PERFORMANCE AND NO_x MODELLING IN A DIRECT INJECTION STRATIFIED CHARGE ENGINE

by

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ABSTRACT

A model has been developed to predict the performance and NO_x emission of the Texaco stratified charge engine. This complete engine cycle program starts from engine geometry, valve and fuel injection timing, fuel characteristics and operating conditions and includes the following phases: valve overlap, intake, compression, combustion, expansion and exhaust.

The fuel mixing process is described by a jet mixing model and the equations are solved in a cylindrical coordinate system with a non-uniform pressure field. The jet shape changes were calculated for the jet impingement effect against a solid wall. The air motion inside the cylinder is determined by a detailed model to specify the field for the fuel jet.

During combustion fuel jet is divided into many elements and the combustion process of each element is analyzed as a mixing process between the jet and surrounding air, entrainment into a flame front and subsequent combustion.

For heat transfer the walls of the combustion chamber are divided into five regions; intake valve, exhaust valve, cylinder head, cylinder wall and piston top. Each region is assumed to have a different temperature and different gas velocity.

Nitric oxide emissions are calculated by using the extended Zel'dovich kinetic scheme, with the steady state assumption for the N concentration and equilibrium values used for H, O, O_2 and OH concentrations.

The model computes combustion rates, heat transfer and NO_x based on the same jet mixing assumptions without appeal to separate mixing processes at each stage.

Comparison of the model prediction with the available experimental data shows reasonably good agreement.

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SYMBOLS

A = heat transfer area

Bore = cylinder bore diameter

b = jet radius in free jet

b_c = jet radius when contacting with wall

C_p = specific heat at constant pressure

E = internal energy

H = specific enthalpy

h = distance from cylinder head to piston top

L_{cnr} = length of connecting rod

M = mass

N = engine speed

Nu = Nusselt number

P = pressure

Q = heat transfer to system

R = radial distance of jet location

R_c = radius of piston cup

Re = Reynolds number

R_g = gas constant

R_p = radius of piston

R_{cr} = radius of crank

s = distance along the jet trajectory

S_e = plume surface area

T = temperature

u = jet velocity

u_e = turbulent eddy entrainment velocity

V = volume

V_c = piston cup volume

v_i = parallel component of cross flow to u

v_n = normal component of cross flow to u

v_r = radial component of jet (swirl) velocity

v_z = vertical component of jet (swirl) velocity

w = angular velocity of jet (swirl)

W = work done by system

X_f = mass fraction of fuel in jet

Z = axial distance of jet location

α = entrainment parameter for the parallel flow

β = entrainment parameter for the normal flow

ρ = density

ϕ = equivalence ratio

θ = tangential component of jet location

θ_i = fuel injection timing

θ_j = jet contacting angle with wall (see Fig. 4)

θ_{cr} = crank angle (0 at top dead center)

λ = Taylor microscale

t_c = characteristic reaction time for the microscale

Subscripts

i = element number i

in = inflow

out = outflow

e = entrained gas in the plume

b = burned gas in the plume

u = unburned gas in the plume

∞ = the gas surrounding the jet

I Introduction

The name, Texaco Controlled Combustion System (TCCS) is used to describe a spark ignited, direct injection, stratified charge engine. The combustion chamber is a deep cup in the piston; relatively higher air swirl is used. This engine may be thought of as a cross between the homogeneous charge, spark-ignition gasoline engine, and the heterogeneous charge, compression-ignition diesel engine. However, since combustion timing is controlled by fuel injection rates; the combustion process more nearly approximates that of an open chamber diesel engine. This engine concept appears to have the well controlled, soft combustion of the spark-ignition engine and, thereby, the lightweight structure of the gasoline engine. The TCCS concept also demonstrates excellent fuel economy, broad fuel tolerance, (multi-fuel capability) and relatively low emissions. The basic conceptual details behind the Texaco Controlled Combustion System are described below while additional hardware details can be found in the references on the TCCS engine (1-4).

TCCS Engine Description

The Texaco Controlled Combustion System, as illustrated in Fig. 1, requires coordination of air swirl, fuel-injection and positive ignition. The high air swirl is obtained from a shrouded inlet valve and is amplified during compression by being forced into a deep narrow combustion chamber. The combustion chamber is essentially a cup having a cylindrical upper section with toroidal bottom cast into the head of the piston. The diameter of the cup is approximately one half of the cylinder diameter.

The high pressure injection system is based on standard diesel practice and uses a special version of a standard Roosa Master Pencil Nozzle. The distinguishing feature of this nozzle is a special flat seat and a single-hole orifice instead of the more usual conical seating, multi-hole sac-tip design. Valve opening pressure is usually set at 1500-2000 psi. For full load, fuel injection duration corresponds approximately to the time for one air swirl and the overall fuel-air ratio is near stoichiometric. At lower loads, obtained by decreased fuel injection duration and quantity, the operation is lean of stoichiometric and over all air to fuel ratio approaches 100:1 at idle conditions.

The usual diesel engine problems of long ignition delay, high rates of pressure rise and high peak pressures with low cetane fuels are avoided in TCCS operation by providing a positive ignition source. The Texaco Ignition System (TTIS) is a high energy, multi-spark unit with controlled duration. The ignition is triggered near the start of injection and continues through part or all of the injection process. The problems of spontaneous ignition and octane requirement associated with conventional gasoline engines is eliminated with TCCS since the residence time of combustible fuel-air mixtures is extremely short.

The TCCS mode of operation thus results in unique characteristics;

high part-load thermal efficiency at lean mixtures and inherently low hydrocarbon and carbon monoxide emissions resulting from excess air operation and controlled combustion rates. In addition, with the high pressure injection system, a wide range of fuel volatility can be tolerated. High compression ratio and/or inlet super charging can be used to produce good operation and performance on low cost fuels. These characteristics, in addition to quick warm-up and excellent driveability are significant factors in achieving an automotive engine with good performance and low exhaust emissions.

The purpose of the research work to be described in the following pages has been to develop a model to predict the performance of the TCCS, stratified charge engine given the engine geometry, operating parameters and the fuel properties. Once the model is shown to be effective in predicting the performance and NO_x, it can then be used as a design tool. With the brief description of the geometry and the mode of operation of the engine given above, we will now proceed to a discussion of the model.

II. Direct Injection Engine Simulation Model

1. Background

In the direct fuel injection engine, a distribution of temperature and equivalence ratio exists inside the combustion chamber. Since formation of NO_x is very much dependent on the local equivalence ratio and temperature, the key problem for this engine simulation is to define the spacial and temporal distribution of these parameters.

Early diesel engine combustion models include work by Lyn (6) and he developed an empirical calculation of the heat release rate by using triangles to simulate mixing and combustion of successive burned elements. Shahed,et. al. (7) integrated this idea with assumptions that have been widely used in spark ignition engine models (8,9) to compute NO_x. In this model, the fuel is assumed to mix with a stoichiometric amount of air before combustion and the mixed gas is divided into many packaged elements which are not mixing with each other. The temperature distribution inside the combustion chamber was explained by the different combustion time of each element. Bastress (34) took into consideration the distribution of equivalence ratio inside the combustion chamber, but this model is not based on physical mixing and combustion processes.

Following this work much effort was placed on developing physical arguments to compute the heat release rate proposed by Lyn. Shipinski (10), Whitehouse (11) and Bracco (12) have explained this delay by using fuel droplet evaporation models. But it is apparent that the combustion process in direct injection engines cannot be predicted only by evaporation time.

Spray formation and mixing in engines was studied using continuum models by Adler (13) and Rife (14). Rife concludes that the motion of the fuel jet can be satisfactorily analyzed with such a model, but this model was not integrated into a combustion calculation.

Hiroyasu (15) made a complete heterogeneous mixture combustion model by assuming a simple cone shaped spray model and a more extensive jet mixing model, which included the effects of cross flow and jet tip shape, was developed by Chiu (16). These models do not include any adjustments of the fuel jet on the wall of the combustion.

Much of the work on heterogeneous combustion is based on gas turbine engine models. Stochastic techniques appear to be a powerful method (17, 18) for including the mixing phenomena in a statistical way. Further, the mixing rates have a physical basis. However, the models lack the geometric detail required for design and consequently have somewhat limited utility. In addition, these models require an enormous computing time in the case of reciprocating engines because of the way the combustion chamber air motion changes with crank angle. It is also possible that air motion inside the reciprocating engine is complicated enough to require more than a single mixing parameter.

In previous work, a model of the TCCS engine was developed by Jain (19). In our first extension of this model to compute NO_x, the combustion chamber is divided into two areas; one a hot burned gas area, the other cold air. Each zone was considered to have uniform equivalence ratio and temperature. NO_x was calculated by using extended Zel'dovich equations. Values for the (NO_x) concentration obtained from this calculation are very low and this result was assumed to be due to the following reasons:

a) During the rapid combustion process, fixed equivalence ratio (1.4) for the combustion zone was assumed. (NO_x) concentration and one way reaction rates decrease sharply as equivalence ratio goes above 1.1 ~ 1.2.

b) The model assumed temperature constant inside the plume thereby making the (NO_x) concentration even lower, when compared with the actual case where a temperature distribution is known to exist.

Consequently we focused our attention on a new model that would include the mixing process through appeal to the equations of motion for a turbulent jet.

2. The New Model

The model divides the complete engine cycle into the following periods:

i) valve overlap period

ii) intake period

iii) compression period

iv) combustion period

v) expansion period

vi) exhaust period

Also the engine cycle is divided into the following items based on physical phenomena:

i) gas exchange

ii) heat transfer

iii) air motion inside the cylinder

iv) fuel jet dynamics

v) heat release

vi) NO_x formation

vii) friction loss

The great benefit of this program is to be able to calculate the jet dynamics coupled with the surrounding air motion, as a basis for calculation of the heat release rate, the NO_x formation and heat transfer between jet elements and combustion wall.

The computer program is based on the following assumptions;

i) Temperatures in the cylinder are functions of time and location.

ii) Pressures in the cylinder are functions of time only.

iii) The charge is assumed homogeneous during intake, compression and exhaust process. (During combustion, the fuel jet is divided into 7-15 elements and each element has a different location and different equivalence ratio.)

iv) The individual elements in the gas mixture are homogeneous but each has two different temperature zones, i.e., burned and unburned mixture. The unburned gas is composed of a low temperature mixture of air, non-reacting fuel and residual gases. The combustion zone is composed of high temperature unburned mixture and combustion products.

v) There is mixing between jet elements and their environment, but no mixing between jet elements themselves.

vi) Quasi-steady adiabatic and isentropic flow is assumed for mass flows past the valves.

vii) The intake and exhaust manifolds are treated as infinite plenums having specified pressure and temperature histories, except during reversed flow past the intake valve, when plug flow is assumed to occur.

viii) Heat transfer is predicted with a model based on concepts introduced by Woschni(20) that have been extended to use local velocities in the combustion chamber.

ix) Thermodynamic characteristics of gas are based on a model proposed by Martin and Heywood(21).

x) Nitric oxide emissions are calculated by using the extended Zel'dovich kinetic scheme, with the steady state assumption for the N concentration and equilibrium valves used for H, O, O_2, and OH concentrations in the adiabatic core.

3. Systems and Thermodynamic Equations

The early complete engine cycle simulation by Borman(22) assumed that the combustion gas as one uniform mixed element. In our model air and fuel are divided into many elements and every element has the same set of system and thermodynamic equations. A schematic of our model is shown in Fig. 2. Every element is viewed as an open system. *

i) State equation:

$$PV_i = M_i R_{gi} T_i$$

$$\frac{\dot{P}}{P} + \frac{\dot{V}_i}{V_i} = \frac{\dot{M}_i}{M_i} + \frac{\dot{T}_i}{T_i} \qquad (3\text{-}1)$$

$R_{gi} = R_{gi}(T_i, P, \phi_i)$ - constant during each computing interval

ii) Mass conservation:

$$\dot{M}_i = M_{in_i} - M_{out_i} \qquad (3\text{-}2)$$

iii) Energy conservation for open system:

$$\dot{E}_i = \dot{Q}_i - \dot{W}_i + M_{in_i} H_{in_i} - M_{out_i} H_{out_i} \qquad (3\text{-}3)$$

*All symbols are defined on pages 10 and 11.

iv) Internal energy equations:

$$E_i = M_i H_i - PV_i$$

$$\dot{E}_i = \dot{M}_i H_i + M_i \dot{H}_i - \dot{P} V_i - P\dot{V}_i \qquad (3\text{-}4)$$

v) Work definition:

$$\dot{W}_i = P\dot{V}_i \qquad (3\text{-}5)$$

vi) Enthalpy definition:

$$\dot{H}_i = C_{pi} \dot{T}_i$$

$$C_{pi} = C_{pi}(T_i, P, \phi_i) \text{ - constant during each computing interval} \qquad (3\text{-}6)$$

vii) Volume constraint:

$$\dot{V}_1 + \dot{V}_2 + \ldots\ldots \dot{V}_n = \dot{V} \qquad (3\text{-}7)$$

viii) From geometry:

$$\dot{V} = R_{cr} \times \sin\theta_{cr} + L_{cnr} \times \frac{(R_{cr}/L_{cnr})^2 \times \sin\theta_{cr} \times \cos\theta_{cr}}{\sqrt{1-(R_{cr} \times \sin\theta_{cr}/L_{cnr})^2}} \times \text{Bore}^2 \times \frac{\pi}{4} \times \frac{d\theta_{cr}}{dt} \qquad (3\text{-}8)$$

Values of $\dot{Q}_i$, M_{in_i} and M_{out_i} are given from several subprograms in advance before these differential equations will be solved. Total number of unknowns is N elements x 6 values ($\dot{E}_i$, $\dot{M}_i$, $\dot{H}_i$, $\dot{V}_i$, $\dot{W}_i$ and $\dot{T}_i$) + 2 ($\dot{P}$ and $\dot{V}$). Since the total number of differential equations is N elements x 6(Eq.(1) ∿ Eq.(6)) + (Eq. (17) and Eq. (8)), these differential equations can be solved.

In the computer program these differential equations are solved according to the following procedure:

We get $\dot{V}_i$ from Eq. (1) ∿ Eq. (6)

$$\dot{V}_i = \frac{V_i}{M_i C_{pi} T_i} (\dot{Q}_i + M_{in_i} H_{in_i} - M_{out_i} H_{out_i} - (M_{in_i} - M_{out_i}) H_i) + \frac{M_{in_i} - M_{out_i}}{M_i} V_i + (\frac{V_i^2}{M_i C_{pi} T_i} - \frac{V_i}{P}) \dot{P} \tag{3-9}$$

Substituting $\dot{V}_i$ in Eq. (7) by Eq. (9), we get

$$\dot{P} = (\dot{V} - A)/B \tag{3-10}$$

where

$$A = \sum_{i=1}^{n} \frac{V_i}{M_i C_{pi} T_i} (\dot{Q}_i + M_{in_i} H_{in_i} - M_{out_i} H_{out_i} - (M_{in_i} - M_{out_i}) H_i) + \frac{M_{in_i} - M_{out_i}}{M_i} V_i \tag{3-11}$$

$$B = \sum_{i=1}^{n} \left(\frac{V_i^2}{M_i C_{pi} T_i} - \frac{V_i}{P} \right) \tag{3-12}$$

4. Jet Model

From the study of diesel combustion in a rapid compression machine by Rife and Heywood(14), it can be concluded that the fuel jet breaks into droplets near the nozzle orifice and the relative velocity of droplets in the jet flow is small. This means the mixing between packaged jet elements themselves is not important and only mixing between jet elements and surrounding air is taken into consideration. From the characteristics lengths analysis by Jain(19) he concluded that most of the droplets can evaporate before reaching the spark plug. Thus the model that fuel ignition is initiated by the spark plug and heat release is controlled only by mixing is now justified.

The mixing model is based on the turbulent entrainment assumptions of Hoult and Weil(23). The rate of entrainment for turbulent plumes introduced by Hoult and Weil have been modified to include the effects of large density variations, as suggested by Ricou and Spalding(24) and Escudier(25).

For the application of these turbulent entrainment theories to reciprocal engines, three more new aspects were added to them.

1) The NO_x value is not determined only by the present gas characteristics, but also it is very much dependent on the previous histories of gas characteristics. For this purpose jet model is solved by using the packaging method in order to identify every jet element at any instant.

2) All the previous jet models were set in a two-dimensional cartesian coordinate system. However, a cylindrical coordinate system is much more appropriate for reciprocal engines. The most important difference between these two systems is that the pressure field is not constant any more in the cylindrical coordinate system, especially in high swirl ratio engines. Jet elements, thus, are affected by the surface forces from the non-uniform pressure field and these surface forces have the same magnitude but opposite direction of the centrifugal forces when the jet elements have the same density and angular velocity as the surrounding air.

3) Restrictions of the combustion wall were taken into account. The cross section geometry of the jet was assumed to be in the shape of a D (Fig. 4) when it is contacting with the wall with the same centerline position and cross section area of the cylindrical jet. This consideration proved to have a good advantage for determining jet trajectory and heat transfer rate between jet elements and the combustion wall.

Let us consider a jet element "1" into a quiescent atmosphere of element "∞" in the absence of any chemical reaction (Fig. 3). Then, the general equations of the jet model reduce to the following.

i) Conservation of mass

when jet is not contacting with the wall

$$\frac{1}{\frac{ds}{dt}} \cdot \frac{1}{dt}(\rho\pi b^2 u) = (\rho/\rho_\infty)^{1/2} \; \rho_\infty \; 2\pi b(\alpha|u-v_i| + \beta|v_n|) \qquad (4\text{-}1)$$

when jet is contacting with the wall

$$\frac{1}{\frac{ds}{dt}} \cdot \frac{1}{dt}(\rho\pi b^2 u) = (\rho/\rho_\infty)^{1/2} \; \rho_\infty \; 2\pi b_c(1-\frac{\theta_j}{2\pi}) \cdot (\alpha|u-v_i| + \beta|v_n|) \quad (4\text{-}1)$$

θ_j: jet contacting angle with the wall (see Fig. 4)

Max. of $\theta_j = \pi$

ii) Conservation of angular momentum

$$\frac{d}{dt}(\rho\pi b^2 uRw) = Rw_s \frac{d}{dt}(\rho\pi b^2 u) - \rho\pi b^2 u \; v_r w \qquad (4\text{-}2)$$

w_s: angular velocity of swirl

$\rho\pi b^2 uV_r w$: coriolis force

iii) Conservation of radial direction momentum

$$\frac{d}{dt}(\rho\pi b^2uv_r) = \rho\pi b^2uRw^2 - \rho_\infty\pi b^2uRw_s^2 + V_{R\infty}\frac{d}{dt}(\rho\pi b^2u) \qquad (4\text{-}3)$$

$\rho\pi b^2uRw^2$: centrifugal force

$\rho_\infty\pi b^2uRw_s^2$: force arising from pressure gradient swirling flow

iv) Conservation of vertical direction momentum

$$\frac{d}{dt}(\rho\pi b^2uv_z) = v_{z\infty}\frac{d}{dt}(\rho\pi b^2u) \qquad (4\text{-}4)$$

v) From geometry

$$u\frac{du}{dt} = R^2w\frac{dw}{dt} + Rw^2\frac{dR}{dt} + v_r\frac{dv_r}{dt} + v_z\frac{dv_z}{dt} \qquad (4\text{-}5)$$

$$\frac{dR}{dt} = v_r \qquad (4\text{-}6)$$

vi) Conservation of fuel

$$\frac{d}{dt}(\rho\pi b^2uX_f) = 0 \qquad (4\text{-}7)$$

vii) Jet is in the combustion chamber

Jet location $(R, \theta, Z) \leq$ combustion chamber (4-8)

viii) For contacting angle θ_j

$$\pi b^2 = \pi b_c^2 \times \left(1 - \frac{\theta_j}{2\pi}\right) + \frac{b_c^2}{2} \sin\theta_j \qquad (4\text{-}9)$$

5. Air Motion Surrounding the Jet

Calculation of gas velocity surrounding the jet is required to define the jet trajectory and mixing ratio between the jet and gas. A first order calculation was made by M. Martin(21). This model is limited to the regions close to the cylinder wall or piston by the assumptions and the model can be extended to the whole region inside the cylinder for our purpose. Since an exact solution including viscous effects is difficult and time-consuming, several assumptions are necessary for simplification of this model.

i) The combustion chamber is divided into three regions (Fig. 6);

Inside each region, axial velocity is uniform on the same horizontal plane, radial velocity and angular velocity is uniform on the same radius.

ii) In region (3) there is no radial velocity.

This assumption is necessary in order to avoid a large velocity discontinuity at the piston cup edge due to a large area discontinuity there.

iii) Boundary conditions.

Axial velocity = 0 at cylinder head,

radial velocity = 0 at cylindar wall,

and axial velocity is the same as piston at piston surface.

iv) Swirl at bottom center is solid body rotation.

v) Angular momentum is not conserved.

After precisely checking the pictures (26) of the rapid compression machine it was found that the swirl amplitude (the ratio of swirl at TDC to swirl at BDC) decreases when swirl magnitude goes up. Under normal Texaco engine operation (swirl ratio is 3.65 x rpm at BDC), this swirl decaying is about 10%. The following equation is used for estimating swirl decaying:

$$\frac{\text{swirl momentum decayed}}{\text{initial swirl momentum}} = C_{DE} \times w^2 \times \text{Time}$$

C_{DE}: swirl decaying factor 6.5×10^{-6} for Texaco engine

w: angular velocity (rad/sec)

Time: time since intake valve closes (sec)

(1) Calculation of Radial Velocities (Fig. 6)

(a) $\underline{R_c < r < R_p}$

$$\frac{dM_2}{dt} = - \frac{dM_1}{dt} = 2\pi r h \rho \bar{v}_r \qquad (5\text{-}1)$$

$$M_1 = \pi(R_p^2 - r^2)\ h\rho \qquad (5\text{-}2)$$

$$M_2 = (\pi r^2 h + V_c)\rho \qquad (5\text{-}3)$$

M_i: the mass in control volume i

t: time

ρ: density of the charge

V_c: piston cup volume

Combining (5-1), (5-2) and (5-3)

$$(\pi r^2 h + V_c)\rho' + \pi r^2 \rho h' = - \pi(R_p^2 - r^2)\ (h'\rho + \rho' h)$$

$$\rho' = -\left(\frac{h'}{K_1 + h}\right)\rho \qquad (5\text{-}4)$$

when $K_1 = \dfrac{V_c}{\pi R_p^2}$ (5-5)

Let $X = \dfrac{h}{K_1}$ (5-6)

Then solving for ρ in terms of initial conditions at time t_o yields

$$\rho(t) = \rho(t_o) \left(\frac{X(t_o) + 1}{X(t) + 1}\right) \qquad (5\text{-}7)$$

From Eq. (5-1) and (5-2) we have

$$\bar{v}_r = \frac{-\frac{dM_1}{dt}}{2\pi r h \rho} = \frac{-\pi(R_p^2 - r^2)(h'\rho + \rho' h)}{2\pi r h \rho}$$

Using (5-4) and letting

$$v_p = \frac{dh}{dt} = \text{piston velocity (upward velocity has negative sign)}$$

We find

$$\bar{v}_r(r,t) = -\left(\frac{r}{2K_1}\right)\left[\left(\frac{R_p^2}{r^2}\right) - 1\right] \frac{v_p(t)}{X(t)\ (1+X(t))} \qquad (5\text{-}8)$$

(b) $\underline{0<r<R_c}$

The radial velocity inside the piston cup is assumed to be zero.

$$\frac{dM_2}{dt} = -\frac{dM_1}{dt} = 2\pi r h \rho \bar{v}_r \qquad (5\text{-}9)$$

$$k_2 = V_c/(\pi R_c^2) \qquad (5\text{-}10)$$

$$M_1 = \pi(R_p^2 - r^2)\ h\rho + \pi(R_c^2 - r^2)\ K_2\rho \tag{5-11}$$

$$M_2 = \pi(h + k_2)r^2\rho \tag{5-12}$$

Combining (5-9), (5-11) and (5-12)

$$\pi(h + k_2)r^2\rho' + \pi r^2\rho h' = -\pi(R_p^2 - r^2)\ (h'\rho + h\rho')$$

$$- \pi(R_c^2 - r^2)\ k_2\rho'$$

$$\rho' = -\left(\frac{h'}{k_1 + h}\right)\rho \tag{5-13}$$

From Eq. (5-9) and (5-12) we have

$$\bar{v}_r(r,t) = \left(\frac{r}{2k_1}\right) \frac{\left(\frac{k_2}{k_1} - 1\right)\ v_p(t)}{X(t)\ (1 + X(t))} \tag{5-14}$$

(2) Calculation of Axial Velocities

(a) $\underline{0<Z<h}$

$$-\frac{dM_1}{dt} = \frac{dM_2}{dt} = \pi R_p^2\ \bar{v}_z\rho \tag{5-15}$$

$$M_1 = \pi R_p^2\rho Z \tag{5-16}$$

$$M_2 = \pi R_p^2 \rho (h-Z) + V_c \rho \tag{5-17}$$

We assume

$$\bar{v}_{z1}(Z,t) = v_p Z/h \quad \text{for } R_c<r<R_p \tag{5-18}$$

From (5-15), (5-16), (5-17) and (5-18) we have

$$\bar{v}_{z2}(Z,t) = v_p Z/h \left\{ 1 - \left(\frac{R_p}{R_c}\right)^2 \frac{1}{(X(t) + 1)} \right\} \quad \text{for } 0<r<R_c \tag{5-19}$$

(b) <u>$h<Z$</u>

$$-\frac{dM_1}{dt} = \frac{dM_2}{dt} = \pi R_c^2 \bar{v}_z \rho \tag{5-20}$$

$$M_1 = \pi R_p^2 h + \pi R_c^2 (Z-h) \tag{5-21}$$

$$M_2 = \pi R_c^2 (k_2 - (Z-h)) \tag{5-22}$$

From (5-20), (5-21) and (5-22) we have

$$\bar{v}_z(Z,t) = \frac{k_1 - k_2 + Z}{k_1 + h} v_p \tag{5-23}$$

(3) Calculation of Angular Velocity

The gas angular velocity inside the cylinder is assumed to be a solid body rotation.

From momentum equation

$$\underbrace{\int_0^{R_p}\int_0^{h}\int_0^{2\pi} \rho w r^3 d\Theta dz dr}_{\text{momentum in region (1)}} + \underbrace{\int_0^{R_c}\int_0^{k_2}\int_0^{2\pi} \rho w r^3 d\Theta dz dr}_{\text{momentum in region (2)}}$$

$$= (1 - \text{DECAY}) \times \underbrace{\left[\int_0^{R_p}\int_0^{h_o}\int_0^{2\pi} \rho_o w_o r^3 d\Theta dz dr + \int_0^{R_c}\int_0^{k_2}\int_0^{2\pi} \rho_o w_o r^3 d\Theta dz dr\right]}_{\text{initial momentum}} \quad (5\text{-}24)$$

DECAY: swirl decaying ratio

From Eq. (5-24)

$$w(t) = (1 - \text{DECAY}) \times \frac{\rho_o}{\rho} \times \frac{k_2 R_c^4 + h_o R_p^4}{k_2 R_c^4 + h R_p^4} \; w_o$$

$$= (1 - \text{DECAY}) \times \frac{(h + k_1)}{(h_o + k_1)} \times \frac{k_2 R_c^4 + h_o R_p^4}{k_2 R_c^4 + h R_p^4} \; w_o \quad (5\text{-}25)$$

Figure 7 and Fig. 8 are the calculation results using these assumptions. At -50 BTDC gas movement is dominated by the piston velocity and swirl. The radial velocity is almost negligible. At - 30 BTDC, the radial velocity begins to grow as the gas in the squish area is forced into the piston cup. At -10 BTDC, the piston is almost stopped and the radial velocity, especially at the edge of the piston cup, is very high. Squish effect can be computed from this study. This more detailed study in general confirms the basic conclusions of Martin but provides more detailed specification of the flows for jet mixing analysis.

6. Combustion Model

From the observation of pictures in the rapid compression machine it was found that the unburned gas mixture hitting the spark plug has a small plume first and this plume grows, entraining surrounding unburned gas mixture. The main flame can be seen a little bit downstream from the spark plug and this ignition delay time is about 0.7 - 0.8 msec at 2000 rpm. These phenomena are also verified by log P-log V diagrams shown in Marsh thesis(27). A mixing and chemical induction time seems to be associated with this delay and the order of magnitude is similar to the delay in a spark ignition engine.

To explain the combustion delay mentioned above, an analytical model for combustion reaction time was developed. In this model a fuel-air element starts to burn when it hits the spark plug but the fuel in the jet element doesn't burn instantaneously because of finite flame speed and a typical induction period. In the early stages of combustion growth, this burning nucleus is so small that this stage can be treated as if there were no combustion. The schematic of this model applied to the TCCS engine is shown in Fig. 9.

i) Entrainment of unburned mixture

The entrainment of the surrounding gas mixture into the burning nucleus has been treated with an analysis based on the work of Blizard and Keck(28) which relates the turbulent eddy entrainment velocity to the engine speed.

The mass rate of entrainment of surrounding gas mixture can be given as

$$\frac{dM_e}{dt} = \sqrt{\rho_u \rho_b} * Se * Ue \tag{6-1}$$

where Se is plume surface area and Ue the turbulent eddy entrainment velocity. In the Blizard and Keck model, the entrainment velocity is based on the velocity of the inlet jet. However, in the TCCS geometry, entrainment into the spark nucleus is dominated by the velocity of the fuel jet

$$Ue \simeq 0.22u \tag{6-2}$$

ii) Combustion delay

Tabaczynski(29) computed a characteristic reaction time (τ) for a large eddy using a characteristic reaction time (τ_c) defined for an eddy of the order of the turbulent microscale. The rate of mass burned in an individual eddy is assumed to be proportional to the mass of unburned gas that exists in the plume

$$\frac{dM_b}{dt} = \frac{M_u}{\tau_c} = \frac{M_e - M_b}{\tau_c}$$

M_e: entrained gas in the plume

M_b: burned gas in the plume

M_u: unburned gas in the plume

$\tau_c = \lambda/Se$ characteristic reaction time for the microscale

λ: Taylor microscale

$$\lambda = 0.17 \times \frac{\text{intake valve lift}}{\text{compression ratio}} \qquad \text{(Ref. (28) and (30))}$$

Se: laminar flame speed (Ref. (28))

7. NO_x Model

The NO_x formation model is based on the same model as combustion mentioned before which is composed of unburned gas mixture outside flame front, burning zone and burned gas. But the temperatures of these zones are defined by only two typical temperatures: burned and unburned gas temperatures, by decoupling the burning zone into these two temperature zones. Figure 12 shows the mass histories of these zones during the period from the fuel injection to fully developed plume. As can be seen, the burning zone is very thin and disappears quickly, and this zone is proved not to have much effect on NO_x amount by computer simulation. This model also calculates the transferred amount of NO_x between elements by mixing. The NO formation model described by Lavoie, Heywood and Keck (32), and Komiyama and Heywood (8) is used, i.e., NO formation is governed by the extended Zel'dovich mechanism:

$$N + NO \underset{K-1}{\overset{K+1}{\rightleftarrows}} N_2 + O \tag{7-1}$$

$$N + O_2 \underset{K-2}{\overset{K+2}{\rightleftarrows}} NO + O \tag{7-2}$$

$$N + OH \underset{K-3}{\overset{K+3}{\rightleftarrows}} NO + H \tag{7-3}$$

The hydrocarbon oxidation reactions are fast relative to the NO formation process and a reasonable approximation is that the species O, O_2, H, OH and N_2 are in equilibrium. A steady-state assumption is made for [N]. The rate of change of NO mass fraction {NO} due to chemical reaction;

$$\frac{d\{NO\}}{dt} = \frac{2M_{no}}{\rho} \frac{(1 - (\{NO\}/\{NO\}_e)^2)R_1}{(1 + K\{NO\}/\{NO\}_e)} \tag{7-4}$$

{NO} = NO mass fraction

M_{no} = molecular weight of NO

ρ = gas density

$R_1 = K_{+1}\,(O)_e\,(N_2)_e = K_{-1}\,(N)_e\,(NO)_e$

$(\ )_e$ = mole concentration in equilibrium

$$K = \frac{R_1}{R_2 + R_3} = \frac{K_{-1}(NO)_e}{K_{+2}(O_2)_e + K_{+3}(OH)_e}$$

8. Heat Transfer Model

Heat transfer calculation of the TCCS engine seems to require a more complicated model than that of the spark ignition engine, because the heterogeneous mixture causes a large temperature distribution inside the combustion chamber, and also heat transfer between the jet and piston top has an important effect on the early stage of combustion like the impingement effect. The wall inside the TCCS engine, thus, is divided into five regions as many diesel engines are so, i.e., piston top, cylinder wall, cylinder head, intake valve and exhaust valve (see Fig. 10). These temperatures are estimated as $650^{o}K$, $600^{o}K$, $650^{o}K$, $500^{o}K$ and $700^{o}K$ respectively. Each wall of the combustion chamber is in contact with the hot, burned gas plume while the remaining are in contact with relatively cold unburned gas mixture.

All the necessary data for the heat transfer calculation like the heat transfer area of the jet elements and gas velocity at the wall are provided by the jet model calculation.

The conventional engine heat transfer correlations of Woschni(20) have been used to model the heat transfer process. The Nusselt number is expressed as;

$$Nu = 0.035\, R_e^{0.8} \qquad (8\text{-}1)$$

Using Woschni's relationships for gas velocities, density, viscosity and thermal conductivity, the convective heat transfer coefficient is expressed as;

$$\mu = 7014\ B_{ore}^{-0.2}\ P^{0.8}\ G^{-0.53}\left[C_1 + 100C_2 \frac{VT_o}{P_oV_o}(P-P_{is}) + C_3v_s\right]^{0.8} \qquad (8\text{-}2)$$

$$Q = C\mu A(T - T_w) \qquad (8\text{-}3)$$

B_{ore}: bore

P: pressure

T: temperature

A: heat transfer area

N: engine speed

V: total volume

v_s: swirl velocity

P_o, T_o and V_o: pressure, temperature and volume when intake valve closes

P_{is}: when compression and expansion are isentropic

Woschni used an average piston speed $(\frac{SN}{30})$ as a gas velocity at the wall in his equations but the swirl velocity has a much higher magnitude than the piston speed for the Texaco engine and the swirl velocity term (V_s) was added to them. Heat transfer is not assumed to occur between jet elements and air.

III Comparison of Simulation Predictions with Experimental Data and Conclusions

Experimental works were performed on a TCCS engine by Marsh (27) and Fly (33). A 3-7/8" x 3-7/8" single cylinder engine designed by Texaco has been set up at the Sloan Automotive Laboratory at MIT to carry out experimental investigations on the TCCS, stratified charge concept. A brief description of the engine set up and cross-cut distillate fuel characteristics are given in Table 1-3. Additional details regarding the engine set up, data taking and data reduction can be found in their theses (27) (33).

The following comparisons of calculation results with experimental data were conducted while changing injection timing and equivalence ratio;

i) Mass fraction burned (Figs. 15,16)

ii) Cylinder pressure (Figs. 17,18)

iii) NO versus injection timing (Fig. 19)

iv) Volumetric efficiency, indicated mean effective pressure and peak pressure versus injection timing (Fig. 20)

v) Exhaust temperature versus injection timing (Fig. 21)

vi) NO concentration histories in each element (Fig. 23) (prediction only).

vii) Swirl effects on indicated mean effective pressure and NO (Fig. 24) (prediction only).

As shown in these figures, every parameter except exhaust temperature was predicted accurately by this simulation model. The major conclusions which have been drawn from this study are:

1. Ignition delays were calculated successfully by the travelling time from fuel nozzle to spark plug and induction time of unburned mixture to the burning zone.

2. The burning rate was accurately predicted by the jet mixing process based on turbulent entrainment assumptions.

3. Good agreement in cylinder pressure during compression and expansion process means that the heat transfer amount between gas and wall was accurately estimated by the model, which calculates the local gas velocities and jet contacting areas with the wall based on the Woschni correlations.

4. NO_x values were predicted within practical errors. NO_x concentration is very sensitive to the mixing process. The figure of NO_x concentration histories in each element shows that exhaust NO_x can be reduced drastically by rapid mixing after the spark plug.

5. The model predicted higher exhaust temperatures than actual data. Heat transfer calculations from gas to port seems to be necessary for precise exhaust temperature prediction.

6. Higher swirl ratio has a good effect on NO concentrations at high equivalence ratios due to the rapid cooling of burned gas. At low equivalence ratios, however, higher swirl ratio has an unfavorable effect on NO concentration due to the coincidence of higher gas temperatures and peak cylinder pressures.

7. Some more detailed calculation about air motion inside the cylinder is recommended to get more accurate NO prediction over wide range engine operations.

8. It is recommended that this model be applied for calculating another size engine performance to check this model validity.

