710 41	+4200 6645 38	+5707 9078 55	+4179 7565 51
	1700 - 2100	+2501 6390 51	+2522 5800 45	-4789 7317 42	+1627 5565 39	+5707 7262 55	+4169 0522 51
	2100 - 2600	+2508 6192 51	+1107 6049 46	-1756 3079 43	+5016 8252 39	+5706 6696 55	+4115 3955 51
	2600 - 3200	+2517 3414 51	+2174 0230 46	-3034 2712 43	+7858 2646 39	+5705 0383 55	+4045 6309 51
	3200 - 3800	+2512 6964 51	+1967 0040 46	-2871 8071 43	+7694 4866 39	+5706 2395 55	+4083 2154 51
	3800 - 4400	+2482 1655 51	-6399 2200 45	-8908 3900 42	+4843 1658 39	+5715 2935 55	+4343 0639 51
	4400 - 5000	+2434 6193 51	-5054 2730 46	+1913 3373 43	+1308 3373 39	+5732 4433 55	+4765 1025 51
	5000 - 6000	+2351 2887 51	-1171 7309 47	+5608 4591 43	-2764 8502 39	+5766 8718 55	+5513 9770 51
N_2	150 - 300	+3501 6234 51	+1419 9930 46	-2221 4814 44	+6337 0257 41	+8539 5697 53	+3078 0353 51
	300 - 500	+3507 3207 51	+6478 8790 46	-7700 5600 44	+1686 9531 42	+8527 6963 53	+3045 5391 51
	500 - 700	+3468 1570 51	-1742 8035 47	+6732 6921 44	+6988 8312 40	+8673 6314 53	+3295 4226 51
	700 - 1000	+3462 1286 51	-4539 6402 47	+1622 1534 45	-6973 0151 41	+8776 6703 53	+3385 9335 51
	1000 - 1300	+3600 4480 51	-4968 5174 47	+1321 7619 45	-4923 4174 41	+8096 8196 53	+2555 2204 51
	1300 - 1700	+3793 9348 51	-3715 9604 47	+7731 5595 44	-2325 2167 41	+6685 5239 53	+1278 3599 51
	1700 - 2100	+3979 4426 51	-2618 0633 47	+4257 4284 44	-1039 0909 41	+4949 4356 53	+3226 6000 48
	2100 - 2600	+4131 6527 51	-1645 9670 47	+2167 0242 44	-4284 4626 40	+3093 6592 53	-1092 8453 51
	2600 - 3200	+4249 0997 51	-1039 9359 47	+1106 6286 44	-1770 7380 40	+1332 3679 53	-1962 7879 51
	3200 - 3800	+4327 0196 51	-7332 7190 46	+6383 0855 43	-8445 0756 39	-4394 6700 51	-2551 1939 51
	3800 - 4400	+4383 7162 51	-5322 6420 46	+3896 3172 43	-4326 2187 39	-1248 3259 53	-2990 7052 51
	4400 - 5000	+4426 8870 51	-3934 9468 46	+2455 1316 43	-2274 3750 39	-2321 5622 53	-3332 6930 51
	5000 - 6000	+4822 3937 51	+1235 5686 47	-7763 4410 43	+8482 4648 39	-1669 0365 54	-6686 7119 51
NH	150 - 300	+3501 4877 51	-1135 4880 46	+3492 4950 43	+1605 9661 41	+5707 5674 55	+1837 3594 51
	300 - 500	+3506 9044 51	+1658 8050 46	-1893 7787 44	+3971 7660 41	+5707 4332 55	+1806 0451 51
	500 - 700	+3507 6770 51	+2796 6700 46	-3019 6472 44	+5706 5528 41	+5707 4505 55	+1802 3997 51
	700 - 1000	+3467 4923 51	-1587 8517 47	+4682 2623 44	-3133 4757 40	+5709 6465 55	+2076 5108 51
	1000 - 1300	+3476 0496 51	-3595 9897 47	+8992 4746 44	-2700 9943 41	+5710 4331 55	+2082 2903 51
	1300 - 1700	+3578 3151 51	-3917 3724 47	+7834 3879 44	-2085 4695 41	+5703 9404 55	+1443 5951 51
	1700 - 2100	+3753 2238 51	-3437 2875 47	+5329 0472 44	-1133 8710 41	+5688 4282 55	+2671 2430 50
	2100 - 2600	+3924 7696 51	-2774 1647 47	+3440 1817 44	-5700 1390 40	+5668 6761 55	-9419 7230 50
	2600 - 3200	+4082 2543 51	-2416 9060 47	+2402 2699 44	-3132 6809 40	+5647 1309 55	-2072 8080 51
	3200 - 3800	+4226 3537 51	-2291 3941 47	+1856 8495 44	-1990 5685 40	+5624 2276 55	-3121 4787 51
	3800 - 4400	-9768 5140 52	-6242 7160 49	+5044 9155 46	-7082 5339 42	+3413 8680 56	+8395 4054 53
	4400 - 5000	-1813 5084 53	-8906 1750 49	+6213 1583 46	-7379 7014 42	+6634 6534 56	+1553 9865 54
	5000 - 6000	-2323 8668 52	-1115 6880 49	+6734 9310 45	-6814 6304 41	+1606 8773 56	+2311 5519 53
NH_3	150 - 300	+4016 0739 51	-5921 7280 47	+2172 9700 45	+8870 2067 42	+4660 2050 55	+2676 3530 50
	300 - 500	+3929 2082 51	-1358 1227 48	+1045 1508 46	-6997 1157 42	+4662 0202 55	+7631 5510 50
	500 - 700	+4204 7432 51	-2082 9945 48	+1039 4443 46	-6167 7796 42	+4656 2775 55	-6133 4010 50
	700 - 1000	+4643 7799 51	-2103 0382 48	+7635 1643 45	-3485 0380 42	+4641 3606 55	-3108 4650 51
	1000 - 1300	+5267 2607 51	-2084 8879 48	+5491 9755 45	-1983 4803 42	+4612 0057 55	-6862 3930 51
	1300 - 1700	+6020 3398 51	-1698 3392 48	+3497 6990 45	-1020 9245 42	+4558 7608 55	-1178 4321 52
	1700 - 2100	+6822 7393 51	-1316 2876 48	+2126 3664 45	-5097 7779 41	+4484 9963 55	-1725 7876 52
	2100 - 2600	+7558 4148 51	-8904 3840 47	+1171 7555 45	-2312 0365 41	+4395 8496 55	-2253 4893 52
	2600 - 3200	+8185 0643 51	-5794 8770 47	+6206 9477 44	-1009 0955 41	+4301 8144 55	-2717 1642 52
	3200 - 3800	+8640 1560 51	-3931 9340 47	+3470 3306 44	-4747 1369 40	+4219 6290 55	-3062 3326 52
	3800 - 4400	+8962 9398 51	-2692 3282 47	+2017 9453 44	-2371 7716 40	+4149 2986 55	-3314 0852 52
	4400 - 5000	+9187 2759 51	-1912 4119 47	+1245 5081 44	-1282 4365 40	+4092 3525 55	-3492 7645 52
	5000 - 6000	+9414 7085 51	-1099 4602 47	+6180 2898 43	-5346 0492 39	+4021 6182 55	-3679 8456 52
NO	300 - 500	+3629 9914 51	+2657 5880 47	-2717 2093 45	+4701 8630 42	+1177 3583 55	+4650 8256 51
	500 - 700	+3526 2159 51	-3327 2407 47	+1496 6665 45	-5017 5332 41	+1180 6009 55	+5285 0742 51
	700 - 1000	+3571 2043 51	-5722 3794 47	+2111 9083 45	-1023 0275 42	+1179 4145 55	+5066 8759 51
	1000 - 1300	+3769 9172 51	-4896 8460 47	+1322 3357 45	-5147 2119 41	+1169 0270 55	+3837 0127 51
	1300 - 1700	+3976 2131 51	-3140 6382 47	+6572 2561 44	-2009 1463 41	+1153 6702 55	+2461 7464 51
	1700 - 2100	+4137 1746 51	-2076 7231 47	+3380 3593 44	-8273 2029 40	+1138 5290 55	+1351 2723 51
	2100 - 2600	+4259 7731 51	-1265 1294 47	+1656 3960 44	-3228 0166 40	+1123 5766 55	+4673 8600 50
	2600 - 3200	+4349 0587 51	-8120 9610 46	+8518 4400 43	-1311 7501 40	+1110 2937 55	-1928 0800 50
	3200 - 3800	+4413 5660 51	-5677 9250 46	+4786 5005 43	-5809 5741 39	+1098 7485 55	-6803 6460 50
	3800 - 4400	+4459 4771 51	-4305 6534 46	+2995 3452 43	-2883 0271 39	+1088 9003 55	-1035 1524 51
	4400 - 5000	+4489 7869 51	-3762 9949 46	+2235 0024 43	-1791 0895 39	+1081 6691 55	-1270 7127 51
	5000 - 5500	+4509 2548 51	-3739 5470 46	+1972 1171 43	-1430 4410 39	+1076 9605 55	-1419 8637 51
	5500 - 6000	+4525 5565 51	-3723 0352 46	+1802 9307 43	-1226 2702 39	+1072 4569 55	-1546 9048 51
O	150 - 300	+2832 8173 51	+1431 7687 48	-1468 4834 46	+2566 9894 43	+3017 4976 55	+3217 0845 51
	300 - 500	+2714 6413 51	+3870 4329 47	-3379 2646 45	+3969 6103 42	+3019 9635 55	+3891 1039 51
	500 - 700	+2629 9259 51	+2286 8597 47	-1271 4552 45	+1065 1442 42	+3021 9345 55	+4354 2996 51
	700 - 1000	+2576 2890 51	+1028 8519 47	-4106 0040 44	+2484 6390 41	+3023 8309 55	+4676 2053 51
	1000 - 1300	+2547 0979 51	+5221 5330 46	-1496 6858 44	+6739 3053 40	+3025 1125 55	+4858 4101 51
	1300 - 1700	+2519 3465 51	+1151 2610 46	-2514 3283 43	+8031 2904 39	+3027 2774 55	+5048 5417 51
	1700 - 2100	+2514 1793 51	+9680 0900 45	-1678 4195 43	+4800 0132 39	+3027 7264 55	+5083 3051 51
	2100 - 2600	+2508 6997 51	+6151 5400 45	-9959 5160 42	+2941 9744 39	+3028 4518 55	+5123 3201 51
	2600 - 3200	+2506 8516 51	+6191 4220 45	-1014 7413 43	+3113 4905 39	+3028 8330 55	+5137 3787 51
	3200 - 3800	+2496 0645 51	-4318 7660 45	-1785 1200 41	+1353 7926 39	+3031 3904 55	+5226 2595 51
	3800 - 4400	+2484 1660 51	-1828 7300 46	+9952 7176 42	-1281 2973 38	+3035 1914 55	+5331 3688 51
	4400 - 5000	+2461 6602 51	-3966 3519 46	+2327 9192 43	-1788 5282 39	+3043 5044 55	+5532 3795 51
O_2	150 - 300	+3507 8622 51	+7336 8300 46	-1566 0917 45	+5367 9823 42	+1022 7365 54	+4678 3884 51
	300 - 500	+3468 1122 51	-2094 4310 47	+1311 3020 45	+4112 4133 41	+1031 5694 54	+4905 2651 51
	500 - 700	+3491 8904 51	-6759 0190 47	+3398 6627 45	-2087 8706 42	+1030 0629 54	+4833 9311 51
	700 - 1000	+3655 2327 51	-6543 3148 47	+2462 0346 45	-1270 0679 42	+9684 3794 53	+3884 7354 51
	1000 - 1300	+3904 0901 51	-4442 4078 47	+1199 2093 45	-4661 9082 41	+8345 0760 53	+2319 0523 51
	1300 - 1700	+4104 9900 51	-2517 0318 47	+5093 9020 44	-1409 3115 41	+6835 7755 53	+9729 7660 50
	1700 - 2100	+4222 7020 51	-1953 0831 47	+2975 1070 44	-5976 9259 40	+5794 9642 53	+1747 6760 50
	2100 - 2600	+4302 7917 51	-1791 1603 47	+2194 9064 44	-3493 6626 40	+4957 1490 53	-3765 2230 50
	2600 - 3200	+4378 2138 51	-1859 5901 47	+1888 4516 44	-2642 8824 40	+4050 9189 53	-8980 5550 50
	3200 - 3800	+4481 6232 51	-1804 0341 47	+1533 7064 44	-1904 1376 40	+2395 5642 53	-1649 5016 51
	3800 - 4400	+4595 4599 51	-1604 0929 47	+1175 2869 44	-1306 8504 40	+6835 3000 51	-2514 2771 51
	4400 - 5000	+4700 9554 51	-1392 3351 47	+9033 6640 43	-9220 7268 39	-2507 6420 53	-3338 5270 51
OH	150 - 300	+3764 1804 51	+1330 9369 48	-1397 7859 46	+2549 9846 43	+2208 6061 55	+6394 1790 50
	300 - 500	+3650 7552 51	+2767 0068 47	-2437 5563 45	+2946 8393 42	+2210 9337 55	+1286 3048 51
	500 - 700	+3583 7943 51	+1516 8258 47	-9296 3300 44	+9667 5264 41	+2212 6553 55	+1658 9638 51
	700 - 1000	+3516 1720 51	-4302 4030 46	+4112 6890 43	+1744 5983 41	+2215 8159 55	+2091 0067 51
	1000 - 1300	+3471 4812 51	-2792 0696 47	+6819 0371 44	-1854 4121 41	+2219 7325 55	+2435 4839 51
	1300 - 1700	+3526 0017 51	-3607 9397 47	+7223 5714 44	-1930 9877 41	+2217 1231 55	+2122 0534 51
	1700 - 2100	+3690 5516 51	-3191 5272 47	+5009 9631 44	-1107 8802 41	+2202 1973 55	+1012 3464 51
	2100 - 2600	+3838 8762 51	-2495 8340 47	+3335 8184 44	-6301 3695 40	+2184 1527 55	-4676 3000 49
	2600 - 3200	+4037 2441 51	-1797 8853 47	+1877 3664 44	-2853 0364 40	+2155 0371 55	-1497 1187 51
	3200 - 3800	+4187 6806 51	-1285 8703 47	+1095 7568 44	-1369 6166 40	+2127 1678 55	-2636 9671 51
	3800 - 4400	+4298 3386 51	-9543 3180 46	+6837 4562 43	-7166 3961 39	+2102 5017 55	-3497 0396 51
	4400 - 5000	+4379 1568 51	-7525 5620 46	+4643 9276 43	-4172 0827 39	+2081 6369 55	-4136 5232 51

[a]All substances in gaseous phase except graphite.

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TABLE II. - INPUT TO VECTOR

AND PROPELLANT DECK*

Product code		
Card column		
44-47	48-50	51-60
	B$\overline{O}$P	
0037	ATM	H
0054	ATM	N
0061	ATM	$\overline{O}$
0450	M$\overline{O}$L	H2
0451	M$\overline{O}$L	H2$\overline{O}$1
0650	M$\overline{O}$L	N2
0651	M$\overline{O}$L	N1$\overline{O}$1
0750	M$\overline{O}$L	$\overline{O}$2
0751	M$\overline{O}$L	$\overline{O}$1H1
	F1	N2H4
	EF1	1547029756
	PF1	1000000053
	X1	H2$\overline{O}$2
	EX1	2868162655
	PX1	1000000053

*The symbol $\overline{O}$ is used to indicate the alphabetic letter; the symbol 0 is used for zero.