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TABLE 1

Engine Specifications

Dimensions

bore	3.875 in.
stroke	3.875 in.
connecting rod	6.625 in.
clearance volume	4.570 $in.^3$

Valve Timings

	Opens		Closes	
inlet valve	10 BTCD	(1)	55 ABDC	(2)
	0	(2)	45	(1)
exhaust valve	55 BBDC	(1)	10 ATDC	(2)
	45	(2)	0	(1)

(1) at 0.006 in. valve lift

(2) valve face flush with head

TABLE 2

Summary of Instrumentation

Temperatures

Air Orifice Inlet	Water Outlet	Bearing Oil
Air Inlet	Exhaust	Fuel Inlet
Water Inlet	Crankcase Oil	Fuel Returns

Instrument - All Points

Chromel - Alumel Thermocouple

Omega DS - 500 Digital Readout

Resolution 1°F

Pressures

	Method	Resolution
Inlet Air	Water Manometer	.1 in.
Crankcase Vacuum	Water Manometer	.1 in.
Oil Pressure	Panel Gage	2 PSI
Exhaust	Mercury Manometer	.1 in.
Dynamometer Load	Mercury Manometer	.1 in.
Injection Line	Kistler 601 Piezoelectric transducer, Kistler 504E Charge Amplifier	30 PSI*
Combustion Chamber	Kistler 609A Piezoelectric Transducer, Kistler 503D Charge Amplifier	.2 PSI**

TABLE 3

Summary of Fuel Properties

	Cross-cut Distillate
Molecular Wt.	∿125
H:C Ratio	1.825
Specific Gravity	.80
Boiling Point ^{o}F	106-648
Lower Heating Valve (Btu/lbm)	18038
Stoichiometric F/A Ratio	.0694
FIA - %	
Aromatics	29.5
Olefins	3.0
Saturates	67.5
Octane No. RON	76.6
Cetane No.	28.3

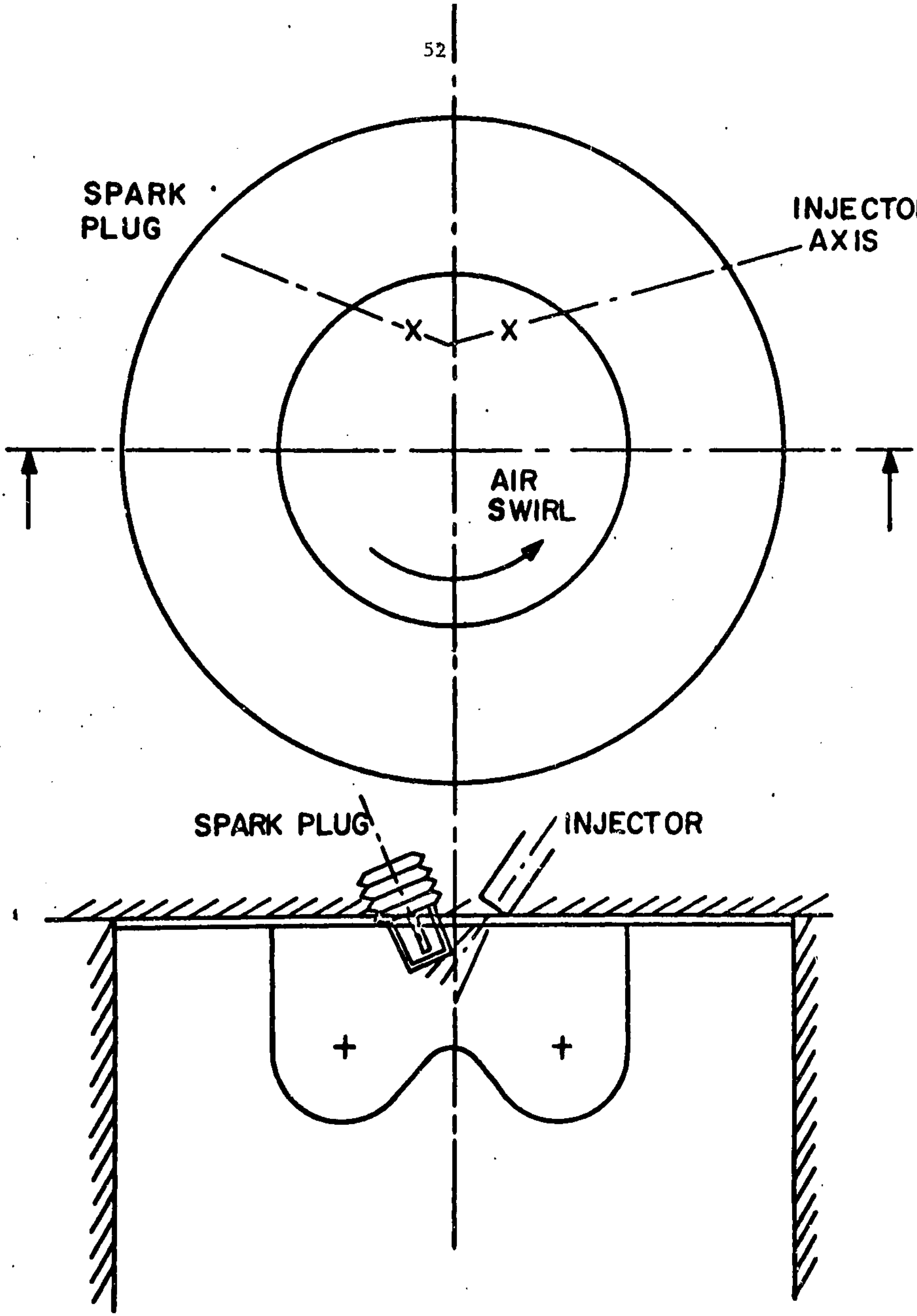


Fig. 1 TEXACO CONTROLLED COMBUSTION SYSTEM (SCHEMATIC)

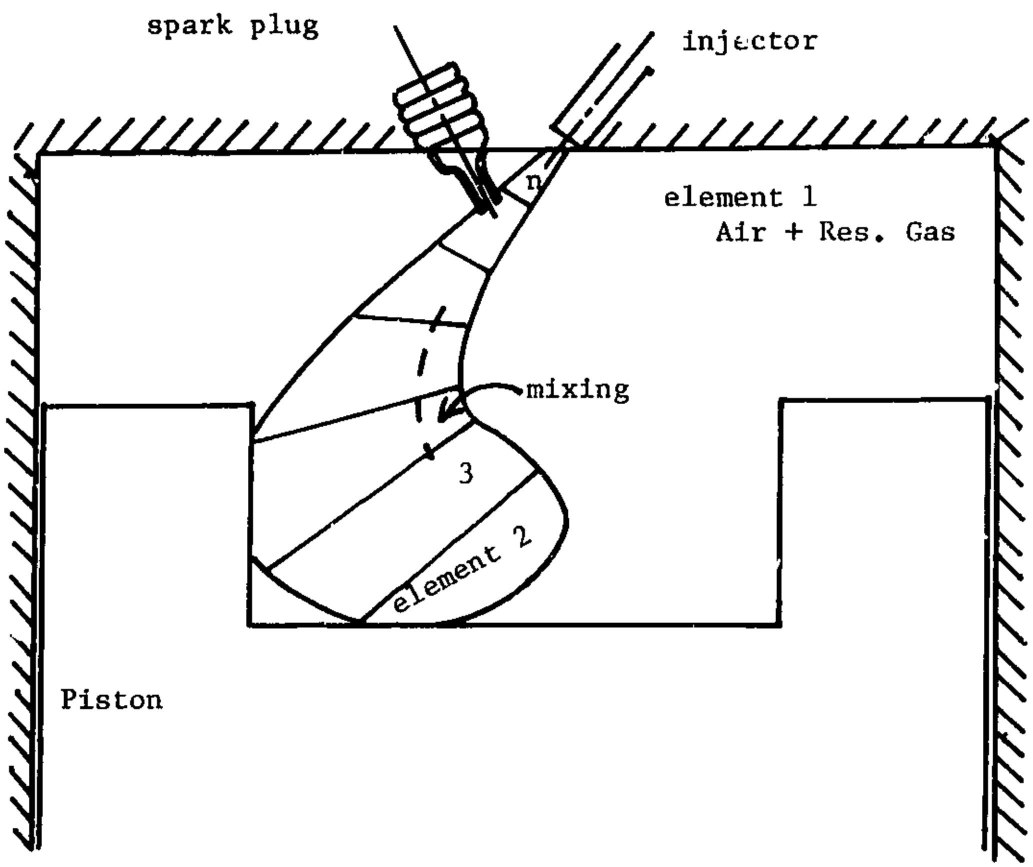
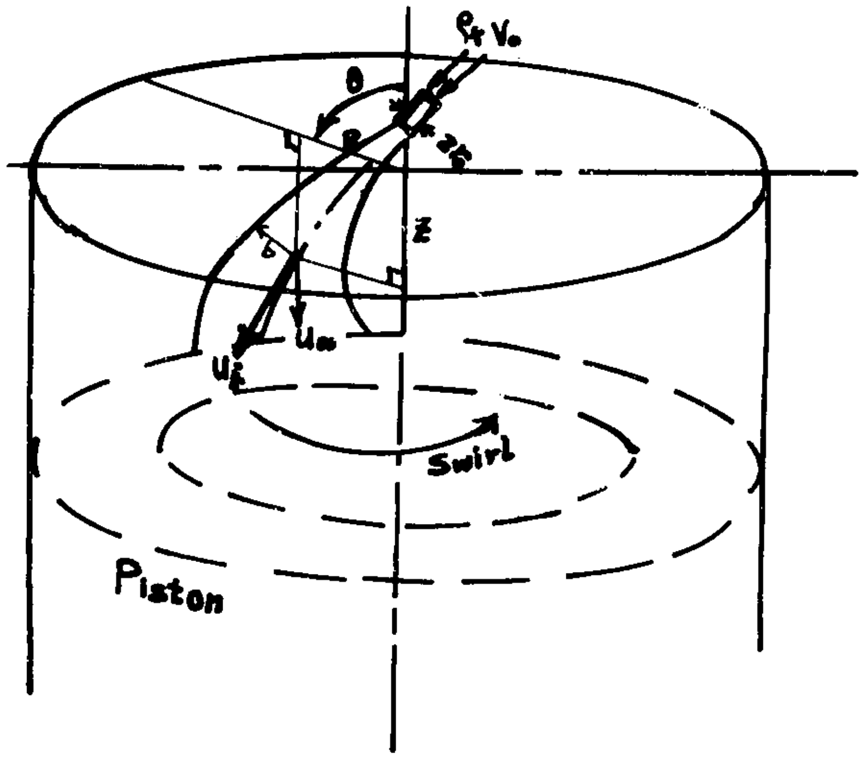


Fig. 2 System Model



Jet Velocity $U_j = U_j(v_R, w, V_z)$

Air Velocity $U_\infty = U_\infty(v_{R\infty}, w_s, V_{z\infty})$

Fig. 3 Jet Model with Swirl

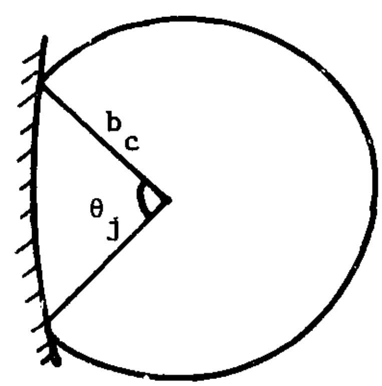
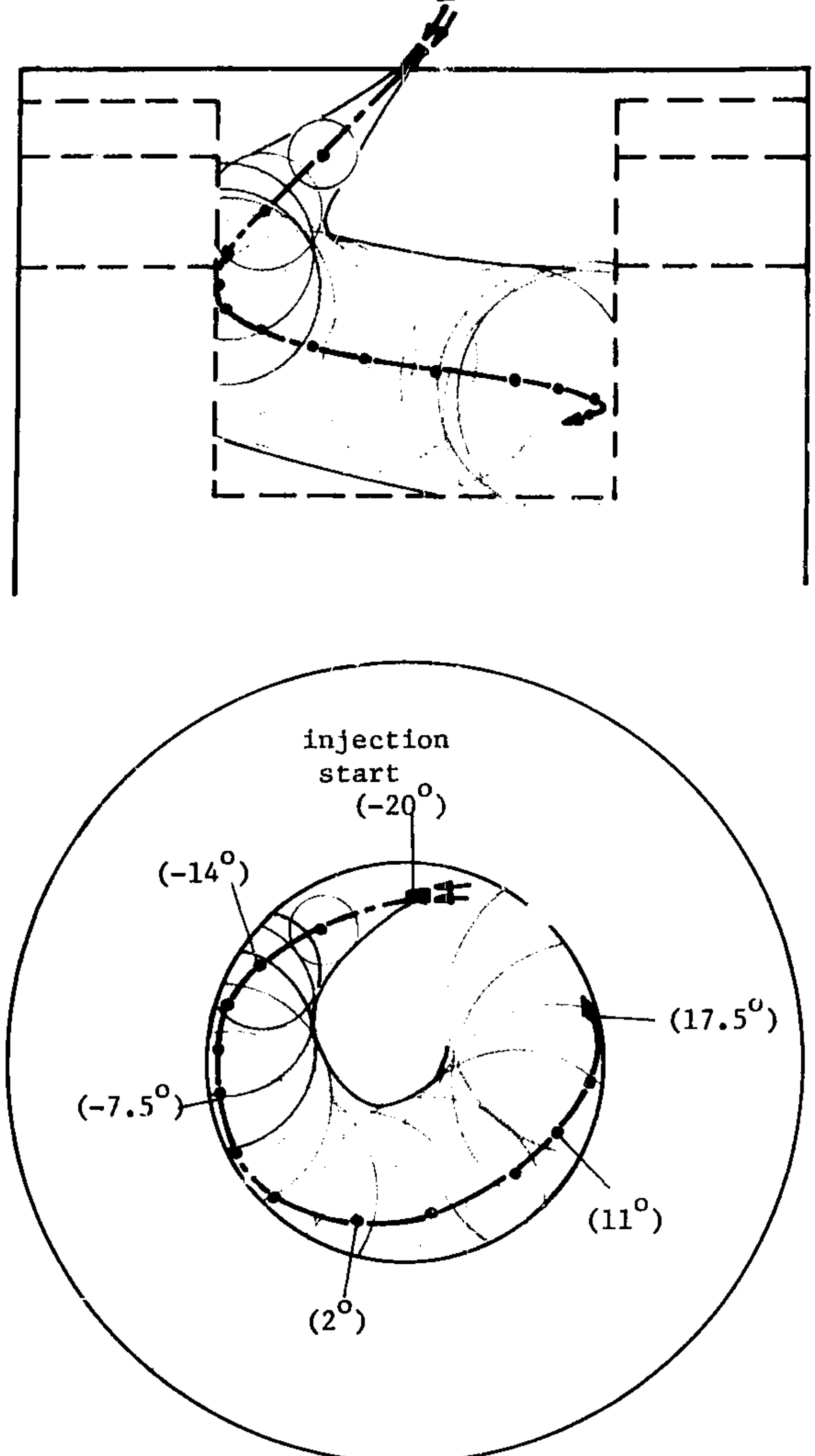


Fig. 4 Jet Cross Cut Shape When Contacting with Wall



Engine Speed = 2000 rpm

Swirl Ratio = 3.65 x Engin
Speed (at

ϕ = 0.545

Fig. 5 Calculation Results of Jet Model
(First Jet Element Trajectory)

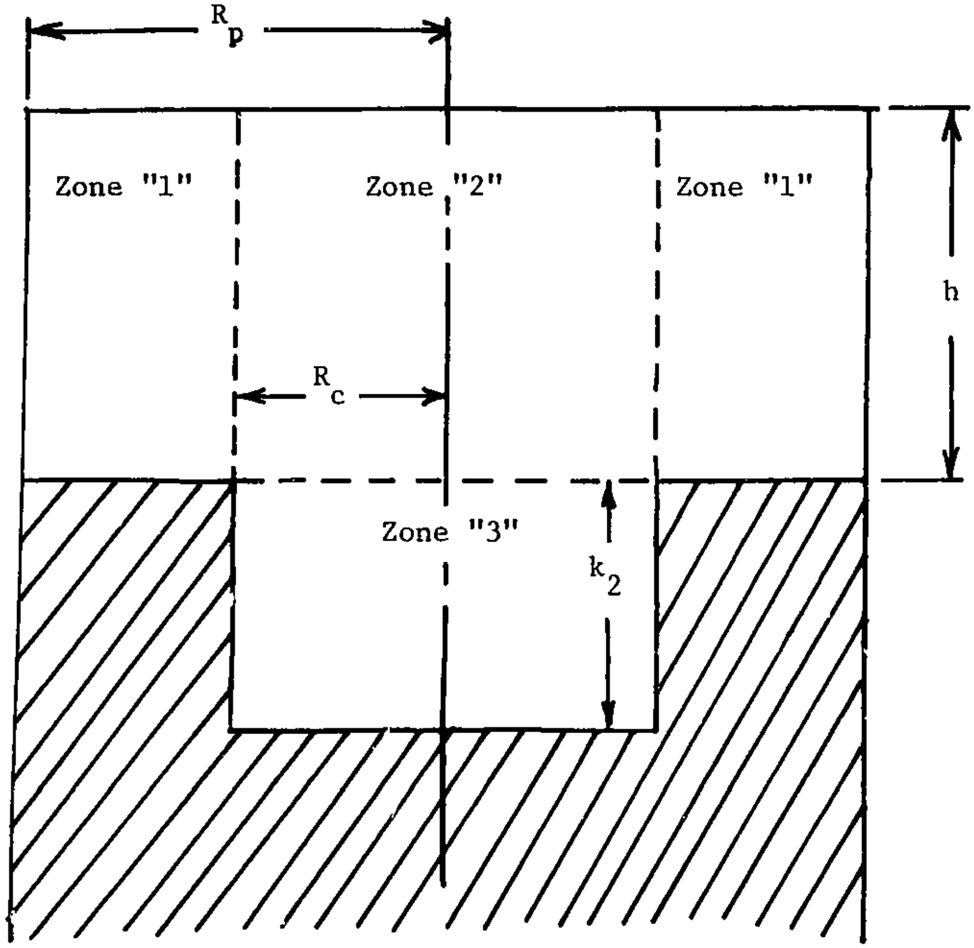


Fig. 6 Model of Air Motion Calculation

RPM = 2500 rpm
SCALE 20 m/s → 1 cm (velocity)

i) at -50° before TDC

piston speed = 11.8 m/s

ii) at -30° before TDC

piston speed = 8.1 m/s

iii) at -10° before TDC

piston speed = 2.9 m/s

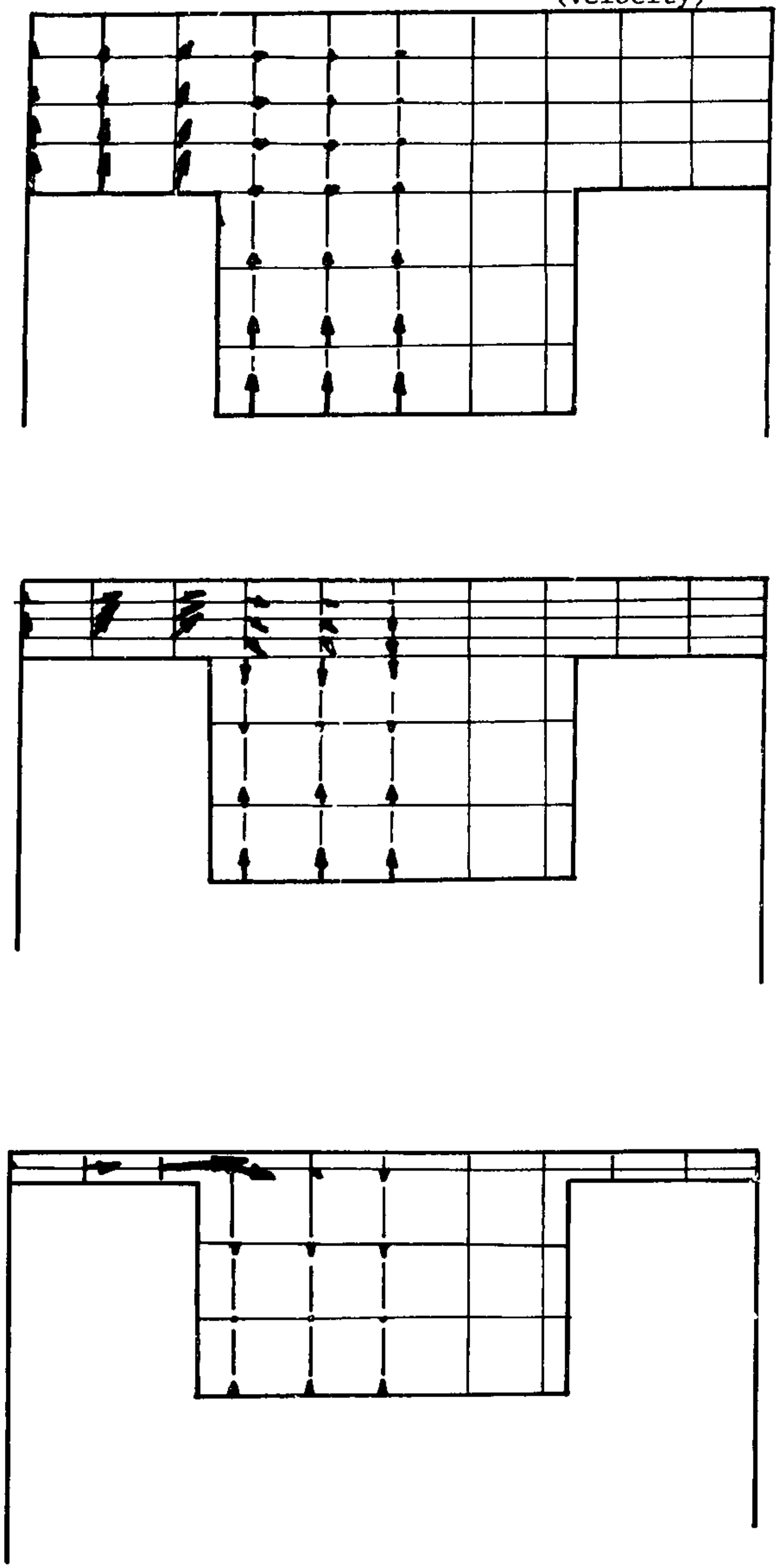


Fig. 7 Air Motion by Calculation

(Radial and Axial Components)

RPM = 2500 rpm

Scale 20m/s → 1 cm (velocity)

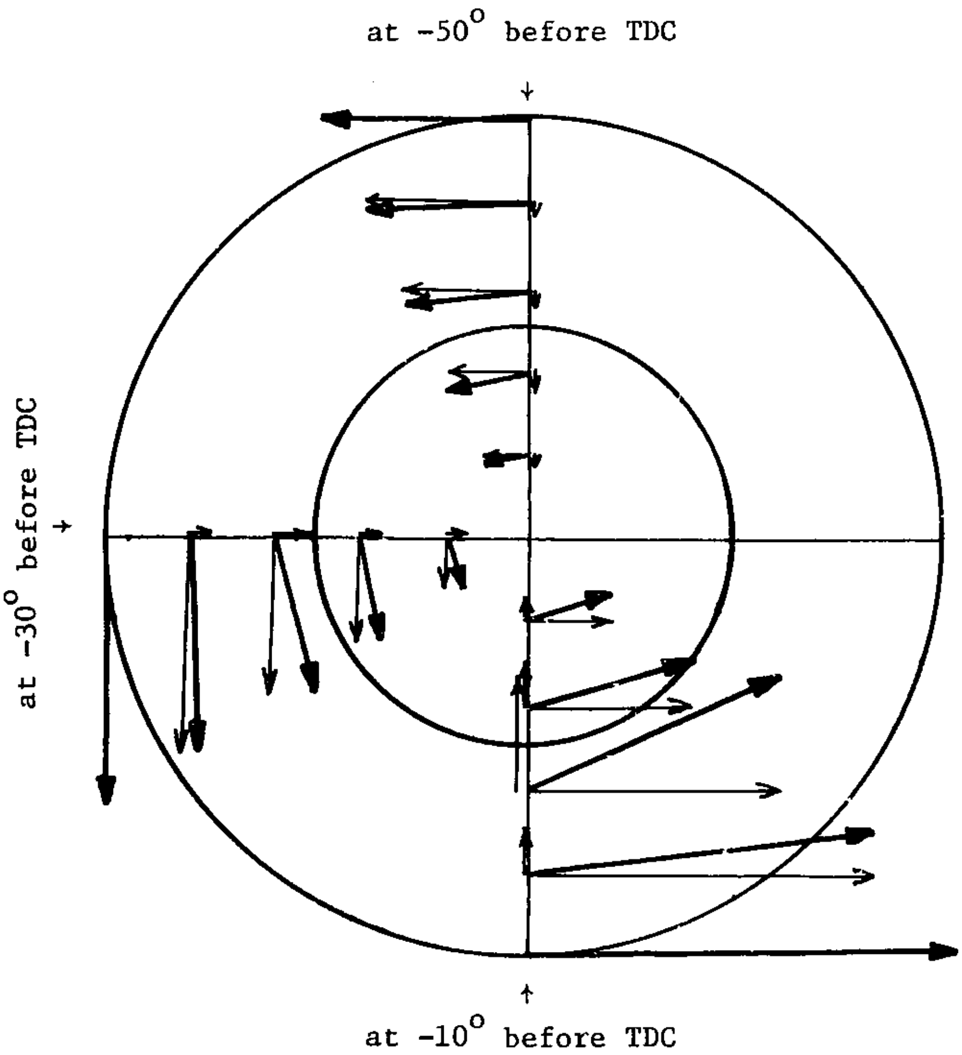


Fig. 8 Air Motion (Prediction)
(Radial and Tangential Components)

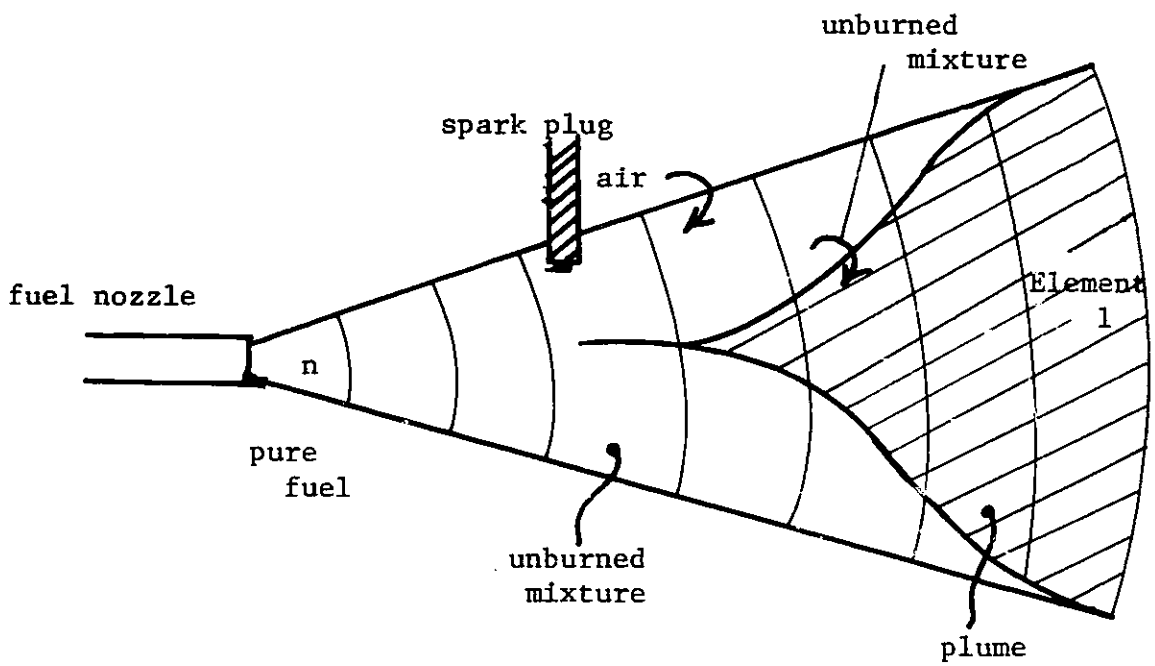
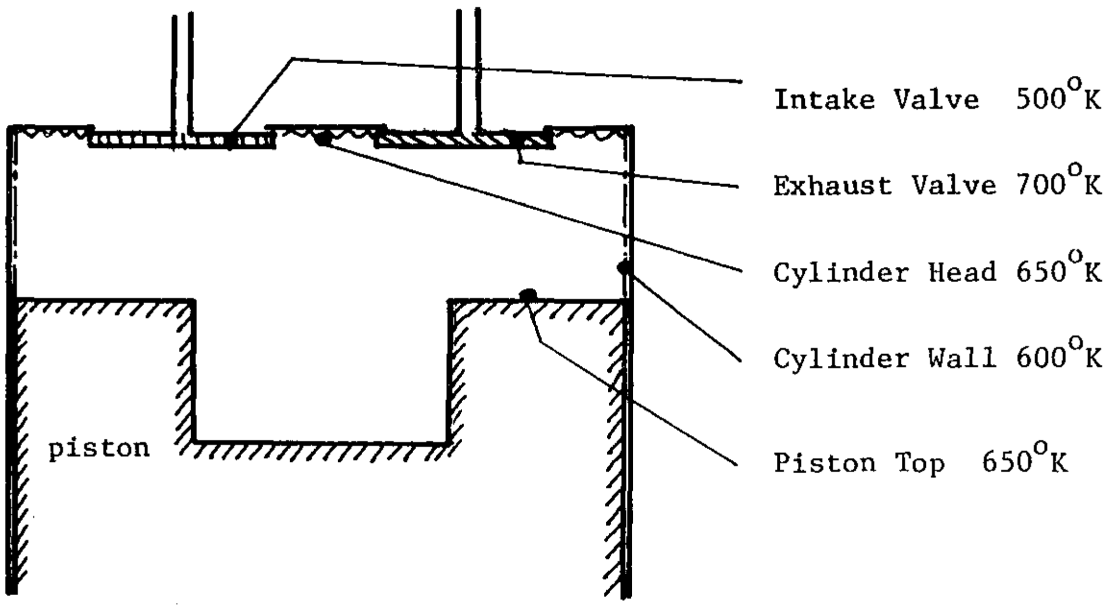


Fig. 9 The Schematic of Ignition Model



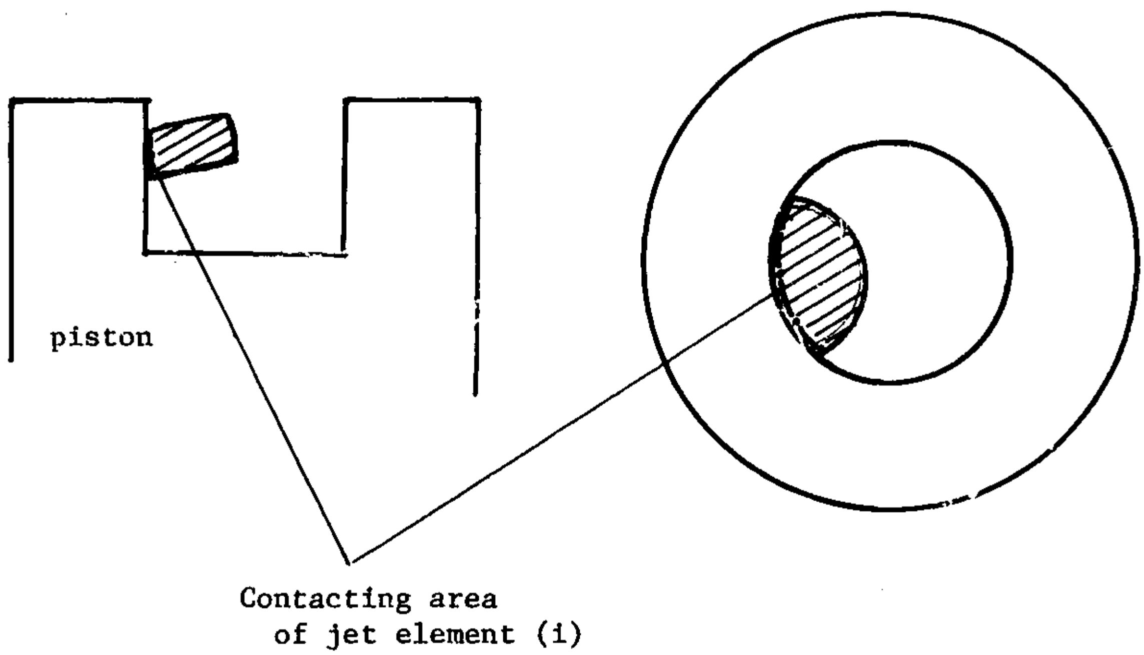


Fig. 10 Heat Transfer Model

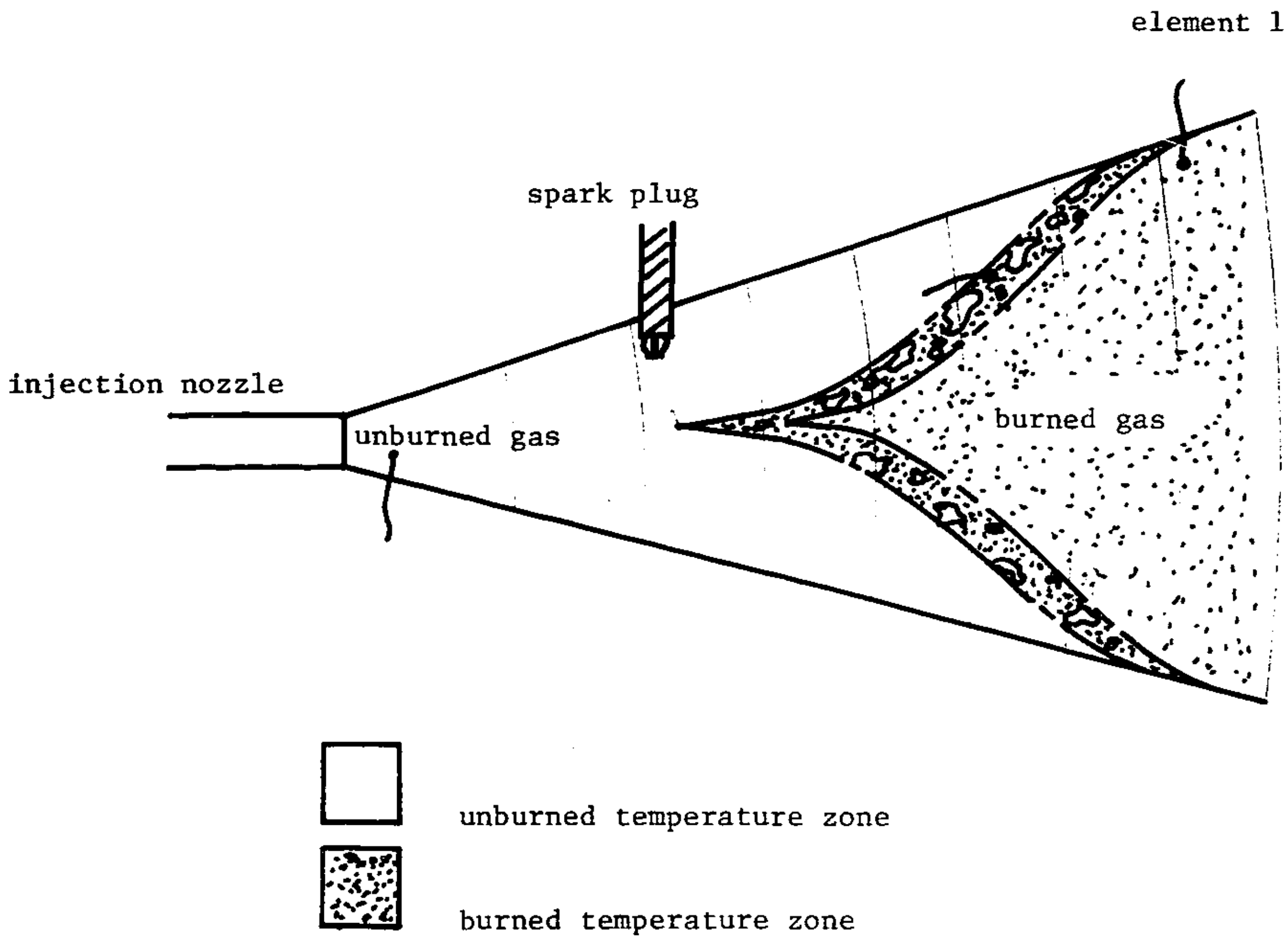


Fig. 11 The Schematic of NO_x Model

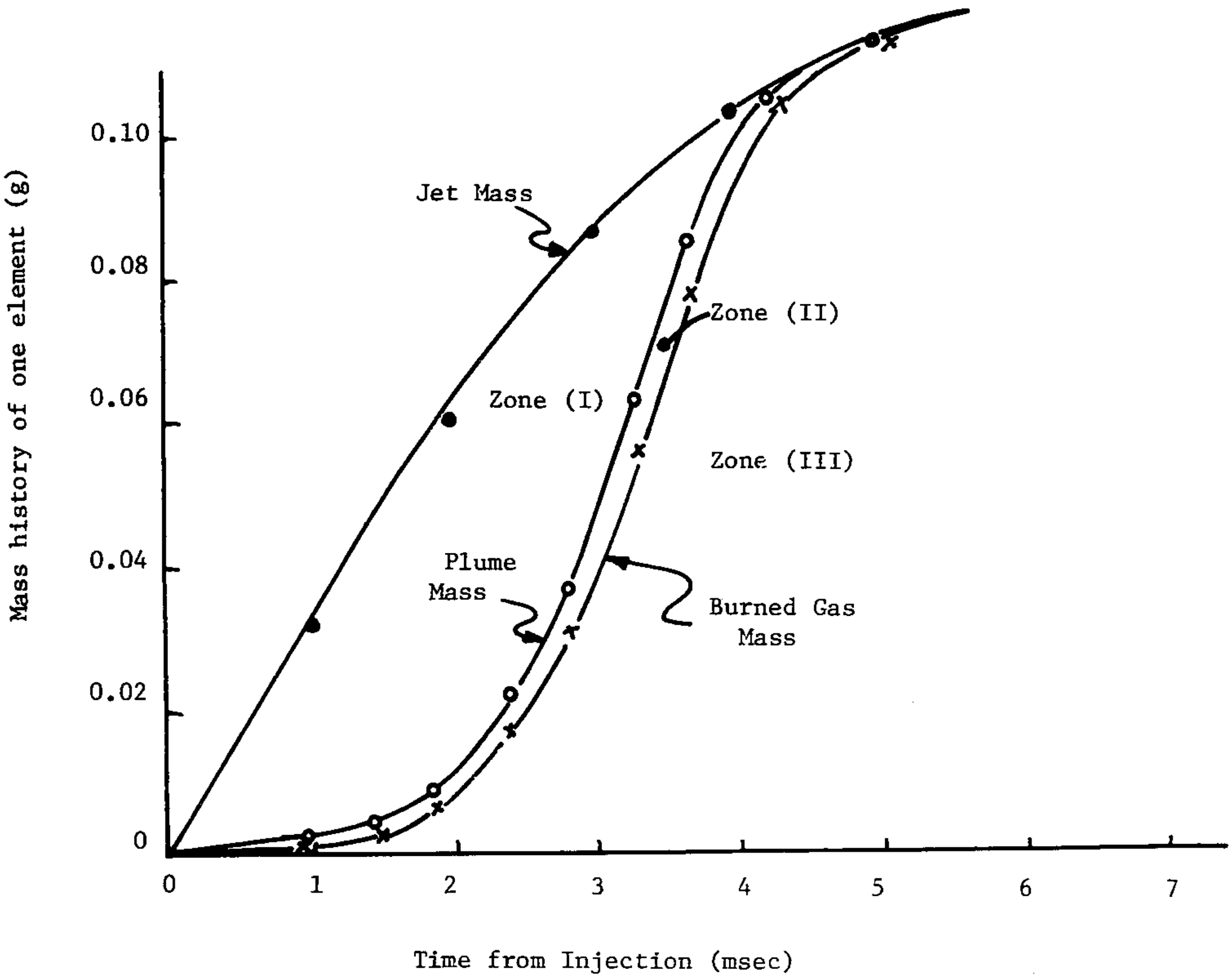


Fig. 12 Mass History of One Element (prediction)

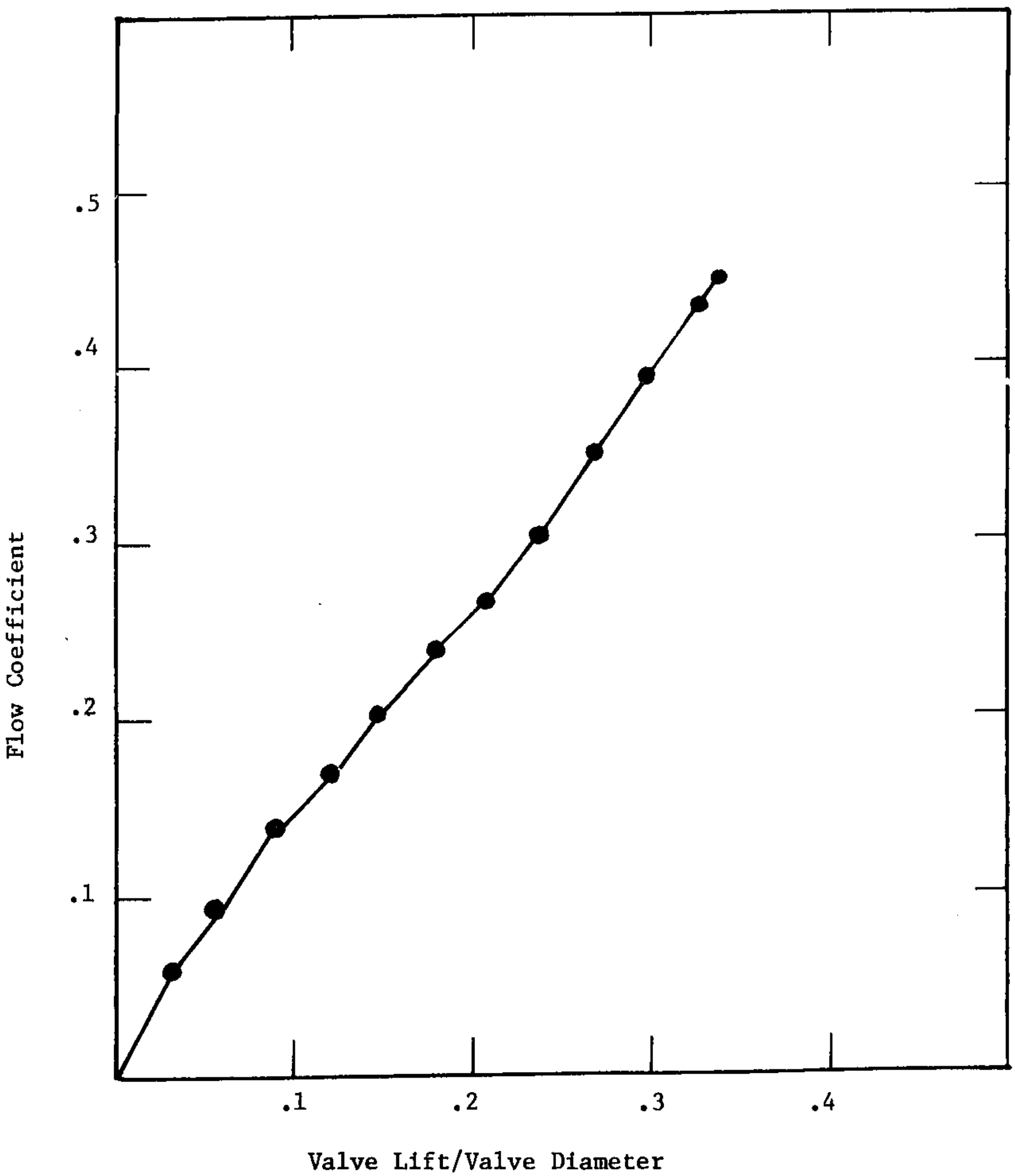


Fig. 13 Valve Flow Coefficient for the Intake Valve

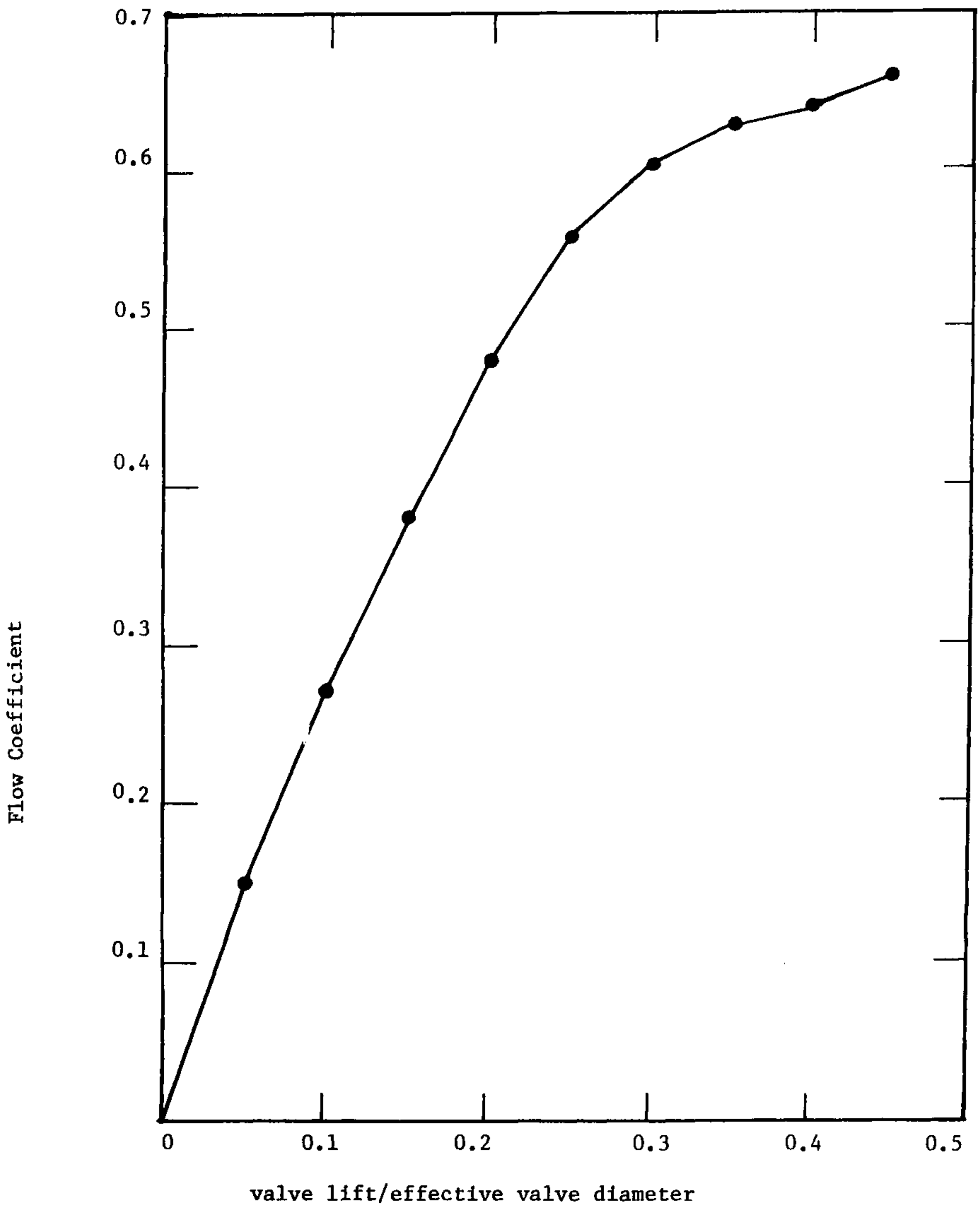


Fig. 14 Valve Flow Coefficient for the Exaust Valve

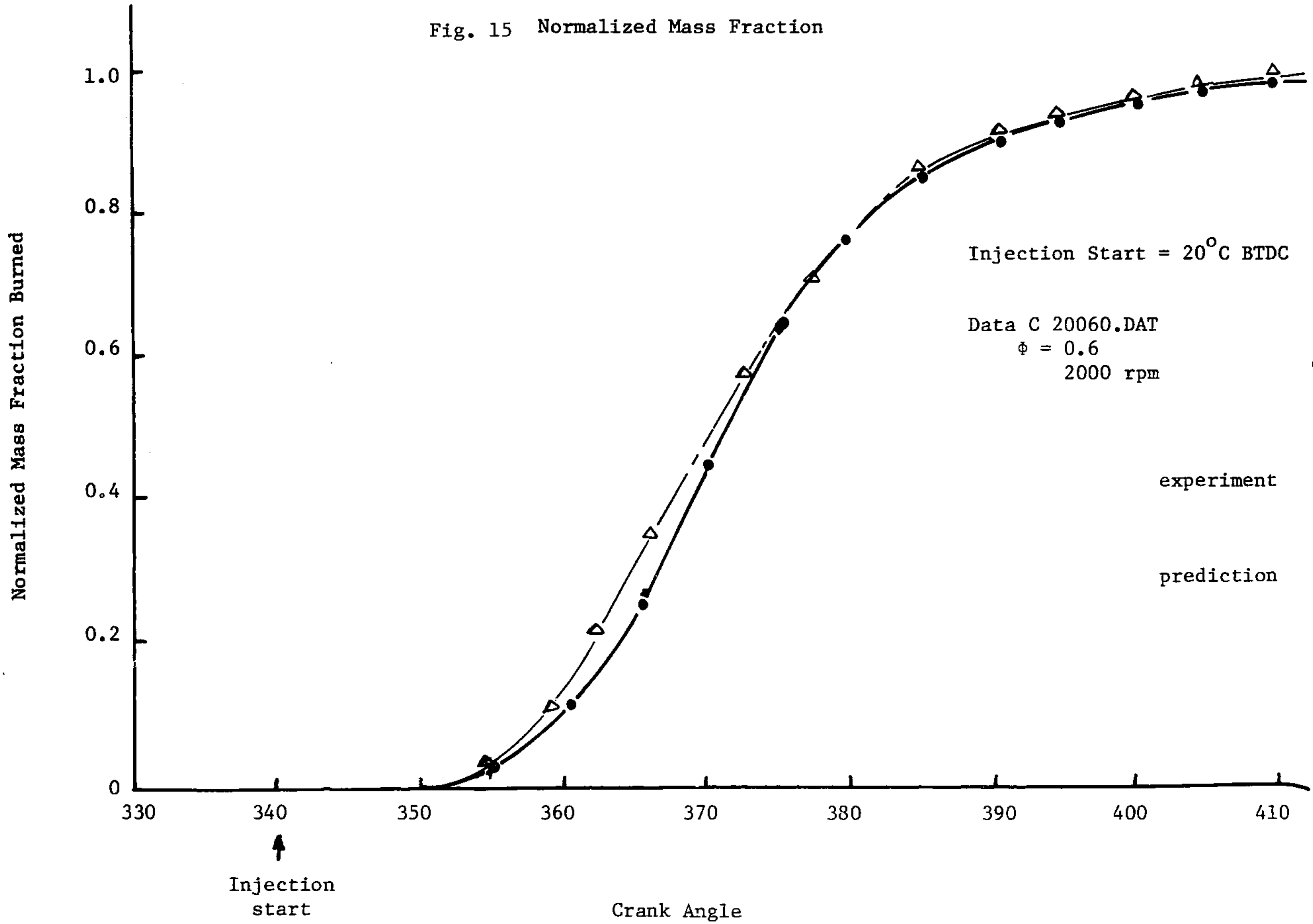
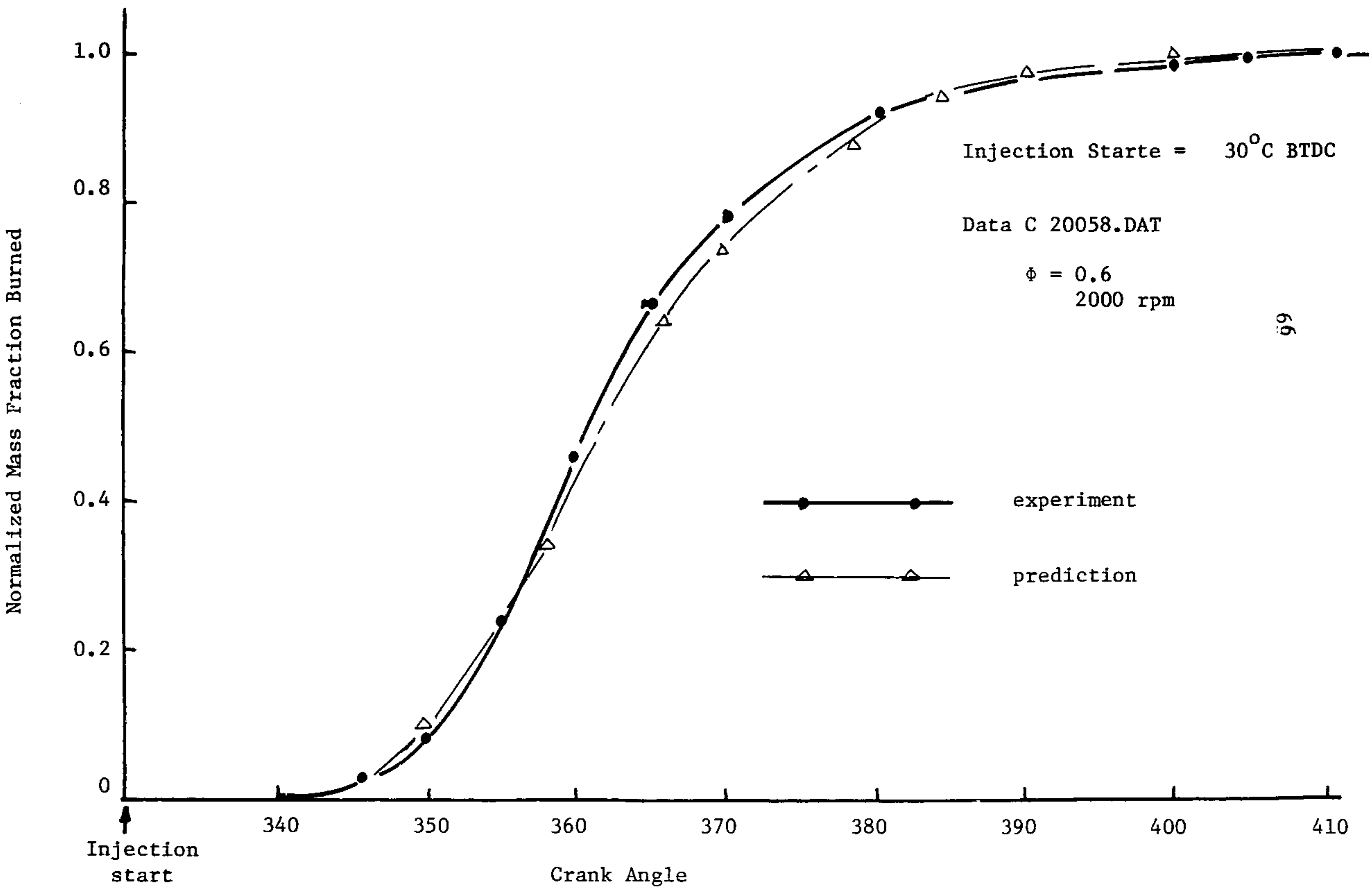


Fig. 15 Normalized Mass Fraction

Fig. 16 Normalized Mass Fraction Burned



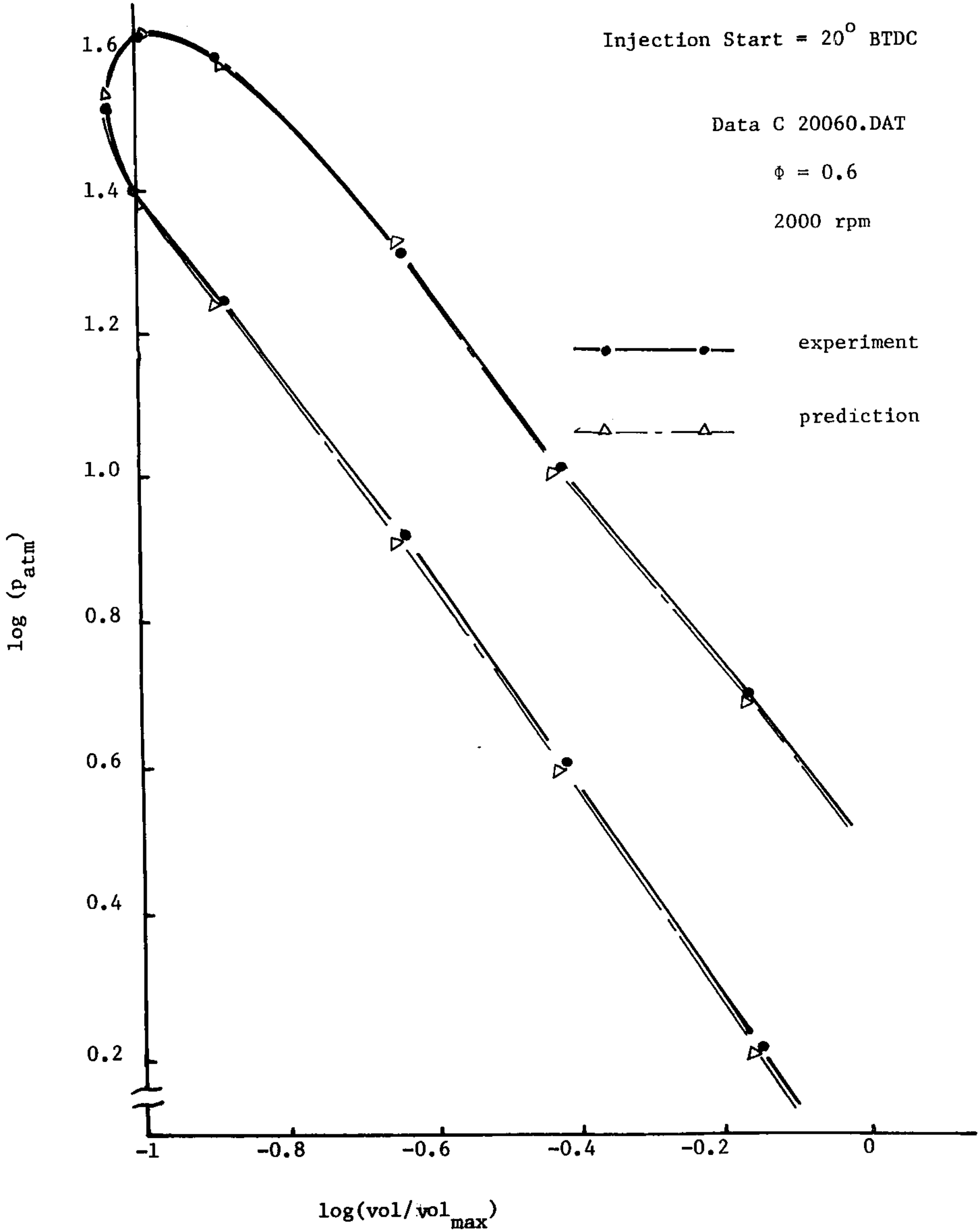


Fig. 17 log P - log V Diagram ($\theta_i = -20^o$)

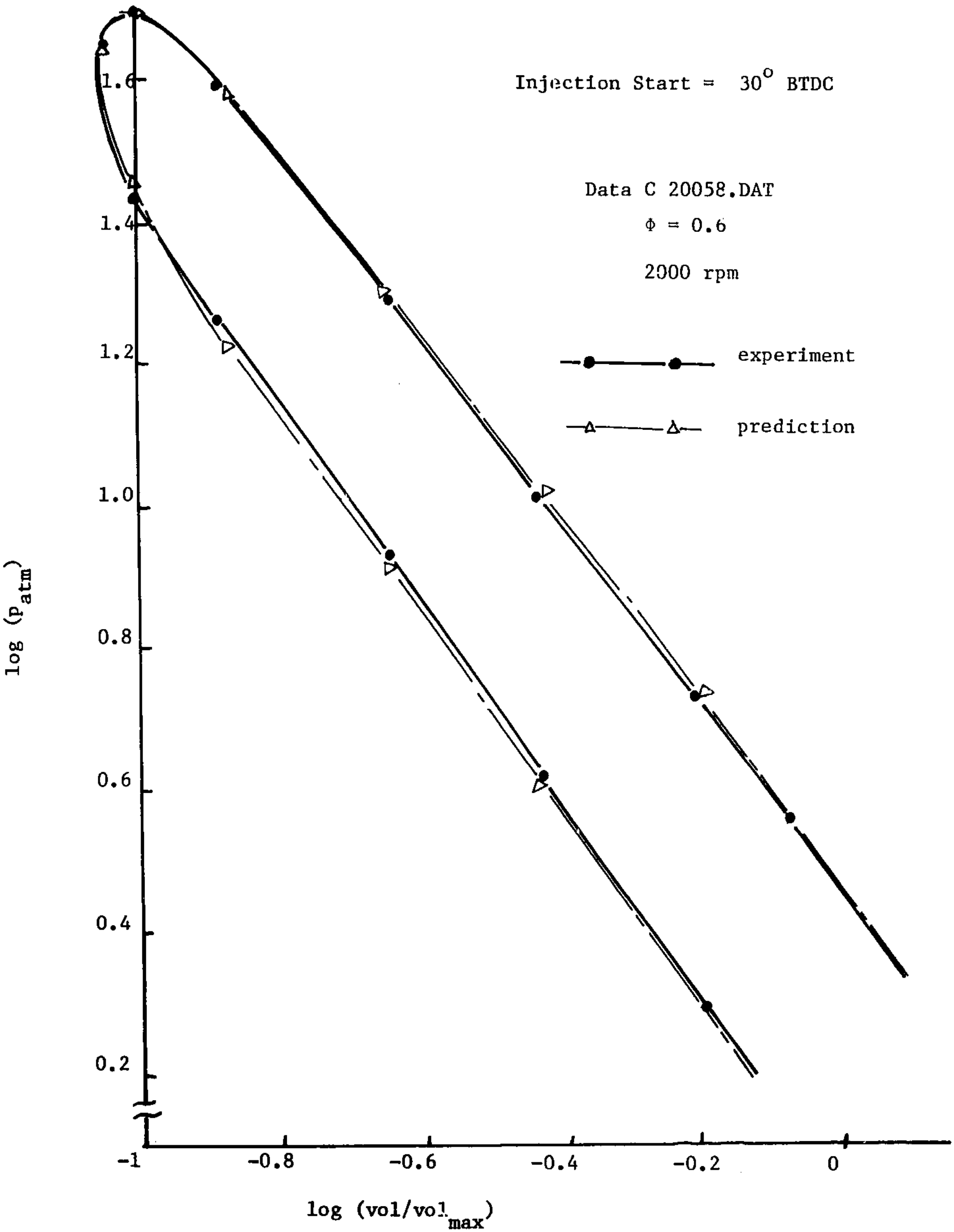


Fig. 18 log P - log V Diagram ($\theta_i = -30^o$)