TABLE III. - OUTPUT OF VECTOR AND PROPELLANT DECK

Type of card	Product code	Packed vector	Product code		
	Card column				
	17-20	31-40	44-47	48-50	51-60
Packed vectors	0037 0054 0061 0450 0451 0650 0651 0750 0751	0000000001 0000000011 0000000021 0000000002 0000000221 0000000012 0000001121 0000000022 0000002101	0037 0054 0061 0450 0451 0650 0651 0750 0751	ATM ATM ATM M$\bar{O}$L M$\bar{O}$L M$\bar{O}$L M$\bar{O}$L M$\bar{O}$L M$\bar{O}$L	H N $\bar{O}$ H2 H2$\bar{O}$1 N2 N1$\bar{O}$1 $\bar{O}$2 $\bar{O}$1H1
Cards for listing only to check input				F1 EF1 PF1 X1 EX1 PX1	N2H4 1547029756 1000000053 H2$\bar{O}$2 2868162655 1000000053

Type of card	Drum location	Contents	Drum location	Contents	Drum location	Contents
	Card column					
	1-4	5-15	16-19	20-30	31-34	35-45
a_f (hydrogen) b_f (nitrogen)	0587	1248127850+	0588	6240639049+		
Fuel enthalpy, h_f Fuel valence, V_f^+	0597	4827226954+	0598	1248127850+		
a_x (hydrogen) c_x (oxygen)	0537	5879586049+	0539	5879586049+		
Oxidant enthalpy, h_x Oxidant valence, V_x^+ Oxidant valence, V_x^-	0547	8431804353+	0548	5879586049+	0549	1175917250-

TABLE IV. - INPUT TO MAIN OPERATING DECK

Card format (see appendix B)	Information on card	Where discussed in text	
Random	Case number	Appendix C	1148 000002 0800+
	O/F, %P, r	Eqs. (99) and (104)	0199 000000 0000+ 0299 000000 0000+ 0399 857142 8650+
	P_c, lb/sq in. abs	Appendix C	1109 600000 0053+
	P_c/F schedule	Appendix C	1075 100000 0051+ 1076 175438 5051+ 1077 204137 1052+ 1078 408274 2052+ 1079 460456 9952+
	a_r, h_r	Eq. (93)	0587 124812 7850+ 0588 624063 9049+
	h_r, V_r^{+}	Eqs. (97), (100), (103)	0597 482722 6954+ 0598 124812 7850+
	a_x, c_x	Eq. (93)	0537 587958 6049+ 0539 587958 6049+
	h_x, V_x^{+}, V_x^{-}	Eqs. (97), (100), (103)	0547 843180 4353+ 0548 587958 6049+ 0549 117591 7250-
Basic load hut	Transfer to vector loading routine	Packed vector loading routine	000000 1999+
SOAP II output	Packed vectors	Packed chemical vector	691954 1953+ 000000 0037+ 240000 8000+ 000000 0001+ 0+ 0 037ATM H 691954 1953+ 000000 0054+ 240000 8000+ 000000 0011+ 0+ 0 054ATM N 691954 1953+ 000000 0061+ 240000 8000+ 000000 0021+ 0+ 0 061ATM O 691954 1953+ 000000 0450+ 240000 8000+ 000000 0002+ 0+ 0 450MOL H2 691954 1953+ 000000 0451+ 240000 8000+ 000000 0221+ 0+ 0 451MOL H2O1 691954 1953+ 000000 0650+ 240000 8000+ 000000 0012+ 0+ 0 650MOL N2 691954 1953+ 000000 0651+ 240000 8000+ 000000 1121+ 0+ 0 651MOL N1O1 691954 1953+ 000000 0750+ 240000 8000+ 000000 0022+ 0+ 0 750MOL O2 691954 1953+ 000000 0751+ 240000 8000+ 000000 2101+ 0+ 0 751MOL O1H1
Basic load hut	Transfer out of vector loading	Packed vector loading routine	000000 0000+
Basic load hut	Thermodynamic coefficients	Sections on thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003744 0500+ 249896 6551+ 559300 8044- 3785 633141+ 451798 8437- 429487 6955+ 450474 0950- 659051 1193+ 005444 0500+ 243461 9551+ 505427 3046- 1913 337343+ 130833 7339+ 573244 3355+ 476510 2551+ 659051 1193+ 006144 0500+ 246166 0251+ 396635 1946- 2327 919243+ 178852 8239- 304350 4455+ 553237 5551+ 659051 1193+ 045044 0500+ 431409 5651+ 162596 2147- 9909 293043+ 858305 4339- 326831 8755+ 100334 8052- 659051 1193+ 045144 0500+ 662471 0551+ 154790 9247- 9747 879043+ 924251 8639- 218720 5954+ 185121 7752- 659051 1193+ 065044 0500+ 442627 5851+ 396671 7046- 2477 670243+ 230199 3239- 230202 7153- 332756 6551- 659051 1193+ 065144 0500+ 448978 6951+ 376299 4946- 2235 002443+ 179108 9539- 108166 9155+ 127071 2751- 659051 1193+ 075044 0500+ 470095 5451+ 139233 5147- 9033 664043+ 922072 6839- 250764 2053- 393852 7051- 659051 1193+ 075144 0500+ 497915 6851+ 752556 2046- 4649 927643+ 417208 2739- 208163 6955+ 413652 3251-
Bell	Temperature interval	Load thermal data routine	0012 00000 0 +440000 0054 +500000 0054
Basic load hut	Thermodynamic coefficients	Sections of thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003738 0440+ 249961 5651+ 277031 0044- 2094 203841+ 289390 3437- 429464 5555+ 455986 9650- 659051 1193+ 005438 0440+ 248216 5551+ 639922 0045- 8908 390042- 484316 5839+ 571529 3555+ 434306 3951+ 659051 1193+ 006138 0440+ 248416 6051+ 182873 0046- 9952 717642+ 128129 7338- 303519 1455+ 533136 8851+ 659051 1193+ 045038 0440+ 425388 4251+ 154292 8147- 1065 966844+ 100106 0140- 327884 2655+ 959698 6051- 659051 1193+ 045138 0440+ 644906 9051+ 202483 8047- 1471 018744+ 159951 0840- 264539 7654+ 171174 2352- 659051 1193+ 065038 0440+ 438382 0951+ 531661 8046- 3891 393243+ 451934 6339- 125122 1753- 299156 6451- 659051 1193+ 065138 0440+ 445947 7151+ 430505 3446- 2995 345243+ 288302 7139- 108890 0355+ 103515 2451- 659051 1193+ 075038 0440+ 459545 9951+ 160409 2967- 1175 286944+ 190685 0440- 683530 0051+ 251427 7151- 659051 1193+ 075138 0440+ 429833 8651+ 954331 8046- 6837 456243+ 716639 6119- 210250 1755+ 349703 9651-
Bell	Temperature interval	Load thermal data routine	0011 00000 0 +580000 0054 +440000 0054
Basic load hut	Thermodynamic coefficients	Sections of thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003732 0380+ 250022 3151+ 687142 4043+ 8940 159040- 146856 7837+ 429448 4255+ 460948 1450- 659051 1193+ 005432 0380+ 251269 6451+ 196700 4046+ 2871 807143- 769448 6639+ 570625 6555+ 408321 5451+ 659051 1193+ 006132 0380+ 249606 4551+ 431876 6045- 1785 120041- 135379 2639+ 303139 0455+ 522625 3551+ 659051 1193+ 045032 0380+ 401515 6451+ 247533 6247- 2172 483444+ 270197 6840- 333215 6855+ 772735 2051- 659051 1193+ 045132 0380+ 619661 0151+ 283314 6247- 2441 136744+ 313019 0040- 171397 6054+ 151498 9352- 659051 1193+ 065032 0380+ 492700 1151+ 733381 5046- 6584 162643+ 844681 9139- 435062 0051- 255104 6051- 659051 1193+ 065132 0380+ 441356 6051+ 567792 5046- 4786 590543+ 580957 4139- 309874 6555+ 680364 6050- 659051 1193+ 075032 0380+ 448162 3251+ 180403 4147- 1533 706444+ 190413 7640- 239556 4255+ 164950 1651- 659051 1193+ 075132 0380+ 418768 0651+ 128587 0347- 1095 736844+ 136961 6640- 212716 7655+ 263696 7151-
Bell	Temperature interval	Load thermal data routine	0010 00000 0 +520000 0054 +380000 0054
Basic load hut	Thermodynamic coefficients	Sections of thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003726 0320+ 250031 0853+ 168276 8944+ 2310 572841- 459420 1237+ 429447 1555+ 461751 9750- 659051 1193+ 005426 0320+ 251734 1451+ 217402 3046+ 3034 271243- 785876 4639+ 570503 8355+ 404563 0951+ 659051 1193+ 006126 0320+ 250685 1651+ 619142 2045+ 1016 741343- 911349 0539+ 302883 3055+ 513737 8751+ 659051 1193+ 045026 0320+ 395044 0951+ 221425 2447- 2252 616044+ 316421 7240- 333749 7655+ 732424 6051- 659051 1193+ 045126 0320+ 583843 9151+ 417361 4447- 4396 920344+ 684320 7740- 388214 5254+ 124256 4452- 659051 1193+ 065026 0320+ 424907 0351+ 104015 2347- 1106 878944+ 177122 0840- 133295 4055+ 196255 6551- 659051 1193+ 065126 0320+ 413905 8751+ 612096 1046- 8518 440043+ 131175 0140- 111029 3755+ 192808 0050- 659051 1193+ 075026 0320+ 457821 3851+ 185959 0147- 1888 451644+ 264288 2440- 405091 8955+ 898055 5050- 659051 1193+ 075126 0320+ 405724 4151+ 179788 5347- 1877 366444+ 285303 6440- 215503 7155+ 149711 8751-
Bell	Temperature interval	Load thermal data routine	0009 00000 0 +260000 0054 +320000 0054
Basic load hut	Thermodynamic coefficients	Sections of thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003721 0260+ 249998 6251+ 481497 7043- 2852 333039+ 759625 3336+ 429454 1055+ 459045 7550- 659051 1193+ 005421 0260+ 250861 9251+ 110760 4946+ 1756 307943- 301682 5239+ 570665 9655+ 411539 5551+ 659051 1193+ 006121 0260+ 250869 9751+ 615154 5045- 8939 516042- 296197 4439+ 102845 1855+ 512332 0151+ 659051 1193+ 045021 0260+ 375937 0651+ 288149 0747- 3649 314144+ 644187 1040- 336557 9655+ 590709 4851- 659051 1193+ 045121 0260+ 541978 6751+ 597513 3047- 7745 713744+ 146762 6041- 451248 5754+ 933825 4051- 659051 1193+ 065021 0260+ 413153 9051+ 164695 7647- 2168 431944+ 428777 2840- 109550 2555+ 109197 5751- 659051 1193+ 065121 0260+ 425977 3151+ 126512 9447- 1656 396044+ 322801 6640- 112357 6855+ 467486 0050+ 659051 1193+ 075021 0260+ 430279 1751+ 179316 0347- 2194 906444+ 349366 2640- 495714 4055+ 376572 3050- 659051 1193+ 075121 0260+ 383887 6251+ 249583 4047- 3335 818444+ 630136 9540- 218415 2755+ 467630 0049-
Bell	Temperature interval	Load thermal data routine	0008 00000 0 +210000 0054 +260000 0054
Basic load hut	Thermodynamic coefficients	Sections of thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003717 0210+ 249927 6451+ 102129 0045- 1742 696542+ 523594 8838- 429462 5455+ 453769 0450- 659051 1193+ 005417 0210+ 250163 9051+ 252258 0045+ 4789 731742- 162755 6539+ 570772 6255+ 416905 2251+ 659051 1193+ 006117 0210+ 251417 9351+ 968009 0045- 1678 419543- 480001 3239+ 102772 8455+ 508390 5351+ 659051 1193+ 045017 0210+ 358412 3551+ 345405 2547- 5355 345144+ 113973 4941- 338629 5755+ 667158 2451- 659051 1193+ 045117 0210+ 498535 5151+ 804282 8047- 1277 984843+ 292686 7541- 503617 0454+ 624032 7051- 659051 1193+ 065017 0210+ 397927 0051+ 262006 1247- 4260 967644+ 104014 4941- 495167 3355+ 651240 0048+ 659051 1193+ 065117 0210+ 413717 4651+ 207672 3147- 3380 359344+ 827120 2940- 113852 9055+ 135127 2351- 659051 1193+ 075017 0210+ 422270 2051+ 195308 3147- 2975 107044+ 597692 5940- 579496 4255+ 174767 6050+ 659051 1193+ 075117 0210+ 369055 1651+ 319152 7247- 5009 963144+ 110788 0241- 222219 7355+ 151236 6451-
Bell	Temperature interval	Load thermal data routine	0007 00000 0 +170000 0054 +210000 0054
Basic load hut	Thermodynamic coefficients	Sections of thermodynamic data and load thermal data routine, eqs. (105) to (107)	659051 1193+ 003713 0170+ 249998 0351+ 110207 7344- 4488 906540+ 483417 0736+ 429453 8955+ 455993 9750- 659051 1193+ 005413 0170+ 250022 0451+ 345625 5044+ 5655 671041- 420086 6538+ 570790 7455+ 417075 6551+ 659051 1193+ 006113 0170+ 251934 6551+ 115126 1046+ 2514 328343- 803129 0439+ 102727 7455+ 304874 1751+ 659051 1193+ 045013 0170+ 347894 6751+ 316028 8047- 6169 765644+ 150596 8741- 339427 6455- 339539 6951- 659051 1193+ 045113 0170+ 456133 8751+ 936121 3047- 1893 335945+ 522738 6241- 542206 6154+ 337678 8151- 659051 1193+ 065013 0170+ 379386 8051+ 371701 3247- 7734 001444+ 232634 7741- 668617 4353+ 377883 9851+ 659051 1193+ 065113 0170+ 397621 3151+ 314063 8247- 4472 256144+ 200914 6341- 115367 0255+ 346174 6651- 659051 1193+ 075013 0170+ 410499 0051+ 291703 1847- 5293 902044+ 140931 1541- 683527 5555+ 972976 6051- 659051 1193+ 075113 0170+ 352600 1751+ 360793 9747- 7223 571444+ 193098 7741- 221732 3155+ 712205 3451-
Bell	Temperature interval	Load thermal data routine	0006 00000 0 +130000 0054 +170000 0054

TABLE V. - OUTPUT OF MAIN OPERATING DECK

		EQUIV RATO R	O/F	PRCNT FUEL	PC PSIA	ENTH CAL/ GM	IDENT FICA TN	
9005	6	+8571 4286 50	+1592 1118 51	+3857 8583 52	+6000 0000 53	+2380 1691 54	+0857 0208 63	1
		A SUB F	B SUB F	C SUB F	D SUB F	E SUB F		
9005	6	+1248 1278 50	+6240 6390 49				+0857 0208 63	2
		F SUB F	G SUB F	H SUB F	I SUB F	J SUB F		
9005	6						+0857 0208 63	3
		FUEL ENTH HF	FUEL +VAL VF+	FUEL -VAL VF-				
9005	6	+4827 2269 54	+1248 1278 50				+0857 0208 63	4
		A SUB X	B SUB X	C SUB X	D SUB X	E SUB X		
9005	6	+5879 5860 49		+5879 5860 49			+0857 0208 63	5
		F SUB X	G SUB X	H SUB X	I SUB X	J SUB X		
9005	6						+0857 0208 63	6
		OXID ENTH HX	OXID +VAL VX+	OXID -VAL VX-				
9005	6	+8431 8043 53	+5879 5860 49	-1175 9172 50			+0857 0208 63	7