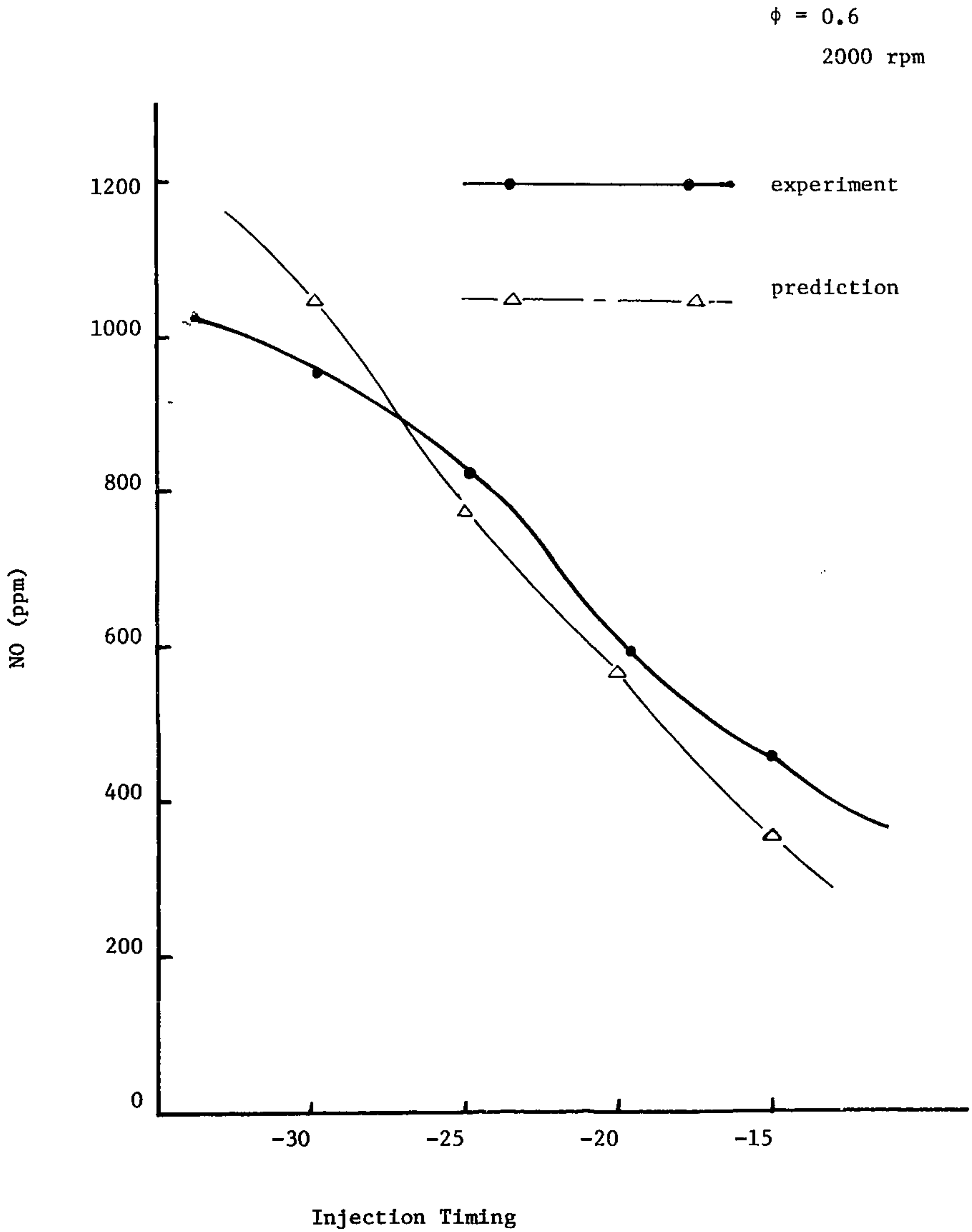


Fig. 19 **Exhaust NO**

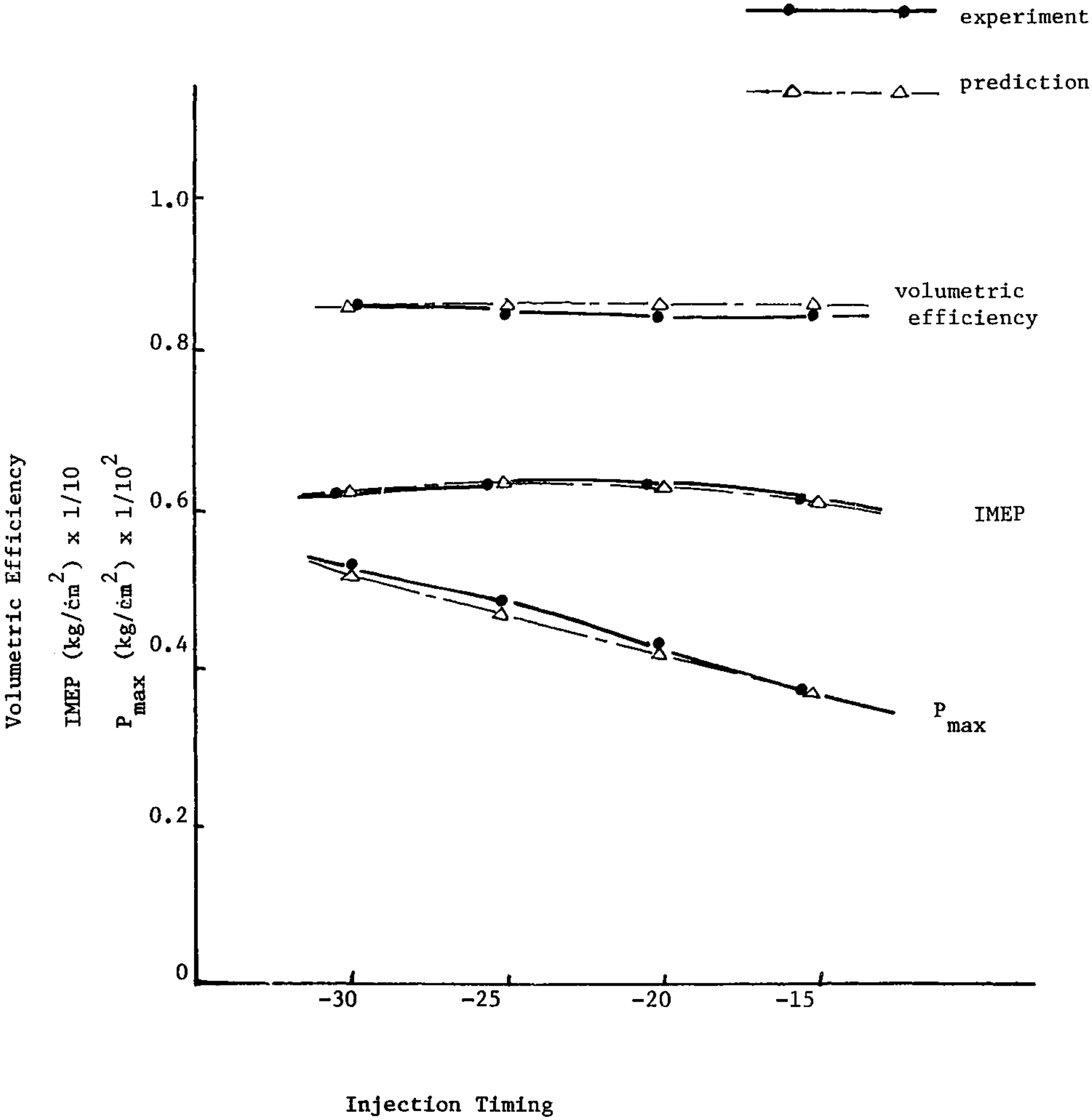


Fig. 20 Volumetric Efficiency, IMEP and P_{max}

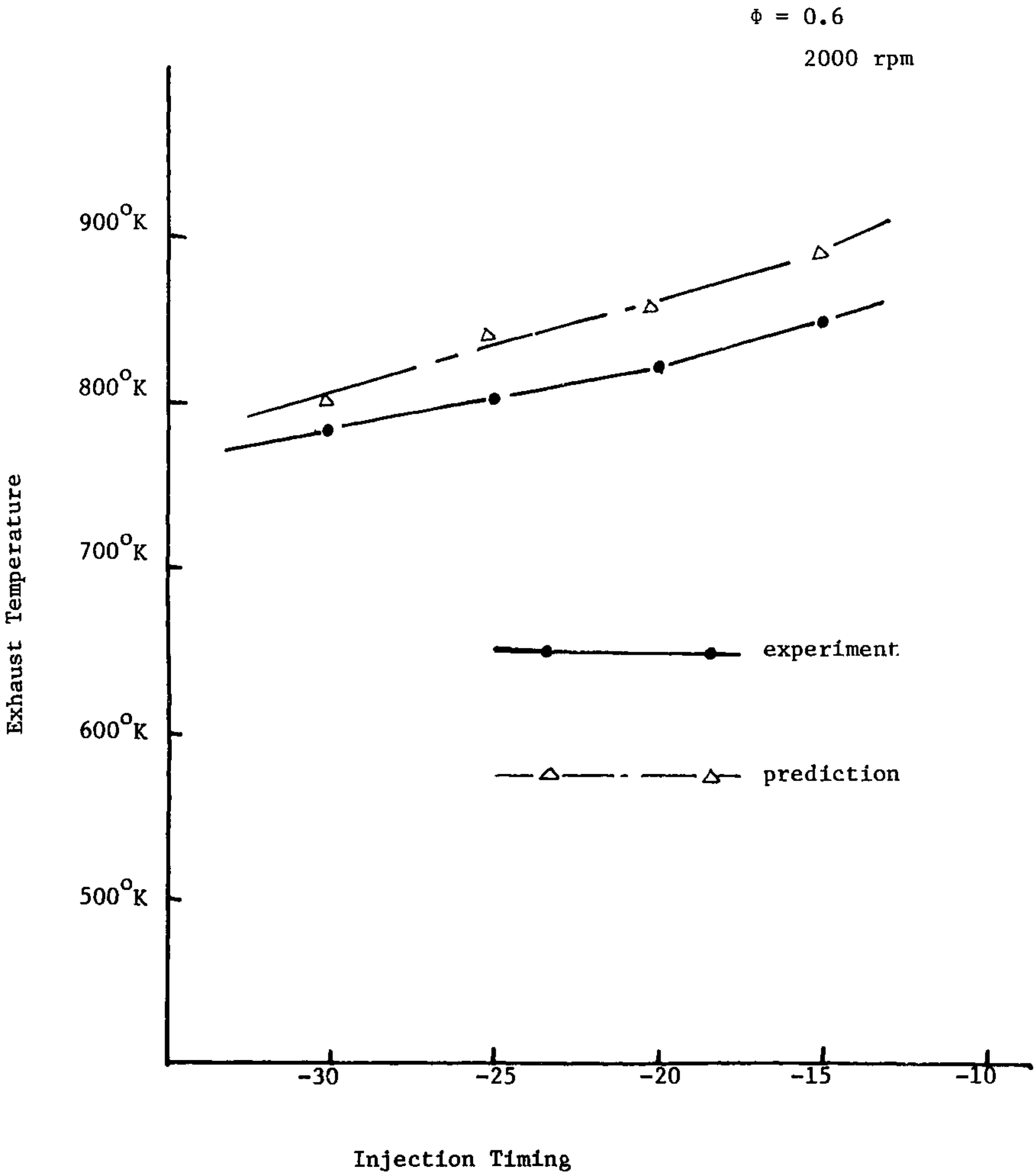


Fig. 21 Exhaust Temperature

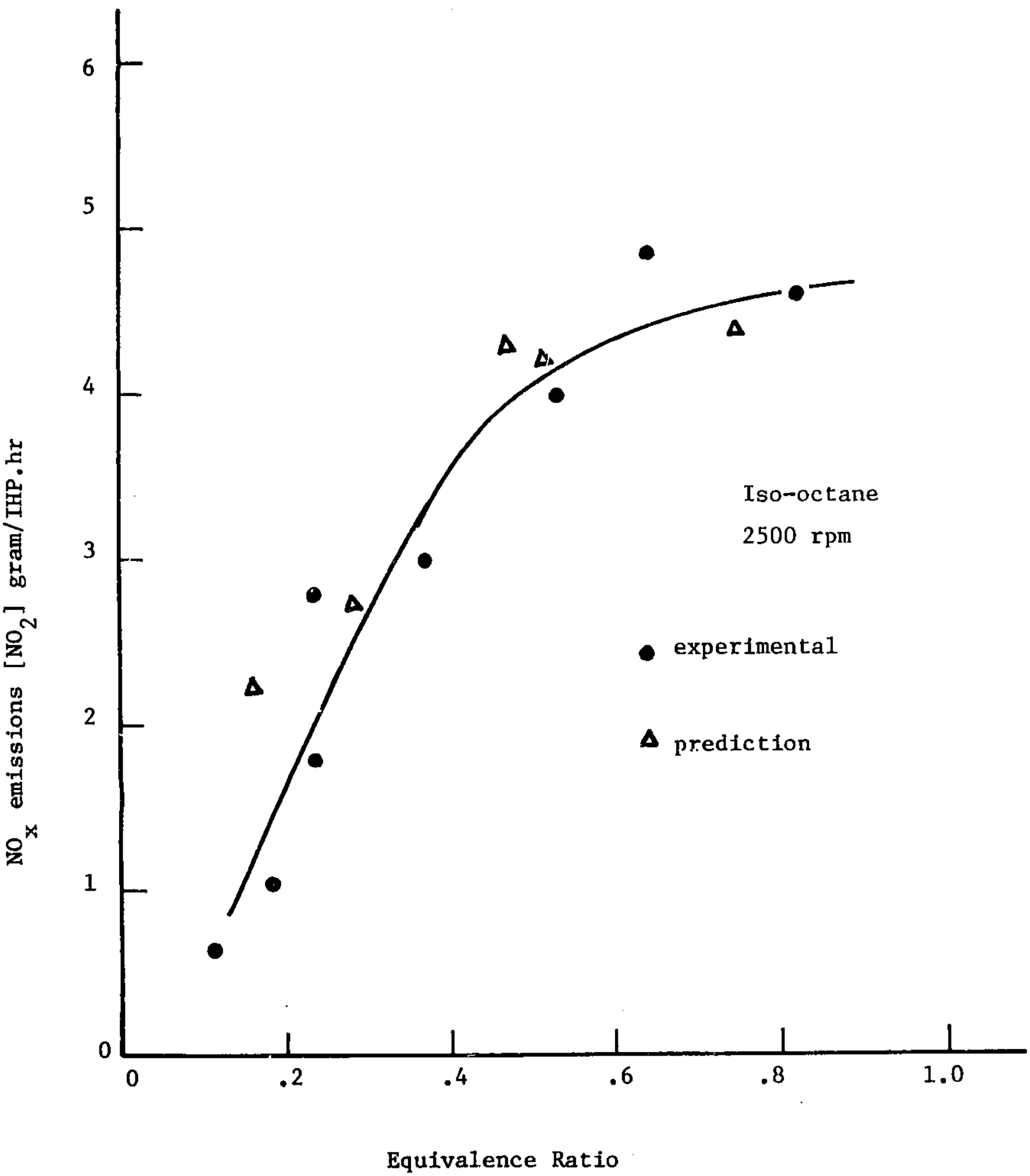


Fig. 22 NO_x vs. Equivalence Ratio

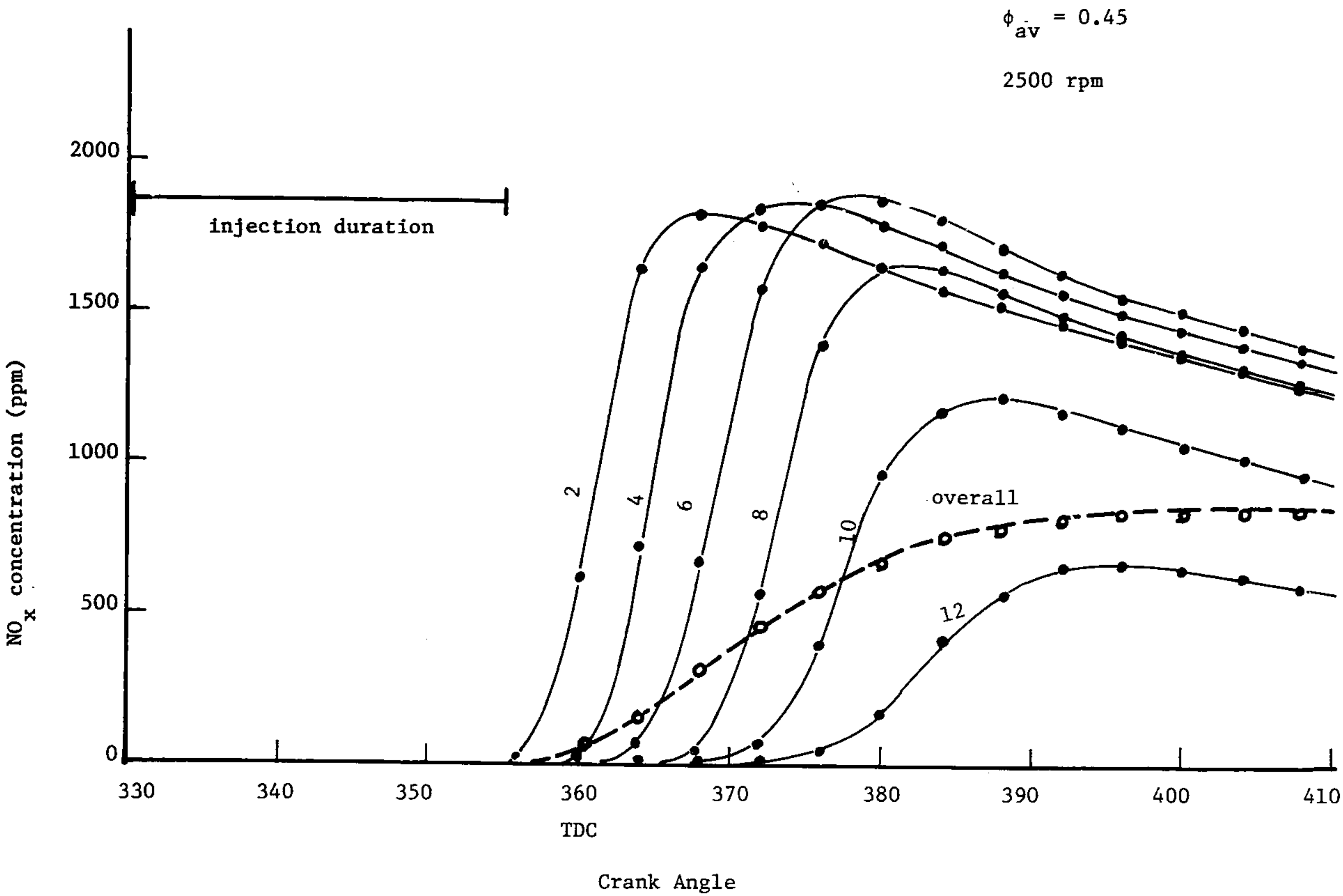


Fig. 23 NO Concentration in Each Element

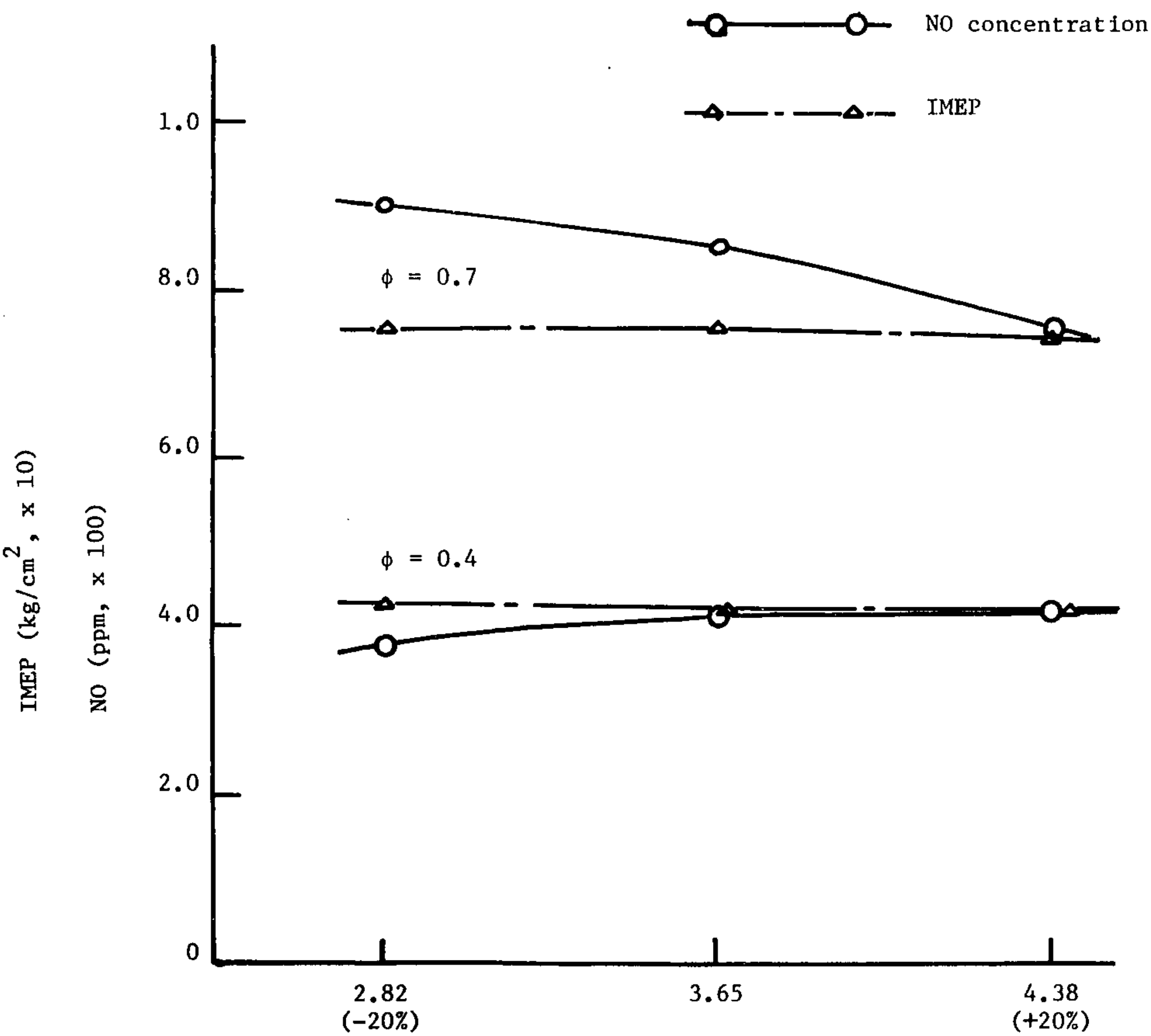


Fig. 24 The Effects of Swirl Ratio on Indicated Mean Effective Pressure and NO Concentration

Appendix A

Gas Exchange Process

During a discussion of exhaust and intake phases in the model description, it was seen that a knowledge of discharge-coefficient and the effective flow areas for both exhaust and intake valves were required. In this section, the experimental data on engine port steady flow tests (obtained from Texaco) will be reported.

Figure 13 and 14 shows the results from the tests mentioned above for the intake and exhaust port in the form of a plot of flow coefficient vs. valve lift to effective valve diameter ratio (L/D).

The mass flow rates through exhaust and intake valves have been treated as quasi-steady flow through a restriction. The governing equations can be written as follows:

$$\dot{M} = C_v A_v \left(\frac{RT_o}{P_o}\right) (\gamma RT)^{1/2} \left\{ 2/(\gamma-1) \right\} \left[\left(\frac{P_2}{P_o}\right)^{2/\gamma} - \left(\frac{P_2}{P_o}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \right]^{1/2}$$

For choked flow, with the condition for choked flow being:

$$\frac{P_o}{P_s} > \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}$$

and

$$\dot{M} = C_v A_v \left(\frac{P_{oc}}{RT_{oc}}\right) (\gamma RT_o)^{1/2} \left\{ \left[\frac{2}{(\gamma+1)}\right]^{\frac{(\gamma+1)}{2(\gamma-1)}} \right\}^{1/2}$$

where C_v = valve dischage coefficient

A_v = valve flow area

P_o, T_o = upstream stagnation pressure and temperature

P_2 = downstream static pressure

The logic to take care of the reverse flows through the valves has been put into the computer program. When there is reverse flow into the intake system (during valve overlap), the mass that flows past the intake valve is recorded. Its composition and temperature while in the intake system are assumed to be the same as those in the combustion chamber gas when intake valve opens. It has been assumed that, before any fresh charge can enter the chamber, all the mass that left the chamber during reverse flow is pulled back in first. For NO_x calculation NO_x mass transfer through the intake valve is taken into consideration.

Appendix B

Friction Loss

The following procedure for determining FMEP for a conventional spark ignition engine is taken from Bishop(33). The equations have been empirically correlated with data from engines ranging from single to eight cylinders, 4:1 to 17:1 compression ratio, and 0.75 to 2.5 bore to stroke ratio.

1. $FMEP_{misc\ \&\ pumps} = 0.39(N/1000)^{1.5}$

2. $FMEP_{cam\ gear} = [30-(4N/1000)]GH^{1.75}/B^2S$

3. $FMEP_{bearing} = (KB/S)N/1000$

4. $FMEP_{crank\ case} = \Sigma$ Eqns. 1,2.3

5. $FMEP_{blowby} = [(P_a-P_1)/14.2]^{1/2}\ [1.72\ R_c^{0.4} - (0.49 + 0.015\ R_c)\ (N/1000)^{1.185}]$

6. $V_p/1000 = SN/6000$

7. $FMEP_{viscous\ piston} = (21.93M/BS)\ V_p/1000$

8. $FMEP_{static\ ring\ tension} = 2.11\ S_n/B^2$

9. $FMEP_{ring\ gas\ pressure} = [(P_a-P_1)/14.2][2.35\ S/B^2][0.088\ R_c + 0.182\ R_c^{(1.33-(0.121\ V_P/1000))}]$

10. $FMEP_{total} = \Sigma$ Eqns. 4,5,7,8,9

Symbols

B: cylinder bore diameter (in)

C: number of cylinder

D: total engine displacement (in^3)

G: number of intake valves per cylinder

H: intake valve head diameter (in)

K: journal bearing size coefficient

M: equivalent length of piston skirt (projected area of skirt ÷ cylinder bore diameter)

N: revolutions per minute of crankshaft

P_a: dry atmospheric pressure (psia)

P: intake manifold vacuum (positive, when less than atmospheric pressure) (psig)

R_c: compression ratio

S: piston stroke (in)

V_p: mean piston velocity (ft/min)

n: total number of piston rings per cylinder

Appendix C

Thermodynamic Properties (hydrocarbon-air combustion)

The thermodynamic properties of the unburned and burned gases must be determined continuously during the entire cycle analysis. In most cases, the assumption of local chemical equilibrium can be justified and; in principal, for a given pressure and temperature, the mass action equations could be solved directly for species concentrations from which the desired thermodynamic properties could be derived. Alternatively, the species concentration which minimized the Gibbs free energy of the system could be calculated. Both approaches are quite involved and the calculations are expensive and time-consuming.

Our calculations use a computational method which is based on curve fitting data obtained from detailed thermochemical calculations to a functional form obtained from a consideration of carbon-air combustion.

This method was developed by M. Martin(21) and additional work done by S.D. Hires(34).

The following effects are taken into consideration by this method:

i) Fuel vapor coefficient for unburned, air and residual gas mixtures.

ii) Chemical dissociation effect above $1000^{o}K$ for burned gases.

I Composition

- unburned gas
  - i) fuel vapor
  - ii) burned gas (residual gas)
  - iii) air

- burned gas
  - i) burned gas

II Combustion reaction equations (hydrocarbon-air, under $1000^{\circ}K$

i) lean mixtures ($\phi<1$)

$$\varepsilon\phi CH_y + O_2 + \psi N_2 \rightarrow \varepsilon\phi CO_2 + 2\phi(1-\varepsilon)H_2O + (1-\phi)O_2 + \psi N_2 \quad \text{(C-1)}$$

ii) rich mixtures ($\phi>1$)

$$\varepsilon\phi CH_y + O_2 + \psi N_2 \rightarrow \varepsilon\phi CO_2 + 2(1-\varepsilon\phi)H_2 + 2(\phi-1)H_2 + \psi N_2) \quad \text{(C-2)}$$

and water gas reaction

$$\underbrace{CO + H_2O}_{C} \leftrightarrow \underbrace{CO_2 + H_2}_{1-C} \quad \text{(C-3)}$$

This reaction is in equilibrium with equilibrium constant K(T). "C" is obtained by solving the following equation for its positive root.

$$(1-K)\ C^2 + 2[1-\varepsilon\phi + K(\phi-1 + \varepsilon\phi)]C - 2K\varepsilon\phi(\phi-1) = 0 \qquad \text{(C-4)}$$

K(T) is determined by curve fitting JANAF Table data(35) over the temperature range 400-3200°K and is given by:

$$\ln(K(T)) = 2.743 - 1.761/t - 1.611/t^2 + 0.2803/t^3 \qquad \text{(C-5)}$$

where

$t = T/1000\ (T = {}^{o}K)$

The coefficients for species are shown in Table C-1.

TABLE C-1

i	Species	$\phi \leq 1$	$\phi > 1$
1	CO_2	$\varepsilon\phi$	$\varepsilon\phi - C$
2	H_2O	$2(1-\varepsilon)\phi$	$2(1-\varepsilon\phi) + C$
3	CO	0	C
4	H_2	0	$2(\phi-1) - C$
5	O_2	$1-\phi$	0
6	N_2	ψ	ψ
	sum	$(1-\varepsilon) + 1 + \psi$	$(2-\varepsilon)\phi + \psi$

where

ψ = the molar N:O ratio of the product

y = the molar H:C ratio of the fuel

$\varepsilon = 4/(4+y)$

ϕ = the fuel-air equivalence ratio

III <u>Grams of product per mole of O_2 reactant</u>

$$\tilde{M} = \phi(8\varepsilon+4) + 32 + 28\psi \qquad \text{(C-6)}$$

IV <u>Specific enthalpy and specific heat at constant pressure</u>

$$\tilde{M}\, C_p = \sum_{i=1}^{6} x_i \sum_{j=1}^{4} (a_{ij}\, t^{j-1} + a_{5j}/t^2) \qquad \text{(C-7)}$$

$$\tilde{M}\, h = \sum_{i=1}^{6} x_i \sum_{j=1}^{4} (a_{ij}\, t^j/j - a_{5j}/t + a_{6j}) \qquad \text{(C-8)}$$

The coefficients a_{ij} are obtained by curve fitting JANAF Table data to the above functional form. The values of a_{ij} are given in Table C-2. The resultant C_p is in cal/g - ^oK and h is in Kcal/g.

TABLE C-2

Coefficients for Polynomial Fit to Thermodynamic Properties

Coefficients for $100^{o}K<T<500^{o}K$

i	Species	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}	a_{i6}*
1	CO_2	4.7373	16.653	-11.232	2.8280	.006767	-93.75793
2	H_2O	7.8097	- .20235	3.4187	-1.1790	.001436	-57.0800
3	CO	6.9738	- .82383	2.9420	-1.1762	.0004132	-27.196
4	H_2	6.9919	.16170	- .21821	.29682	-.016252	- .11819
5	O_2	6.2957	2.3884	- .031479	- .32674	.004359	.103637
6	N_2	7.0922	- 1.2958	3.2069	-1.2022	-.0003458	- .013967
7	C_8H_{18}**	- .55313	181.62	-97.787	20.402	-.03095	-60.518

Coefficients for $500^{o}K<T<6000^{o}K$

i	Species	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}	a_{i6}*
1	CO_2	11.940	2.0886	- .47029	.037363	-.58945	-97.1418
2	H_2O	6.1391	4.6078	- .93560	.066695	.03358	-56.6259
3	CO	7.0996	1.2760	- .28775	.022356	-.15987	-27.7346
4	H_2	5.5557	1.7872	- .28813	.019515	.16118	.76498
5	O_2	7.8658	.68837	- .031944	-.002687	-.20139	- .89346
6	N_2	6.8078	1.4534	- .32899	.025610	-.11895	- .33184
7	C_8H_{18}**	.55313	181.62	-97.787	20.402	-.03095	-60.518

*picked to give enthalpy datum at $0^{o}K$

**The coefficients apply to 2,2,4 trimethyl pentene (iso-octane). Different equations may be needed for different fuels.

V) Molecular weight of the burned mixture

$$\bar{M} = \begin{cases} \tilde{M}/((1-\varepsilon)\phi+1 +\psi) & \phi\leq 1 \\ \tilde{M}/((2-\varepsilon)\phi+ \psi) & \phi>1 \end{cases}$$

APPENDIX D Computer Program

Program Listing

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                              C
C  ***  PREDICTING THE DETAILED PERFORMANCE AND EMISSION CHARACTERISTICS***    C
C  ***  OF THE TEXACO CONTROLLED-COMBUSTION,STRATIFIED CHARGE ENGINE     ***   C
C                                                                              C
C  ***  THIS PROGRAM HAS BEEN DEVELOPED IN ORDER TO PREDICT THE          ***   C
C  ***  DETAILED PERFORMANCE AND THE NOX EMISSION CHARACTERISTICS OF THE  **   C
C  ***  TCCS, STRATIFIED CHARGE ENGINE, GIVEN ENGINE GEOMETRY, FUEL PROPERTIES C
C  ***  AND THE OPERATING CONDITIONS.                                          C
C  ***                                          THE DETAILS  OF THE THEORY     C
C  ***  AND ANY OTHER INFORMATION REGARDING THIS PROGRAM CAN BE HAD FROM       C
C  ***                  SAB(H),HIRAKI,31-159, 253-2388                   ***   C
C                                                                              C
C*** ALL RIGHTS RELATED TO THIS PROGRAM ARE RESERVED BY SLOAN AUTOMOTIVE
C***      LABORATORY, M.I.T.
C
C***WARNING*** THIS PROGRAM IS NOT FINAL VERSION.  THIS PROGRAM WILL
C  BE CHANGED WITHOUT NOTICING IN FUTURE.
C
C  INPUT VARIABLES
C    SEE INPUT SUBROUTINE
C
C  OUTPUTS
C   ANGLE= CRANK ANGLE DEG
C   P,PRESS= CYLINDER PRESSURE ATA
C   PPM= NOX CONCENTRATION PPM
C   WNO= NOX MASS G*10**6
C   NUM=ELEMENT NUMBER
C   #=1 NOT YET BURNED
C     2 PLUME IS DEVELOPING
C     3 PLUME HAS FULLY DEVELOPED
C   T,T,AV= TEMPERATURE OF THE ELEMENT
C   UTEM= UNBURNED TEMPERATURE K(FOR JET ELEMENT)
C   BTEM= BURNED   TEMPERATURE K(FOR JET ELEMENT)
C   MASS= TOTAL MASS OF THE ONE ELEMENT MG
C   PMASS= PLUME MASS   MG(FOR JET ELEMENT)
C   BMASS= BURNED GAS MASS   MG(FOR JET ELEMENT)
C   V = VOLUME     CM**3
C   EQUI= EQUIVALENCE RATIO
C   CP= SPECIFIC HEAT AT CONSTANT PRESSURE CAL/G K
C   ENTH= ENTHALPY     CAL/G
C   PPM= NO CONCENTRATION       PPM
C   WNO= MASS OF NO     G*10**6
C   R= JET LOCATION     RADIAL    CM
C   Z= JET LOCATION     AXIAL    CM.
C   DEG= JET LOCATION  TANGENTIAL  DEG
C   HLOS= HEAT LOSS    CAL
C   RATIO= BURNED MASS FRACTION
C   PS= OUTPUT POWER TOTAL SINCE INTAKE VALVE OPENS PS
C   AEFI= INTAKE EFFECTIVE FLOW AREA  CM**2
C   GWI= INTAKE MASS FLOW    G/S
C   AEFE= EXHAUST EFFECTIVE FLOW AREA  CM**2
C   GWE= EXHAUST MASS FLOW  G/S
C
C
C  SUBROUTINES REQUIRED
C   1. RUNGE
C   2. OPERA
C   3. INPOR
C   4. EXPOR
```

```
C     5. HEATR
C     6. INPUT
C     7. CALCU
C     8. DELTA
C     9. DCAL
C    10. JET
C    11. VGAS
C    12. CONT
C    13. ENT
C    14. VOLCY
C    15. HPROD
C    16. CLDPRD
C    17. DERIVS
C    18. DNODT
C    19. FOI3
C    20. TWODIM
C    21. UPROP
C    22. PTCHEM
C    23. NXNSOL
C    24. FRICT   FRICTIONS
C
C
      COMMON/EPROP/ IECHF(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DUEMAS(100),
     1 ERGAS(100),ECP(100),FENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /STATE/ ANGLFI,ANGLE,JCOND,ASTEP,NSTEP,IF
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,FSK
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /SUM1/ STGINT,STGEXT,STOEXT
      COMMON /HETRS/ NDIVID,TMETAL(10),QHTRC(10),ARE(10)
      COMMON /HETR1/ PBASE,TBASE,VBASE,COHT1,COHT2,COHT,RHR(10)
      COMMON /SUM2/ TTSINT,TTGEXT,TTOEXT,TTQHTR(10),TQHTR(10),PS
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PST,SAFC,VACAL
      COMMON /JETS/ RJET(50),HJET(50),AJET(50),BJET(50),THER(50),
     1 VRJET(50),VZJET(50),WJET(50),VJET(50),AINJ(50),RHJET(50),
     2 PITCH(50)
      COMMON /PLUME/ PMASS(50),BMASS(50),RPLUM(50),HRMASS(50)
      COMMON /JETDAT/ WSWIRO,ALPHA,BETA,PHGAS
      COMMON /SUPGAS/ FSWIR,WSWIR,SDECAY
      COMMON/COMP/ RPLUMO,ENTUR,RLESP,ASPARK,TSCALE
      COMMON /OSOPE/ LPT,INP,LINECO,LINEST,ITEL,LITEL
      COMMON /NOXSP/ CONNO(100),PPMNO(100),WNO(100),SUMDM(100),PPMEXT
      DIMENSION ZMOER(5),TMSPI(100)
      REAL*4 MBAR
      COMMON /FUEL/ AF(6),ENW,CX,HY,OZ,QLOWER
      COMMON/OXDANT/XI/CMPSTN/X(7),MBAR
      COMMON/CONTL/ ASTIN,ASTCL,ASTCR,ASTEX,ASTOV,PRININ,PRINCL,PRINEX,
     1 PRINOV
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON/EXFLO/NEXEF,XEXEF(20),YEXEF(20),AREEXD,PEXT,TEXT,GEXT,
     1 TGLEFT,TLEFT,QEXT,QFLOW,ELEFT,AREEXT,XEXV
      COMMON /AMBIE/ TAMB,PAMB
      COMMON /FRTOT/ RSKIRT,FCOE,RINGN,FMEP(10)
      DIMENSION HPTEMP(50),PLTEMP(50),PLENT(50)
      DIMENSION XTEMP(10),YCP(10)
      DIMENSION XPOM(2),YPOM(2)
C
```

```
C  DATA OF SPECIFIC HEAT AT CONSTANT PRESSURE VS TEMPERATURE
C   DATA OF TEMPERATURE
      DATA XTEMP/
     1 500.,1000.,1500.,2000.,2250.,2500.,2750.,3000.,3250.,3500./
C   DATA OF SPECIFIC HEAT AT CONSTANT PRESSURE
      DATA YCP/
     1 0.26,0.3,0.34,0.37,0.43,0.51,0.72,0.84,1.24,1.6/
C
C
C  CARD READER AND LINE PRINTER
      INP=5
      LPT=6
C
C   JCOND=1 VALVE OVERLAP PERIOD
C   JCOND=2 INTAKE PROCESS
C   JCOND=3 COMPRESSION PERIOD
C   JCOND=4 COMBUSTION AND EXPANSION PERIOD
C   JCOND=5 EXHAUST PROCESS
C
 9001 CONTINUE
      ASTEP=2.0
      PSI=3.76
C
C  INITIALIZE COMBUSTION CONDITION
C      IECHE=1   NOT YET BURNED
C      IECHE=2   PLUME IS DEVELOPING IN THE JET
C      IECHE=3   PLUME IS FULLY DEVELOPED
      DO 1010 I=1,100
      IECHE(I)=1
      CONNO(I)=0.
 1010 CONTINUE
      ERMAX=10.
      MAXITS=15
      JLAST=1
      LITEL=1
      RESFRK=0.
C
C  INPUT SUBROUTINE
C
      CALL INPUT
C
C
C  NOCUL=0   PERFORMANCE ONLY
C  NOCUL=1   (NO) CALCULATION WILL BE DONE
      NOCUL=1
C  DO YOU WANT NOX CALCULATION?
      READ(INP,302) NOCUL,PPMEXT
C
C  CALCULATION STARTING CRANK ANGLE AND ENDING CRANK ANGLE
      READ(INP,23) ANGLES,ALAST
      DEL=ZN/ZM
      EFUEL(1)=0.
      ENTIN1=ENT(TINT,EQUINT,SAFC)
      IF=1
      ANGLE=ANGLES
      ANGLE1=ANGLES
      CALL VOLCY(ANGLE,EVOL(2,1),DVCYL,STROKE,BORE,CONL,VCLEAR,VCUP)
      VCYLO=EVOL(2,1)
      EENTH(2,1)=ENT(ETEMP(2,1),EEQUI(2,1),SAFC)
      ENTIN2=EENTH(2,1)
```

```
      CALL HPROD(PCYL(2),ETEMP(2,1),EEQUI(2,1),DEL,PST,DUM,DUM,DUM,DUM,
     1 DUM,DUM,EMWT(1),ERGAS(1),CVBG,DUM)
      ECP(1)=ERGAS(1)/41.443+CVHG
      EMASS(2,1)=PCYL(2)*EVOL(2,1)/(ERGAS(1)*ETEMP(2,1))
C
C   INITIAL CONDITION
  100 TTGINT=0.
      TTGEXT=0.
      TTOEXT=0.
      IGLEFT=0
      TMAX=0.
      PMAX=0.
      PS=0.
      PSIN=0.
      PSEX=0.
      JCOND=0
      ENTINT=ENTIN2
  200 CONTINUE
      DO 10 I=1,NDIVID
      TOHTR(I)=0.
   10 TTOHTR(I)=0.
C
C  SWIRL DECAYING FACTOR  FSWIR=1. AT THE TIME OF INTAKE VALVE CLOSING
      FSWIR=1.
 3000 CONTINUE
      PCYLO=PCYL(2)
C
      CALL OPERA
C
C   RUNGE KUTTA METHOD
      CALL RUNGE(ENTINT)
      ANGLE1=ANGLE1+ASTEP
      TTGINT=TTGINT+STGINT*ASTEP
      TTGEXT=TTGEXT+STGEXT*ASTEP
      TTOEXT=TTOEXT+STOEXT*ASTEP
      DO 3900 I=1,NDIVID
 3900 TTOHTR(I)=TTOHTR(I)+TOHTR(I)*ASTEP
C
C  CHECK THE INTAKE FLOW
      IF(JCOND.GE.3) GO TO 570
      IF(TTGINT.GT.0.) GO TO 572
C
C  INTAKE FLOW IS RESIDUAL GAS
      ENTINT=ENTIN2
      GO TO 570
C
C  INTAKE FLOW IS FLESH AIR
  572 ENTINT=ENTIN1
  570 CONTINUE
      CALL VOLCY(ANGLE1,VCYLN,DVCYL,STROKE,BORE,CONL,VCLEAR,VCUP)
      DPS=((PCYL(2)+PCYLO)/2.-PAMB)*(VCYLN-VCYLO)*CYLN*RPM/900000.
      VCYLO=VCYLN
      PS=PS+DPS
      IF(JCOND-2) 580,580,590
  580 PSIN=PSIN+DPS
      GO TO 530
  590 IF(JCOND-5) 530,595,530
  595 PSEX=PSEX+DPS
  530 DO 16 I=1,NDIVID
   16 TTOHTR(I)=TTOHTR(I)+TOHTR(I)*ASTEP
```

```
      IF(IGLEFT) 500,500,510
  500 GLEFT=GLEFT-STGEXT
      IF(GLEFT) 520,520,510
  520 IGLEFT=1
  510 CONTINUE
      IF(JCOND.NE.4) GO TO 4500
C
C  COMBUSTION ROUTINE
C
C  ESTIMATE THE PLUME TEMPERATURE
      DO 3700 I=1,IF
      IF(IECHE(I).EQ.2) GO TO 3800
      URTEMP(I)=ETEMP(2,I)
      PLTEMP(I)=ETEMP(2,I)
      PLENT(I)=EENTH(2,I)
      GO TO 3700
 3800 ENTJET=EENTH(2,1)
      CALL TWODIM(10,XTEMP,YCP,PLTEMP(I),PLCP1)
      PLCP=PLCP1
      ENTPL=(EENTH(2,I)*EMASS(2,I)-ENTJET*(EMASS(2,I)-PMASS(I)))/
     1  PMASS(I)
      DPLT=(ENTPL-PLENT(I))/PLCP
      DO 3820 J=1,3
      PLT=PLTEMP(I)+DPLT
      TDUM2=PLTEMP(I)+DPLT/3.
      TDUM3=PLTEMP(I)+DPLT*2./3.
      TDUM4=PLTEMP(I)+DPLT
      CALL TWODIM(10,XTEMP,YCP,TDUM2,CPDUM2)
      CALL TWODIM(10,XTEMP,YCP,TDUM3,CPDUM3)
      CALL TWODIM(10,XTEMP,YCP,TDUM4,CPDUM4)
      DPLT=(ENTPL-PLENT(I))*(1./PLCP1+2./CPDUM2+2./CPDUM3+1./CPDUM4)/6.
 3820 CONTINUE
      PLENT(I)=ENTPL
      PLTEMP(I)=PLT
 3700 CONTINUE
      IF(NOCUL.EQ.0) GO TO 4500
C
C  CALCULATION OF NOX CHANGE BY MASS TRANSFER
C
      DO 4012 I=2,IF
      CONNO(I)=CONNO(I)+CONNO(1)*SUMDM(I)/(EMASS(2,1)-SUMDM(1))
 4012 CONTINUE
      CONNO(1)=CONNO(1)+CONNO(1)*SUMDM(1)/(EMASS(2,1)-SUMDM(1))
      DO 4010 I=1,IF
      TMSPI(I)=EMASS(2,I)/EMWT(I)
      IF(IECHE(I).EQ.1) GO TO 4020
      IF(IECHE(I).EQ.3) GO TO 4040
      PLSPI=PMASS(I)/EMWT(I)
      GO TO 4050
 4040 PLSPI=TMSPI(I)
 4050 CONTINUE
      CALL EQIB(PLTEMP(I) ,PCYL(2),EEQUI(2,I),IFLAG,ZMOFR)
      IF(PLTEMP(I).GT.2400.) GO TO 4022
      IINOM=1
      GO TO 4024
 4022 IINOM=4
 4024 ASTNO=ASTEP/FLOAT(IINOM)
      DO 4026 IINO=1,IINOM
      CALL DNODT(PLTEMP(I) ,PCYL(2),PLSPI    ,ZMOFR,IIFLAG,CONNO(I),
     1 DCONNO)
```

```
      CONNO(I)=CONNO(I)+DCONNO*ASTNO/(RPM*6.)
 4026 CONTINUE
 4020 PPMNO(I)=1000000.*CONNO(I)/TMSPI(I)
      WNO(I)=30.*CONNO(I)
 4010 CONTINUE
      TWSPI=0.
      TCONNO=0.
      TTMSPI=0.
      TWNO=0.
      DO 4030 I=1,IF
      TCONNO=TCONNO+CONNO(I)
      TTMSPI=TTMSPI+TMSPI(I)
      TWNO=TWNO+WNO(I)
 4030 CONTINUE
      TPPM=1000000.*TCONNO/TTMSPI
 4500 CONTINUE
      LINECO=LINECO-1
      IF(LINECO) 2000,2000,2010
C
C  PRINT OUT
 2000 GO TO (2100,2200,2300,2400,2500),JCOND
C
C  VALVE OVERLAP PERIOD
 2100 GGNT=STGINT*CYLN*6.*RPM
      GGXT=STGEXT*CYLN*6.*RPM
      HTRS1=-TOHTR(1)
      HTRS2=-TTOHTR(1)
      WRITE(LPT,2900) ANGLE1,PCYL(2),ETEMP(2,1),EVOL(2,1),PS,
     1 EMASS(2,1),HTRS1    ,HTRS2     ,AREINT,GGNT,AREEXT,GGXT
      GO TO 9100
C
C  INTAKE PROCESS
 2200 GGNT=STGINT*CYLN*6.*RPM
      HTRS1=-TOHTR(1)
      HTRS2=-TTOHTR(1)
      WRITE(LPT,2910) ANGLE1,PCYL(2),ETEMP(2,1),EVOL(2,1),PS,
     1 EMASS(2,1),HTRS1    ,HTRS2     ,AREINT,GGNT
      GO TO 9100
C
C  COMPRESSION PROCESS
 2300 SRAT=WSWIR*180./(3.1416*6.*RPM)
      HTRS1=-TOHTR(1)
      HTRS2=-TTOHTR(1)
      WRITE(LPT,2920) ANGLE1,PCYL(2),ETEMP(2,1),EVOL(2,1),PS,
     1 EMASS(2,1),HTRS1    ,HTRS2     ,FSWIR,SRAT
      GO TO 9100
C
C  COMBUSTION PERIOD
C  EXPANSION PERIOD
 2400 CONTINUE
      IF(IE.EQ.1) GO TO 2300
      HTRS1=-TOHTR(1)
      HTRS2=-TTOHTR(1)
      TRATBU=0.
      DO 2410 I=2,IF
 2410 TRATBU=TRATBU+HRMASS(I)
      TRATBU=TRATBU/FUEL
      SRAT=WSWIR*180./(3.1416*6.*RPM)
      IF(NOCUL.EQ.0) GO TO 5010
      TWNOXX=TWNO*10.**6
```

```
      WRITE(LPT,2930) ANGLE1,PCYL(2),PS,FSWIR,SRAT,HTRS2
      WRITE(LPT,2931) TRATBU,VCYLN,PHIO,TRPM,TWNOXX,HTRS1
      GO TO 5015
 5010 WRITE(LPT,2930) ANGLE1,PCYL(2),PS,FSWIR,SRAT,HTRS2
      WRITE(LPT,2932) TRATBU,VCYLN,PHIO,            HTRS1
 5015 DO 5020 I=1,IF
      HHLOS=DHLOS(I)
      IF(NOCUL.EQ.0) GO TO 5022
      IF(I.EQ.1) GO TO 5024
C
C  NOX AND JET ELEMENT
      AJE=AJET(I)*180./3.1416
      ACO=THER(I)*180./3.1416
      EMASMG=EMASS(2,I)*1000.
      PMASMG=PMASS(I)*1000.
      BMASMG=BMASS(I)*1000.
      RATBU=HRMASS(I)/EFUEL(I)
      WNOMMG=WNO(I)*10.**6
      WRITE(LPT,2936) I,IECHE(I),ETEMP(2,I),PLTEMP(I),RATBU     ,
     1 EMASMG    ,PMASMG  ,BMASMG  ,EVOL(2,I),EEQUI(2,I),ECP(I),
     2 EENTH(2,I),PPMNO(I),WNOMMG,RJET(I),HJET(I),AJE,BJET(I),ACO,HHLOS
      GO TO 5020
C
C NOX AND AIR
 5024 EMASMG=EMASS(2,I)*1000.
      WNOMMG=WNO(I)*10.**6
      WRITE(LPT,2937) I,IECHE(I),ETEMP(2,I),
     1 EMASMG,                       EVOL(2,I),EEQUI(2,I),ECP(I),
     2 EENTH(2,I),PPMNO(I),WNOMMG,                          HHLOS
      GO TO 5020
C
C  PERFORMANCE AND JET
 5022 IF(I.EQ.1) GO TO 5026
      AJE=AJET(I)*180./3.1416
      ACO=THER(I)*180./3.1416
      EMASMG=EMASS(2,I)*1000.
      PMASMG=PMASS(I)*1000.
      BMASMG=BMASS(I)*1000.
      RATBU=HRMASS(I)/EFUEL(I)
      WRITE(LPT,2934) I,IECHE(I),ETEMP(2,I),PLTEMP(I),RATBU     ,
     1 EMASMG    ,PMASMG  ,BMASMG  ,EVOL(2,I),EEQUI(2,I),ECP(I),
     2 EENTH(2,I),                  RJET(I),HJET(I),AJE,BJET(I),ACO,HHLOS
      GO TO 5020
C
C  PERFORMANCE AND AIR
 5026 EMASMG=EMASS(2,I)*1000.
      WRITE(LPT,2938) I,IECHE(I),ETEMP(2,I),
     1 EMASMG,                       EVOL(2,I),EEQUI(2,I),ECP(I),
     2 EENTH(2,I),                                          HHLOS
 5020 CONTINUE
      GO TO 9100
C
C  EXHAUST PROCESS
 2500 GGXT=SIGEXT*CYLN*6.*RPM
      HTRS1=-TOHTR(1)
      HTRS2=-TIOHTR(1)
      WRITE(LPT,2940) ANGLE1,PCYL(2),ETEMP(2,1),EVOL(2,1),PS,
     1 EMASS(2,1),HTRS1    ,HTRS2    ,AREEXT,GGXT
      GO TO 9100
 2900 FORMAT(1H ,F5.1,
```

```
     1               1X,F6.2,1X,F5.0,1X,F6.0,1X,F6.2,2X,F8.3,
     1            E11.3   ,E11.3    ,1X,F6.2,1X,F7.2,2X,F6.2,1X,F7.2)
 2910 FORMAT(1H ,F5.1,
     1               1X,F6.2,1X,F5.0,1X,F6.0,1X,F6.2,2X,F8.3,
     1 E11.3    ,E11.3   ,1X,F6.2,1X,F7.2 )
 2920 FORMAT(1H ,F5.1,
     1               1X,F6.2,1X,F5.0,1X,F6.0,1X,F6.2,2X,F8.3,
     1 E11.3,E11.3,1X,F6.3,1X,F6.2)
 2930 FORMAT(/,1X,F5.1,2X,'PRESS.=',F6.2,1X,'PS=',F6.1,1X,'FSWIP=',F6.3,
     1 1X,'S.RT=',F6.3,1X,'SUM.H.REJ=',E9.3)
 2931 FORMAT(2X,5HTOTAL,14X,F7.3,21X,2F7.2,14X,F7.0,F7.0,30X,E9.2)
 2932 FORMAT(2X,5HTOTAL,14X,F7.3,21X,2F7.2,14X,           44X,E9.2)
 2934 FORMAT(2X,I2,1X,I2,2F7.0,F7.3,3F7.1,2F7.2,F7.3,F7.1,14X,
     1 F6.1,F6.2,F6.0,F6.3,F6.0,E9.2)
 2936 FORMAT(2X,I2,1X,I2,2F7.0,F7.3,3F7.1,2F7.2,F7.3,F7.1,F7.0,F7.2,
     1 F6.1,F6.2,F6.0,F6.3,F6.0,E9.2)
 2937 FORMAT(2X,I2,1X,I2, F7.0,14X,F7.1,14X,2F7.2,F7.3,F7.1,F7.0,
     1 F7.0,      18X,12X,E9.2)
 2938 FORMAT(2X,I2,1X,I2, F7.0,14X,F7.1,14X,2F7.2,F7.3,F7.1,
     1 32X,12X,E9.2)
 2940 FORMAT(1H ,F5.1,
     1               1X,F6.2,1X,F5.0,1X,F6.0,1X,F6.2,2X,F8.3,
     1 E11.3,  E11.3   ,1X,F6.2,1X,F7.2)
 9100 CONTINUE
      LINECO=LINEST
 2010 IF(PMAX-PCYL(2)) 7000,7030,7030
 7000 PMAX=PCYL(2)
      PMAXAN=ANGLE1
 7030 CONTINUE
C
C  IF THE TEMPERATIRES OF EVERY ELEMENTS ARE BELOW TEMLOW(AROUND 1700K).
C  THEREWILL BE NO CHANGE IN NO VALUE.
C  WE WILL CONSIDER ONLY ONE AVERAGE ELEMENT.
      TEMLOW=2200.
      IF(JCOND.NE.4) GO TO 7300
      AAN=ANGLE1-(AFUELE+30.)
      IF(AAN.LT.0.) GO TO 7300
      IF(IE.EQ.1) GO TO 7300
      IF(ETEMP(2,2).GT.TEMLOW) GO TO 7300
      IF(ETEMP(2,IE).GT.TEMLOW) GO TO 7300
C
C  CALCULATE THE  TOTAL MASS AND  ENTHALPY
      TENTH=0.
      TMASS=0.
      DO 7320 I=1,IE
      TENTH=TENTH+EENTH(2,I)*EMASS(2,I)
      TMASS=TMASS+EMASS(2,I)
 7320 CONTINUE
C
C  CALCULATE THE AVERAGE ENTHALPY
      AVENT=TENTH/TMASS
C
C  CALCULATE THE AVERAGE TEMPERATURE
C  FIRST FIND OUT THE ELEMENT WHICH ENTHALPY IS CLOSE TO THE
C  AVERAGE ENTHALPY
      DENTM=1000.
      II=1
      DO 7330 I=1,IE
      DENT=ABS(AVENT-EENTH(2,I))
      IF(DENTM.LT.DENT) GO TO 7330
```

```
      DENTM=DENT
      II=I
 7330 CONTINUE
C
C  DEFINE THE NEW PROPERTIS
      ETEMP(2,1)=ETEMP(2,II)+(AVENT-FENTH(2,II))/ECP(II)
      FEQUI(2,1)=PHIO
      FENTH(2,1)=AVENT
      EMASS(2,1)=TMASS
      CALL HPROD(PCYL(2),ETEMP(2,1),FEQUI(2,1),DEL,PSI,ENTHLP,CSUBP,
     1 CSUBT,RHO,DRHODT,DRHODP,EMWT(1),ERGAS(1),CVBG,EBGR)
      ECP(1)=ERGAS(1)/41.443+CVBG
      EVOL(2,1)=VCYLN
      IE=1
      WRITE(LPT,7340)
      WRITE(LPT,7342) PCYL(2),ETEMP(2,1),EEQUI(2,1),FENTH(2,1),
     1 EMASS(2,1)
      IF(NOCUL.EQ.0) GO TO 7331
C
C  NOX AMOUNT WILL BE DEFINED.
C   EXHAUST NOX ON MASS BASE
      ANOXEX=TWNO*ITGINT/TMASS*RPM/120.
      WRITE(LPT,7450) TPPM,ANOXEX
 7331 CONTINUE
      WRITE(LPT,7420)
      WRITE(LPT,7430)
 7340 FORMAT(//,10X,'***EXPANSION PROCESS IS CALCULATED AS ONE ELEMENT**
     1*')
 7342 FORMAT(15X,18HPRESSURE          = ,F10.2,'ATA',/,
     1  15X,18HAV. TEMPERATURE  = ,F10.1,'K DEG',/,
     2   15X,18HAV. EQUI. RATIO  = ,F10.3,/,
     3   15X,18HAV. ENTHALPY     = ,F10.2,'CAL/G',/,
     4   15X,18HTOTAL MASS       = ,F10.4,'G')
 7420 FORMAT(/2X,4HTHED,3X,4H  P ,3X,4H  T ,3X,4H  V ,3X,4HWORK,
     1 3X,7HCYL.MAS,3.   H HEAT  TRANSFER,7X,4HESWR,3X,4HS.PT)
 7430 FORMAT(2X ,4HDEG ,3,,4HATA ,3X,4H  K ,2X,5HCM**3,3X,4H PS ,
     1 3X,7H   G    ,3X,15H CAL/A   CAL    ,11X,3X,4H*RPM)
 7450 FORMAT(//,10X,'**EXHAUST NOX***',/,
     1   15X,15HNOX CONCEN.    = ,F10.1,'PPM',/,
     2   15X,15HTOTAL MASS     = ,E12.3,'G')
 7300 CONTINUE
      IF(ANGLEI-ALAST) 7040,7050,7050
 7040 GO TO 3000
 7050 CONTINUE
      ITEXT=1
      QMANI=TTOEXT/TTGEXT
      TEXT=700.
 7240 DO=ENT(TEXT,EEQUI(2,1),SAFC)-QMANI
      RO=DO/QMANI
      IF(ABS(RO)-0.003) 7220,7220,7230
 7230 IF(ITEXT-2) 7200,7210,7210
 7200 ITEXT=2
      XROM(1)=700.
      YROM(1)=RO
      TEXT=600.
      GO TO 7240
 7210 CALL CONT(TEXT,RO,0.,0.,XROM,YROM,ITEXT)
      ITEXT=ITEXT+1
      IF(ITEXT-20) 7240,7220,7220
 7220 CONTINUE
```

```
      ITFL=ITFL+1
      WRITE(LPT,8090) TEXT
      GO TO 7060
7070  CONTINUE
      IF(ITFL-LITFL) 7260,7260,7060
7260  ANGLE1=ANGLE1-720.
      GO TO 100
7060  CONTINUE
      VSTROK=BORE*BORE*STROKE/4.*3.1416
      CALL FRICT
      WRITE(LPT,8092) FMEP(2),FMEP(3),FMEP(4),FMEP(5),FMEP(6),
     1 FMEP(7),FMEP(8),FMEP(1)
      AIMEP=PS/VSTROK*7500000./(RPM/120.)
      PIMEP=PSIN/VSTROK*7500000./(RPM/120.)
      PEMEP=PSEX/VSTROK*7500000./(RPM/120.)
      BMEP=AIMEP-FMEP(1)
      BHP=BMEP*VSTROK/7500000.*(RPM/120.)
      AISFC= FUEL*3600./PS*RPM/120.
      BSFC= FUEL*3600./BHP*RPM/120.
      WRITE(LPT,8000) PIMEP,PSIN
      WRITE(LPT,8010) PEMEP,PSEX
      WRITE(LPT,8020) AIMEP,PS,AISFC
      WRITE(LPT,8030) BMEP,BHP,BSFC
      RHERE=TTQHTR(1)/(FUEL*(FKCAL-VACAL))
      PERMI=CYLN*RPM/2.
      DO 17 I=1,NDIVID
   17 TTQHTR(I)=TTQHTR(I)*PERMI
      WRITE(LPT,8055)
      WRITE(LPT,8056) (TTQHTR(I),I=1,NDIVID),RHERE
      WRITE(LPT,8070) PMAX,PMAXAN
   23 FORMAT(8F10.0)
  301 FORMAT(I2)
  302 FORMAT(I2,F10.0)
8000  FORMAT(///,10X,'PIMEP=',F8.2,'G/CM**2',5X,'PSIN=',F8.2,'HP')
8010  FORMAT(1H ,10X,'PEMEP=',F8.2,'G/CM**2',5X,'PSEX=',F8.2,'HP')
8020  FORMAT(1H ,/,10X,'AIMEP=',F8.0,'G/CM**2',5X,'IHP=',F8.2,'HP',
     1 5X,'AISFC=',F8.2,'G/IHP.HR')
8030  FORMAT(1H ,/,10X,' BMEP=',F8.0,'G/CM**2',5X,'BHP=',F8.2,'HP',
     1 5X,' BSFC=',F8.2,'G/BHP.HR')
8055  FORMAT(1H ,//,10X,'HEAT REJECTION=   CAL/MIN')
8056  FORMAT(1H , 9X,15HTOTAL H. REJ  = ,F10.4,/,
     1           10X,15HCYL. LINER     =,F10.4,/,
     2           10X,15HPISTON TOP     =,F10.4,/,
     3           10X,15HPISTON CUP     =,F10.4,/,
     4           10X,15HCYL. HEAD      =,F10.4,/,
     5           10X,15HINT. VALVE     =,F10.4,/,
     6           10X,15HEXH. VALVE     =,F10.4,//,
     7           7X,18HHEAT REJ./FUEL    =,F10.3)
8070  FORMAT(1H ,//,10X,'PEAK CYL PRESS=' ,F10.1,'AT',F5.1,'DEG. CA')
8090  FORMAT(1H ,/10X,'EXHAUST TEMPERATURE=',F8.1,'KDEG')
8092  FORMAT(//,'**PREDICTION OF THE FRICTION LOSS**',/,
     1 5X,16HMISC. AND PUMPS= , F12.3,7HG/CM**2,/,
     1 5X,16HCAM GEAR        = , F12.3,7HG/CM**2,/,
     1 5X,16HBEARING         = , F12.3,7HG/CM**2,/,
     1 5X,16HBLOWBY          = , F12.3,7HG/CM**2,/,
     1 5X,16HVISCOUS PISTON  = , F12.3,7HG/CM**2,/,
     1 5X,16HRING TENSION    = , F12.3,7HG/CM**2,/,
     1 5X,16HRING GAS PRESS  = , F12.3,7HG/CM**2,/,
     14X,'-----------------------------------------------------',/,
     1 5X,16HTOTAL LOSS      = , F12.3,7HG/CM**2)
```

```
6001 FORMAT(2X,2I2,7E12.4)
6010 FORMAT(//,F10.1)
6000 FORMAT(2X,2I2,9E12.4)
6050 FORMAT(2E12.4)
6080 FORMAT(6F10.2,2F10.0,3F10.4)
9000 READ(INP,301) NEXTO
     IF(NEXTO.EQ.1) GO TO 9001
     CALL EXIT
     END
```

```
      SUBROUTINE DCAL
C
C
C  CALCULATION OF HEAT RELEASE FOR EACH ELEMENT
      COMMON/FPROP/ IECHE(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /STATE/ ANGLEI,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PSI,SAFC,VACAL
      COMMON /JETS/ RJET(50),HJET(50),AJET(50),BJET(50),THER(50),
     1 VRJET(50),VZJET(50),WJET(50),VJET(50),AINJ(50),RHJET(50),
     2 PITCH(50)
      COMMON /PLUME/ PMASS(50),BMASS(50),RPLUM(50),HRMASS(50)
      COMMON /JETDAT/ WSWIRO,ALPHA,BETA,RHGAS
      COMMON/COMP/ RPLUMO,ENTUR,RLFSP,ASPARK,TSCALE
      DEL=ZN/ZM
      IF(IE.EQ.1) GO TO 300
      DO 100 I=2,IE
      AJE=AJET(I)*180./3.1416
C  HEAT RELEASE =0  UNLESS SPECIFIED LATER
      DHFUEL(I)=0.
C
C  CHECK WHETHER THE FUEL ELEMENT REACHES THE SPARK PLUG OR NOT.
      IF(AJE.LT.ASPARK) GO TO 100
      IF(PMASS(I).GT.1.E-7) GO TO 400
C
C  SET THE INITIAL PLUME MASS AND BURNED MASS
      RPLUM(I)=RPLUMO
      PMASS(I)=RHJET(I)*4./3.*3.1416*RPLUMO**3
C
C  SCALE FACTOR
      PMASS(I)=PITCH(I)/2.*PMASS(I)
      BMASS(I)=PMASS(I)*2./3.
      IECHE(I)=2
  400 DO 410 IP=1,10
C
C  TURBULENT ENTRAINMENT RATE
      U2=ENTUR*VJET(I)
      DPMASS=   SQRT(RHJET(I)*RHJET(I))*4.*3.1416*RPLUM(I)**2*U2
      DPMASS=DPMASS*ASTEP/(6.*RPM)/10.
C
C  SCALE FACTOR
      DPMASS=DPMASS*PITCH(I)/2.
C
C  EFFECT OF FLAME COMING BACK
      IF(IECHE(2).NE.3) GO TO 402
      DPMASS=DPMASS*2.
  402 CONTINUE
      PMASS(I)=PMASS(I)+DPMASS
      IF(PMASS(I).LT.EMASS(2,I)) GO TO 420
      PMASS(I)=EMASS(2,I)
      IECHE(I)=3
  420 TCHA=TSCALE/RLFSP
      DBMASS=(PMASS(I)-BMASS(I))/TCHA*ASTEP/(6.*RPM)/10.
C
      BMASS(I)=BMASS(I)+DBMASS
C  NEXT EQUATION INCLUDES THE SCALE FACTOR ABOUT CALCULATION PITCH
      RPLUM(I)=(PMASS(I)*3./PITCH(I)/(RHJET(I)*4.*3.1416))**0.333
```

```
  410 CONTINUE
      CALL UPROP(PCYL(I),FTEMP(1,I),FEQUI(2,I),DEL,PSI,0.,ENTAIR,
     1 DUM,DUM,DUM,DUM,DUM,DUM,DUM,DUM)
      CALL HPROD(PCYL(I),FTEMP(1,I),FEQUI(2,I),DEL,PSI,ENTGAS,
     1 DUM,DUM,DUM,DUM,DUM,DUM,DUM,DUM,DUM)
C
C  INCLUDING THE FORMATION ENTHALPY
      XX=(ENTAIR-ENTGAS)*1000./FKCAL/FEQUI(2,I)*(SAFC+FEQUI(2,I))
      IF(XX-1.) 430,440,440
  440 XX=1.
  430 HRMASO=HRMASS(I)
      HRMASS(I)=FFUEL(I)*BMASS(I)/EMASS(2,I)*XX
      DHFUEL(I)=(HRMASS(I)-HRMASO)*FKCAL/ASTEP
       TBMASS=TBMASS+HRMASS(I)
      TOBMAS=TOBMAS+OBMASS
  100 CONTINUE
  300 DHFUEL(1)=0.
      RETURN
      END
```