							IDENT FICA TN		CARD NO.
		PRESS RATO	TEMP K	PRESS ATM	ENTH CAL/ GM	SPEC IMP	RRRR		1
		MOLEC WT	THRST COEF CF	AREA RATO	MACH NO.	I VAC	CASE		2
		CP CAL/ GM	GAMMA	DLNM/ DLNP T	DLNM/ DLNT P	ENTRO PY	PC		3
		PI SUB I	PI SUB T	PI SUB EP	PISUB CSTR	C STAR		PE	4
		CODE 0 37	H	CODE 0 54	N				5
		CODE 0 61	O	CODE 4 50	H2				6
		CODE 4 51	H2O	CODE 6 50	N2				7
		CODE 6 51	NO	CODE 7 50	O2				8
		CODE 7 51	OH						9

9005	6	+1000 0000 51	+2820 0975 54	+4082 7418 52	+2380 1693 54		+0857 0208 63	1	7 0001
9005	6	+1832 4978 52					+0857 0208 63	1	0 0002
9005	6	+8600 2537 50	+1170 6861 51	+3918 7000 48	-8967 4585 49	+3202 5166 51	+0857 0208 63	1	0 0003
9005	6		+1130 7117 49				+0857 0208 63	1	0 0004
9005	6	+0000 0000 37	+1884 9336 50	+0000 0000 54	+1198 2934 46		+0857 0208 63	1	0 0005
9005	6	+0000 0000 61	+7941 1497 48	+0000 0004 50	+4652 5476 51		+0857 0208 63	1	0 0006
9005	6	+0000 0004 51	+2661 5805 52	+0000 0006 50	+8986 4247 51		+0857 0208 63	1	0 0007
9005	6	+0000 0006 51	+3950 4512 49	+0000 0007 50	+1860 7803 49		+0857 0208 63	1	0 0008
9005	6	+0000 0007 51	+3180 8095 50				+0857 0208 63	1	0 0009
9005	6	+1763 0118 51	+2599 0325 54	+2315 7770 52	+2213 8880 54	+1202 8578 53	+0857 0208 63	2	7 0001
9005	6	+1839 4694 52	+6718 3421 50	+1000 0000 51	+9999 9900 50	+2218 3977 53	+0857 0208 63	2	0 0002
9005	6	+7500 1172 50	+1184 4539 51	+1866 4000 48	-4600 4567 49	+3202 5172 51	+0857 0208 63	2	0 0003
9005	6	+3211 9738 48	+6C78 4200 48		+1279 7000 48	+5760 4609 54	+0857 0208 63	2	0 0004
9005	6	+0000 0000 37	+6129 6978 49	+0000 0000 54	+1574 5346 45		+0857 0208 63	2	0 0005
9005	6	+0000 0000 61	+1289 9700 48	+0000 0004 50	+2592 6825 51		+0857 0208 63	2	0 0006
9005	6	+0000 0004 51	+1528 1160 52	+0000 0006 50	+5123 4150 51		+0857 0208 63	2	0 0007
9005	6	+0000 0006 51	+8852 1215 48	+0000 0007 50	+3154 4989 48		+0857 0208 63	2	0 0008
9005	6	+0000 0007 51	+8591 8027 49				+0857 0208 63	2	0 0009
9005	6	+2041 3710 52	+1703 3560 54	+2000 0000 51	+1650 2977 54	+2520 0886 53	+0857 0208 63	3	7 0001
9005	6	+1846 0004 52	+1407 5494 51	+3609 2728 51	+2542 3479 51	+2836 6442 53	+0857 0208 63	3	0 0002
9005	6	+5727 2366 50	+1231 6744 51	+1190 0000 46	-4021 9322 47	+3202 5170 51	+0857 0208 63	3	0 0003
9005	6	+9255 6857 47	-1309 3700 48	-3527 1000 48		+5760 4609 54	+0857 0208 63	3	0 0004
9005	6	+0000 0000 37	+7135 4999 46	+0000 0000 54	+3884 2841 39		+0857 0208 63	3	0 0005
9005	6	+0000 0000 61	+5726 6914 42	+0000 0004 50	+2221 9334 50		+0857 0208 63	3	0 0006
9005	6	+0000 0004 51	+1333 2781 51	+0000 0006 50	+4444 3360 50		+0857 0208 63	3	0 0007
9005	6	+0000 0006 51	+6396 0183 44	+0000 0007 50	+1556 5795 43		+0857 0208 63	3	0 0008
9005	6	+0000 0007 51	+2297 8421 46				+0857 0208 63	3	0 0009
9005	6	+4082 7420 52	+1491 5306 54	+1000 0000 51	+1531 2268 54	+2717 8889 53	+0857 0208 63	4	7 0001
9005	6	+1846 0388 52	+1518 0271 51	+5861 1205 51	+2917 3868 51	+2974 9172 53	+0857 0208 63	4	0 0002
9005	6	+5517 8364 50	+1242 4039 51	+1500 0000 45	-6049 8219 5	+3202 5166 51	+0857 0208 63	4	0 0003
9005	6	+6988 0686 47	-1429 7700 48	-3409 9000 48		+5760 4609 54	+0857 0208 63	4	0 0004
9005	6	+0000 0000 37	+5278 4766 45	+0000 0000 54	+2759 3682 37		+0857 0208 63	4	0 0005
9005	6	+0000 0000 61	+3627 2626 40	+0000 0004 50	+1111 0859 50		+0857 0208 63	4	0 0006
9005	6	+0000 0004 51	+6666 6369 50	+0000 0006 50	+2222 2154 50		+0857 0208 63	4	0 0007
9005	6	+0000 0006 51	+1479 0822 43	+0000 0007 50	+1023 7844 41		+0857 0208 63	4	0 0008
9005	6	+0000 0007 51	+9075 8745 44				+0857 0208 63	4	0 0009
9005	6	+6804 5699 52	+1348 1969 54	+6000 0001 50	+1453 1962 54	+2840 0511 53	+0857 0208 63	5	7 0001
9005	6	+1846 0433 52	+1586 2586 51	+8449 4012 51	+3195 2580 51	+3062 3705 53	+0857 0208 63	5	0 0002
9005	6	+5361 3060 50	+1251 2292 51	+3000 0000 44	-1082 3995 46	+3202 5168 51	+0857 0208 63	5	0 0003
9005	6	+5786 3339 47	-1481 9800 48	-3340 6000 48		+5760 4609 54	+0857 0208 63	5	0 0004
9005	6	+0000 0000 37	+5962 6786 44	+0000 0000 54	+2889 5353 35		+0857 0208 63	5	0 0005
9005	6	+0000 0000 61	+4808 4378 35	+0000 0004 50	+6666 6369 49		+0857 0208 63	5	0 0006
9005	6	+0000 0004 51	+3999 9971 50	+0000 0006 50	+1333 3327 50		+0857 0208 63	5	0 0007
9005	6	+0000 0006 51	+6167 0896 41	+0000 0007 50	+1403 8250 39		+0857 0208 63	5	0 0008
9005	6	+0000 0007 51	+5969 0563 43				+0857 0208 63	5	0 0009

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Type of equation	Equation number in text	Gaseous molecules				Gaseous atoms				Condensed phases					
		$\Delta \ln n_1$	$\Delta \ln n_2$	$\Delta \ln n_3$	---	$\Delta \ln n_Z$	$\Delta \ln n_Y$	$\Delta \ln n_X$	---	---	$\Delta \ln n_M$	$\Delta \ln n_N$	$-\Delta \ln A$	$\Delta \ln T$	Constant
Gaseous equilibria	(29)	1	0	0	0	$-a_1$	$-b_1$	$-c_1$	---	0	0	0	0	$-q_1$	$-\delta_1$
		0	1	0	0	$-a_2$	$-b_2$	$-c_2$	---	0	0	0	0	$-q_2$	$-\delta_2$
		0	0	1	0	$-a_3$	$-b_3$	$-c_3$	---	0	0	0	0	$-q_3$	$-\delta_3$
		0	0	0	---	---	---	---	---	0	0	0	0	---	---
Mass balance	(28)	a_1n_1	a_2n_2	a_3n_3	---	n_Z	0	0	0	---	a_Mn_M	a_Nn_N	$\sum a_i n_i$	0	$A\Delta a$
		b_1n_1	b_2n_2	b_3n_3	---	0	n_Y	0	0	---	b_Mn_M	b_Nn_N	$\sum b_i n_i$	0	$A\Delta b$
		c_1n_1	c_2n_2	c_3n_3	---	0	0	n_X	0	---	c_Mn_M	c_Nn_N	$\sum c_i n_i$	0	$A\Delta c$
		----	----	----	---	0	0	0	---	---	----	----	----	0	---
Condensed-phase equilibria	(30)	0	0	0	0	---	---	---	---	0	0	0	0	---	---
		0	0	0	0	a_M	b_M	c_M	---	0	0	0	0	q_M	δ_M
		0	0	0	0	a_N	b_N	c_N	---	0	0	0	0	q_N	δ_N
Pressure	(31)	p_1	p_2	p_3	---	p_Z	p_Y	p_X	---	0	0	0	0	0	ΔP
Enthalpy*	(32)	$(H_T^o)_1 n_1$	$(H_T^o)_2 n_2$	$(H_T^o)_3 n_3$	---	$(H_T^o)_Z n_Z$	$(H_T^o)_Y n_Y$	$(H_T^o)_X n_X$	---	---	$(H_T^o)_M n_M$	$(H_T^o)_N n_N$	$\sum (H_T^o)_i n_i$	$T\sum (C_p^o)_i n_i$	$A\Delta H$

*Row vector to be substituted in place of enthalpy row for isentropic expansion to assigned pressure:

Entropy	(33)	$(S_T)'_1 n_1$	$(S_T)'_2 n_2$	$(S_T)'_3 n_3$	---	$(S_T)'_Z n_Z$	$(S_T)'_Y n_Y$	$(S_T)'_X n_X$	---	---	$(S_T)'_M n_M$	$(S_T)'_N n_N$	$\sum (S_T)_i n_i$	$\sum (C_p^o)_i n_i$	$A\Delta S$

Figure 1. - General matrix of correction equations for adiabatic combustion at assigned pressure.

Type of equation	Gaseous atoms				Condensed phases					
	$\Delta \ln p_Z$	$\Delta \ln p_Y$	$\Delta \ln p_X$	---	---	Δn_M	Δn_N	$-\Delta \ln A$	$\Delta \ln T$	Constant
Mass balance	$\sum a_i^2 p_i$	$\sum a_i b_i p_i$	$\sum a_i c_i p_i$	---	---	a_M	a_N	$\sum a_i n_i$	$\sum a_i q_i p_i$	$A\Delta a + \sum a_i \delta_i p_i$
	$\sum a_i b_i p_i$	$\sum b_i^2 p_i$	$\sum b_i c_i p_i$	---	---	b_M	b_N	$\sum b_i n_i$	$\sum b_i q_i p_i$	$A\Delta b + \sum b_i \delta_i p_i$
	$\sum a_i c_i p_i$	$\sum b_i c_i p_i$	$\sum c_i^2 p_i$	---	---	c_M	c_N	$\sum c_i n_i$	$\sum c_i q_i p_i$	$A\Delta c + \sum c_i \delta_i p_i$
	------	------	------	---	---	--	--	----	------	------
Condensed-phase equilibria	------	------	------	---	0	0	0	0	------	------
	a_M	b_M	c_M	---	0	0	0	0	q_M	δ_M
	a_N	b_N	c_N	---	0	0	0	0	q_N	δ_N
Pressure	$\sum a_i p_i$	$\sum b_i p_i$	$\sum c_i p_i$	---	0	0	0	0	$\sum q_i p_i$	$\Delta P + \sum \delta_i p_i$
Enthalpy*	$\sum (H_T^o)_i a_i p_i$	$\sum (H_T^o)_i b_i p_i$	$\sum (H_T^o)_i c_i p_i$	---	---	$(H_T^o)_M$	$(H_T^o)_N$	$\sum (H_T^o)_i n_i$	$T \sum (C_P^o)_i n_i + \sum (H_T^o) q_i p_i$	$A\Delta H + \sum (H_T^o)_i \delta_i p_i$

*Row vector to be substituted in place of enthalpy row for isentropic expansion to assigned pressure:

Entropy	$\sum (S_T)'_i a_i p_i$	$\sum (S_T)'_i b_i p_i$	$\sum (S_T)'_i c_i p_i$	---	---	$(S_T)'_M$	$(S_T)'_N$	$\sum (S_T)_i n_i$	$\sum (C_P^o)_i n_i + \sum (S_T)'_i q_i p_i$	$A\Delta S + \sum (S_T)'\delta_i p_i$

Figure 2. - General reduced augmented matrix for adiabatic combustion at assigned pressure. (Summations in terms of p_i for gaseous products only. Summations in terms of n_i for all products.)

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Type of equation	Gaseous atoms				Condensed phases				
	$\left(\frac{\partial \ln p_Z}{\partial \ln T}\right)_P$	$\left(\frac{\partial \ln p_Y}{\partial \ln T}\right)_P$	$\left(\frac{\partial \ln p_X}{\partial \ln T}\right)_P$			$\left(\frac{\partial n_M}{\partial \ln T}\right)_P$	$\left(\frac{\partial n_N}{\partial \ln T}\right)_P$	$-\left(\frac{\partial \ln A}{\partial \ln T}\right)_P$	Constant
Mass balance	$\sum a_i^2 p_i$	$\sum a_i b_i p_i$	$\sum a_i c_i p_i$	---	---	a_M	a_N	$\sum a_i n_i$	$\sum a_i q_i p_i$
	$\sum a_i b_i p_i$	$\sum b_i^2 p_i$	$\sum b_i c_i p_i$	---	---	b_M	b_N	$\sum b_i n_i$	$\sum b_i q_i p_i$
	$\sum a_i c_i p_i$	$\sum b_i c_i p_i$	$\sum c_i^2 p_i$			c_M	c_N	$\sum c_i n_i$	$\sum c_i q_i p_i$
	------	------	------	---	---	--	--	----	------
Condensed-phase equilibria	------	------	------	---	0	0	0	0	------
	a_M	b_M	c_M	---	0	0	0	0	q_M
	a_N	b_N	c_N	---	0	0	0	0	q_N
Pressure	$\sum a_i p_i$	$\sum b_i p_i$	$\sum c_i p_i$	---	0	0	0	0	$\sum q_i p_i$

Figure 3. - General reduced augmented matrix for partial derivatives at constant pressure. (Summations in terms of p_i for gaseous products only. Summations in terms of n_i for all products.)

Type of equation	Gaseous atoms				Condensed phases			
	$\left(\frac{\partial \ln p_Z}{\partial \ln A}\right)_T$	$\left(\frac{\partial \ln p_Y}{\partial \ln A}\right)_T$	$\left(\frac{\partial \ln p_X}{\partial \ln A}\right)_T$			$\left(\frac{\partial n_M}{\partial \ln A}\right)_T$	$\left(\frac{\partial n_N}{\partial \ln A}\right)_T$	Constant
Mass balance	$\sum a_i^2 p_i$	$\sum a_i b_i p_i$	$\sum a_i c_i p_i$	---	---	a_M	a_N	$\sum a_i n_i$
	$\sum a_i b_i p_i$	$\sum b_i^2 p_i$	$\sum b_i c_i p_i$	---	---	b_M	b_N	$\sum b_i n_i$
	$\sum a_i c_i p_i$	$\sum b_i c_i p_i$	$\sum c_i^2 p_i$	---	---	c_M	c_N	$\sum c_i n_i$
	------	------	------	---	---	--	--	----
Condensed-phase equilibria	--	--	--	---	---	0	0	0
	a_M	b_M	c_M	---	---	0	0	0
	a_N	b_N	c_N	---	---	0	0	0

Figure 4. - General reduced augmented matrix for partial derivatives at constant temperature. (Summations in terms of p_i for gaseous products only. Summations in terms of n_i for all products.)

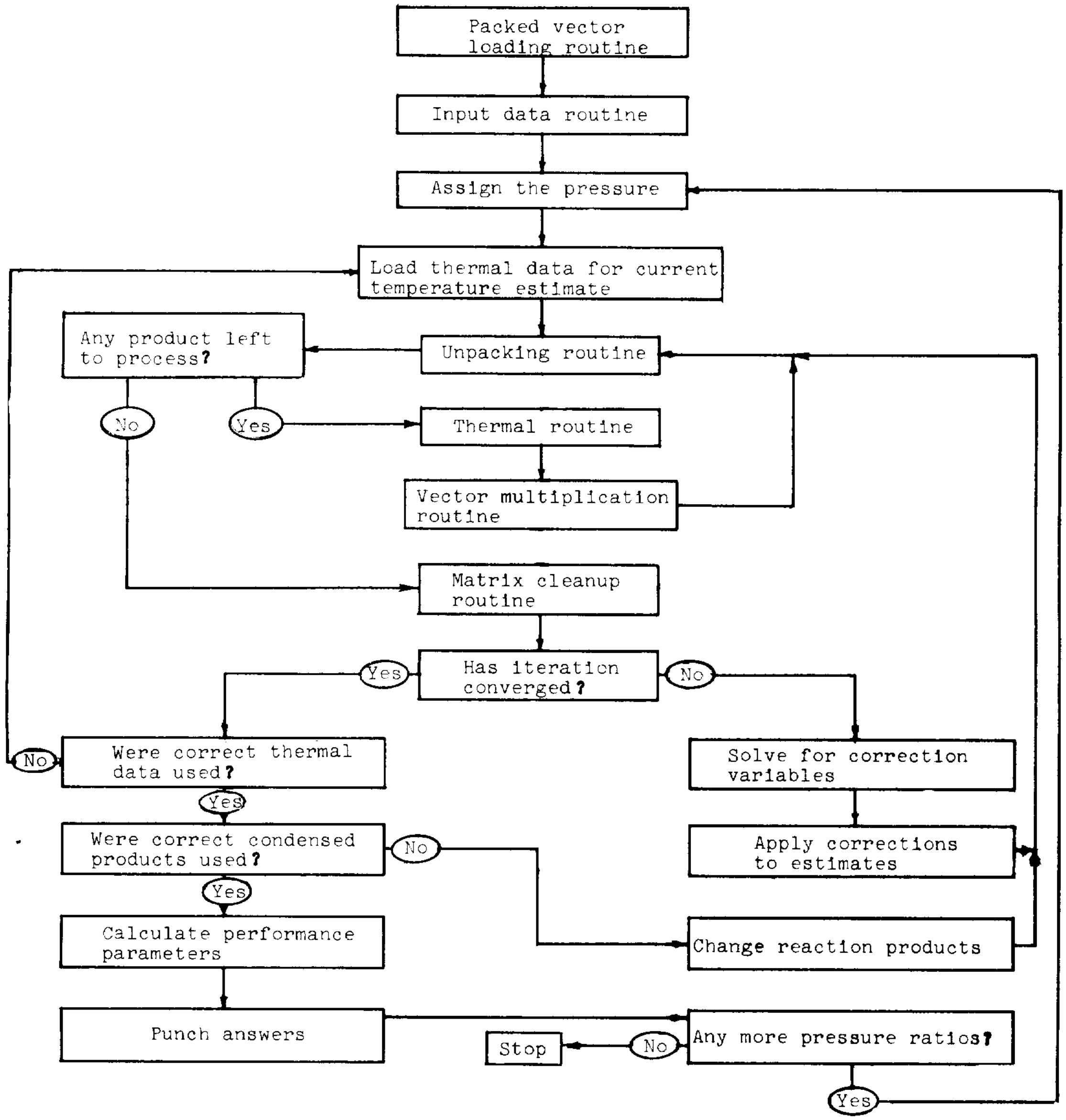

Figure 5. - Flow chart for Main Calculating Program.

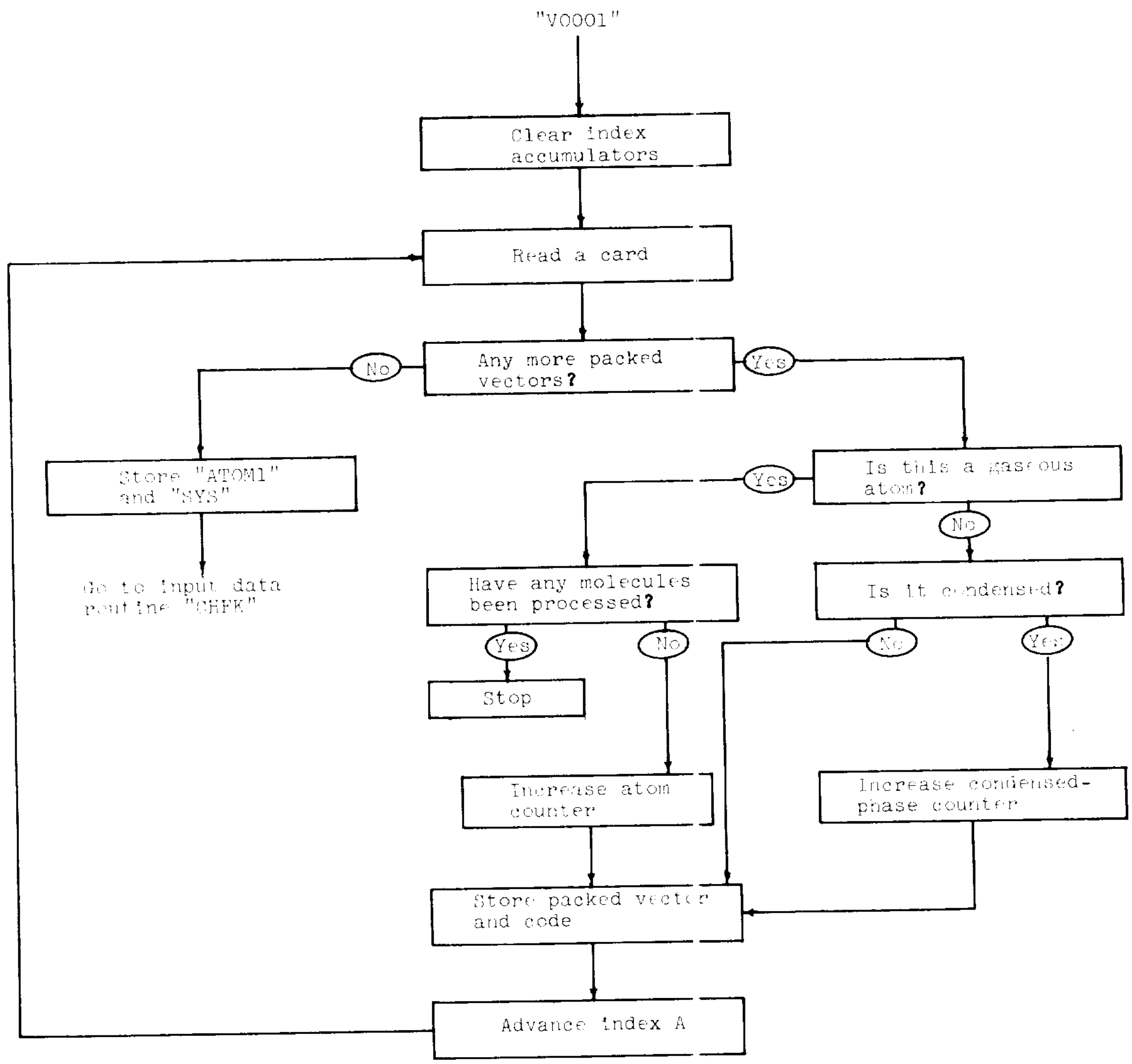

Figure 6. - Flow chart for packed vector loading.

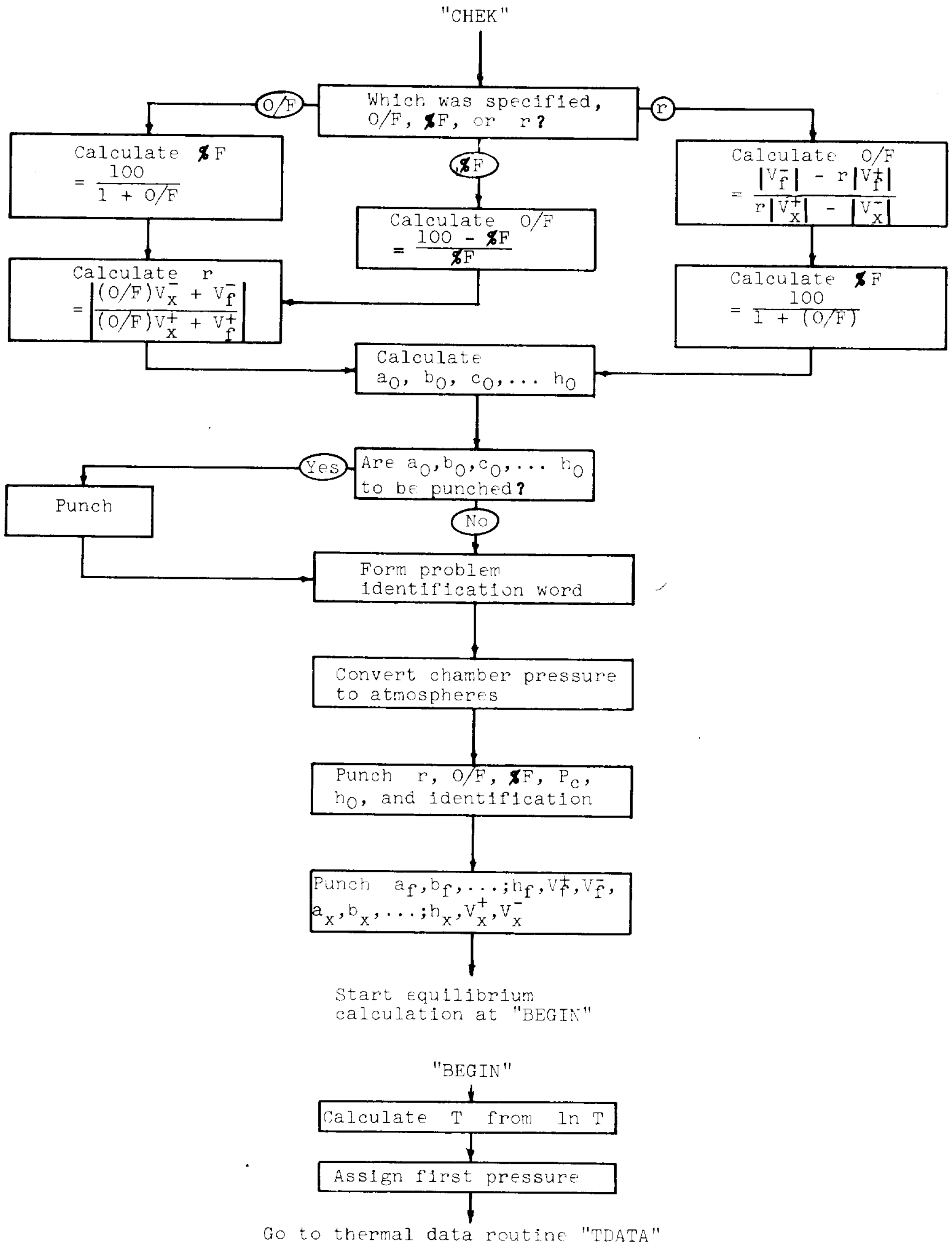

Figure 7. - Flow chart for input data routine.

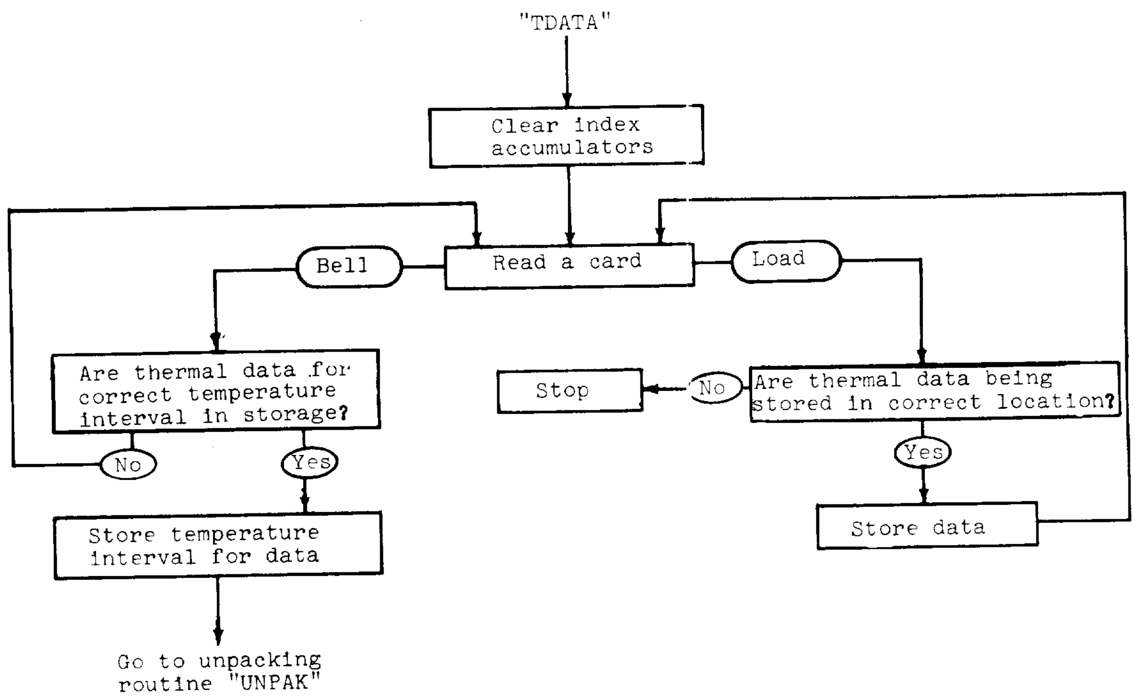

Figure 8. - Flow chart for load thermal data.