```
      SUBROUTINE INPUT
      COMMON/EPROP/ IECHF(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 EPGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /HETRS/ NDIVID,TMETAL(10),QHTRC(10),ARE(10)
      COMMON /STATE/ ANGLE1,ANGLE,JCOND,ASTEP,NSTEP,IF
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PSI,SAFC,VACAL
      COMMON /JETS/ RJET(50),HJET(50),AJET(50),BJET(50),THER(50),
     1 VRJET(50),VZJET(50),WJET(50),VJET(50),AINJ(50),RHJET(50),
     2 PITCH(50)
      COMMON /PLUME/ PMASS(50),BMASS(50),RPLUM(50),HRMASS(50)
      COMMON /JETDAT/ WSWIRO,ALPHA,BETA,RHGAS
      COMMON /SURGAS/ FSWIR,WSWIR,SDECAY
      COMMON/COMB/ RPLUMO,ENTUR,RLESP,ASPARK,TSCALE
      COMMON /OSOPE/ LPT,INP,LINECO,LINEST,ITEL,LITEL
      REAL*4 MBAR
      COMMON /FUEL/ AF(6),ENW,CX,HY,OZ,QLOWER
      COMMON/OXDANT/XI/CMPSTN/X(7),MBAR
      COMMON/CONTL/ ASTIN,ASTCL,ASTCB,ASTEX,ASTOV,PRININ,PRINCL,PRINEX,
     1 PRINOV
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON/EXFLO/NEXEF,XEXEF(20),YEXEF(20),AREEXD,PEXT,TEXT,GEXT,
     1 IGLEFT,TLEFT,QEXT,QFLOW,ELEFT,AREEXT,XEXV
      COMMON /AMBIE/ TAMB,PAMB
      COMMON /HETR1/ PBASE,TBASE,VBASE,COHT1,COHT2,COHT,HR(10)
      COMMON /FRIDT/ RSKIRT,FCOE,RINGN,FMEP(10)
      DIMENSION XINLI(20) ,XCOEI(20),YCOEI(20),YEXLI(20),XCOEE(20),
     1 YCOEE(20)
      INP=5
      LPT=6
      RESERK=0.
      DEL=ZN/ZM
      WRITE(LPT,3000)
 3000 FORMAT(1H1,2X,'**CYCLE SIMULATION FOR DIRECT INJECTION ENGINE**
     1VERSION 1***')
      READ(INP,3010)
      WRITE(LPT,3010)
 3010 FORMAT(80H
     1                                                          )
      WRITE(LPT,3020)
 3020 FORMAT(1H ,//,1H ,33X,'TABLE OF INPUT DATA AND INITIAL ENGINE COND
     1ITIONS',/,5X,120(1H*))
C
C  READ AND WRITE THE DATA OF ENGINE GEOMETORY
C
C    STROKE=STROKE(CM)
C    CONL=CONNECTING ROD(CM)
C    VCLEAR=CLEARENCE VOLUME( EXCLUDING CUP VOLUME,CM**3)
C    VCUP=CUP VOLUME( CM**3)
C    RCUP= CUP RADIUS (CM)
C    CYLN= NUMBER OF CYLINDER
      READ(INP,23) STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
C
C  READ AND WRITE THE DATA OF VALVE AND FUEL INJECTION TIMING
C
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```
C    AINTO=INTAKE VALVE STARTS TO OPEN(CRANK DEGREE. AROUND -10)
C     AEXTO=EXHAUST VALVE STARTS TO OPEN (AROUND 520)
C    AINTC=INTAKE VALVE STARTS TO CLOSE(AROUND 200)
C    AEXTC=EXHAUST VALVE STARTS TO CLOSE(AROUND 10)
C    AFUELS=FUEL INJECTION STARTS (AROUND 330)
C    AFUELE= FUEL INJECTION ENDS (AROUND 355)
       READ(INP,23) AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
C
C   READ AND WRITE FUEL PROPERTIES
C
C    ZM= CHEMICAL FORMURA. NUMBER OF H
C    ZN=  CHEMICAL FORMURA. NUMBER OF  C
C    SAFC= CHEMICALLY CORRECT AIR-FUEL RATIO
C    FKCAL= LOWER HEATING VALUE OF THE FUEL
C    VACAL=LATENT HEAT VALUE   (CAL/G)
       READ(INP,23) ZM,ZN,SAFC,FKCAL,VACAL
       CX=ZN
       HY=ZM
       QLOWER=FKCAL/1000.
       AF(1)=-0.553
       AF(2)=182.
       AF(3)=-97.8
       AF(4)=20.4
       AF(5)=-0.0309
       AF(6)=-60.5
       XI=3.76
       ENW=0.
       O7=0.
C
C   READ AND WRITE THE DATA OF THE ENGINE OPERATING CONDITION
C
C    FUEL=TOTAL FUEL AMOUNT/ 1 SHOT (GRAM)
C    RPM=ENGINE SPEED (RPM)
C    EGR=EXHAUST GAS RECIRCULATION
       READ(INP,23) FUEL,RPM,EGR
C
C   HOW MANY REGIONS WILL YOU TAKE FOR HEAT TRANSFER AREA?(NDIVID=6)
       NDIVID=6
C
C   ELEMENT 1 IS FOR TOTAL
       NDIVID=NDIVID+1
C
C   READ AND WRITE THE DATA OF THE TEMPERATURE INSIDE ENGINE
C
C    TP= TEMPERATURE OF PISTON TOP
C    TINT= TEMPERATUPE OF INTAKE VALVE
C    TEXV= TEMPERATURE OF EXHAUST VALVE
C    TW= TEMPERATURE OF CYLINDER WALL
C    TCYLH= TEMPERATUPE OF CYLINDER HEAD
       READ(INP,23) TP,TINV,TEXV,TW,TCYLH
       TMETAL(2)=TW
       TMETAL(3)=TP
       TMETAL(4)=TP
       TMETAL(5)=TCYLH
       TMETAL(6)=TINV
       TMETAL(7)=TEXV
C
C   CALCULATIONS FOR THE DISTANCES FROM THE CENTER POINT
C    THESE DATA WILL BE USED TO CALCULATE THE VELOCITIES AT THE WALL
       RHR(2)=BORE/2.
       RHR(3)=(BORE/2.+RCUP)/2.
```

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      RHR(4)=RCUP
      RHR(5)=BORE/(2.*1.414)
      RHR(6)=BORE/4.
      RHR(7)=BORE/4.
C
C  HEAT TRASFER COEFFICIENTS
C
C   COHT1,COHT2= HEAT TRANSFER COEFFICIENT
C     COHT1=2.28
C     COHT2=0.0032
C     COHT=ADJUSTING TOTAL HEAT TRANSFER AMOUNT(MAYBE 1)
      READ(INP,23) COHT1,COHT2,COHT
C
C  READ AND WRITE THE DATA OF INITIAL JET CONDITIONS
C
C   AINJV=JET DIRECTION ANGLE FROM VERTICAL LINE (DEGREE)
C   AINJT=JET DIRETION ANGLE FROM TANGENTIAL LINE (DEGREE)
C   RINIT= JET RADIAL LOCATION WHEN FUEL IS INJECTED (CM)
C   BINIT= JET INITIAL RADIUS (CM)
      READ(INP,23) AINJV,AINJT,RINIT,BINIT
      AINJV= AINJV*3.1416/180.
      AINJT= AINJT*3.1416/180.
C
C  READ AND WRITE DATA OF AIR ENTRAINMENT PARAMETER
C
C   WSRATO= SWIRL RATIO AT BDC (*RPM)
C   ALPHA= ENTRAINMENT PARAMETER FOR PARARELL VELOCITY DIFFERENCE
C                  (0.11 IS RECOMMENDED)
C   BETA= ENTRAINMENT PARAMETER FOR NORMAL VELOCITY DIFFERENCE
C                  (BETA=0.6 IS RECOMMENDED)
C   RHFUEL= DENCITY OF FUEL (GRAM/CM**3)
C   RHGAS= DENCITY OF SURROUNDING GAS (GRAM/CM**3)
C   SDECAY = SWIRL DECAYING FACTOR (6.5E-6 IS RECOMMENDED FOR
C          TCCS ENGINE)
      READ(INP,23) WSRATO,ALPHA,BETA,RHFUEL,RHGAS,SDECAY
      WSWIR0=3.1416/180.*RPM*6.*WSRATO
C
C  READ DATA OF COMBUSTION PARAMETER
C
C   RPLUM0= INTIAL PLUME RADIUS(CM)
C   ENTUR= TURBULENCE ENTRAINMENT PARAMETER
C   RLFSP= LAMINAR FLAME SPEED(CM/SEC)
C   ASPARK=SPARK PLUG LOCATION FROM FUEL INJECTION NOZZLE(DEG)
      READ(INP,23) RPLUM0,ENTUR,RLFSP,ASPARK
C
C
C  DATA OF INTAKE AND EXHAUST SYSTEM
C   DINV= DIAMETER OF INTAKE VALVE
C   SINV=MAXIMUM LIFT OF INTAKE VALVE
C   XINV=NUMBER OF INTAKE VALVE
CB  DEXV= DIAMETER OF EXHAUST VALVE
C   SEXV= MAXMUM LIFT OF EXHAUST VALVE
C   XEXV=NUMBER OB EXHAUST VALVE
      READ(INP,23) DINV,SINV,DEXV,SEXV,XINV,XEXV
      AREIND=3.1416*DINV*SINV*XINV
      AREEXD=3.1416*DEXV*SEXV*XEXV
      ARE(3)=3.1416/4.*(BORE*BORE-RCUP*RCUP*4.)
      ARE(4)=VCUP*2./RCUP
      ARE(6)=3.1416/4.*DINV*DINV
      ARE(7)=3.1416/4.*DEXV*DEXV
```

```
      ARE(5)=3.1416/4.*BORE*BORE-ARE(6)-ARE(7)
C
C
C  DATA OF FRICTIONS
C   RSKIRT= EQUIVALENT LENGTH OF PISTON SKIRT( PROJECTED ARE OF SKIRT
C          / CYLINDER BORE DIAMETER)
C   FCOE= JOURNAL BEARING SIZE COEFFICIENT
C   RINGN= TOTAL NUMBER OF PISTON RINGS PER CYLINDER
      READ(INP,23) RSKIRT,FCOE,RINGN
C  READ DATA OF VALVE LIFT VS. NORMALIZED CRANK ANGLE FOR INTAKE VALVE
      READ(INP,301) NINEF
      READ(INP,301) NINCO
      READ(INP,23)  (XINEF(I),I=1,NINEF)
      READ(INP,23)  (YINLI(I),I=1,NINEF)
      READ(INP,23)  (XCOEI(I),I=1,NINCO)
      READ(INP,23)  (YCOEI(I),I=1,NINCO)
      DO 1000 I=1,NINEF
      VLIFR=SINV*YINLI(I)/DINV
      CALL TWODIM(NINCO,XCOEI,YCOEI,VLIFR,COEF)
      YINEF(I)=YINLI(I)*COEF
 1000 CONTINUE
C  READ DATA OF VALVE LIFT VS. NORMALIZED CRANK ANGLE FOR EXHAUST VALVE
      READ(INP,301) NEXEF
      READ(INP,301) NEXCO
      READ(INP,23)  (XEXEF(I),I=1,NEXEF)
      READ(INP,23)  (YEXLI(I),I=1,NEXEF)
      READ(INP,23)  (XCOEE(I),I=1,NEXCO)
      READ(INP,23)  (YCOEE(I),I=1,NEXCO)
      DO 1010 I=1,NEXEF
      VLIFR=SEXV*YEXLI(I)/DEXV
      CALL TWODIM(NEXCO,XCOEE,YCOEE,VLIFR,COEF)
      YEXEF(I)=YEXLI(I)*COEF
 1010 CONTINUE
C
C  HOW MANY ELEMENTS DO YOU WANT TO DIVIDE THE INJECTED FUEL INTO ?
C   10 ELEMENTS ARE RECOMMENDED
      READ(INP,301) NJET
C
C  AMBIENT CONDITION
C   TAMB= AMBIENT TEMPERATURE
C   PAMB= AMBIENT PRESSURE
      READ(INP,23) TAMB,PAMB
C
C  INTAKE AND EXHAUST PRESSURE
C   PINT=INTAKE PRESSURE (ATA)
C   PEXT=EXHAUST PRESSURE (ATA)
      READ(INP,23) PINT,PEXT,TINT
C
C  COMPUTING INCREMENT
      READ(INP,23) ASTIN,ASTCL,ASTCB,ASTEX,ASTOV
C
C  PRINT CONTROL DATA
      READ(INP,23) PRININ,PRINCL,PRINEX,PRINOV
C
C  INITIAL ENGINE CONDITION
      READ(INP,23) PCYL(2),ETEMP(2,1),EEQUI(2,1),TEXT
      ELEFT=EEQUI(2,1)
      TLEFT=ETEMP(2,1)
C
C   COMPRESSION RATIO
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```
      DISP=3.1416*BORE*BORE/4.*STROKE
      CR=(VCLEAR+VCUP+DISP)/(VCUP+VCLEAR)
C
C   TAYLOR MICRO SCALE
      TSCALE=SINV/CP*0.17
       VINIT= FUEL/RHFUEL/(3.1416*BINIT**2*(AFUELE-AFUELS))*(6.*RPM)
      WRITE(6,5200)
      WRITE(6,5210) VINIT
 5200 FORMAT(2X,'INITIAL JET SPEED')
 5210 FORMAT(10X,'VINIT=',F12.1,'CM/SEC')
C
C  SET THE INITIAL CONDITIONS FOR ALL JET ELEMENTS
      ASTCB=(AFUELE-AFUELS)/FLOAT(NJET)
      ASTEP=ASTCB
      NNJET=NJET+1
      DO 100 I=2,NNJET
      BJET(I)=BINIT
      THER(I)=0.
      VJET(I)=VINIT
      WJET(I)=VINIT*SIN(AINJV)*COS(AINJT)/RINIT
      VRJET(I)=-VINIT*SIN(AINJV)*SIN(AINJT)
      VZJET(I)=VINIT*COS(AINJV)
      RJET(I)=RINIT
      HJET(I)=0.
      AJET(I)=0.
      RHJET(I)=RHFUEL
      RPLUM(I)=RPLUM0
      PMASS(I)=0.
      BMASS(I)=0.
      HRMASS(I)=0.
      AINJ(I)=AFUELS+FLOAT(I-2)*ASTEP
C  NEXT ASSUMTION( FEQUI=3. ) WAS MADE FOR GETTING APPROPRIATE
C   THERMODYNAMIC PROPERTIES
      FEQUI(2,I)=3.
      DD=AFUELE-((FLOAT(I)-1.)*ASTEP+AFUELS)
      IF(DD.LT.0.) GO TO 90
      EMASS(2,I)=3.1416*BINIT**2.*VINIT*ASTEP/(6.*RPM)*RHFUEL
      EFUEL(I)=EMASS(2,I)
      PITCH(I)=ASTEP
      GO TO 100
   90 EMASS(2,I)=3.1416*BINIT**2.*VINIT*(AFUELE-((FLOAT(I)-2.)*ASTEP+
     1 AFUELS))/(6.*RPM)*RHFUEL*ASTEP
      EFUEL(I)=EMASS(2,I)
      PITCH(I)=AFUELE-((FLOAT(I)-2.)*ASTEP+AFUELS)
      GO TO 110
  100 CONTINUE
  110 CONTINUE
C
C  CALCULATION OF INTAKE AIR PROPERTIES
      EQUINT=EGR*ELEFT*SAFC/((1.-EGR)*(ELEFT+SAFC)+EGR*SAFC)
      WRITE(LPT,7020)
      WRITE(LPT,7010) STROKE,AINTO,ZM,TP,
     1                CONL,AEXTO,ZN,TW,
     2                BORE,AINTC,SAFC,TCYLH,
     3                VCLEAR,AEXTC,EKCAL,TINV
      WRITE(LPT,7011) VCUP,AFUELS,VACAL,TEXV,
     5                AFUELE,RHFUEL
      WRITE(LPT,7020)
      AINVV=AINJV*180./3.1416
      AINTT=AINJT*180./3.1416
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      WRITE(LPT,7030) WSRATO,PPLUMO,
     1                AINVV,ENTUR,
     1                AINTT,ALPHA,RLESP,
     3                BINIT,BETA,ASPARK,
     4                RINIT,RHGAS
      WRITE(LPT,7031) RCUP,SDECAY,TSCALE
      WRITE(LPT,7020)
      WRITE(LPT,7040) RPM,PINT,ASTOV,PRINOV,
     1  FUEL,TINT,ASTIN,PRININ,
     2  EGR,EQUINT,ASTCL,PRINCL
      WRITE(LPT,7041) ASTCB,PRINCL,
     1  PAMB,PEXT,ASTCL,PRINCL,
     2  TAMB,TEXT,ASTEX,PRINEX,
     3  ELEFT
      WRITE(LPT,7020)
      WRITE(LPT,7050) DINV,ARE(6) ,PCYL(2),
     1    SINV,ARE(7) ,COHT,FTEMP(2,1),
     2    XINV,ARE(3) ,COHT1,FEQUI(2,1)
      WRITE(LPT,7051) ARE(4) ,COHT2,TEXT,
     4    DEXV,ARE(5) ,
     5    SEXV,
     6    XEXV
      WRITE(LPT,7020)
      WRITE(LPT,7060) RSKIRT,
     1      FCOE,
     2        RINGN
      WRITE(LPT,7020)
      WRITE(LPT,7100)
      WRITE(LPT,7110)
      WRITE(LPT,7000) (XINEF(I),I=1,NINEF)
      WRITE(LPT,7120)
      WRITE(LPT,7000) (YINEF(I),I=1,NINEF)
      WRITE(LPT,7140)
      WRITE(LPT,7110)
      WRITE(LPT,7000) (XEXEF(I),I=1,NEXEF)
      WRITE(LPT,7120)
      WRITE(LPT,7000) (YEXEF(I),I=1,NEXEF)
      RETURN
   23 FORMAT(8F10.0)
 6020 FORMAT(5E12.4)
 6030 FORMAT(6E12.4)
 6040 FORMAT(4E12.4)
 6050 FORMAT(2E12.4)
 6060 FORMAT(I2)
 6070 FORMAT(10E12.4)
  301 FORMAT(I2)
 7000 FORMAT(10X,10F10.3)
 7010 FORMAT(32H          ENGINE GEOMETRY          *,
     1       32H                TIMING             *,
     2       36H                FUEL PROPERTIES         *,
     3       30H    ESTIMATE TEMPERATURES    ,/,
     4 2X,12HSTROKE      =,F10.3,8HCM       *,
     5 17H  INT.VAL.OPEN  =,F9.1,6HDEG   *,
     6 19H  ZM(NO. OF H)     =,F10.1,7H        *,
     7 18H  PISTON TOP(TP) =, F10.1,1HK,/,
     8 2X,12HCON.ROD     =,F10.2,8HCM       *,
     9 17H  EXH.VAL.OPEN  =, F9.1,6HDEG   *,
     1 19H  ZN(NO. OF C)     =, F10.1,7H        *,
     2 18H  CYL.WALL(TW)    =, F10.1,1HK,/,
     3 2X,12HBORE        =, F10.3,8HCM       *,
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    4 17H  INT.VAL.CLOSE =, F9.1,6HDEG  *,
    5 19H  SAFC(STOICH.A/F)= , F10.1,7H      *,
    6 18H  CYL.HEAD(TCYLH)=, F10.1,1HK,/,
    7 2X,12HCLEAR.VOL. =, F10.2,8HCM**3  *,
    8 17H  EXH.VAL.CLOSE =, F9.1,6HDEG  *,
    9 19H  LOWER HEATING   =, F10.0,7H CAL/G*,
    5 18H  INT.VALVE(TINV)=, F10.1,1HK)
7011 FORMAT(2X,
    2     12HCUP VOL.    =, F10.2,8HCM**3  *,
    3 17H  FUEL INJ.START=,F9.1,6HDEG  *,
    4 19H  VAPORIZING HEAT =, F10.0,7H CAL/G*,
    5 18H  EXH.VALVE(TEXV)=,F10.1,1HK,/,
    6 32X,
    7 17H  FUEL INJ.END  =, F9.1,6HDEG  *,
    8 19H  DENSITY          =,  F9.3,7HG/CM**3 ,1H*)
7020 FORMAT(2X,128H-----------------------------------------------------------
    1-----------------------------------------------------------------
    2---                    )
7030 FORMAT(42H           INITIAL JET DATA               *,
    1  44H           JET MIXING PARAMETER               *,
    2  43H                PLUME MODEL                   ,/,
    3  2X,20HJET DIRECTION**      ,19X,1H*,
    4  27H SWIRL RATIO AT BDC        =,F10.3,7H*RPM  *,
    5  23H INITIAL PLUME RADIUS =,F10.4,7H CM   *,/,
    6 2X,20H ANGLE(VERTICAL)   =,F10.2,10H DEG     *,
    7  27H AIR ENTRAIN. PARAMETER    , 16X,1H*,
    8 23H ENTRAIN. PARAMETER   =, F10.3,9X,1H*,/,
    9  2X,20H ANGLE(TANGENTIAL)= ,F10.2,10H DEG     *,
    1  27H   ALPHA                  =, F10.3,6X,1H*,
    1  23H LAM. FLAME SPEED      =, F10.2,10H CM/SEC  *,/,
    2   22H JET RADIUS           =,F10.5,10H CM       *,
    3  27H   BETA                   =, F10.3,6X,1H*,
    4  23H SPARK PLUG LOCATION  =, F10.2,10H DEG      *,/,
    5   22H JET LOCATION(R)      =, F10.3,10H CM       *,
    6  27H DENSITY OF SURROUD. GAS  =,F10.5,7H G/CC *,
    7  8X,19H(FROM INJ. NOZZLE) )
7031 FORMAT(
    8   22H PISTON CUP RADIUS    =, F10.3,10H CM       *,
    9  27H SWIRL DECAY FACTOR       =, E10.3,6X,1H*,
    1  23H TAYLOR MICRO SCALE    =, F10.4,10H CM        )
7040 FORMAT(2X,31H       ENGINE CONDITION        *,
    1 31H        INTAKE CONDITIONS      *,
    2 31H      COMPUTING INTERVALS     *,
    3 31H         PRINT CONTROL         ,/,
    4 2X,15HENGINE SPEED  =,  F8.0,8H RPM   *,
    5 15H PRESSURE      =, F8.3,8H ATA    *,
    6 15H VALVE OVERLAP=, F8.2, 8H DEG    *,
    6 15H VALVE OVERLAP=, F8.2,8X,/,
    8 2X,15HFUEL AMOUNT   =, F8.5, 8H G/SHOT*,
    9 15H TEMPERATURE  =, F8.2,8H K      *,
    9 15H INTAKE        =, F8.2,8H DEG    *,
    1 15H INTAKE        =, F8.2,8X,/,
    2 2X,15HEGR            =, F8.3,7X,1H*,
    3 15H EQUI. RATIO  =,F8.3,7X,1H*,
    4 15H COMPRESSION  =, F8.2,8H DEG    *,
    5 15H COMPRESSION  =, F8.2 )
7041 FORMAT(2X,
    6 31H       AMBIENT CONDITIONS      *,
    7 31H  EXHAUST CONDITIONS(ASSUME)   *,
    8 15H COMBUSTION    =, F8.2,8H DEG    *,
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    9 15H COMBUSTION   =, F8.2,8X,/,
    9 2X,15HPRESSURE        =, F8.2,8H ATA    *,
    9 15H PRESSURE     =, F8.2,8H ATA    *,
    2 15H EXPANSION    =,F8.2,8H DEG    *,
    3 15H EXPANSION    =,F8.2,8X,/,
    42X,15HTEMPERATURE    =, F8.2,8H K       *,
    5 15H TEMPERATURE  =, F8.2,8H K       *,
    6 15H EXHAUST      =, F8.2,8H DEG    *,
    7 15H EXHAUST      =, F8.2,8X,/,
    4 32X,1H*,
    5 15H EQUI. RATIO  =,F8.3,7X,1H*)
7050 FORMAT(2X,31H          INTAKE VALVE            *,
    1 31H        HEAT TRANS. AREA        *,
    2 31H       HEAT TRANS. COEFF        *,
    3 31H       INITIAL CONDITION        , /,
    4 2X,15HDIAMETER        =, F9.3,7H CM    *,
    5 15H INTAKE VALVE = ,F9.3,7H CM**2*,
    6 31H                 (WOSCHNI'S EQ.) * ,
    7 15H CYL. PRESS.  =,F9.2,7H ATA    ,/,
    8 2X,15HLIFT            =,F9.3,7H CM    *,
    9 15H EXHAUST VALVE= ,F9.3,7H CM**2*,
    9 15H COHT         =,F9.5,6X,1H*,
    1 15H CYL. TEMP.   =,F9.1,7H DEG    ,/,
    2 2X,15HNUMBER          =,F9.1,6X,1H*,
    3 15H PISTON TOP   =,F9.3,7H CM**2*,
    4 15H COHT1        =,F9.5,6X,1H*,
    5 15H CYL. EQUI.   = ,F9.3)
7051 FORMAT(2X,31H          EXHAUST VALVE            *,
    1 15H PISTON TOP   = ,F9.3,7H CM**2*,
    2 15H COHT2        =,F9.5,6X,1H*,
    3 15H EXHAUST TEMP.=,F9.1,7H DEG  *,/,
    4 2X,15HDIAMETER        = ,F9.3,7H CM    *,
    5 15H CYL. HEAD    =,F9.3,7H CM**2*,/,
    6 2X,15HLIFT            =,F9.3,7H CM    *,
    7 15H CYL. WALL    =,7X,9HVARIABLE* ,/,
    8 2X,15HNUMBER          =,F9.1,6X,1H*)
7060 FORMAT(2X,31H          FRICTION LOSS            *,/,
    1 2X,15HPISTON SKIRT  = , F9.3,7H CM    *,/,
    2 2X,15HJOU. BEAR. COF= , F9.3,6X,1H*,/,
    3 2X,15HNO. OF RINGS  = ,F9.1,6X,1H*)
7100 FORMAT(1H1,//,2X,
    1 'INTAKE VALVE--EFFECTIVE FLOW AREA VS. CRANK ANGLE')
7110 FORMAT(5X,'NORMALIZED CRANK ANKLE')
7120 FORMAT(5X,'NORMALIZED EFFECTIVE FLOW AREA')
7140 FORMAT(//,2X,
    1 'EXHAUST VALVE--EFFECTIVE FLOW AREA VS. CRANK ANGLE')
     END
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      SUBROUTINE RUNGE(ENTINT)
C
C  THIS PROGRAM WAS MADE FOR OPERATING RUNGE-KUTTA METHOD
C
      COMMON/ERROR/ IECHE(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /STATE/ ANGLE1,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /HETRS/ NDIVID,TMETAL(10),QHTRC(10),ARE(10)
      COMMON /HETR1/ PBASE,TBASE,VBASE,COHT1,COHT2,COHT,RHR(10)
      COMMON /SUM1/ STGINT,STGEXT,STOEXT
      COMMON /SUM2/ TTGINT,TTGEXT,TTOEXT,TTQHTR(10),TQHTR(10),PS
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PSI,SAFC,VACAL
      REAL*4 MBAR
      COMMON /FUEL/ AF(6),ENW,CX,HY,OZ,QLOWER
      COMMON/OXDANT/XI/CMPSTN/X(7),MBAR
      COMMON /JETS/ RJET(50),HJET(50),AJET(50),BJET(50),THER(50),
     1 VRJET(50),VZJET(50),WJET(50),VJET(50),AINJ(50),RHJET(50),
     2 PITCH(50)
      COMMON /PLUME/ PMASS(50),BMASS(50),RPLUM(50),HRMASS(50)
      COMMON /JETDAT/ WSWIR0,ALPHA,BETA,PHGAS
      COMMON /SURGAS/ FSWIR,WSWIR,SDECAY
      COMMON/COMR/ RPLUM0,ENTUR,RLESP,ASPARK,TSCALE
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON/EXFLO/NEXEF,XEXEF(20),YEXEF(20),AREEXD,PEXT,TEXT,GEXT,
     1 IGLEFT,TLEFT,QEXT,QFLOW,ELEFT,AREEXT,XEXV
      COMMON /NOXSP/ CONNO(100),PPMNO(100),WNO(100),SUMDM(100),PPMEXT
      DIMENSION SUMHT(30)
      DEL=ZN/ZM
      STGINT=0.
      STGEXT=0.
      STOEXT=0.
      GINT=0.
      GEXT=0.
      QEXT=0.
      RESERR=0.0
      NSTEP=1
      IEE=IE+1
      DO 31 I=1,IEE
      SUMHT(I)=0.
   31 CONTINUE
      DO 24 I=1,NDIVID
   24 TQHTR(I)=0.
      ANGLE=ANGLE1
      GO TO(20,20,22,22,22),JCOND
   22 CALL VGAS(0.001,0.001,RPM,ANGLE1,DUM,DUM,WSWIR,DUM,FSWIR)
      FSWIR=FSWIR-SDECAY*WSWIR*WSWIR*ASTEP/(6.*RPM)
      GO TO 21
   20 FSWIR=1.0
      WSWIR=WSWIR0
   21 CONTINUE
      IF(JCOND.EQ.4) GO TO 30
      GO TO 40
```

```
C   CALCULATION OF JET MODEL IN ORDER TO GET THE ENTRAINMENT AIR
   30 DOEMAS(1)=0.
C   CHECK WHETHER NEW FUEL ELEMENT IS INJECTED OR NOT
      NNJET=NJET+1
      IF(IE-NNJET) 1010,1020,1020
 1010 AXX=AFUELE+10.
      IF(ANGLE.GT.AXX) GO TO 40
      IE=IE+1
      ETEMP(2,IE)=ETEMP(2,1)
      CALL UPRUP(PCYL(2),ETEMP(2,IE),FEQUI(2,IE),DEL,PSI,
     1 RESERK,EENTH(2,IE),CSUBP,CSUBT,RHO,DRHODT,DRHODP,CHI,
     2 ERGAS(IE),CVBG)
      EENTH(2,IE)=EENTH(2,IE)*1000.
      EMWT(IE)=MBAR
      ECP(IE)=ERGAS(IE)/41.443+CVBG
      EVOL(2,IE)=EMASS(2,IE)*ERGAS(IE)*ETEMP(2,IE)/PCYL(2)
 1020 CONTINUE
      DO 32 I=2,IE
      FEQUIO=FEQUI(2,I)
      EMASSO=EMASS(2,I)
      IF(EMASS(2,1).LT.0.040) GO TO 35
      IF(EMASS(2,1).GT.DOEMAS(1)) GO TO 37
C
C   ALL AIR HAS BEEN ENTRAINED BY JET
   35 ALPHA=0.
      BETA=0.
   37 CONTINUE
      IF(BJET(I).LT.0.2) GO TO 220
      IF(BJET(I).LT.1.0) GO TO 222
      JSTEP=4
      GO TO 230
  222 JSTEP=8
      GO TO 230
  220 JSTEP=50
  230 CALL JET(RJET(I),HJET(I),AJET(I),BJET(I),THER(I),VRJET(I),
     1 VZJET(I),WJET(I),TOM,EMASS(2,I),ASTEP,JSTEP,RPM,ANGLE,PITCH(I),
     1 FSWIR,WSWIR)
      VJET(I)=SQRT(VRJET(I)**2+VZJET(I)**2+(RJET(I)*WJET(I))**2)
      VOL=(3.1416*RJET(I)**2*(1.-THER(I)/(2.*3.1416))+BJET(I)**2
     1 *SIN(THER(I))/2.)*VJET(I)*PITCH(I)/(6.*RPM)
      RHJET(I)=EMASS(2,I)/VOL
      FEQUI(2,I)=EFUEL(I)*(SAFC+FEQUI(2,1))/(EMASS(2,I)-EFUEL(I))
     1 +FEQUI(2,1)
      FEQUI(3,I)=(FEQUI(2,I)-FEQUIO)/ASTEP
      DIEMAS(I)=TOM/ASTEP
      SUMOM(I)=TOM
      DOEMAS(I)=0.
      DOEMAS(1)=DOEMAS(1)+DIEMAS(I)
      EMASS(2,I)=EMASSO
      FEQUI(2,I)=FEQUIO
   32 CONTINUE
      SUMOM(1)=-DOEMAS(1)*ASTEP
      DIEMAS(1)=0.
      FEQUI(3,1)=0.
   40 CONTINUE
      PCYL(1)=PCYL(2)
      DO 100 I=1,IE
      EMASS(1,I)=EMASS(2,I)
      FEQUI(1,I)=FEQUI(2,I)
      EVOL(1,I)=EVOL(2,I)
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```
      ETEMP(1,I)=ETEMP(2,I)
      EENTH(1,I)=EENTH(2,I)
  100 CONTINUE
      ANGLE=ANGLE1
      CALL CALCU(DVCYL,ENTINT)
      CALL DELTA(DVCYL,ENTINT)
      STGINT=STGINT+GINT/6.
      STGEXT=STGEXT+GEXT/6.
      STQEXT=STQEXT+QEXT/6.
      DO 120 I=1,NDIVID
  120 TQHTR(I)=TQHTR(I)+QHTRC(I)/6.
C
C     SECOND STEP
C
      NSTEP=NSTEP+1
      PCYL(4)=PCYL(3)*ASTEP
      PCYL(1)=PCYL(2)+PCYL(4)/2.
      DO 200 I=1,IE
      EMASS(4,I)=EMASS(3,I)*ASTEP
      EEQUI(4,I)=EEQUI(3,I)*ASTEP
      EVOL(4,I)=EVOL(3,I)*ASTEP
      ETEMP(4,I)=ETEMP(3,I)*ASTEP
      EENTH(4,I)=EENTH(3,I)*ASTEP
      EMASS(1,I)=EMASS(2,I)+EMASS(4,I)/2.
      EEQUI(1,I)=EEQUI(2,I)+EEQUI(4,I)/2.
      EVOL(1,I)=EVOL(2,I)+EVOL(4,I)/2.
      ETEMP(1,I)=ETEMP(2,I)+ETEMP(4,I)/2.
      EENTH(1,I)=EENTH(2,I)+EENTH(4,I)/2.
      IF(IECHE(I).EQ.1) GO TO 210
      CALL BPROD(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,EMWT(I),ERGAS(I),CVBG,ERGR)
      GO TO 212
  210 CALL UPROP(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,RESERK,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,CHI,ERGAS(I),CVBG)
      EMWT(I)=MBAR
  212 CONTINUE
      ECR(I)=ERGAS(I)/41.443+CVBG
      SUMHT(I)=SUMHT(I)-DHLOS(I)/6.
  200 CONTINUE
      ANGLE=ANGLE1+ASTEP/2.
      CALL CALCU(DVCYL,ENTINT)
      CALL DELTA(DVCYL,ENTINT)
      STGINT=STGINT+GINT/3.
      STGEXT=STGEXT+GEXT/3.
      STQEXT=STQEXT+QEXT/3.
      DO 225 I=1,NDIVID
  225 TQHTR(I)=TQHTR(I)+QHTRC(I)/3.
C
C     THIRD STEP
C
      PCYL(5)=PCYL(3)*ASTEP
      PCYL(1)=PCYL(2)+PCYL(5)/2.
      DO 300 I=1,IE
      EMASS(5,I)=EMASS(3,I)*ASTEP
      EEQUI(5,I)=EEQUI(3,I)*ASTEP
      EVOL(5,I)=EVOL(3,I)*ASTEP
      ETEMP(5,I)=ETEMP(3,I)*ASTEP
      EENTH(5,I)=EENTH(3,I)*ASTEP
      EMASS(1,I)=EMASS(2,I)+EMASS(5,I)/2.
      EEQUI(1,I)=EEQUI(2,I)+EEQUI(5,I)/2.
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      EVOL(1,I)=EVOL(2,I)+EVOL(5,I)/2.
      ETEMP(1,I)=ETEMP(2,I)+ETEMP(5,I)/2.
      EENTH(1,I)=EENTH(2,I)+EENTH(5,I)/2.
      IF(IECHE(I).EQ.1) GO TO 310
      CALL HPROD(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,EMWT(I),ERGAS(I),CVBG,FBGR)
      GO TO 312
  310 CALL HPROP(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,RESERK,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,CHI,ERGAS(I),CVBG)
      EMWT(I)=MBAR
  312 CONTINUE
      ECP(I)=ERGAS(I)/41.443+CVBG
      SUMHT(I)=SUMHT(I)-DHLOS(I)/3.
  300 CONTINUE
      ANGLE=ANGLEI+ASTEP/2.
      CALL CALCU(DVCYL,ENTINT)
      CALL DELTA(DVCYL,ENTINT)
      STGINT=STGINT+GINT/3.
      STGEXT=STGEXT+GEXT/3.
      STOEXT=STOEXT+OEXT/3.
      DO 320 I=1,NDIVID
  320 TOHTR(I)=TOHTR(I)+OHTRC(I)/3.
C
C     FOURTH STEP
C
      PCYL(6)=PCYL(3)*ASTEP
      PCYL(1)=PCYL(2)+PCYL(6)
      DO 400 I=1,IE
      EMASS(6,I)=EMASS(3,I)*ASTEP
      EEQUI(6,I)=EEQUI(3,I)*ASTEP
      EVOL (6,I)=EVOL (3,I)*ASTEP
      ETEMP(6,I)=ETEMP(3,I)*ASTEP
      EENTH(6,I)=EENTH(3,I)*ASTEP
      EMASS(1,I)=EMASS(2,I)+EMASS(6,I)
      EEQUI(1,I)=EEQUI(2,I)+EEQUI(6,I)
      EVOL (1,I)=EVOL (2,I)+EVOL (6,I)
      ETEMP(1,I)=ETEMP(2,I)+ETEMP(6,I)
      EENTH(1,I)=EENTH(2,I)+EENTH(6,I)
      IF(IECHE(I).EQ.1) GO TO 410
      CALL HPROD(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,EMWT(I),ERGAS(I),CVBG,FBGR)
      GO TO 412
  410 CALL HPROP(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,RESERK,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,CHI,ERGAS(I),CVBG)
      EMWT(I)=MBAR
  412 CONTINUE
      ECP(I)=ERGAS(I)/41.443+CVBG
      SUMHT(I)=SUMHT(I)-DHLOS(I)/3.
  400 CONTINUE
      ANGLE=ANGLEI+ASTEP
      CALL CALCU(DVCYL,ENTINT)
      CALL DELTA(DVCYL,ENTINT)
      STGINT=STGINT+GINT/6.
      STGEXT=STGEXT+GEXT/6.
      STOEXT=STOEXT+OEXT/6.
      DO 420 I=1,NDIVID
  420 TOHTR(I)=TOHTR(I)+OHTRC(I)/6.
C
C     FIFTH STEP
C
```

```
      PCYL(7)=PCYL(3)*ASTEP
      PCYL(2)=PCYL(2)+(PCYL(4)+2.*PCYL(5)+2.*PCYL(6)+PCYL(7))/6.
      DO 500 I=1,IE
      EMASS(7,I)=EMASS(3,I)*ASTEP
      EEQUI(7,I)=EEQUI(3,I)*ASTEP
      EVOL  (7,I)=EVOL  (3,I)*ASTEP
      ETEMP(7,I)=ETEMP(3,I)*ASTEP
      EENTH(7,I)=EENTH(3,I)*ASTEP
      EMASS(2,I)=EMASS(2,I)+(EMASS(4,I)+2.*EMASS(5,I)+2.*EMASS(6,I)
     1 +EMASS(7,I))/6.
      EEQUI(2,I)=EEQUI(2,I)+(EEQUI(4,I)+2.*EEQUI(5,I)+2.*EEQUI(6,I)
     1 +EEQUI(7,I))/6.
      EVOL  (2,I)=EVOL  (2,I)+(EVOL  (4,I)+2.*EVOL  (5,I)+2.*EVOL  (6,I)
     1 +EVOL  (7,I))/6.
      ETEMP(2,I)=ETEMP(2,I)+(ETEMP(4,I)+2.*ETEMP(5,I)+2.*ETEMP(6,I)
     1 +ETEMP(7,I))/6.
      EENTH(2,I)=EENTH(2,I)+(EENTH(4,I)+2.*EENTH(5,I)+2.*EENTH(6,I)
     1 +EENTH(7,I))/6.
      IF(IECHE(I).EQ.1) GO TO 510
      CALL HPROP(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,EMWT(I),ERGAS(I),CVBG,EBGR)
      GO TO 512
  510 CALL UPROP(PCYL(1),ETEMP(1,I),EEQUI(1,I),DEL,PSI,RESFRK,ENTHLP,
     1 CSUBP,CSUBT,RHO,DRHODT,DRHODP,CHI,ERGAS(I),CVBG)
      EMWT(I)=MBAR
  512 CONTINUE
      ECP(I)=ERGAS(I)/41.443+CVBG
      DHLOS(I)=(SUMHT(I)-DHLOS(I)/6.)*ASTEP
  500 CONTINUE
C   INJECTED FUEL HAS SAME TEMP AND ENTHALPY AS AIR.( THIS ASSUMTION IS
C    NECESSARY  FOR THE ACCURATE CALCULATION, BECAUSE THE MASS JUST AFTER
CC    INJECTED IS SO SMALL THAT IT WILL CAUSE A LARGE AMOUNT OF ERROR.)
      IF(ANGLE.GT.AFUELE) GO TO 530
      IF(IE.EQ.1) GO TO 530
      ETEMP(2,IE)=ETEMP(2,1)
      EENTH(2,IE)=EENTH(2,1)
  530 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CALCU(DVCYL,ENTINT)
C
C  THIS SUBROUTINE IS TO SET THE DATA FOR SUBROUTINE RUNGE
      COMMON/EPROP/ TECHE(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),FENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /STATE/ ANGLF1,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /HETRS/ NDIVID,TMETAL(10),QHTRC(10),ARF(10)
      COMMON /HETR1/ PBASE,TBASE,VBASE,COHT1,COHT2,COHT,RHR(10)
      COMMON /SUM2/ TTGINT,TTGEXT,TTQEXT,TTQHTR(10),TQHTR(10),PS
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PSI,SAFC,VACAL
      COMMON /JETS/ RJET(50),HJET(50),AJET(50),BJET(50),THER(50),
     1 VRJET(50),VZJET(50),WJET(50),VJET(50),AINJ(50),RHJET(50),
     2 PITCH(50)
      COMMON /PLUME/ PMASS(50),BMASS(50),RPLUM(50),HRMASS(50)
      COMMON /JETDAT/ WSWIRO,ALPHA,BETA,RHGAS
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON/EXFLO/NEXEF,XEXEF(20),YEXEF(20),AREEXD,PEXT,TEXT,GEXT,
     1 IGLEFT,TLEFT,QEXT,QFLOW,ELEFT,AREEXT,XEXV
      COMMON/COMB/ RPLUMO,ENTUR,RLFSP,ASPARK,TSCALE
C
C   CYLINDER VOLUME
      CALL VOLCY(ANGLE,VCYL,DVCYL,STROKE,BORE,CONL,VCLEAR,VCUP)
C
C   HEAT TRANSFER
      CALL HEATR
C
C  NO HEAT RELEASE FOR ELEMENT 1(AIR)
      DHFUEL(1)=0.
      GO TO (100,200,300,400,600),JCOND
C
C  WHEN THE INTAKE AND EXHAUST VALVE OPEN
C   INTAKE PORT CALCULATION
  100 CALL INPOR
      DIEMAS(1)=GINT
      IF(GINT) 700,710,710
C
C  INTAKE FLOW IS FROM PORT TO CYLINDER
  710 EEQO=EEQUI(1,1)
      EEQN=(EMASS(1,1)*EEQUI(1,1)*(EQUINT+SAFC)+GINT*EQUINT*
     1 (EEQUI(1,1)+SAFC))/(EMASS(1,1)*(EQUINT+SAFC)+GINT*(EEQUI(1,1)
     2 +SAFC))
      EEQUI(3,1)=EEQN-EEQO
      QFLOW=GINT*ENTINT
      GO TO 720
C
C  INTAKE FLOW IS FROM CYLINDER TO PORT (BACK FLOW)
  700 EEQUI(3,1)=0.