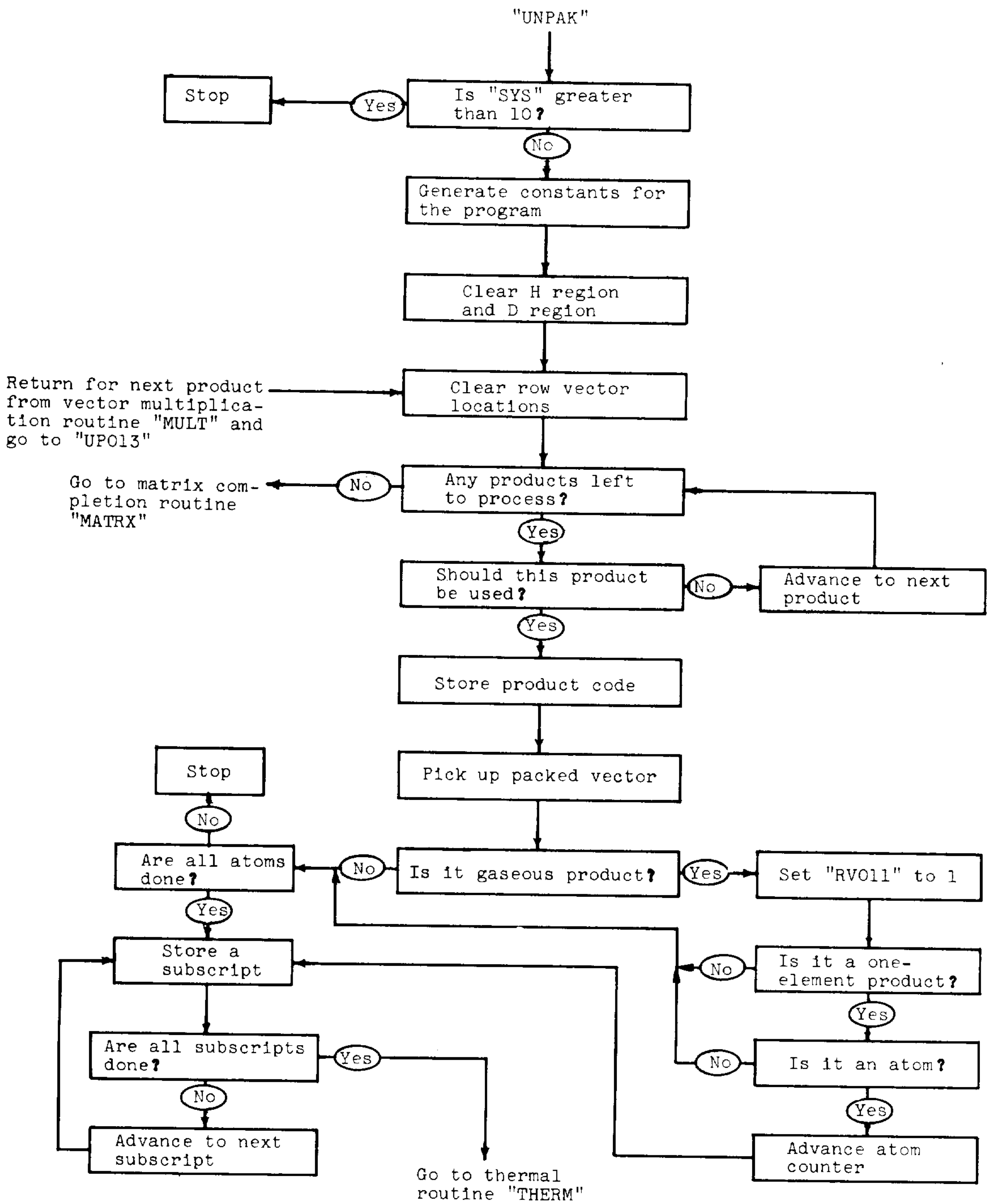

Figure 9. - Flow chart for unpacking routine.

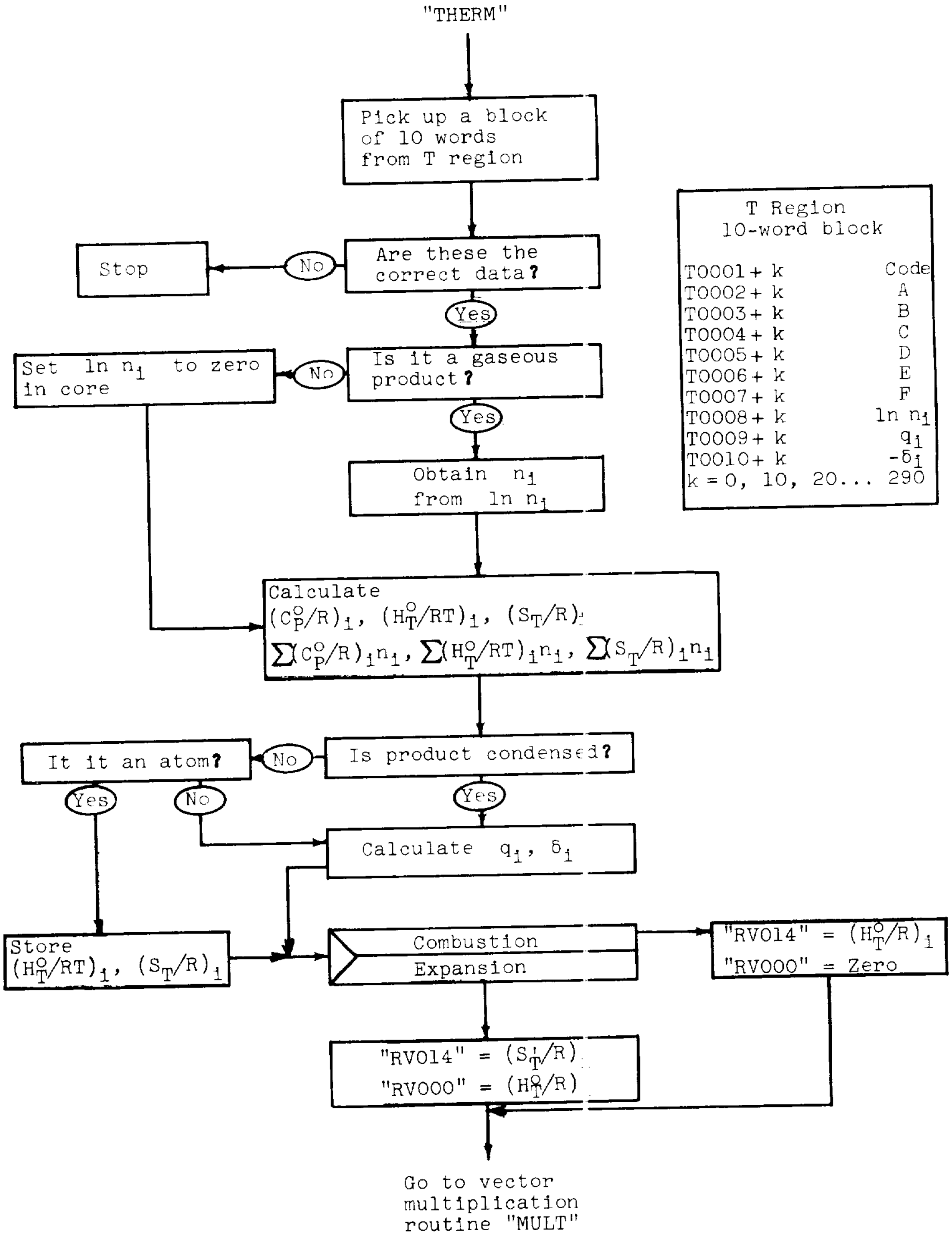

Figure 10. - Flow chart for thermal routine.

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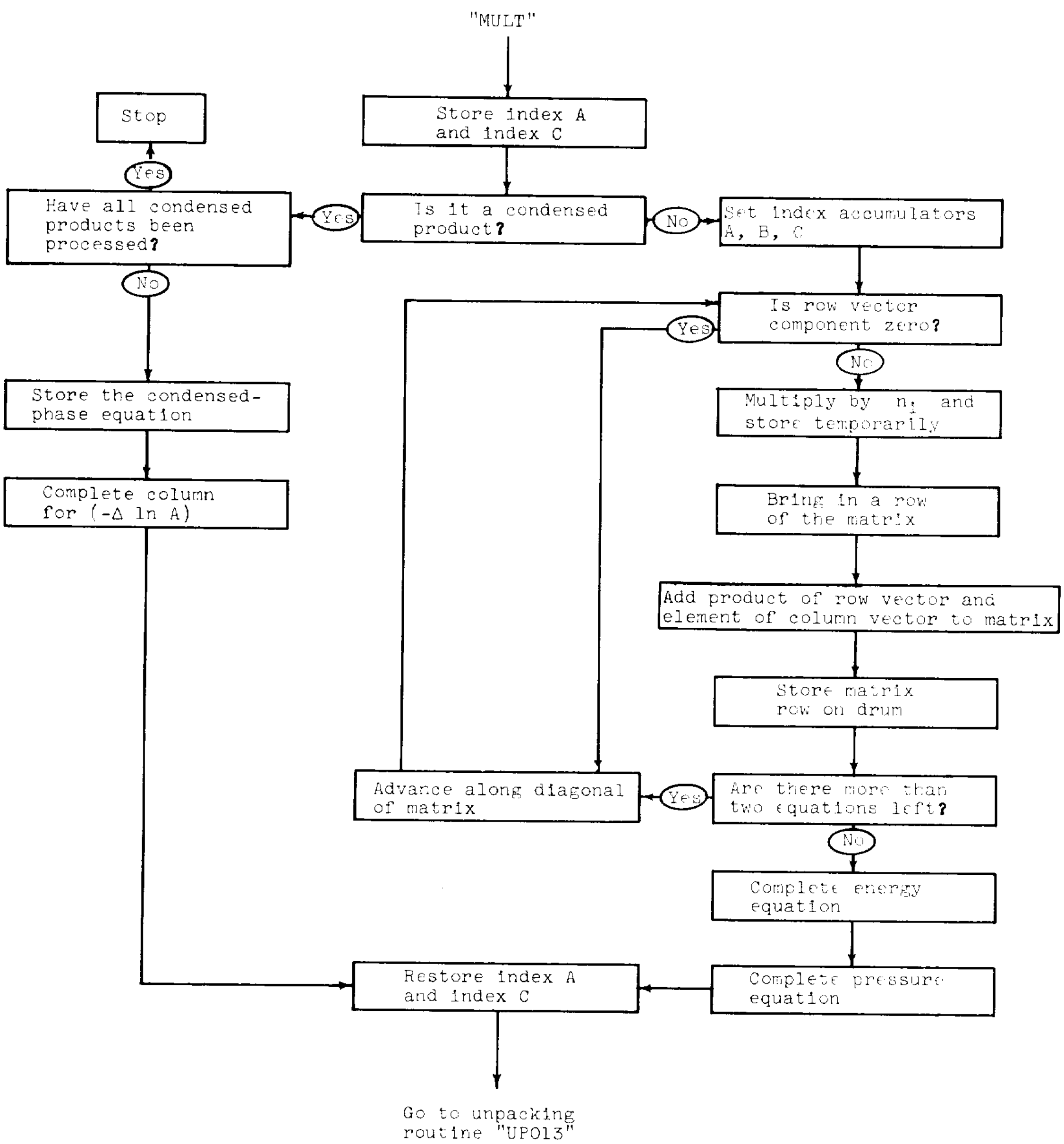

Figure 11. - Flow chart for vector multiplication routine.

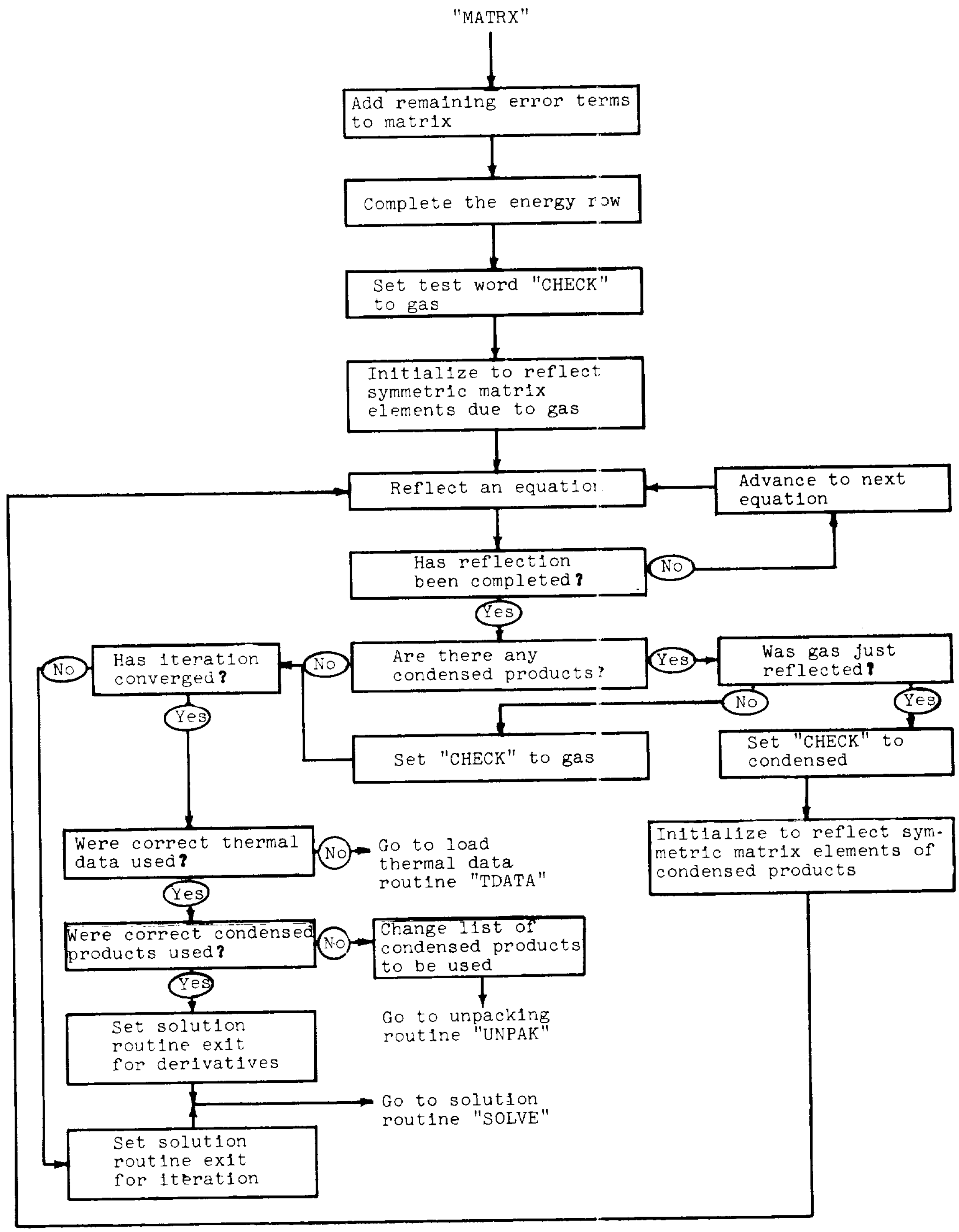

Figure 12. - Flow chart for matrix completion routine.

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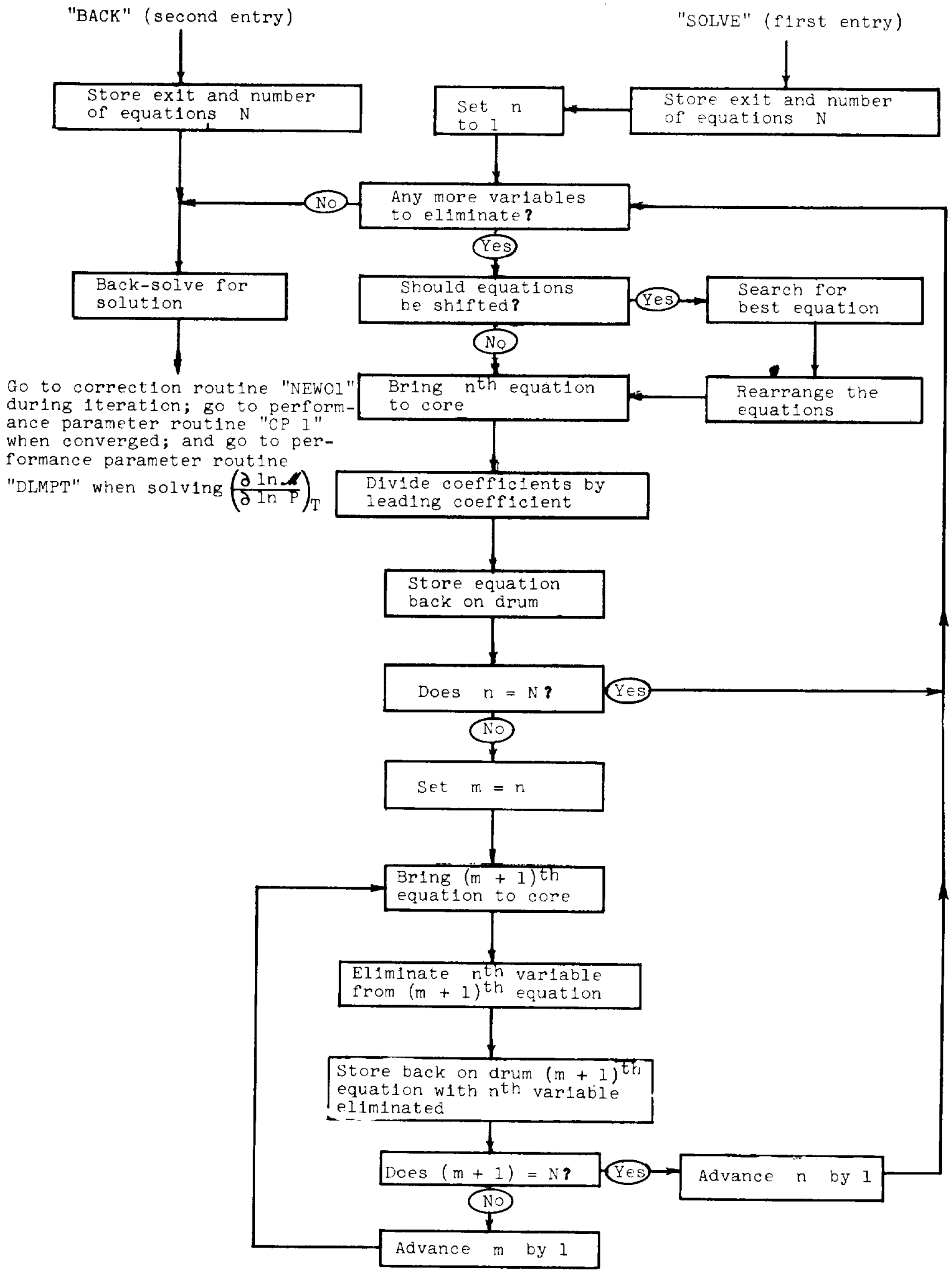

Figure 13. - Flow chart for matrix solution routine.

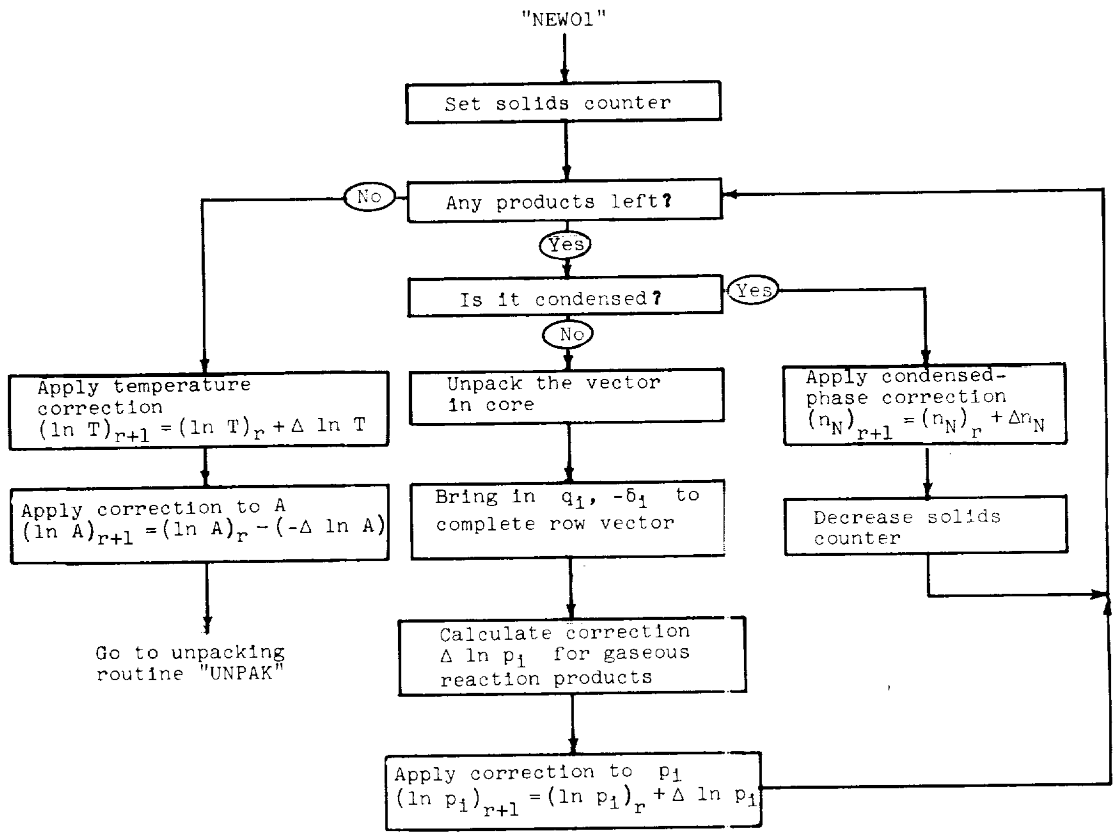

Figure 14. - Flow chart for correction routine.

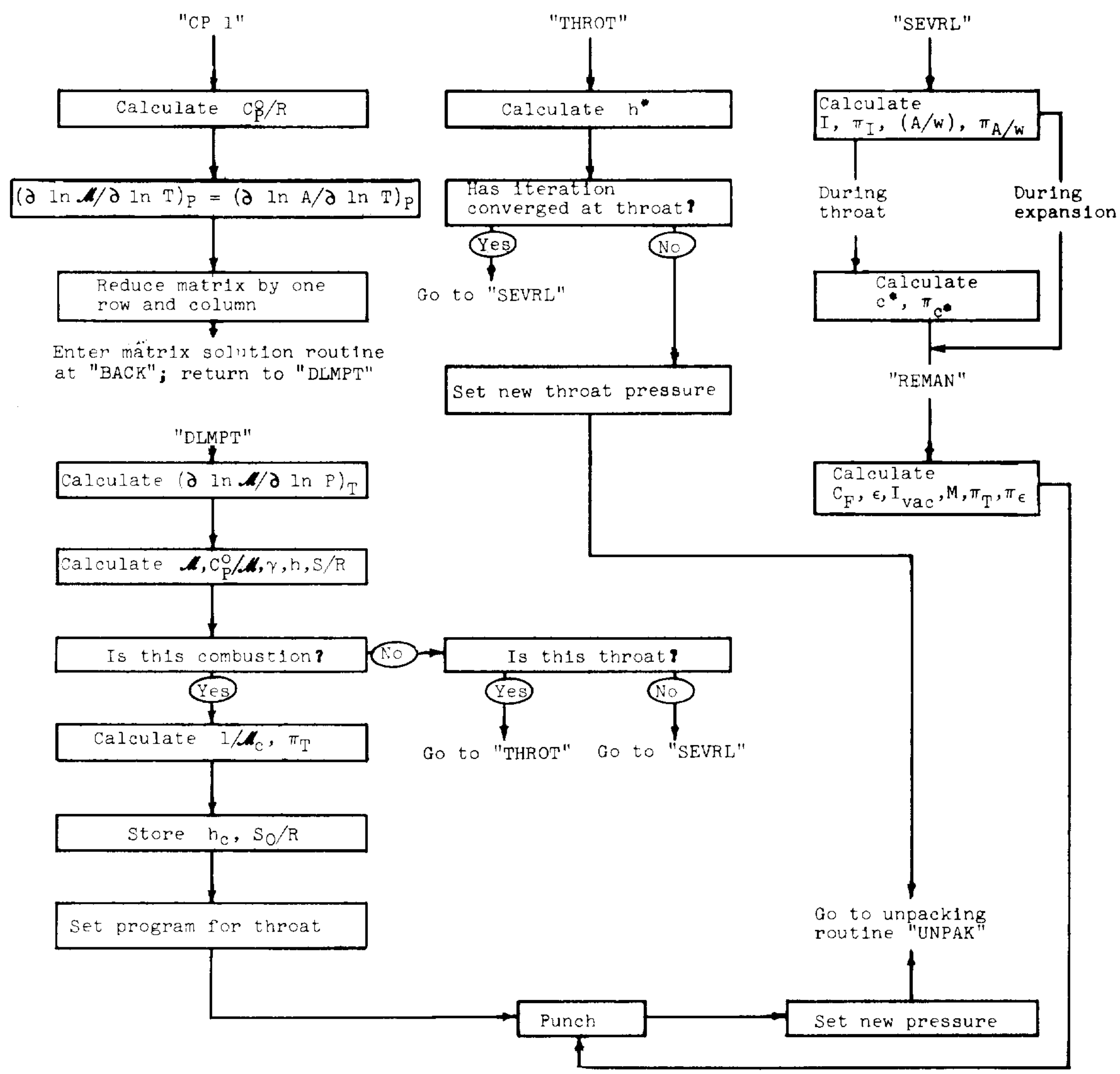

Figure 15. - Flow chart for performance-parameter routine.

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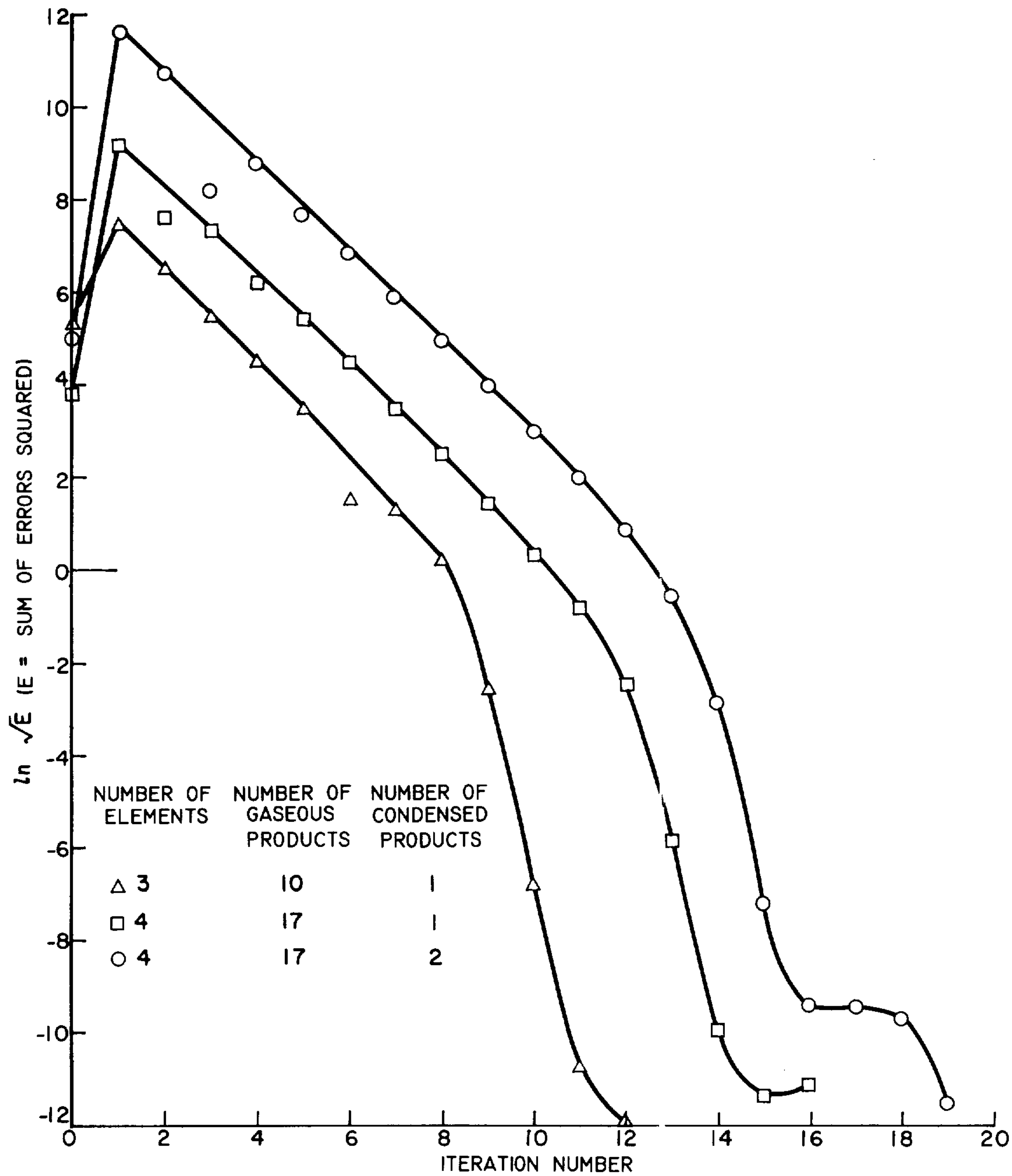

Figure 16. - Rate of convergence for several propellants.

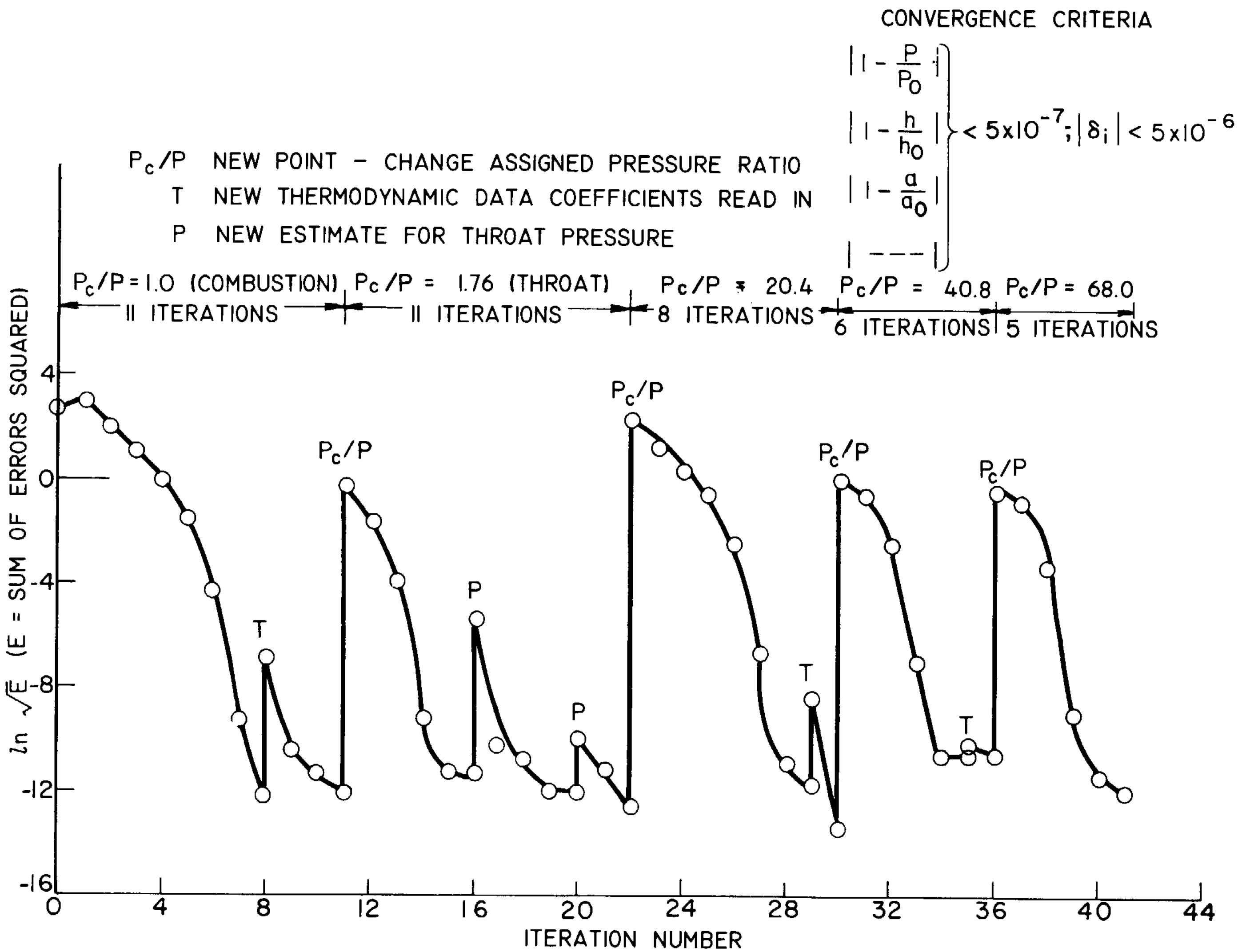

Figure 17. - Convergence for reaction $N_2H_4 + \frac{3}{[illegible]} H_2O_2$.