      QFLOW=GINT*ENT(ETEMP(1,1),EEQUI(1,1),PCYL(1))
C
C  EXHAUST PORT CALCULATION
  720 CALL EXPOR
      DOEMAS(1)=-GEXT
      EMASS(3,1)=GINT+GEXT
      QFLOW=QFLOW+GEXT*FENTH(1,1)
```

```
      GO TO 2000
C
C  WHEN THE INTAKE PROCESS CALCULATION
C    INTAKE PORT CALCULATION
  200 CALL INPOR
      DIEMAS(1)=GINT
      IF(GINT) 800,810,810
C
C  INTAKE FLOW IS FROM PORT TO CYLINDER
  810 EEQO=EEQUI(1,1)
      EEQN=(EMASS(1,1)*EEQUI(1,1)*(EQUINT+SAFC)+GINT*EQUINT*
     1 (EEQUI(1,1)+SAFC))/(EMASS(1,1)*(EQUINT+SAFC)+GINT*(EEQUI(1,1)
     2 +SAFC))
      EEQUI(3,1)=EEQN-EEQO
      QFLOW=GINT*ENTINT
      GO TO 820
C
C   INTAKE FLOW IS FROMCYLINDER TO PORT (BACK FLOW)
  800 EEQUI(3,1)=0.
      QFLOW=GINT*EENTH(1,1)
  820 GEXT=0.
      QEXT=0.
      EMASS(3,1)=GINT
      GO TO 2000
C
C  COMPRESSION AND EXPANSION
  300 EEQUI(3,1)=0.
      EMASS(3,1)=0.
      QFLOW=0.
      GINT=0.
      GEXT=0.
      QEXT=0.
      GO TO 2000
C
C   COMBUSTION AND EXPANSION PROCESS
  400 CONTINUE
      IF(IE.EQ.1) GO TO 300
      IF(NSTEP.GE.2) GO TO 410
      CALL DCAL
C
C  THE EFFECT OF PUSHING THE FUEL ELEMENT INTO CYLINDER
      IF(ANGLE.GE.AFUELE) GO TO 410
      DDV=EVOL(1,IE)/ASTEP
  410 CONTINUE
      QFLOW=-DOEMAS(1)*EENTH(1,1)
      GINT=0.
      GEXT=0.
      QEXT=0.
      IF(ANGLE.GE.AFUELE) GO TO 420
      DVCYL=DVCYL-DDV
  420 CONTINUE
      GO TO 2000
C
C  EXHAUST VALVE OPEN
  600 EEQUI(3,1)=0.
      CALL EXPOR
      DOEMAS(1)=-GEXT
      EMASS(3,1)=GEXT
      QFLOW=GEXT*EENTH(1,1)
 2000 RETURN
      END
```

```
      SUBROUTINE FRICT
C
C  CALCULATION OF THE FRICTION LOSSES
C  THIS PROGRAM WAS ORIGINALLY MADE BASED ON IN.-LB UNITS.
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON /AMBIE/ TAMB,PAMB
      COMMON /FRIDT/ RSKIRT,FCOE,RINGN,FMEP(10)
      FAC1=2.54
      FAC2=1000./14.2
      BOREX=BORE/FAC1
      STROX=STROKE/FAC1
      RSKIX=RSKIRT/FAC1
      CR=(3.1416*BORE*BORE*STROKE/4.+VCUP+VCLEAR)/(VCUP+VCLEAR)
C
C  MISCELLANEOUS AND PUMPS
      FMEP(2)=FAC2*0.39*(RPM/1000.)**1.5
C
C  CAM GEAR
      DINTV=SQRT(AREIND*4./(3.1416*XINV))/FAC1
      FMEP(3)=FAC2*(30.-(4.*RPM/1000.))*XINV*DINTV**1.75/(BOREX*BOREX
     1*STROX)
C
C  BEARING
          FMEP(4)=FAC2*(FCOE*BOREX/STROX)*RPM/1000.
C
C  BLOWBY
      XX=ABS(PAMB-PINT)
      IF(XX.LT.0.) XX=0.
      FMEP(5)=FAC2*SQRT(XX)*(1.72*CR**0.4-(0.49+0.015*CR)*(RPM/1000.)**
     1 1.185)
C
C  VISCOUS PISTON
      FMEP(6)=FAC2*(21.93*RSKIX/(BOREX*STROX)*STROX*RPM/5000.)
C
C  STATIC RING TENSION
      FMEP(7)=FAC2*2.11*STROX*RINGN/(BOREX*BOREX)
C
C  RING GAS PRESSURE
      FMEP(8)=FAC2*XX*(2.35*STROX/(BOREX*BOREX))*(0.088*CR+0.182*CR**
     1 (1.33-(0.121*STROX*RPM/5000.)))
C
C  TOTAL FRICTION LOSS
      FMEP(1)=0.
      DO 100 I=2,8
      FMEP(1)=FMEP(1)+FMEP(I)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VGAS(RJET,HJET, RPM,  ANGLE,VRGAS,VZGAS,WSWIR,VPIS,
     1 FSWIR)
C
C
C  CALCULATION OF THE GAS VELOCITY SURROUDING THE JET
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /JETDAT/ WSWIRO,ALPHA,BETA
C  RJET=JET RADIUS FROM CENTER(CM)                     (GIVEN)
C  HJET=JET VERTICAL LOCATION FROM CYLINDER HEAD       (GIVEN)
C  RPM= ENGINE SPEED                                   (GIVEN)
C  ANGLE= CRANK ANGLE (DEG),TDC=360                    (GIVEN)
C  VRGAS=VELOCITY COMP. OF RADIAL DIRECTION            (GIVEN)
C  VZGAS=VELOCITY COMP. OF VERTICAL DIRECTION          (GIVEN)
C  WSWIR=ANGULAR VELOCITY(RAD/SEC)                     (GIVEN)
C  VPIS= PISTON SPEED(CM/SEC)                          (GIVEN)
C  FSWIR=CONSERVATION RATIO OF SWIRL                   (GIVEN)
C  STROKE ,BORE,CONL,VCLEAR,VCUP,RCUP,WSWIRO ARE GIVEN IN COMMON
C     (SEE THE INPUT ROUTINE TO CHECK THE MEANINGS OF THESE VALUES)
C  NO SUBROUTINES ARE REQUIRED
      RCYL=BORE/2.
      AK1=VCUP/(3.1416*RCYL*RCYL)
      AK2=VCUP/(3.1416*RCUP*RCUP)
      ANG=ANGLE*3.1416/180.
      ANG0=3.1416
C
C   PISTON HIGHT FROM THE PISTON TO THE CYLINDER HEAD
      HIGH=SQRT(1.-(STROKE/2.*SIN(ANG)/CONL)**2 )
      HIGH=VCLEAR/(3.1416*BORE*BORE/4.)+STROKE/2.*(1.-COS(ANG))
     1 +CONL*(1.-HIGH)
C
C  PISTON HIGHT AT BDC
      HIGH0=SQRT(1.-(STROKE/2.*SIN(ANG0)/CONL)**2 )
      HIGH0=VCLEAR/(3.1416*BORE*BORE/4.)+STROKE/2.*(1.-COS(ANG0))
     1 +CONL*(1.-HIGH0)
C
C  PISTON SPEED
      VPIS=SQRT(CONL*CONL-STROKE*STROKE/4.*SIN(ANG)*SIN(ANG))
      VPIS=STROKE/2*SIN(ANG)+STROKE*STROKE/4.*SIN(ANG)*COS(ANG)/VPIS
      VPIS=VPIS*3.1416/180.*RPM*6.
      XX=HIGH/AK1
      IF(RJET.LT.RCUP) GO TO 100
      IF(HJET.LT.HIGH) GO TO 200
      VZGAS=0.
      VRGAS=0.
      GO TO 400
C
C  GAS VELOCITY COMPONENTS ABOVE THE PISTON( FLAT PART)
  200 VRGAS=RJET/(2.*AK1)*(RCYL*RCYL/(RJET*RJET)-1.)*VPIS/(XX*(1.+XX))
      VZGAS=HJET/HIGH*VPIS
      GO TO 400
  100 IF(HJET.LT.HIGH) GO TO 300
C
C  GAS VELOCITY COMPONENTS INSIDE THE CUP
      VRGAS=0.
      VZGAS=(AK1-AK2+HJET)/(AK1+HIGH)*VPIS
      GO TO 400
C
```

```
C  GAS VELOCITY COMPONENTS  ABOVE PISTON CUP
  300 VRGAS=RJET/(2.*AK1)*(1.-AK2/AK1)/(XX*(XX+AK2/AK1))
      VRGAS=-VRGAS*VPIS
      VZGAS=(1.-RCYL*RCYL/(RCUP*RCUP*(XX+1.)))*HJET/HIGH*VPIS
C
C  GAS VELOCITY (TANGENTIAL COMPONENT)
  400 WSWIR=(HIGH+AK1)/(HIGH0+AK1)*WSWIR0*(AK2*RCUP**4.
     1 +HIGH0*RCYL**4.)/(AK2*RCUP**4.+HIGH*RCYL**4.)
      WSWIR=WSWIR*FSWIR
      RETURN
      END
      SUBROUTINE CONT(XX,YY,X1,Y0,X,Y,N)
      DIMENSION X(2),Y(2)
      IF(N-2) 10,20,30
   10 X(1)=XX
      Y(1)=YY
      XX=XX+X1
      N=2
      RETURN
   20 X(2)=XX
      Y(2)=YY
      N=3
      GO TO 60
   30 IF((Y(2)-Y0)*(YY-Y0 )) 40,50,50
   40 X(1)=XX
      Y(1)=YY
      GO TO 60
   50 X(2)=XX
      Y(2)=YY
   60 XX=(Y0-Y(1))*(X(2)-X(1))/(Y(2)-Y(1))+X(1)
      RETURN
      END
```

```
      SUBROUTINE JET(RJET,HJET,AJET,RJET,THER,VRJET,VZJET,WJET,TDM,
     1 AMJET,ASTEP,JSTEP,RPM,ANGLE,PITCH,FSWIR,WSWIR)
C
C
C  THIS SUBROUTINE IS FOR GETTING JET TRAJECTORY AND AIR ENTRAINMENT
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /JETDAT/ WSWIR0,ALPHA,BETA,RHGAS
C  RJET=RADIAL JET LOCATION FROM CENTER(CM)         (GIVEN AND RETURNED)
C  HJET=VERTICAL JET LACATION FROM CYL. HEAD        (GIVEN AND RETURNED)
C  AJET=TANGEN. JET LOCATION FROM NOZZLEHEAD        (GIVEN AND RETURNED)
C  AJET=TANGEN. JET LOCATION FROM INJECTION NOZZ.   (GIVEN AND RETURNED)
C  BJET=JET RADIUS(CM)                              (GIVEN AND RETURNED)
C  THER=CONTACTING ANGLE(RAD)                       (GIVEN AND RETURNED)
C  VRJET=JETVELOCITY OF RADIAL DIRECTION(CM/SEC)    (GIVEN AND RETURNED)
C  VZJET=JET VEL. VERTICAL DIRECTION(CM/SEC)        (GIVEN AND RETURNED)
C  WJET=JET ANGULAR VELOCITY(RAD/SEC)               (GIVEN AND RETURNED)
C  TDM=ENTRAINED MASS(G/GIVEN TIME)                 (RETURNED)
C  AMJET=JET MASS(G)                                (GIVEN AND RETURNED)
C  ASTEP=CALCULATION INTERVAL OF MAIN PROGRAM(DEG)  (GIVEN)
C  JSTEP=HOW MANY TIMES DO YOU WANT TO CALCULATE IN ONE CALCULATION
C       INTERVAL OF MAIN PROGRAM                    (GIVEN)
C  RPM=ENGINE SPEED(RPM)                            (GIVEN)
C  ANGLE=CRANKANGLE (DEG).TDC =360                  (GIVEN)
C  PITCH=PITCH OF JET ELEMENT(GIVEN INPUT ROUTINE   (GIVEN)
C  FSWIR=CONSERVATION RATIO OF SWIRL                (GIVEN)
C  STROKE ,BORE,CONL,VCLEAR,VCUP,RCUP,WSWIR0,ALPHA,BETA,RHGAS ARE
C   GIVEN IN COMMON
C    (SEE THE INPUT ROUTINE TO CHECK THE MEANINGS OF THESE VALUES)
C  SUBROUTINE REQUIRED:
C    VGAS
C    CONT
      DIMENSION XX(2),YY(2)
      RCUP=2.4638
      RCYL=BORE/2.
      TDM=0.
      AASTEP=ASTEP/FLOAT(JSTEP)
      C1=ASTEP/(6.*RPM)
      C2= AASTEP/(6.*RPM)
      C3=1./(6.*RPM)
      VJET=SQRT(VRJET**2 +VZJET**2 +(RJET*WJET)**2 )
      DO 3000 I=1,JSTEP
      RHJET=AMJET/((3.1416*BJET**2*(1.-THER/(2.*3.1416))+BJET**2
     1 *SIN(THER)/2.)*VJET*PITCH/(6*RPM))
      ANGLJ=ANGLE+FLOAT(I)*AASTEP
      ANG=ANGLJ*3.1416/180.
      HIGH=SQRT(1.-(STROKE/2.*SIN(ANG)/CONL)**2 )
      HIGH=VCLEAR/(3.1416*BORE*BORE/4.)+STROKE/2.*(1.-COS(ANG))
     1 +CONL*(1.-HIGH)
C
C  GAS VELOCITY SURROUNDING THE JET
      CALL VGAS(RJET,HJET,RPM,   ANGLJ,VRGAS,VZGAS,WSWIR,VPIS,FSWIR)
 1111 FORMAT(7E12.4)
C
C  CALCULATION OF THE PARARELL VELOCITY COMPONENT TO THE JET
      VI=SQRT(VRJET**2 +(RJET*WJET )**2 +VZJET**2 )
      VI=(VRJET*VRGAS+RJET**2.*WSWIR*WJET+VZJET*VZGAS)/VI
C
C  CALCULATION OF THE NORMAL VELOCITY COMPONENT TO THE JET
      VN=VRGAS**2 +(RJET*WSWIR)**2 +VZGAS**2
      XXX=VN-VI**2
```

```
      IF(XXX.GT.0.) GO TO 50
      VN=0.
      GO TO 60
   50 VN=SQRT(VN-VI**2)
   60 CONTINUE
C
C  CHANGES OF MASS AND VELOCITY COMPONENTS OF THE JET
C  CHANGE OF MASS(G)
      DM=   VJET*SQRT(RHJET/RHGAS)*RHGAS*PITCH/(6.*RPM)
      DM=DM*2.*3.1416*RJET*(ALPHA*ABS(VJET-VI)+BETA*ABS(VN))
      DM=DM*(1.-THER/(2.*3.1416))
      DM=DM*C2
      TDM=TDM+DM
      AMJET=AMJET+DM
C  CHANGE OF VERTICAL VELOCITY
      DVZ=DM/AMJET*(VZGAS-VZJET)
C  CHANGE OF RADIAL VELOCITY
      DVR=AMJET*RJET*(WJET**2 -RHGAS/RHJET*WSWIR**2 )
      DVR=DVR*C2
      DVR=(DVR-(VRJET-VRGAS)*DM)/AMJET
C  CHANGE OF ANGULAR VELOCITY
      DW=((WSWIR-WJET)*RJET*DM-2.*AMJET*VRJET*WJET*C2)/(AMJET*RJET)
C  CHANGE OF TOTAL JET VELOCITY
      DV=(RJET**2.*WJET*DW+RJET*WJET**2 *VRJET*C2+VRJET*DVR+VZJET*DVZ)
      DV=DV/VJET
C
C  NEW STATE CONDITIONS OF THE JET
      VJET=VJET+DV
      WJET=WJET+DW
      VRJET=VRJET+DVR
      VZJET=VZJET+DVZ
      RJET=RJET+VRJET*C2
      ALJET=VJET*PITCH/(6.*RPM)
      VOLJE=DM/RHGAS+(AMJET-DM)/RHJET
C  JET RADIUS WITHOUT CONTACTING ANY WALLL
      BJET0=SQRT(VOLJE/(3.1416*ALJET))
      HJET=HJET+VZJET*C2
      AJET=AJET+WJET*C2
C
C  CALCULATION OF THE JET CONFIGURATION
      X1=RJET+BJET0
      X2=HJET+BJET0
      X5=HIGH+VCUP/(3.1416*RCUP*RCUP)
      IF(HJET.GT.HIGH) GO TO 100
      IF(RCYL.GT.X1) GO TO 200
      IF(RCYL.GT.RJET) GO TO 300
C
C  JET IS RESTRICTED BY THE CYLINDER WALL(VRJET=0.)
      VRJET=0.
      BJET=1.414*BJET0
      THER=3.1416
      RJET=RCYL
      GO TO 2000
C
C  JET IS CONTACTING WITH THE CYLINDER WALL
  300 NN=0
      X3=RJET
      X4=RCYL
      GO TO 1500
  200 IF(X2.LT.HIGH) GO TO 400
```

```
      IF(X1.LT.RCUP) GO TO 400
      IF(RJET.LT.RCUP) GO TO 500
C
C  JET IS CONTACTING WITH THE PISTON HEAD
      NN=0
      X3=HJET
      X4=HIGH
      GO TO 1500
C
C  JET IS NOT CONTACTING
  400 RJET=RJETO
      THER=0.
      GO TO 2000
  100 IF(RJET.LT.RCUP) GO TO 600
      SL=ABS(HJET-HIGH)
      SR=ABS(RJET-RCUP)
      IF(SL.GT.SR) GO TO 700
C
C  JET IS RESTRICTED BY THE PISTON HEAD(VZJET=VPIS)
      VZJET=VPIS
      RJET=1.414*RJETO
      THER=3.1416
      HJET=HIGH
      GO TO 2000
  700 IF(HJET.GT.X5) GO TO 800
C
C  JET IS RESTRICTED BY THE PISTON CUP(VRJET=0.)
      VRJET=0.
      RJET=1.414*RJETO
      THER=3.1416
      RJET=RCUP
      GO TO 2000
C
C  JET IS RESTRICTED BY THE PISTON CUP EDGE(VRJET=0. AND VZJET=VPIS)
  800 VRJET=0.
      VZJET=VPIS
      RJET=RCUP
      HJET=X5
      RJET=1.414*RJETO
      GO TO 2000
  600 IF(RCUP.LT.X1) GO TO 900
      IF(X5.LT.X2) GO TO 1000
C
C  JET IS IN THE PISTON CUP WITHOUT ANY RESTRICTION
      RJET=RJETO
      THER=0
      GO TO 2000
 1000 IF(X5.LT.HJET) GO TO 1100
C  JET IS CONTACTING WITH THE PISTON BOTTOM
C
      NN=0
      X3=HJET
      X4=X5
      GO TO 1500
C
C  JET IS RESTRICTED BY THE PISTON BOTTOM
 1100 RJET=1.414*RJETO
      THER=3.1416
      HJET=X5
      VZJET=VPIS
```

```
      GO TO 2000
  900 IF(RCUP.LT.RJET) GO TO 1200
C
C  JET IS CONTACTING WITH THE PISTON CUP WALL
  500 NN=0
      X3=RJET
      X4=RCUP
      GO TO 1500
C
C  JET IS RESTRICTED BY THE PISTON CUP WAL_
 1200 BJET=1.414*BJETO
      THER=3.1416
      RJET=RCUP
      VRJET=0.
      GO TO 2000
C
C  SOLVE THE CONTACTING ANGLE
 1500 ITEL=1
 1550 IF(BJET.GT.(X4-X3)) GO TO 1600
      BJET=X4-X3
 1600 ANG1=2.*ATAN(SQRT(BJET*BJET-(X4-X3)*(X4-X3))/(X4-X3))
      THER=ANG1
      AREA1=3.1416*BJET*BJET*(1.-ANG1/(2.*3.1416))+(X4-X3)*SIN(ANG1
     1  /2.)*BJET
      AREA2=3.1416*BJETO*BJETO
      ERRO=(AREA1-AREA2)/AREA2
      IF(ABS(ERRO).LT.0.005) GO TO 2000
      Y0=0.
      XNEXT=0.1
      CALL CONT(BJET,ERRO,XNEXT,Y0,XX,YY,NN)
 1998 FORMAT(2E12.4)
      ITEL=ITEL+1
      IF(ITEL.GT.30) GO TO 1990
      GO TO 1550
 1990 WRITE(6,1999)
 1999 FORMAT('STOP DUE TO THE OVER ITELATION')
 2000 CONTINUE
 3000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OPERA
C
C
C  THIS SUBROUTINE IS FOR OPERATION OF EACH PROCESS
      COMMON/EPROP/ IECHE(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /STATE/ ANGLEI,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PST,SAFC,VACAL
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /OSOPE/ LPT,INP,LINECO,LINEST,ITEL,LITEL
      COMMON/CONTL/ ASTIN,ASTCL,ASTCB,ASTEX,ASTOV,PRININ,PRINCL,PRINEX,
     1 PRINOV
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /HETR1/ PBASE,TBASE,VBASE,COHT1,COHT2,COHT,RHR(10)
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /SUM2/ TTGINT,TTGEXT,TTOEXT,TTQHTR(10),TQHTR(10),PS
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON /AMBIE/ TAMB,PAMB
      COMMON /NOXSP/ CONNO(100),PPMNO(100),WNO(100),SUMDM(100),PPMEXT
      ANGLE=ANGLE+ASTEP
      IF(ANGLE-AEXTC) 100,120,120
  100 IF(JCOND-1) 110,9000,9000
  110 IF(JLAST.EQ.1) GO TO 112
C
C  SET THE LAST COMPUTING STEP
      ASTEP=AINTO-(ANGLE-ASTEP)
      ANGLE=AINTO
      JLAST=1
      GO TO 9000
C
C  INTAKE AND EXHAUST VALVE OPEN
  112 JCOND=1
      JLAST=0
      ASTEP=ASTOV
      LINEST=IFIX(PRINOV)
      LINECO=0
      WRITE(LPT,7000)
      WRITE(LPT,7010)
      WRITE(LPT,7020)
      WRITE(LPT,7030)
      GO TO 9000
  120 IF(ANGLE-AINTC) 130,140,140
  130 IF(JCOND-2) 150,9000,9000
  150 IF(JLAST.EQ.1) GO TO 152
      ASTEP=AEXTC-(ANGLE-ASTEP)
      ANGLE=AEXTC
      JLAST=1
      GO TO 9000
C
C  INTAKE VALVE OPENS
  152 JCOND=2
      JLAST=0
      ASTEP=ASTIN
      LINEST=IFIX(PRININ)
      LINECO=0
      WRITE(LPT,7200)
      WRITE(LPT,7010)
```

```
      WRITE(LPT,7220)
      WRITE(LPT,7230)
      GO TO 9000
  140 IF(ANGLE-AFUELS) 160,170,170
  160 IF(JCOND-3) 180,9000,9000
  180 IF(JLAST.EQ.1) GO TO 182
      ASTEP=AINTC-(ANGLE-ASTEP)
      ANGLE=AINTC
      JLAST=1
      GO TO 9000
C
C  COMPRESSION PROCESS
  182 JCOND=3
      JLAST=0
      ASTEP=ASTCL
      LINEST=IFIX(PRINCL)
      LINECO=0
C
C  CALCULATE THE OVERALL EQUIVALENCE RATIO
C
      PHIO=0.5
      DO 172 I=1,4
      FRES=(EMASS(2,1)-TTGINT)*PHIO/(SAFC+1.)
      FEGR=TTGINT*PHIO*EGR/(SAFC+1.)
      PHIO=(FUEL+FRES+FEGR)/(EMASS(2,1)-FRES+FEGR)*SAFC
  172 CONTINUE
C
C  CALCULATE THE VOLUMETRIC EFFICIENCY
      DEL=ZN/ZM
      CALL UPROP(PAMB,TAMB,0.,DEL,PST,0.,DUM,DUM,DUM,DUM,DUM,DUM,
     1 DUM,RGAS,DUM)
      DISP=3.1416/4.*BORE*BORE*STROKE
      THMASS=PAMB*DISP/(RGAS*TAMB)
      EFFVOL=TTGINT/THMASS
C
C  CORRECT THE EQUIVALENCE RATIO OF CHARGED AIR
      EEQUI(2,1)=(FRES+FEGR)/(EMASS(2,1)-FRES-FEGR)*SAFC
      TBASE=ETEMP(2,1)
      PBASE=PCYL(2)
      VBASE=EVOL(2,1)
C
C  NOX CONCENTRATION FOR CHARGED AIR
      CONNO(1)=(EMASS(2,1)-TTGINT)/EMWT(1)*PPMEXT/1000000.
     1 +TTGINT*EGR/EMWT(1)*PPMEXT/1000000.
      PPMNO(1)=1000000.*CONNO(1)*EMWT(1)/EMASS(2,1)
      WNO(1)=30.*CONNO(1)
      WRITE(LPT,6100) PHIO
      WRITE(LPT,6120) EFFVOL
      WRITE(LPT,6140) EEQUI(2,1)
      WRITE(LPT,6160) PPMNO(1),WNO(1)
      WRITE(LPT,7400)
      WRITE(LPT,7010)
      WRITE(LPT,7420)
      WRITE(LPT,7430)
      GO TO 9000
  170 IF(ANGLE-AEXTO) 190,200,200
  190 IF(JCOND-4) 210,192,192
  192 IF(ANGLE-AFUELE-20.) 9000,9000,194
  194 ASTEP=ASTCL
       GO TO 9000
```

```
  210 IF(JLAST.EQ.1) GO TO 212
      ASTEP=AFUELS-(ANGLE-ASTEP)
      ANGLE=AFUELS
      JLAST=1
      GO TO 9000
C
C  FUEL STARTS TO BE INJECTED
C  COMBUSTION AND EXPANSION
  212 JLAST=0
      JCOND=4
      ASTEP=ASTCB
      LINEST=IFIX(PRINCL)
      LINECO=0
      WRITE(LPT,7600)
      WRITE(LPT,7010)
      WRITE(LPT,7620)
      WRITE(LPT,7630)
      GO TO 9000
  200 IF(ANGLE-AINTO-720.) 220,230,230
  220 IF(JCOND-5) 240,9000,9000
  240 IF(JLAST.EQ.1) GO TO 242
      ASTEP=AEXTO-(ANGLE-ASTEP)
      ANGLE=AEXTO
      JLAST=1
      GO TO 9000
C
C  EXHAUST VALVE OPENS
  242 JCOND=5
      JLAST=0
      ASTEP=ASTEX
      LINEST=IFIX(PRINEX)
      LINECO=0
      IF(IE.EQ.1) GO TO 244
C
C  CALCULATE THE  TOTAL MASS AND  ENTHALPY
      TENTH=0.
      TMASS=0.
      DO 7320 I=1,IE
      TENTH=TENTH+EENTH(2,I)*EMASS(2,I)
      TMASS=TMASS+EMASS(2,I)
 7320 CONTINUE
C
C  CALCULATE THE AVERAGE ENTHALPY
      AVENT=TENTH/TMASS
C
C  CALCULATE THE AVERAGE TEMPERATURE
C  FIRST FIND OUT THE ELEMENT WHICH ENTHALPY IS CLOSE TO THE
C  AVERAGE ENTHALPY
      DENTM=1000.
      II=1
      DO 7330 I=1,IE
      DENT=ABS(AVENT-EENTH(2,I))
      IF(DENTM.LT.DENT) GO TO 7330
       DENTM=DENT
      II=I
 7330 CONTINUE
C
C  DEFINE THE NEW PROPERTIS
      ETEMP(2,1)=ETEMP(2,II)+(AVENT-EENTH(2,II))/ECP(II)
      EEQUI(2,1)=PHIO
```

```
      FENTH(2,1)=AVENT
      EMASS(2,1)=TMASS
      CALL HPROD(PCYL(2),ETEMP(2,1),EEQUI(2,1),DEL,PSI,ENTHLP,CSUBP,
     1 CSUBT,RHO,DRHODT,DRHODP,EMWT(1),ERGAS(1),CVBG,EBGR)
      ECP(1)=ERGAS(1)/41.443+CVBG
      EVOL(2,1)=VCYLN
      IE=1
C
C  NOX AMOUNT WILL BE DEFINED.
C   EXHAUST NOX ON MASS BASE
      ANOXEX=TWNO*TTGINT/TMASS*RPM/120.
      WRITE(LPT,7340)
      WRITE(LPT,7342) PCYL(2),ETEMP(2,1),EEQUI(2,1),FENTH(2,1),
     1 EMASS(2,1)
      WRITE(LPT,7450) TPPM,ANOXEX
 7340 FORMAT(//,10X,'***EXPANSION PROCESS IS CALCULATED AS ONE ELEMENT**
     1*')
 7342 FORMAT(15X,18HPRESSURE          = ,F10.2,'ATA',/,
     1  15X,18HAV. TEMPERATURE   = ,F10.1,'K DEG',/,
     2    15X,18HAV. EQUI. RATIO   = ,F10.3,/,
     3    15X,18HAV. ENTHALPY      = ,F10.2,'CAL/G',
     4    15X,18HTOTAL MASS        = ,F10.4,'G')
  244 CONTINUE
      WRITE(LPT,7800)
      WRITE(LPT,7010)
      WRITE(LPT,7820)
      WRITE(LPT,7230)
      GO TO 9000
  230 JCOND=5
 9000 ANGLE=ANGLE-ASTEP
      RETURN
 6100 FORMAT(//,10X,'OVERALL EQUIVALENCE RATIO =',F12.3)
 6120 FORMAT(10X,'VOLUMETRIC EFFICIENCY=',F12.3)
 6140 FORMAT(10X,'CORRECT CHARGED AIR PHI =',F12.3)
 6160 FORMAT(10X,'INDUCED AIR AND REG. GAS NOX',/,
     1  15X,'PPM =',F12.1,5X,'MASS =',E12.3,'G')
 7000 FORMAT(1H1,5X,'INTAKE AND EXHAUST VALVE OPEN',/)
 7010 FORMAT (1H ,'OUTPUT DATA')
 7020 FORMAT(2X ,4HTHED,3X,4H  P ,3X,4H  T ,3X,4H  V ,3X,4HWORK,
     1 3X,7HCYL.MAS,3X,15H HEAT  TRANSFER ,6X,4HAEFI,3X,4H GWI,5X,
     2 4HAEFE,3X,4H GWE)
 7030 FORMAT(2X ,4HDEG ,3X,4HATA ,3X,4H  K ,2X,5HCM**3,3X,4H PS ,
     1 3X,7H  KG   ,3X,15H CAL/A    CAL   ,5X,5HCM**2,3X,4H G/S,4X,
     2 5HCM**2,3X,4H G/S,/)
 7200 FORMAT(1H1,5X,'INTAKE VALVE OPEN',/)
 7220 FORMAT(2X ,4HTHED,3X,4H  P ,3X,4H  T ,3X,4H  V ,3X,4HWORK,
     1 3X,7HCYL.MAS,3X,15H HEAT  TRANSFER,6X,4HAEFI,3X,4H GWI)
 7230 FORMAT(2X ,4HDEG ,3X,4HATA ,3X,4H  K ,2X,5HCM**3,3X,4H PS ,
     1 3X,7H   G   ,3X,15H CAL/A    CAL   ,5X,5HCM**2,3X,4H G/S,/)
 7400 FORMAT(1H1,5X,'COMPRESSION',/)
 7420 FORMAT(2X ,4HTHED,3X,4H  P ,3X,4H  T ,3X,4H  V ,3X,4HWORK,
     1 3X,7HCYL.MAS,3X,15H HEAT  TRANSFER,7X,4HFSWR,3X,4HS.RT)
 7430 FORMAT(2X ,4HDEG ,3X,4HATA ,3X,4H  K ,2X,5HCM**3,3X,4H PS ,
     1 3X,7H   G   ,3X,15H CAL/A    CAL   ,11X,3X,4H*RPM)
 7450 FORMAT(//,10X,'**EXHAUST NOX***',/,
     1    15X,15HNOX CONCEN.    = ,F10.1,'PPM',/,
     2    15X,15HTOTAL MASS     = ,E12.3,'G')
 7600 FORMAT(1H1,5X,'COMBUSTION AND EXPANSION',/)
 7620 FORMAT(2X,4HTHED,3X,'PRESS',9X,'PS',7X,'FSWIR',7X,'S.RT',7X,
     1 'PPM',9X,'WNO',/,1X,
```

```
     1                       3HNUM,1X,2H**,3X,4HT.AV,3X,4HBTEM,3X,4HB.RT,
     1 3X,4HMASS,3X,4HPMAS,3X,4HBMAS, 3X,4H  V ,3X,4HEQUI,3X,4H  CP,
     2 3X,4HENTH,3X,4H PPM,3X,4H WNO,1X,18H   JET LOCATIONS   ,1X,
     1 4HRJET,1X,5HC.ANG ,2X,4HH.T, )
7630 FORMAT( 6X,4X,4H  K ,3X,4H  K ,3X,4X    ,3X,4H MG ,3X,4H MG ,
     1 3X,4H MG ,2X,5HCM**3, 7X,2X,5HCAL/G,2X,5HCAL/G,2X,4H PPM,
     2 1X,7HG*10**6,1X,5HR(CM), 1X,5HZ(CM),1X,5H DEG ,2X,4H CM ,2X,
     3 4H DEG,2X,4H CAL)
7800 FORMAT(1H1,5X,'EXHAUST VALVE OPEN',/)
7820 FORMAT(2X ,4HTHED,3X,4H  P ,3X,4H  T ,3X,4H  V ,3X,4HWORK,
     1 3X,7HCYL.MAS,3X,15H HEAT  TRANSFER,5X,4HAEFE,3X,4H GWE)
      END
```

```
      SUBROUTINE EXPOR
C
C  EXHAUST PORT CALCULATION
C   THIS PROGRAM WAS ORIGINALLY MADE USING METER-KG UNIT
C
C
      COMMON/EPROP/ IECHF(100),EFJEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON/EXFLO/NEXEF,XEXEF(20),YEXEF(20),AREEXD,PEXT,TEXT,GEXT,
     1 IGLEFT,TLEFT,QEXT,QFLOW,ELEFT,AREEXT,XEXV
      COMMON /STATE/ ANGLE1,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /FUELP/ FUEL,FKCAL,ZM,ZN,PSI,SAFC,VACAL
      COMMON /STAT1/ RPM,JLAST,NJET,PHIO,EGR
      IF(PEXT-PCYL(1)) 50,50,60
C  EXHAUST FLOW IS FROM CYLINDER TO EX. PORT
C   P VALUE DOESN'T CHANGE MUCH.
   50 CEXT=-1.
      PHIGH=ERGAS(1)*9.8
      PHIGH=PCYL(1)*10000.
      PREX=PEXT/PCYL(1)
      EHIGH=EEQUI(1,1)
      IF(IGLEFT) 51,51,52
C  IGLEFT=1   THERE IS RESIDUAL GAS
C  IGLEFT=0   THERE IS NOT RESIDUAL GAS
   52 THIGH=ETEMP(1,1)
      AKCYL=1.34
      AKHIGH=AKCYL
      GO TO 100
   51 THIGH=TLEFT
      PHIGH=ERGAS(1)*9.8
      AKLEF=1.34
      AKHIGH=AKLEF
      GO TO 100
C  EXHAUST FLOW IS FROM EX. PORT TO CYLINDER
   60 PHIGH=ERGAS(1)*9.8
      CEXT=1.
      EHIGH=EEQUI(1,1)
      PHIGH=PEXT*10000.
      PREX=PCYL(1)/PEXT
      THIGH=ETEMP(1,1)
      AKEXT=1.34
      AKHIGH=AKEXT
C
C  CALCULATE THE EFFECTIVE EXHAUST FLOW AREA
  100 IF(ANGLE-360.) 150,150,160
  150 ANAE=(ANGLE-(AEXTO-720.))/(AEXTC-(AEXTO-720.))
      GO TO 200
  160 ANAE=(ANGLE-AEXTO)/(AEXTC-AEXTO+720.)
  200 CALL TWODIM(NEXEF,XEXEF,YEXEF,ANAE,AREFAC)
      AREEXT=AREEXD*AREFAC
      AREEXT=AREEXT/10000.
      PRCRIT=(2./(AKHIGH+1.))**(AKHIGH/(AKHIGH-1.))
C
C  CHECK WHETHER FLOW IS CHOKED OR NOT
      IF(PRCRIT-PREX) 300,300,310
C
C  CHOKED
```

```
  310 PREX=PRCRIT
C
C  NEXT EQUATION IS BASED ON METER -KG UNIT
  300 GEXT=                     SQRT(ABS(2.*AKHIGH*9.8/RHIGH/THIGH
     1 /(AKHIGH-1.)*(PREX**(2./AKHIGH)-PREX**((AKHIGH+1.)
     2 /AKHIGH))))
      GEXT=PHIGH*AREEXT/6./RPM*GEXT
      GEXT=CEXT*GEXT
      GEXT=GEXT*1000.
      AREEXT=AREEXT*10000.
      IF(CEXT) 410,410,400
  410 TMANI=THIGH*PREX**((AKHIGH-1.)/AKHIGH)
      QEXT=GEXT*ENT(TMANI,EHIGH,SAFC)
      GO TO 1000
  400 QEXT=GEXT*ENT(TEXT,EHIGH,SAFC)
 1000 RETURN
      END
```

```
C
      SUBROUTINE VOLCY(ANGLF,VCYL,DVCYL,STROKE,BORE,CONL,VCLEAR,VCUP)
      PAI=3.141593
      ANGRAD=ANGLE*PAI/180.
      HSTROK=STROKE/2.
C  DELTA VOLUME CALCULATION
      DVCYL=PAI*BORE**2/4.*(HSTROK*SIN(ANGRAD)+HSTROK**2*SIN(ANGRAD)
     1  *COS(ANGRAD)/SQRT(CONL**2-HSTROK**2*SIN(ANGRAD)**2))*PAI/180.
C  VOLUME CALCULATION
      DISTTB=CONL*(1.-SQRT(1.-(HSTROK/CONL)**2*SIN(ANGRAD)**2))
     1  +HSTROK*(1.-COS(ANGRAD))
      VCYL=VCLEAR+VCUP+PAI*BORE*BORE/4.*DISTTB
      RETURN
      END
C
```

```
      SUBROUTINE TWODIM(N,X,Y,XIN,YOUT)
      DIMENSION X(1),Y(1)
      XDUMMY=XIN
      IF(XDUMMY-X(1)) 510,810,810
  510 XDUMMY=X(1)
  810 CONTINUE
      IF(XDUMMY-X(N)) 820,820,520
  520 XDUMMY=X(N)
  820 CONTINUE
      J=0
    3 J=J+1
    5 IF(XDUMMY-X(J)) 1,2,3
    2 YOUT=Y(J)
      GO TO 4
    1 YOUT=Y(J)-(X(J)-XDUMMY)/(X(J)-X(J-1))*(Y(J)-Y(J-1))
    4 RETURN
      END
```

```
      SUBROUTINE HEATR
C
C  HEAT TRANSFER CALCULATION
      COMMON/ERROR/ IECHE(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DUEMAS(100),
     1 ERGAS(100),EGR(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /STATE/ ANGLEI,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /STATI/ RPM,JLAST,NJET,PHIO,EGR
      COMMON /GEOMT/ STROKE,BORE,CONL,VCLEAR,VCUP,RCUP,CYLN
      COMMON /HETRS/ NDIVID,TMETAL(10),QHTRC(10),ARE(10)
      COMMON /JETS/ RJET(50),HJET(50),AJET(50),BJET(50),THER(50),
     1 VRJET(50),VZJET(50),WJET(50),VJET(50),AINJ(50),RHJET(50),
     2 PITCH(50)
      COMMON /SURGAS/ ESWIR,WSWIR,SDECAY
      COMMON /HETRI/ PBASE,TBASE,VBASE,COHT1,COHT2,COHT,RHR(10)
      DIMENSION HTCO2(10),HTI(10)
      ANGRAD=ANGLE*3.1416/180.
      CALL VOLCY(ANGLE,CYLV,DUM,STROKE,BORE,CONL,VCLEAR,VCUP)
C
C  GET THE H.T. AREA OF CYLINDER WALL
C
      ARE(2) =(CYLV-VCUP)*4./BORE
      DO 200 I=1,NDIVID
      QHTRC(I)=0.
  200 CONTINUE
      DO 202 I=1,IE
      DHLOS(I)=0.
  202 CONTINUE
      HTCON1=COHT*7014.*BORE**(-0.2)*PCYL(1)**0.8/(2.16*10.**8*RPM)
      GO TO (210,210,220,220,210),JCOND
C
C  ISENTROPIC TEMPERATURE
  220 PISEN=PBASE*(VBASE/CYLV)**1.32
      HTCON2=COHT1*(STROKE*RPM/30.)+100.*COHT2*CYLV*TBASE/(PBASE
     1 *VBASE)*(PCYL(1)-PISEN)
      GO TO 230
C
C  FOR PROCESS --INTAKE,EXHAUST AND VALVE OVERLAP
  210 PISEN=PCYL(1)
      HTCON2=COHT1*(STROKE*RPM/30.)
  230 CONTINUE
      DO 300 I=2,NDIVID
C
C  0.4 IS AN ADJUSTING FACTOR
      HTCO2(I)=(HTCON2+WSWIR*RHR(I)*0.4)**0.8
  300 CONTINUE
      IFILL=0
      IF(IE.EQ.1) GO TO 1000
      TAREA=0.
      DO 2900 J=1,IE
      I=IE+1-J
      IF(I.EQ.1) GO TO 2120
C
C  THE AREA OF JET CONTACTING WITH WALL
      AREATH=RJET(I)*SIN(THER(I)/2.)*2.*VJET(I)*PITCH(I)/(6.*RPM)
      TAREA=TAREA+AREATH
C
C  CHECK WHETHER THE PISTON CUP IS FULL WITH JET ELEMENTS OR NOT
C
```

```
      IF(TAREA.GT.ARE(4) ) GO TO 2090
      RTAREA=ARE(2)+ARE(3)+ARE(5)+ARE(6)+ARE(7)
C
C  PISTON CUP IS NOT FILLED WITH JET ELEMENTS
      DHLOS(I)=HTCON1*ETEMP(1,I)**(-0.53)*HTCO2(4)*AREATH*
     1 (ETEMP(1,I)-TMETAL(4))
      QHTRC(4)=QHTRC(4)+DHLOS(I)
      QHTRC(1)=QHTRC(1)+DHLOS(I)
      GO TO 2900
C
C  PISTON CUP IS FILLED WITH JET ELEMENTS
 2090 IFILL=1
 2100 AA=AREATH*HTCON1*ETEMP(1,I)**(-0.53)
      RTAREA=ARE(2)+ARE(3)+ARE(5)+ARE(6)+ARE(7)
 2116 DO 2110 JJ=2,NDIVID
      IF(IFILL.EQ.0) GO TO 2112
      IF(JJ.EQ.4) GO TO 2110
 2112 HTI(JJ)=AA*ARE(JJ) /RTAREA*HTCO2(JJ)*(ETEMP(1,I)-TMETAL(JJ))
      QHTRC(JJ)=QHTRC(JJ)+HTI(JJ)
      DHLOS(I)=DHLOS(I)+HTI(JJ)
      QHTRC(1)=QHTRC(1)+HTI(JJ)
 2110 CONTINUE
      GO TO 2900
C
C  FOR ELEMENT 1
 2120 XX=ARE(4)
      IF(IFILL.EQ.0) GO TO 2114
      AA=(ARE(2)+ARE(3)+ARE(4)+ARE(5)+ARE(6)+ARE(7)-TAREA)*HTCON1*
     1 ETEMP(1,I)**(-0.53)
      RTAREA=ARE(2)+ARE(3)+ARE(5)+ARE(6)+ARE(7)
      GO TO 2116
 2114 RTAREA=ARE(2)+ARE(3)+ARE(5)+ARE(6)+ARE(7)+ARE(4)-TAREA
      XX=ARE(4)
      ARE(4)=ARE(4)-TAREA
      AA=RTAREA*HTCON1*ETEMP(1,I)**(-0.53)
      GO TO 2116
 2900 CONTINUE
      ARE(4)=XX
      GO TO 9000
 1000 HTCO11=HTCON1*ETEMP(1,1)**(-0.53)
      DO 1900 I=2,NDIVID
      QHTRC(I)=HTCO11*HTCO2(I)*(ETEMP(1,1)-TMETAL(I))*ARE(I)
      QHTRC(1)=QHTRC(1)+QHTRC(I)
 1900 CONTINUE
      DHLOS(1)=QHTRC(1)
 9000 RETURN
      END
```

```
      SUBROUTINE DELTA(DVCYL,ENTINT)
      COMMON/EPROP/ IECHE(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON /STATE/ ANGLEI,ANGLE,ICOND,ASTEP,NSTEP,IE
      COMMON/EXFLO/NEXEF,XEXEF(20),YEXEF(20),AREEXD,PEXT,TEXT,GEXT,
     1 IGLEFT,TLEFT,QEXT,QFLOW,FLEFT,AREEXT,XEXV
      DIMENSION DQ(100),HENTH(100)
      AJ=42.68
      DO 50 I=1,IE
      DQ(I)=DHFUEL(I)-DHLOS(I)
      HENTH(I)=EENTH(1,I)
   50 CONTINUE
      ENTCYL=HENTH(1)
      AA=DQ(1)+QFLOW                                  -(DIEMAS(1)-
     1 DOEMAS(1))*HENTH(1)
      AA=AA*EVOL(1,1)/(EMASS(1,1)*ECP(1)*ETEMP(1,1))+(DIEMAS(1)
     1 -DOEMAS(1))/EMASS(1,1)*EVOL(1,1)
      BB=EVOL(1,1)*EVOL(1,1)/(EMASS(1,1)*ECP(1)*ETEMP(1,1)*AJ)
     1-EVOL(1,1)/PCYL(1)
      IF(IE.LT.2) GO TO 200
      DO 100 I=2,IE
      AA=AA+EVOL(1,I)/(EMASS(1,I)*ECP(I)*ETEMP(1,I))*(DQ(I)
     1 +DIEMAS(I)*HENTH(1)   -DOEMAS(I)*HENTH(I)   -(DIEMAS(I)
     2 -DOEMAS(I))*HENTH(I)) +(DIEMAS(I)-DOEMAS(I))/EMASS(1,I)
     3 *EVOL(1,I)
      BB=BB+EVOL(1,I)*EVOL(1,I)         /(EMASS(1,I)*ECP(I)
     1 *ETEMP(1,I)*AJ)-EVOL(1,I)/PCYL(I)
  100 CONTINUE
  200 PCYL(3)=(DVCYL-AA)/BB
      EVOL(3,1)=EVOL(1,1)/(EMASS(1,1)*ECP(1)*ETEMP(1,1))
     1 *(DQ(1)+QFLOW                                  -(DIEMAS(1)
     2-DOEMAS(1))*HENTH(1)   )+(DIEMAS(1)-DOEMAS(1)))/EMASS(1,1)