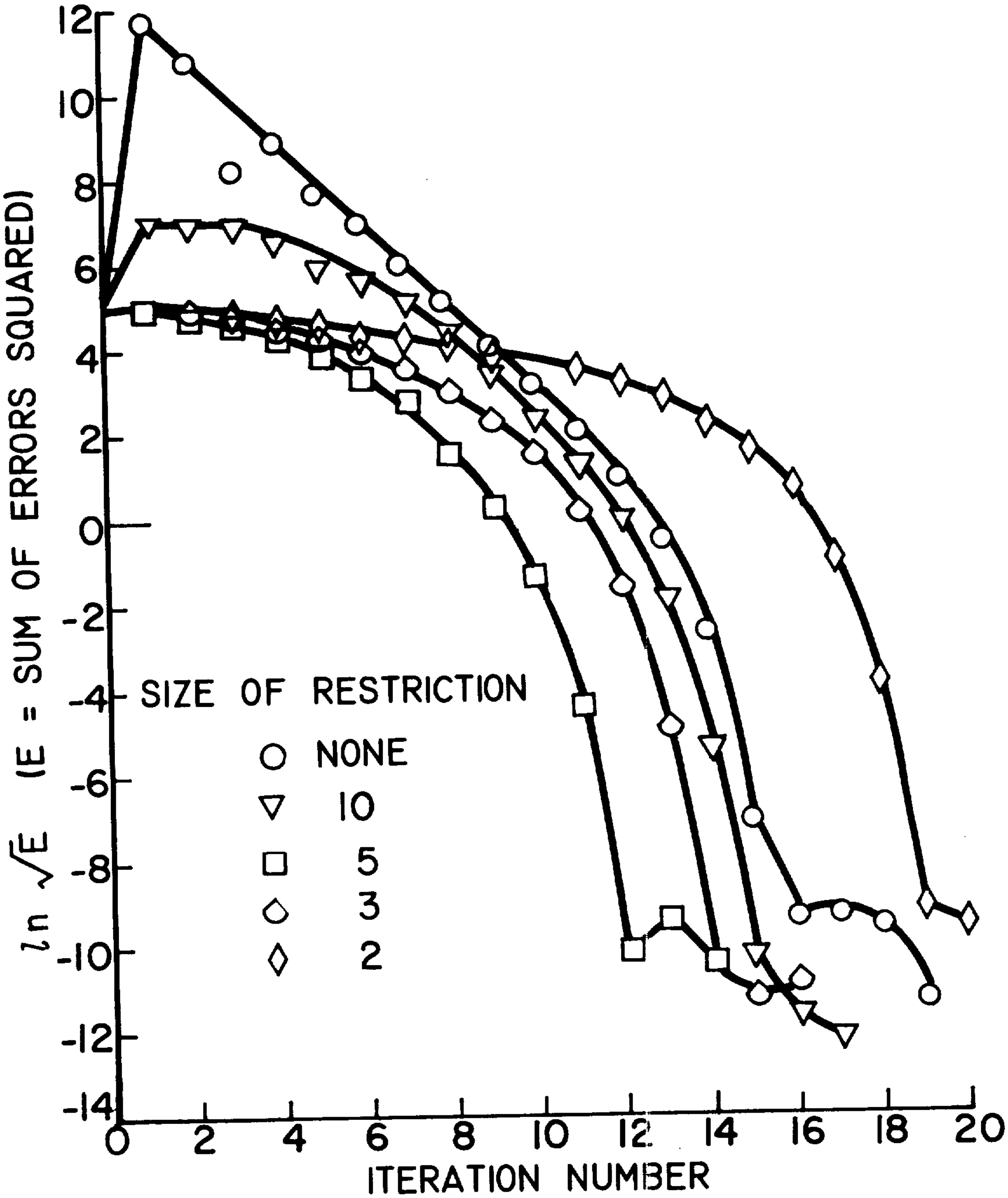

Figure 18. - Solution vector control and convergence; 4 elements, 17 gaseous products, 2 condensed products.

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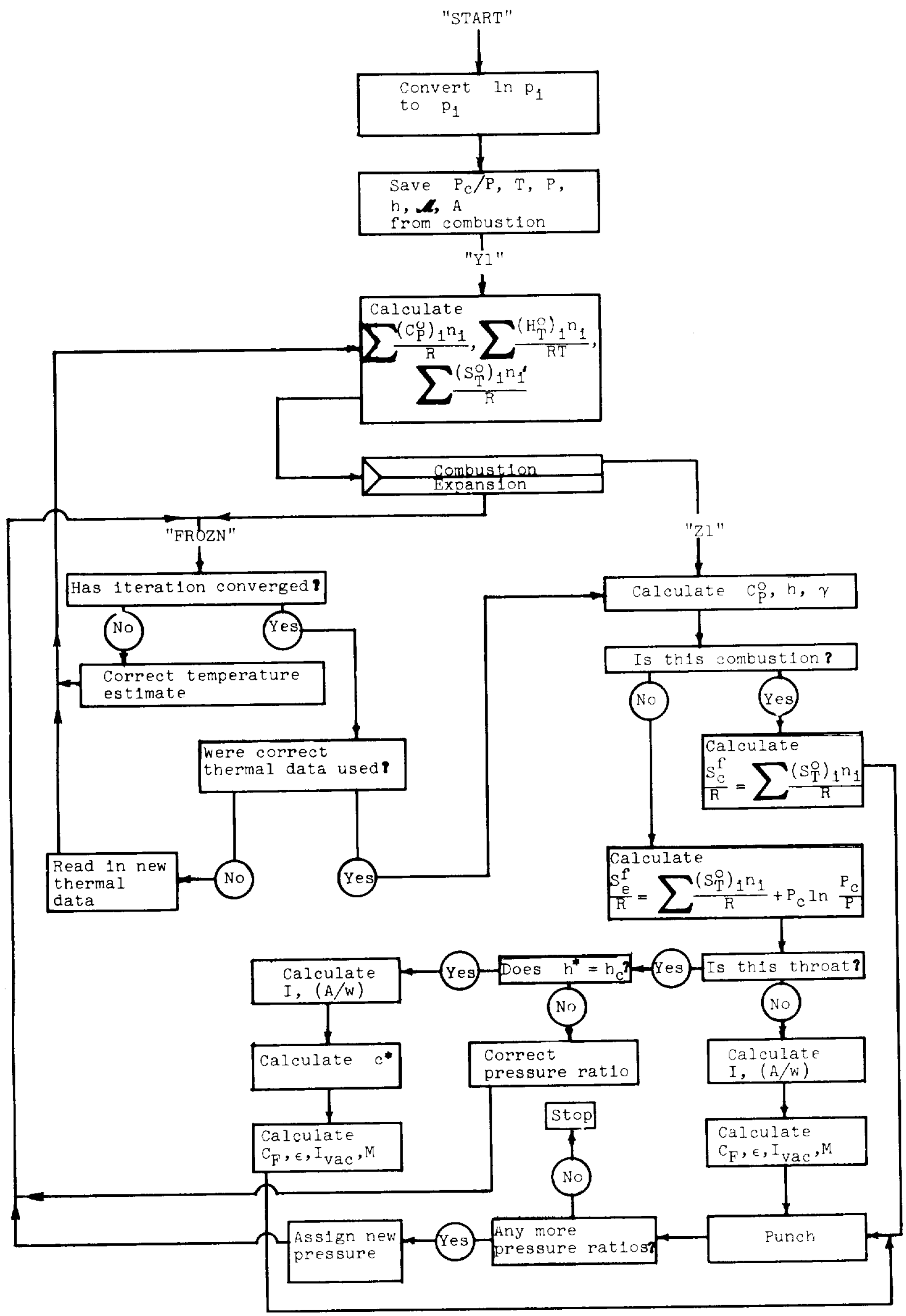

Figure 19. - Flow chart for frozen-composition routine.

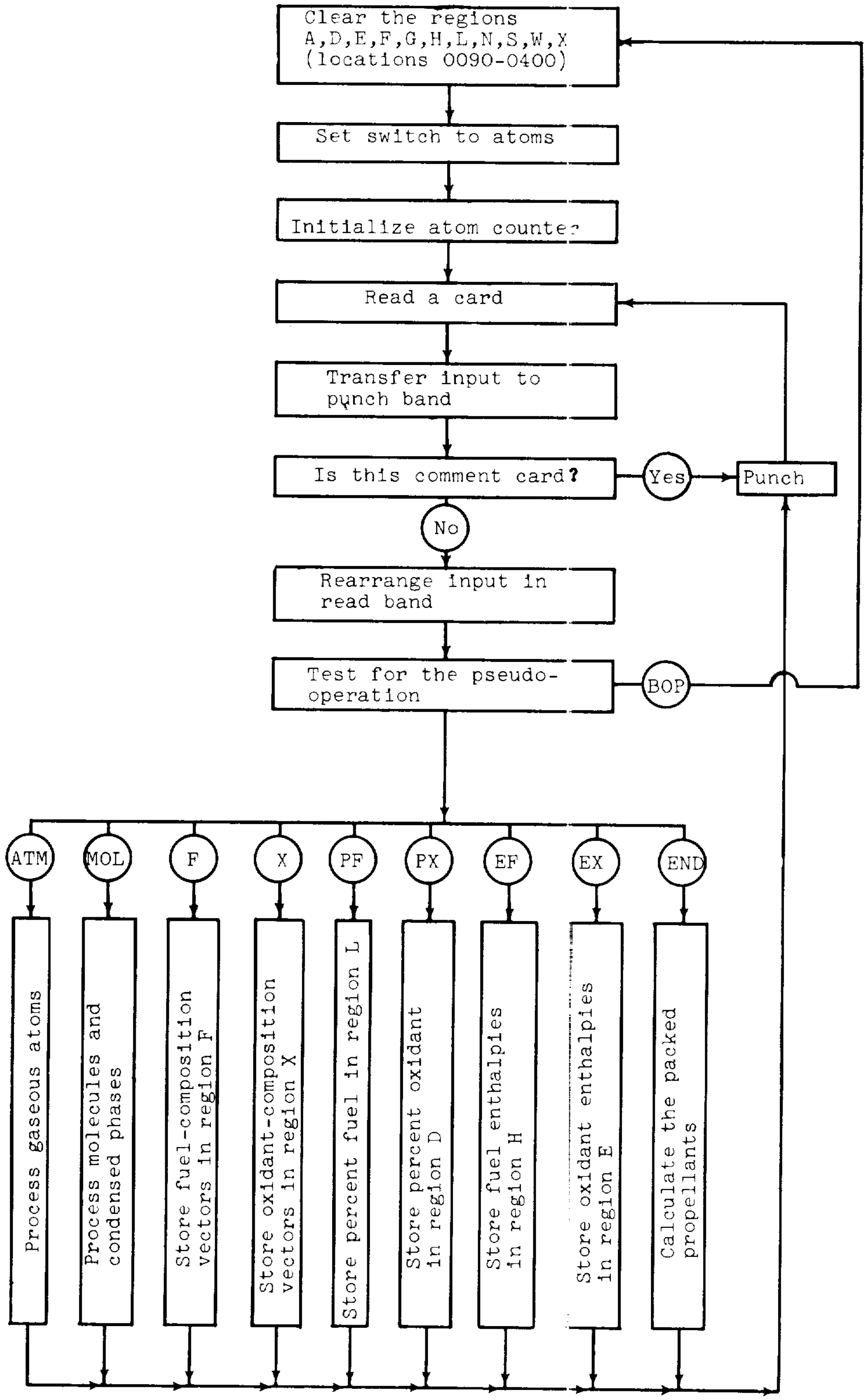

Figure 20. - Flow chart for Vector and Propellant Program.

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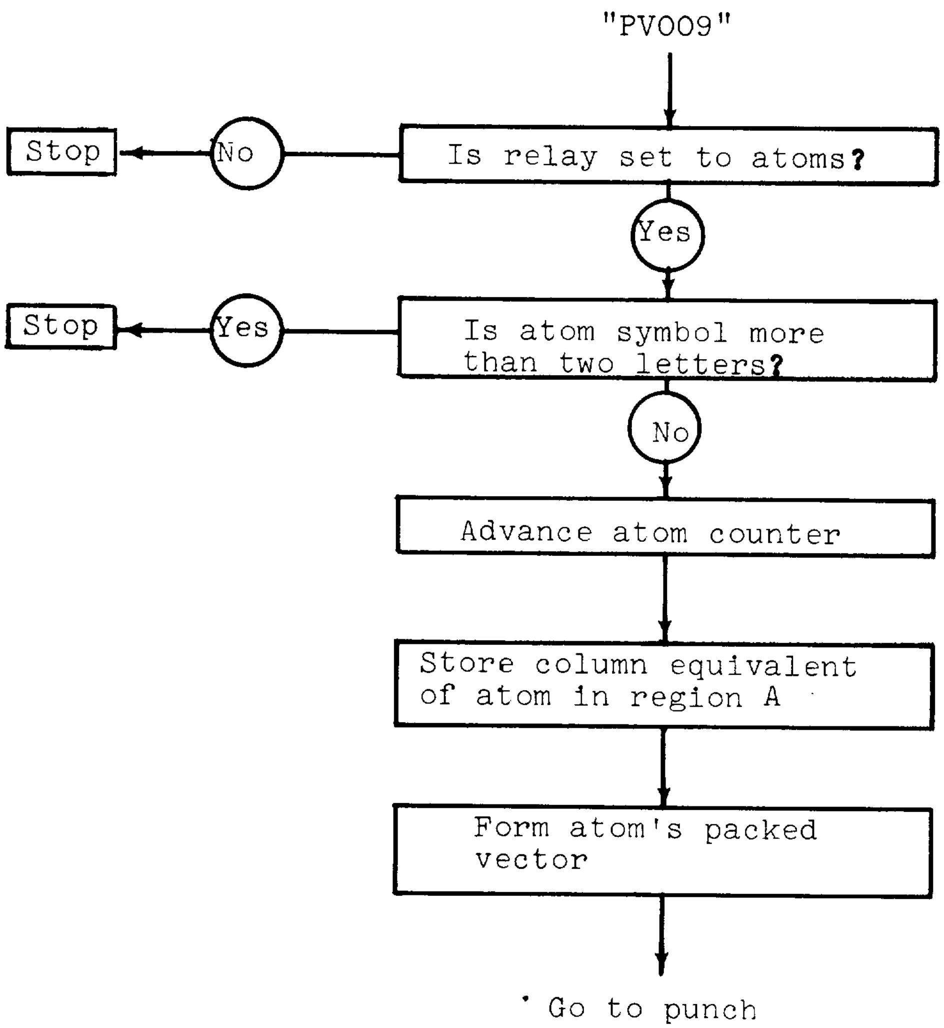

Figure 21. - Flow chart for ATM (pseudo-operation).

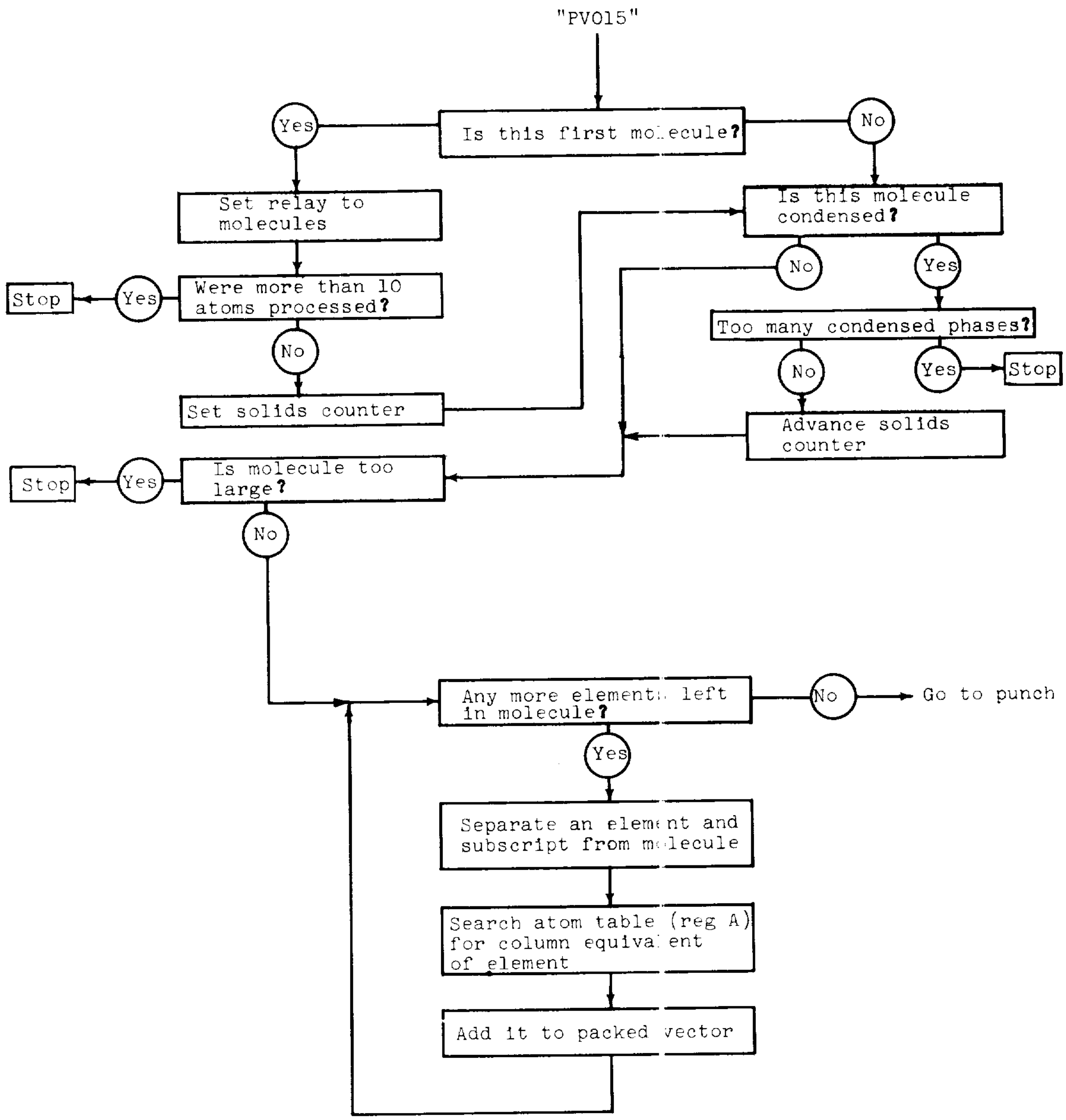

Figure 22. - Flow chart for MOL (pseudo-operation).

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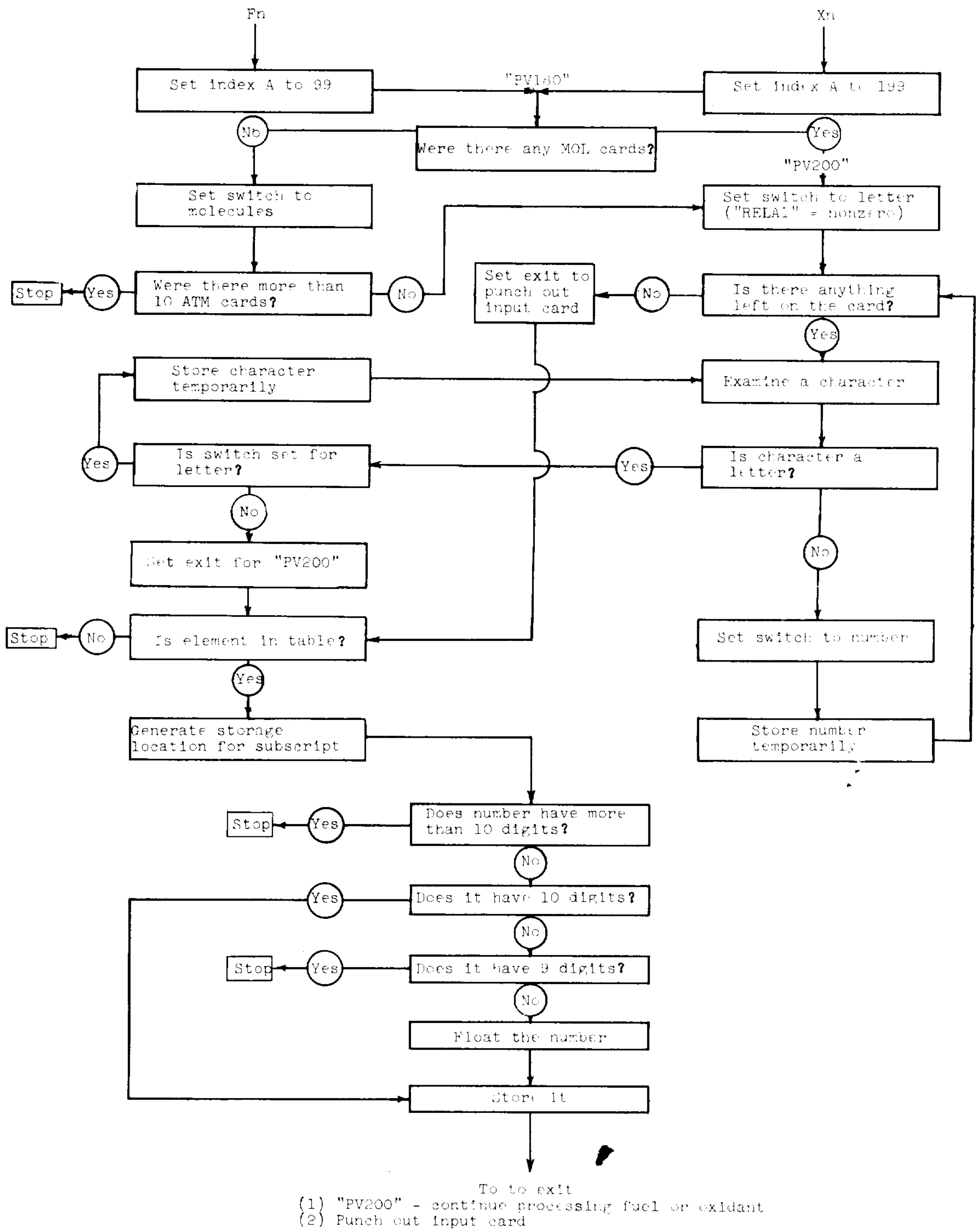

Figure 23. - Flow chart for F and X (pseudo-operations).

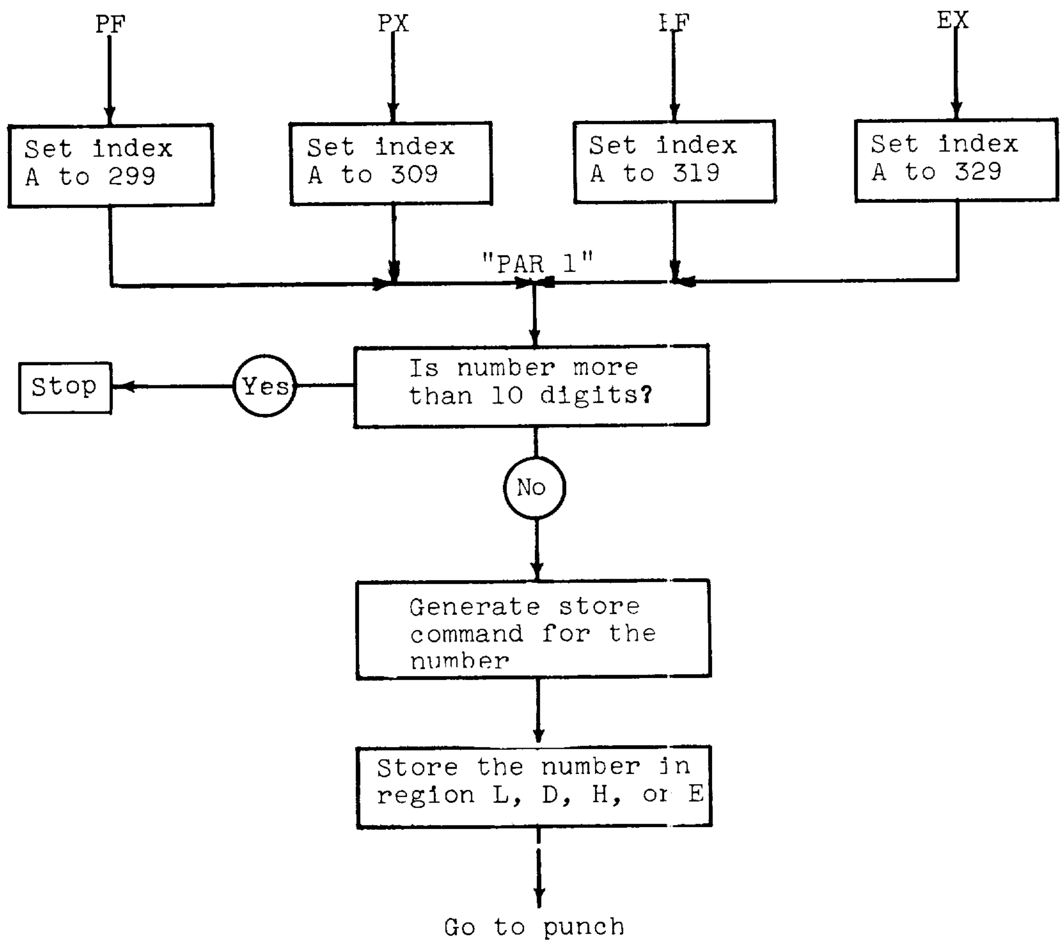

Figure 24. - Flow chart for percent fuel or oxidant and enthalpy of fuel or oxidant (pseudo-operations).

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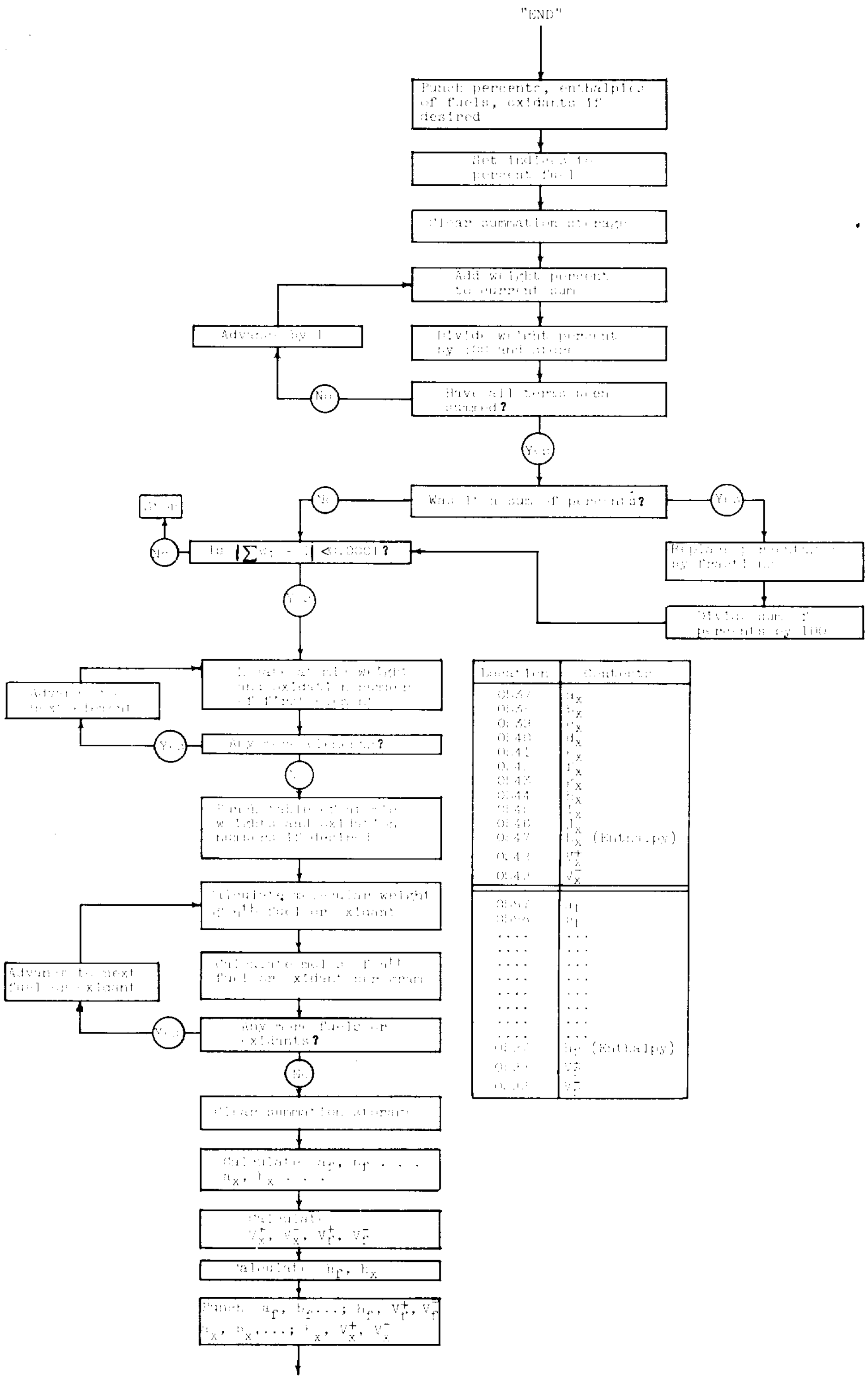

Figure [illegible]. - Flow chart for [illegible] propellants routine.

NASA TN D-132
National Aeronautics and Space Administration.
A GENERAL METHOD FOR AUTOMATIC COMPUTATION OF EQUILIBRIUM COMPOSITIONS AND THEORETICAL ROCKET PERFORMANCE OF PROPELLANTS. Sanford Gordon, Frank J. Zeleznik, and Vearl N. Huff. October 1959. 161p. diagrs., tabs. OTS price, $3.00.
(NASA TECHNICAL NOTE D-132)

A general computer program for chemical equilibrium and rocket performance calculations was written for the IBM 650 computer with 2000 words of drum storage 60 words of high-speed core storage, indexing registers, and floating point attachments. The program can carry out combustion and isentropic-expansion calculations on a chemical system that may include as many as 10 different chemical elements, 30 reaction products, and 25 pressure ratios. It calculates composition, temperature, pressure, specific impulse, specific impulse in vacuum, characteristic velocity, thrust coefficient, area ratio, molecular weight, Mach (over)

Copies obtainable from NASA, Washington

1. Engines, Rocket (3.1.8)
2. Fuels - Rockets (Includes Fuel and Oxidant) (3.4.3.3)
3. Combustion - Rocket Engines (3.5.2.5)

I. Gordon, Sanford
II. Zeleznik, Frank J.
III. Huff, Vearl N.
IV. NASA TN D-132

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number, specific heat, isentropic exponent, enthalpy, entropy, and several thermodynamic first derivatives.

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