     3 *EVOL(1,1)+(EVOL(1,1)*EVOL(1,1)/(EMASS(1,1)*ECP(1)*ETEMP(1,1)
     4 *AJ)-EVOL(1,1)/PCYL(1))*PCYL(3)
      ETEMP(3,1)=ETEMP(1,1)*(PCYL(3)/PCYL(1)+EVOL(3,1)/EVOL(1,1)
     1 -(DIEMAS(1)-DOEMAS(1))/EMASS(1,1))
      EMASS(3,1)=DIEMAS(1)-DOEMAS(1)
      EENTH(3,1)=ECP(1)*ETEMP(3,1)
      IF(IE.LT.2) GO TO 400
      DO 300 I=2,IE
      EVOL(3,I)=EVOL(1,I)/(EMASS(1,I)*ECP(I)*ETEMP(1,I))
     1*(DQ(I)+DIEMAS(I)*HENTH(1)   -DOEMAS(I)*HENTH(I)   -(DIEMAS(I)-
     2 DOEMAS(I))*HENTH(I)) +(DIEMAS(I)-DOEMAS(I))/EMASS(1,I)
     3 *EVOL(1,I)+(EVOL(1,I)*EVOL(1,I)/(EMASS(1,I)*ECP(I)*ETEMP(1,I)*AJ)
     4 -EVOL(1,I)/PCYL(I))*PCYL(3)
      ETEMP(3,I)=ETEMP(1,I)*(PCYL(3)/PCYL(I)+EVOL(3,I)/EVOL(1,I)-
     1 (DIEMAS(I)-DOEMAS(I))/EMASS(1,I))
      EMASS(3,I)=DIEMAS(I)-DOEMAS(I)
      EENTH(3,I)=ECP(I)*ETEMP(3,I)
  300 CONTINUE
  400 RETURN
      END
```

```
      FUNCTION ENT(T,E,XXX)
C
C  TO CALCULATE THE ENTHALPY OF GAS AT LOW PRESSURE .(T<1800 K)
C  THIS SUBROUTINE IS USED FOR CALCULATING THE ENTHALPY OF INITIAL GAS
C   INSIDE THE CYLINDER, INTAKE AIR AND EXHAUST GAS.
C  IT IS RECOMENDED THAT  M.MARTIN'S PROGRAMS BE USED FOR HIGH PRESSURE
C   OR HIGH TEMPERATURE GASES.
C
      SAFC=14.4
      IF(E.LT.0.01)  GO TO 100
      AF=SAFC/E
      GO TO 200
  100 AF=0.
  200 CONTINUE
      IF(T-800.) 10,10,20
   10 ENT  =-0.405671  +0.243353*T  -0.164608E-4*T**2  +0.157984E-7
     1    *T**3+0.253172E-10*T**4 -0.179767E-13*T**5
      IF(AF) 99,99,40
   40 ENT  =ENT  +(14.9607  -0.126357*T  +0.769710E-3*T**2-0.517585E-6
     1    *T**3  +0.595961E-10*T**4  +0.833377E-13*T**5  )/(AF+1.)
      RETURN
   20 ENT  =11.3176 +0.190755*T +0.637625E-4*T**2 -0.182173E-7*T**3
     1    +0.223445E-11*T**4
      IF(AF) 99,99,30
   30 ENT  =ENT  +(-42.2372 +0.199892*T +0.871219E-4*T**2 +0.600828E-7
     1    *T**3  -0.299545E-10*T**4 +0.391857E-14*T**5 )/(AF+1.)
   99 RETURN
      END
```

```
C****************** VERSION 1.0 *** 5/29/74 ********************** ***
C
C      SUBROUTINE HPROD
C
C      PURPOSE:
C         TO CALCULATE THE SPECIFIC ENTHALPY OF THE PRODUCTS OF HYDRO
C         CARBON-AIR COMBUSTION AS A FUNCTION OF TEMPERATURE AND PRES
C         SURE, USING AN APPROXIMATE CORRECTION FOR DISSOCIATION.
C         THE PARTIAL DERIVATIVES OF H WITH RESPECT TO THESE VARIABLES
C         ARE ALSO CALCULATED, ALONG WITH THE GAS DENSITY AND ITS PAR
C         TIAL DERIVATIVES
C
C      USAGE:
C         CALL HPROD(P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,DRHODT,
C                    DRHODP)
C
C      DESCRIPTION OF PARAMETERS:
C       GIVEN:
C         P      - ABSOLUTE PRESSURE OF PRODUCTS (ATM)
C         T      - TEMPERATURE OF PRODUCTS (DEG K)
C         PHI    - EQUIVALENCE RATIO (FUEL/AIR RATIO DIVIDED BY THE
C                  CHEMICALLY CORRECT FUEL/AIR RATIO)
C         DEL    - MOLAR C:H RATIO OF THE PRODUCTS
C         PSI    - MOLAR N:O RATIO OF THE PRODUCTS
C       RETURNS:
C         ENTHLP- SPECIFIC ENTHALPY OF THE PRODUCTS (KCAL/G)
C         CSUBP - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO T
C                 AT CONSTANT P    (CAL/G-DEG K)
C         CSUBT - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO P
C                 AT CONSTANT T    (CC/G)
C         RHO   - DENSITY OF THE PRODUCTS       (G/CC)
C         DRHODT- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO T AT
C                 CONSTANT P    (G/CC-DEG K)
C         DRHODP- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO P AT
C                 CONSTANT T    (G/CC-ATM)
C
C      REMARKS:
C         1)  ENTHALPY DATUM STATE IS AT T = 0 ABSOLUTE WITH
C             O2,N2,H2 GASEOUS AND C SOLID GRAPHITE
C         2) IN CASE OF PROBLEMS CONTACT MIKE MARTIN AT 253-2411
C            (ROOM 3-339 D)
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED:
C             DERIVS,CLDPRD
C
C      METHOD:
C         SEE MARTIN & HEYWOOD 'APPROXIMATE RELATIONS FOR THE THERMO-
C         DYNAMIC PROPERTIES OF HYDROCARBON-AIR COMBUSTION PRODUCTS'
C
C****************************************************************** ***
C
      SUBROUTINE HPROD(P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,DRHODT,
     1    DRHODP,AMWT,RAVG,CVAVG,ENERGY)
      LOGICAL RICH,LEAN,NOTHOT,NOTWRM,NOTCLD
C
C      INITIALIZE PARAMETERS USED IN THE CALCULATION
C
      DATA AHFCO2,AHFH2O,AHFCO/-93.965,-57.103,-27.200/
      DATA ROVR2/.99345E-3/
      DATA TCOLD,THOT /1000.,1100./
```

```
C
      RICH = PHI .GE. 1.0
      LEAN = .NOT. RICH
      NOTHOT = T .LT. THOT
      NOTCLD = T .GT. TCOLD
      NOTWRM = .NOT. (NOTCLD .AND. NOTHOT)
      EPS=(4.*DEL)/(1. + 4.*DEL)
C
C     USE SIMPLE ROUTINE FOR LOW TEMPERATURE MIXES
C
      IF (NOTCLD) GO TO 5
      CALL CLOPRD(P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,DRHODT,
     1     DRHODP,IER,AMWT)
      GO TO 30
C
C     CALCULATE EQUILIBRIUM CONSTANTS FOR DISSOCIATION.
C     (NOTE THAT UNITS ARE INVERSE PRESSURE TO THE 1/2 POWER)
C
    5 AK1 = .39E-4 * EXP(-.3*EPS + 34000./T)
      AK2 = .14E-3 * EXP(1.3*EPS + 29000./T)
C
C     CALCULATE A, X, Y, AND U AS IN NOTES
C
      A = ((2.- EPS + PSI)/(4.*P*AK1*AK1))**(.33333333)
C
      T1 = 2.- EPS + PSI
      T2 = 1. + 2.*T1
      T3 = EPS*A
      X = A*(3.*T1 + T2*T3)/(3.*(1.+ 2.*T3)*T1 + 2.*T2*T3*T3)
C
      Z = (1.- PHI)/X
      IF (RICH)  Y = X/(1.- .64*Z + .30*Z**2)
      IF (LEAN)  Y = X*(1.+ Z + .36*Z**2)/(1. + .36*Z) - (1. - PHI)
      U = (2. - EPS + PSI)*(1.- 2.*EPS*X)/(4.*AK1*AK2*P*X)
C
C     CALCULATE THE ENTHALPY OF FORMATION FOR THIS APPROXIMATE
C     COMPOSITION
C
      ENTFOR = 1000.*ROVR2*((117. + 30.*EPS)*Y + 135.*EPS*U)
      XH2O = 2.*(1.- EPS)*PHI
      T1 = 7.*PSI + 5.*Y + 3.*U
      T2 = PSI - 3.*Y - U
C
      IF (LEAN)  GO TO 10
C
      RCVT = 2. + 2.*(7. - 4.*EPS)*PHI + T1
      RCVV = 4. + (2.- 3.*EPS)*PHI + T2
      XCO2 = 2.- (2.- EPS)*PHI
      XCO = 2.*(PHI - 1.)
      ENTFOR = ENTFOR - 1000.*ROVR2*13.*(PHI - 1.)/EPS
      GO TO 20
C
   10 RCVT = 7. + (9. - 8.*EPS)*PHI + T1
      RCVV = 1. + (5.- 3.*EPS)*PHI + T2
      XCO = 0.
      XCO2 = EPS*PHI
C
   20 ENTFOR = ENTFOR + (XCO2*AHFCO2 + XH2O*AHFH2O + XCO*AHFCO)
C
C     ADD IN TRANSLATIONAL,VIBRATIONAL, AND ROTATIONAL TERMS TO GET
```

```
C     TOTAL ENTHALPY
C
      TV = (3000.- 2000.*EPS + 300.*PSI)/(1.- .5*EPS + .09*PSI)
      TV = TV/( EXP(TV/T) - 1.)
      AMCP = (8.*EPS + 4.)*PHI + 32. + 28.*PSI
C
      ENTHLP = (ROVR2*(RCVT*T + RCVV*TV*2.) + ENTFOR)/AMCP
C
C     CALCULATE AVERAGE MOLECULAR WEIGHT, AND GET DENSITY BY
C     USING THE PERFECT GAS LAW
C
      IF (LEAN)  AMWT = AMCP/(1. + (1.- EPS)*PHI + PSI + Y + U)
      IF (RICH)  AMWT = AMCP/((2.- EPS)*PHI + PSI + Y + U)
      RHO = .012187*AMWT*P/T
C
C     GET PARTIAL DERIVATIVES BY WAY OF A SUBROUTINE CALL
C
      CALL DERIVS(P,T,PHI,EPS,PSI,A,X,Y,U,AMWT,CSUBP,CSUBT,DRHODT,
     1   DRHODP)
C
C
C     IF CALCULATING FOR AN INTERMEDIATE TEMPERATURE, USE A WEIGHTED
C     AVERAGE OF THE RESULTS FROM THIS ROUTINE AND THOSE FROM THE
C     SIMPLE ROUTINE
C
      IF (NOTWRM) GO TO 30
C
      CALL CLDPRO(P,T,PHI,DEL,PSI,TH,TCP,TCT,TRHO,TDRT,TDRP,IER,AMWT)
      W1 = (T - TCOLD)/(THOT - TCOLD)
      W2 = 1.0 - W1
C
      ENTHLP = W1*ENTHLP + W2*TH
      CSUBP = W1*CSUBP + W2*TCP
      CSUBT = W1*CSUBT + W2*TCT
      RHO = W1*RHO + W2*TRHO
      DRHODT = W1*DRHODT + W2*TDRT
      DRHODP = W1*DRHODP + W2*TDRP
C
   30 RAVG=82.057/AMWT
      CVAVG=CSUBP-1.98/AMWT
      ENERGY=1000.*ENTHLP-1.98*T/AMWT
C
      RETURN
      END
```

```
C******************** VERSION 1.1 ***
C
C      SUBROUTINE CLDPRD
C
C      PURPOSE:
C         TO CALCULATE THE SPECIFIC ENTHALPY OF THE PRODUCTS OF HC-AIR
C         COMBUSTION AT TEMPERATURES AND PRESSURES WHERE DISSOCIATION
C         OF THE PRODUCT GASES MAY BE IGNORED.  THE DENSITY OF THE
C         PRODUCT GAS IS ALSO CALCULATED, AS ARE THE PARTIAL
C         DERIVATIVES OF BOTH OF THESE QUANTITIES WITH RESPECT TO
C         PRESSURE AND TEMPERATURE.
C
C      USAGE:
C         CALL CLDPRD(P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,DRHODT,
C                     DRHODP,IER)
C
C      DESCRIPTION OF PARAMETERS:
C       GIVEN:
C         P      - ABSOLUTE PRESSURE OF PRODUCTS (ATM)
C         T      - TEMPERATURE OF PRODUCTS (DEG K)
C         PHI    - EQUIVALENCE RATIO (FUEL/AIR RATIO DIVIDED BY THE
C                  CHEMICALLY CORRECT FUEL/AIR RATIO)
C         DEL    - MOLAR C:H RATIO OF THE PRODUCTS
C         PSI    - MOLAR N:O RATIO OF THE PRODUCTS
C       RETURNS:
C         ENTHLP- SPECIFIC ENTHALPY OF THE GAS (KCAL/G)
C         CSUBP - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO T
C                  AT CONSTANT P    (CAL/G-DEG K)
C         CSUBT - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO P
C                  AT CONSTANT T    (CC/G)
C         RHO    - DENSITY OF THE MIXTURE (G/CC)
C         DRHODT- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO T AT
C                  CONSTANT P (G/CC-DEG K)
C         DRHODP- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO P AT
C                  CONSTANT T (G/CC-ATM)
C         IER    - FLAG, SET TO 1 FOR T<100 DEG K
C                                2 FOR T> 6000 DEG K
C                                0 OTHERWISE
C
C      REMARKS:
C         1)  ENTHALPY DATUM STATE IS AT T  =  0 ABSOLUTE WITH
C             O2,N2,H2 GASEOUS AND C SOLID GRAPHITE
C         2) IN CASE OF PROBLEMS CONTACT MIKE MARTIN AT 253-2411
C            (ROOM 3-339 D)
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS NEEDED:  NONE
C
C      METHOD:
C         DESCRIBED IN APPENDIX IV OF WRITEUP
C
C******************************************************************* ***
      SUBROUTINE CLDPRD(P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,
     1 DRHODT,DRHODP,IER,MBAR)
C
      LOGICAL RICH,LEAN
      DIMENSION A(6,6,2),X(6)
      DIMENSION A1(36),A2(36)
```

```
      EQUIVALENCE (A1(1),A(1,1,1)),(A2(1),A(1,1,2))
      REAL*4  MBAR,K
C
C        INITIALIZE PARAMETERS, AND CHECK TO SEE IN WHAT TEMPERATURE
C        RANGE WE ARE SO THAT THE CORRECT FITTED COEFFICIENTS WILL B
C        USED. FLAG TEMPERATURES TOO BIG OR TOO SMALL
C
      DATA A1/11.94033,2.088581,-0.47029,.037363,-.589447,-97.1418,
     1 6.139094,4.60783,-.9356009,.06669498,.0335801,-56.62588,
     2  7.099556,1.275957,-.2877457,.022355,-.1598696,-27.73464,
     3  5.555680,1.787191,-.2881342,.01951547,.1611828, .76498,
     4  7.865847,.6883719,-.031944,-.00268708,-.2013873,-.893455,
     5  6.807771,1.453404,-.328985,.02561035,-.1199462,-.331835/
      DATA A2/4.737305,16.65283,-11.23249,2.828001,.00676702,-93.75793,
     7  7.809672,-.2023519,3.418708,-1.179013,.00143629,-57.08004,
     8  6.97393,-.8238319,2.942042,-1.176239,.0004132409,-27.19597,
     9  6.991878,.1617044,-.2182071,.2968197,-.01625234,-.118189,
     &  6.295715,2.388387,-.0314788,-.3267433,.00435925,.103637,
     -  7.092199,-1.295825,3.20688,-1.202212,-.0003457938,-.013967/
C
      RICH = PHI .GT. 1.0
      LEAN =  .NOT. RICH
      EPS = 4.*DEL/(1. + 4.*DEL)
      IER = 0
      IF (T .LT. 100.) IER = 1
      IF (T .GT. 6000.) IER  =  2
      IR = 1
      IF (T .LT. 500.) IR = 2
C
C        GET THE COMPOSITION IN MOLES/MOLE OXYGEN
C
      IF (RICH)  GO TO 10
      X(1) = EPS*PHI
      X(2) = 2.*(1.- EPS)*PHI
      X(3) = 0.
      X(4) = 0.
      X(5) = 1.- PHI
      GO TO 20
   10 Z = 1000./T
      K = EXP(2.743 + Z*(-1.761 + Z*(-1.611 + Z*.2803)))
      ALPHA = 1. - K
      BETA = (2.*(1.- EPS*PHI) + K*(2.*(PHI - 1.) + EPS*PHI))
      GAMMA = 2.*K*EPS*PHI*(PHI - 1.)
      C = ( - BETA + SQRT(BETA*BETA + 4.*ALPHA*GAMMA))/(2.*ALPHA)
      X(1) = EPS*PHI - C
      X(2) = 2.*(1. - EPS*PHI) + C
      X(3) = C
      X(4) = 2.*(PHI - 1.) - C
      X(5) = 0.
   20 X(6) = PSI
C
C        CONVERT COMPOSITION TO MOLE FRACTIONS AND CALCULATE AVERAGE
C        MOLECULAR WEIGHT
C
      IF (LEAN) TMOLES = 1. + PSI + PHI*(1.-EPS)
      IF (RICH) TMOLES = PSI + PHI*(2.-EPS)
      DO 30 J = 1,6
   30    X(J) = X(J)/TMOLES
      MBAR = ((8.*EPS + 4.)*PHI + 32. + 28.*PSI)/TMOLES
C
```

```
C         CALCULATE H, CP, AND CT AS IN WRITEUP, USING FITTED
C         COEFFICIENTS FROM JANAF TABLES
C
      ENTHLP = 0.
      CSURP = 0.
      CSURT = 0.
      ST = T/1000.
      DO 40 J = 1,6
         TH = ((( A(4,J,IR)/4.*ST + A(3,J,IR)/3. )*ST
     1         + A(2,J,IR)/2. )*ST + A(1,J,IR) )*ST
         TCP = (( A(4,J,IR)*ST + A(3,J,IR) )*ST
     1               + A(2,J,IR) )*ST + A(1,J,IR)
         TH  =  TH - A(5,J,IR)/ST  +  A(6,J,IR)
         TCP  =  TCP  +   A(5,J,IR)/ST**2
         ENTHLP  =  ENTHLP  +  TH*X(J)
   40    CSURP  =  CSURP  +  TCP*X(J)
      ENTHLP = ENTHLP/MBAR
      CSURP = CSURP/MBAR
C
C         NOW CALCULATE RHO AND ITS PARTIAL DERIVATIVES
C         USING PERFECT GAS LAW
C
      RHO = .012187*MBAR*P/T
      DRHODT = -RHO/T
      DRHODP = RHO/P
C
C         ALL DONE
      RETURN
      END
```

```
      SUBROUTINE DERIVS(P,T,PHI,EPS,PSI,A,X,Y,U,AMWT,CSUBP,CSUBT,
     1   DRHODT,DRHODP)
      LOGICAL RICH,LEAN
      DATA ROVR2/.99345/
      DATA SCALF/41.29287/
C
      RICH = PHI .GE. 1.0
      LEAN = .NOT. RICH
C
      C3 = (117. + 30.*EPS)*1000.
      C4 = 1.35E5*EPS
      C5 = 2.0 - EPS + PSI
      C6 = 5.0 - 2.*EPS + 2.*PSI
C
      DUDTPX = 6.3E4*U/T**2
      DUDPTX = -U/P
      DUDXPT = -U/(X*(1. - 2.*EPS*X))
C
      DADTP = (3.4E4*2./3.)*A/T**2
      DADPT = -A/(3.*P)
C
      AP = EPS*A
      T5 = 3.*C5
      DXDA = T5*(T5 + 2.*C6*AP)/(T5*(1. + 2.*AP) + 2.*C6*AP**2)**2
C
      Z = (1. - PHI)/X
      IF (LEAN) DYDX = (1. + .72*Z)/(1. + .36*Z)**2
      IF(RICH) DYDX = (1.- 1.28*Z + .90*Z**2)/(1.-.64*Z + .3*Z**2)**2
C
      DYDTP = DYDX*DXDA*DADTP
      DYDPT = DYDX*DXDA*DADPT
      DUDTP = DUDXPT*DXDA*DADTP + DUDTPX
      DUDPT = DUDXPT*DXDA*DADPT + DUDPTX
C
      DHFDPT = C3*DYDPT + C4*DUDPT
      DC2DPT = -2.*(3.*DYDPT + DUDPT)
      DC1DPT = 5.*DYDPT + 3.*DUDPT
      DHFDTP = C3 * DYDTP + C4*DUDTP
      DC2DTP = -2.*(3.*DYDTP + DUDTP)
      DC1DTP = 5.*DYDTP + 3.*DUDTP
C
      TV0 = (3000. - 2000.*EPS + 300.*PSI)/(1. - .5*EPS + .09*PSI)
      EARG = EXP(TV0/T)
      TV = TV0/(EARG - 1.)
      DTVDTP = TV0*EARG/(T*(EARG - 1.))**2 *TV0
C
      AMCP = (8.*EPS + 4.)*PHI + 32. + 28.*PSI
      C1 = 7.*PSI + 5.*Y + 3.*U
      C2 = 2.*(PSI - 3.*Y - U)
      IF (LEAN) C1 = C1 + 7. + (9. - 8.*EPS)*PHI
      IF (RICH) C1 = C1 + 2. + 2.*(7. - 4.*EPS)*PHI
      IF (LEAN) C2 = C2 + 2.*(1. + (5. - 3.*EPS)*PHI)
      IF (RICH) C2 = C2 + 2.*(4. + (2. - 3.*EPS)*PHI)
C
      CSUBP = ROVR2/AMCP*(C1 + T*DC1DTP + C2*DTVDTP + TV*DC2DTP
     1             + DHFDTP)
      CSUBT = ROVR2/AMCP*(T*DC1DPT + TV*DC2DPT + DHFDPT)*SCALF
C
      IF (LEAN) G = 1. + (1.-EPS)*PHI + PSI + Y + U
      IF (RICH) G = (2.- EPS)*PHI + PSI + Y + U
```

```
      G = -AMCP/G**2
      DMDTP = G*(DYDTP + DUDTP)
      DMDPT = G*(DYDPT + DUDPT)
C
      DRHODT = .012187*P/T*(DMDTP - AMWT/T)
      DRHODP = .012187/T*(AMWT + P*DMDPT)
C
      RETURN
      END
```

```
      SUBROUTINE INPOR
C
C  INTAKE PORT CALCULATION
C   THIS PROGRAM WAS ORIGINALLY MADE USING METER-KG UNIT
      COMMON/EPROP/ IECHF(100),EFUEL(100),EANGL(100),EMWT(100),
     1 DHFUEL(100),DHLOS(100),DIEMAS(100),DOEMAS(100),
     1 ERGAS(100),ECP(100),EENTH(8,100),EMASS(8,100),EEQUI(8,100),
     1 EVOL(8,100),ETEMP(8,100),PCYL(8)
      COMMON/INFLO/ NINEF,XINEF(20),YINEF(20),AREIND,PINT,TINT,GINT,
     1 EQUINT,AREINT,XINV
      COMMON /STATE/ ANGLE1,ANGLE,JCOND,ASTEP,NSTEP,IE
      COMMON /TIMIG/ AINTO,AEXTO,AINTC,AEXTC,AFUELS,AFUELE
      COMMON /STATI/ RPM,JLAST,NJET,PHIO,EGR
C
      IF(PINT-PCYL(1)) 50,50,60
C
C  INTAKE FLOW IS FROM CYLINDER TO PORT (BACK FLOW)
   50 CINT=-1.
      RHIGH=ERGAS(1)*9.8
      PHIGH=PCYL(1)*10000.
      PRIN=PINT/PCYL(1)
      THIGH=ETEMP(1,1)
      AKHIGH=1.35
      GO TO 100
C
C  INTAKE FLOW IS FROM PORT TO CYLINDER
C   R VALUE DOESN'T CHANGE MUCH.
   60 RINT=ERGAS(1)*9.8
      CINT=1.
      RHIGH=RINT
      PHIGH=PCYL(1)*10000.
      PRIN=PCYL(1)/PINT
      THIGH=TINT
      AKHIGH=1.35
C
C  CALCULATE THE EFFECTIVE INTAKE FLOW AREA
  100 ANAI=(ANGLE-AINTO)/(AINTC-AINTO)
      CALL TWODIM(NINEF,XINEF,YINEF,ANAI,AREFAC)
      AREINT=AREIND*AREFAC
      AREINT=AREINT/10000.
C
C  NEXT EQUATION IS BASED ON METER-KG UNIT
      GINT=                    SQRT(ABS(2.*AKHIGH*9.8/RHIGH/THIGH
     1  /(AKHIGH-1.)*(PRIN**(2./AKHIGH)-PRIN**((AKHIGH+1.)
     2  /AKHIGH))))
      GINT=PHIGH*AREINT/6./RPM*GINT
      GINT=GINT*CINT
      GINT=GINT*1000.
      AREINT=AREINT*10000.
      RETURN
      END
```

```
C      SUBROUTINE UPROP
C
C      PURPOSE:
C         TO CALCULATE THE ENTHALPY AND DENSITY OF A HOMOGENOUS MIXTURE
C         OF AIR, RESIDUAL GAS, AND FUEL AS A FUNCTION OF
C         EQUIVALENCE RATIO, TEMPERATURE, AND PRESSURE
C
C      USAGE:
C         CALL UPROP(P,T,PHI,DEL,PSI,RESFRK,ENTHLP,CSUBP,CSUBT,RHO,
C                    DRHODT,DRHODP,CHI)
C
C      DESCRIPTION OF PARAMETERS:
C       GIVEN:
C         P      - ABSOLUTE PRESSURE OF PRODUCTS (ATM)
C         T      - TEMPERATURE OF PRODUCTS (DEG K)
C         RESFRK- RESIDUAL GAS FRACTION
C         PHI    - EQUIVALENCE RATIO (FUEL/AIR RATIO DIVIDED BY THE
C                  CHEMICALLY CORRECT FUEL/AIR RATIO)
C       GIVEN IN COMMON AREA /FUEL/:
C         AF(I) - 6 DIMENSIONAL VECTOR OF ENTHALPY COEFFICIENTS SUCH
C                  THAT THE ENTHALPY OF FUEL VAPOR AS A FUNCTION
C                  OF TEMPERATURE ( T DEG K ) IS GIVEN BY:
C                    H(T) = AF(1)*ST + (AF(2)*ST**2)/2 + (AF(3)*ST**3)/3
C                         + (AF(4)*ST**4)/4 - AF(5)/ST + AF(6)
C                    WHERE ST = T/1000 AND H(T) = <KCAL/MOLE>
C                  FOR MOST APPLICATIONS THE ENTHALPY FUNCTION H(T) SHOULD
C                  BE VALID OVER AT LEAST THE FOLLOWING TEMPERATURE RANGE:
C                                        300 < T < 1000
C                  ENTHALPY DATUM STATE IS AT T = 0 ABSOLUTE WITH O2,N2,
C                  AND H2 GASEOUS AND C SOLID GRAPHITE.
C         ENW    - AVERAGE NUMBER OF NITROGEN ATOMS PER FUEL MOLECULE
C         CX     - AVERAGE NUMBER OF CARBON ATOMS PER FUEL MOLECULE
C         HY     - AVERAGE NUMBER OF HYDROGEN ATOMS PER FUEL MOLECULE
C         OZ     - AVERAGE NUMBER OF OXYGEN ATOMS PER FUEL MOLECULE
C         QLOWER- LOWER HEATING VALUE (KCAL/G)
C         XI     - MOLAR N:O RATIO OF THE OXIDANT (FOR AIR XI = 3.76)
C
C       RETURNS:
C         DEL    - MOLAR C:H RATIO OF THE PRODUCTS
C         PSI    - MOLAR N:O RATIO OF THE PRODUCTS
C         CHI    - EQUIVALENCE RATIO OF THE PRODUCTS FOR AN EQUIVALENT
C                  HYDROCARBON-OXIDANT COMBUSTION
C         ENTHLP- SPECIFIC ENTHALPY OF THE PRODUCTS (KCAL/G)
C         CSUBP - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO T
C                  AT CONSTANT P    (CAL/G-DEG K)
C         CSUBT - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO P
C                  AT CONSTANT T    (CC/G)
C         RHO    - DENSITY OF THE PRODUCTS         (G/CC)
C         DRHODT- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO T AT
C                  CONSTANT P    (G/CC-DEG K)
C         DRHODP- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO P AT
C                  CONSTANT T    (G/CC-ATM)
C       RETURNS IN COMMON AREA CMPSTN:
C         X(1)   - CARBON DIOXIDE MOLE FRACTION
C         X(2)   - WATER VAPOR MOLE FRACTION
C         X(3)   - CARBON MONOXIDE MOLE FRACTION
C         X(4)   - HYDROGEN MOLE FRACTION
C         X(5)   - OXYGEN MOLE FRACTION
C         X(6)   - NITROGEN MOLE FRACTION
C         X(7)   - FUEL MOLE FRACTION
```

```
C        MBAR  - MOLECULAR WEIGHT OF UNBURNED MIXTURE
C
C     REMARKS:
C        1)  ENTHALPY DATUM STATE IS AT T = 0 ABSOLUTE WITH
C            O2,N2,H2 GASEOUS AND C SOLID GRAPHITE
C        2)  THIS IS A MODIFIED VERSION OF MIKE MARTIN'S SUBROUTINE
C            UPROP.  IN CASE OF PROBLEMS CONTACT COLIN FERGUSON AT
C            253-5348 (ROOM 31-158)
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS NEEDED:  NONE
C
C    METHOD:
C        DESCRIBED IN APPENDIX A OF HIRES ET AL. SAE PAPER # 760161
C
C*****************************************************************
      SUBROUTINE UPROP(P,T,PHI,DEL,PSI,RESFRK,ENTHLP,CSUBP,CSUBT,RHO,
     C DRHODT,DRHODP,CHI,RAVG,CVAVG)
      COMMON /FUEL/ AF(6),ENW,CX,HY,OZ,QLOWER
      LOGICAL RICH,LEAN
      DIMENSION A(6,7,2)
      DIMENSION A1(42),A2(42),TABLE(7)
      EQUIVALENCE (A1(1),A(1,1,1)),(A2(1),A(1,1,2))
      REAL*4  MBAR,K
      COMMON /OXDANT/ XI /CMPSTN/ X(7),MBAR
C
C        INITIALIZE PARAMETERS, AND CHECK TO SEE IN WHAT TEMPERATURE
C        RANGE WE ARE SO THAT THE CORRECT FITTED COEFFICIENTS WILL BE
C        USED. FLAG TEMPERATURES TOO BIG OR TOO SMALL
C
      DATA A1/11.94033,2.088581,-0.47029,.037363,-.589447,-97.1418,
     1 6.139094,4.60783,-.9356009,6.669498E-02,.0335801,-56.62588,
     2  7.099556,1.275957,-.2877457,.022356,-.1598696,-27.73464,
     3  5.555680,1.787191,-.2881342,1.951547E-02,.1611829, .76498,
     4  7.865847,.6883719,-.031944,-2.68708E-03,-.2013873,-.893455,
     5  6.807771,1.453404,-.328985,2.561035E-02,-.1189462,-.331835,
     6  6*0.0/
      DATA A2/4.737305,16.65283,-11.23249,2.828001,6.76702E-03,-93.75793
     7 ,7.809672,-.2023519,3.418708,-1.179013,1.43629E-03,-57.08004,
     8  6.97393,-.8238319,2.942042,-1.176239,4.132409E-04,-27.19597,
     9  6.991878,.1617044,-.2132071,.2968197,-1.625234E-02,-.118189,
     &  6.295715,2.388387,-.0314788,-.3267433,4.35925E-03,.103637,
     -  7.092199,-1.295825,3.20688,-1.202212,-3.457938E-04,-.013967,
     $  6*0.0/
      DATA TABLE /-1.,1.,1.,-1.,0.,0.,0./
C
C        ENTER INTO ARRAYS A1 AND A2 THE FUEL PARAMETERS
C
      DO 5 I=1,6
      A1(I + 36)=AF(I)
5     A2(I + 36)=AF(I)
      RICH = PHI .GT. 1.0
      LEAN =  .NOT. RICH
      W = ENW/CX
      Z = OZ/CX
      DEL = CX/HY
      EPS = 4.*DEL/(1. + 4.*DEL - 2.*DEL*Z)
C     IER = 0
C     IF (T .LT. 100.) IER = 1
C     IF (T .GT. 6000.) IER  =  2
      IR = 1
      IF (T .LT. 500.) IR = 2
```

```
C
C        GET THE COMPOSITION IN MOLES/MOLE OXYGEN OF OXIDANT
C
      PCTRES = RESFRK
      PCTNEW = 1.0 - RESFRK
      IF (RICH) GO TO 10
      X(1) = EPS*PHI*PCTRES
      X(2) = (2.*(1. - EPS) + EPS*Z)*PHI*PCTRES
      X(3) = 0.
      X(4) = 0.
      X(5) = (1. - PHI)*PCTRES + PCTNEW
      DCDT = 0.
      GO TO 20
   10 ZT = 1000./T
      K = EXP(2.743 + ZT*(-1.761 + ZT*(-1.611 + ZT*.2803)))
      DKDT = -K*ZT*(-1.761 + ZT*(-3.222 + ZT*.9409))/T
      ALPHA = 1.0 - K
      BETA = 2.*(1.- EPS*PHI) + K*(2.*(PHI - 1.) + EPS*PHI)
      BETA = BETA + EPS*PHI*Z
      GAMMA = 2.*K*EPS*PHI*(PHI - 1.)
      C = (-BETA + SQRT(BETA*BETA + 4.*ALPHA*GAMMA))/(2.*ALPHA)
      DCDT = -DKDT*(C*C + (2.*(PHI - 1.) + EPS*PHI)*C - GAMMA/K)
      DCDT = DCDT/(2.*ALPHA*C + BETA)
      X(1) = (EPS*PHI - C)*PCTRES
      X(2) = (2.0*(1. - EPS*PHI) + EPS*PHI*Z + C)*PCTRES
      X(3) = C*PCTRES
      X(4) = (2.0*(PHI - 1.) - C)*PCTRES
      X(5) = PCTNEW
   20 X(6) = XI + EPS*PHI*W/2.*PCTRES
      X(7) = PCTNEW * EPS*PHI/CX
C
C        CONVERT COMPOSITION TO MOLE FRACTIONS AND CALCULATE AVERAGE
C        MOLECULAR WEIGHT
C
      IF (LEAN) TMOLES = XI + (1. + EPS*PHI/CX)*PCTNEW
     +                + (1. + (1.- EPS)*PHI + EPS*PHI*(Z + W/2.))*PCTRES
      IF (RICH) TMOLES = XI + (1. + EPS*PHI/CX)*PCTNEW
     +                + ((2. - EPS)*PHI + EPS*PHI*(Z + W/2.))*PCTRES
      DO 30 J = 1,7
   30    X(J) = X(J)/TMOLES
      MBAR = EPS*PHI*(12. + 1./DEL + 16.*Z + 14.*W) + 32. + 28.*XI
      MBAR = MBAR/TMOLES
C
C        CALCULATE H, CP, AND CT AS IN WRITEUP, USING FITTED
C        COEFFICIENTS FROM JANAF TABLES
C
      ENTHLP = 0.
      CSUBP = 0.
      CSUBT = 0.
      ST = T/1000.
      DO 40 J = 1,7
         TH = ((( A(4,J,IR)/4.*ST + A(3,J,IR)/3. )*ST
     1           +   A(2,J,IR)/2.)*ST + A(1,J,IR)   )*ST
         TCP = (( A(4,J,IR)*ST + A(3,J,IR) )*ST
     1           + A(2,J,IR))*ST + A(1,J,IR)
         TH  =  TH - A(5,J,IR)/ST  +  A(6,J,IR)
         TCP  =  TCP  +   A(5,J,IR)/ST**2
         ENTHLP  =  ENTHLP  +  TH*X(J)
   40    CSUBP  =  CSUBP  +  TCP*X(J)+ 1000.*TH*DCDT*PCTRES*TABLE(J)
      ENTHLP = ENTHLP/MBAR
```

```
      CSUBP = CSUBP/MBAR
C
C        NOW CALCULATE RHO AND ITS PARTIAL DERIVATIVES
C        USING PERFECT GAS LAW
C
      RHO = .012187*MBAR*P/T
      DRHODT = -RHO/T
      DRHODP = RHO/P
C
C        CALCULATE PSI AND CHI FOR BURNED GASES
C
      PSI = (XI + EPS*PHI*W/2.)/(1. + EPS*Z*PHI/2.)
      CHI = PHI*(1. + EPS*Z/2.)/(1. + EPS*Z*PHI/2.)
C
C
      RAVG=82.057/MBAR
      CVAVG=CSUBP-1.98/MBAR
C
C        ALL DONE
      RETURN
      END
```

```
      SUBROUTINE EQIB(TTTT,PPPP,PHIC,IFLAG,Z)
C
C VARIABLES LIST
C
      REAL*8 DPPATM,DPTEMP,DEQIB,XMOFR
      DIMENSION DEQIB(4),XMOFR(14),YMOFR(14),Z(5)
C CALCULATE RATIOS OF H/C,N/C,O/C,AND C/C WHERE C=1.
      TEMP=TTTT
      PATM=PPPP
      SLB=15.1
      EBURN=1./PHIC
      IF(TEMP.LT.1800.) GO TO 101
      IFLAG=0
      WHY=(12.*SLB-137.4)/(-SLB+.25*137.4)
      XWHY=1.+.25*WHY
      DEQIB(1)=WHY
      DEQIB(2)=1.
      DEQIB(4)=2.*XWHY*EBURN
      DEQIB(3)=3.764*DEQIB(4)
C
C CALCULATE N AND NO EQIB. AND EQIB. MOLEFRACTIONS
      DPPATM=PATM
      DPTEMP=TEMP
      CALL PTCHEM(DPTEMP,DPPATM,DEQIB,XMOFR,ISENT)
      DO 100 I=1,14
      YMOFR(I)=XMOFR(I)
  100 CONTINUE
      GO TO 103
  101 IFLAG=1
      DO 102 J=1,14
  102 YMOFR(J)=0.
  103 Z(1)=YMOFR(2)
      Z(2)=YMOFR(5)
      Z(3)=YMOFR(8)
      Z(4)=YMOFR(9)
      Z(5)=YMOFR(14)
      RETURN
      END
```

```
      SUBROUTINE DNODT(TTTT,PPPP,TOTMOL,ZMOFR,IFLAG,XNO,F)
C
C VARIABLE LIST
C
C
C     F              FINAL EVALUATION OF R.H.SIDE RATE EQUATION
C     W,X,Y,Z        DUMMY VARIABLES
C     VOL            VOLUME OF ELEMENT
C     XNO            AMOUNT OF NITRIC OXIDE
C     RC1F           RATE CONSTANT FOR FIRST REACTION,FORWARD
C     RC1R           RATE CONSTANT FOR FIRST REACTION,REVERSE
C     RC2F           RATE CONSTANT FOR SECOND REACTION,FORWARD
C     RC2R           RATE CONSTANT FOR SECONDREACTION,REVERSE
C     TEMP           TEMPERATURE OF ELEMENT
C     RTEMP          RECIPROCAL OF TEMP
C
      DIMENSION ZMOFR(5)
      TEMP=TTTT
      PATM=PPPP
      VOL=82.06*TEMP*TOTMOL/PATM
      IF(TEMP.LT.1800.) GO TO 2000
      IF(IFLAG.GT.0) GO TO 2000
      IF(TOTMOL.LE.0.0) GO TO 2000
C   4.COMPUTE RATE CONSTANTS (FUNCTIONS OF TEMPERATURE ONLY)
      RTEMP=1.9857*TEMP
      RC1F=7.6E+13*EXP(-75460./RTEMP)
      RC1R=1.6E+13
      RC2F=6.4E+09*EXP(-6255./RTEMP)*TEMP
      RC2R=1.5E+09*EXP(-38720./RTEMP)*TEMP
      RCOH=4.1E+13
C
      TMOLNO=ZMOFR(4)*TOTMOL
      TMOLN=ZMOFR(3)*TOTMOL
      XMOLCO=ZMOFR(1)
C   5.CALCULATE DNO/DT=F(VOL,TEMP,PATM,EBURN,ZMOFR,XNO)
      ZR=RC1R*ZMOFR(4)
      WR=RC2F*ZMOFR(5)+RCOH*ZMOFR(2)
      CAPL=ZR/WR
      ALPHA=XNO/TMOLNO
C
      TERM1=2.*RC1R*TMOLN*TMOLNO/VOL*(1.-ALPHA*ALPHA)
      TERM2=1.+ALPHA*CAPL
      F=TERM1/TERM2
C
      GO TO 3000
 2000 F=0.
 3000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PTCHEM ( TMP, PRS, D, XMOFR, ISENT )
C
C
C     THE ORIGINAL MIT EQUILIBRIUM PTCHEM SUBROUTINE HAS BEEN REDUCED
C     AND IS DESIGNED TO PROCESS 4 ELEMENTS & 14 SPECIES
C
C     ARRAY D CONTAINS RATIOS OF ELEMENTS H, C, N, O RESPECTIVELY:
C
C     E.G., DATA D / 1.43, 1.0, 13.0, 3.46 /
C
C
C     ARRAY XMOFR CONTAINS MOLE FRACTIONS OF EACH SPECIES:
C     SYMBOLS OF EACH SPECIES 1 TO 14 (HEX'E') ARE AS FOLLOWS:
C
C    0           'HCO ', 'CO  ', 'CO2 ', 'H   ', 'OH  ', 'H2  ',
C    1           'H2O ', 'N   ', 'NO  ', 'NO2 ', 'N2  ', 'N2O ',
C    2           'O   ', 'O2  ' /
C
C
C     INPUT:     ( DOUBLE PREC. )
C
C        TMP   = TEMPERATURE ( DEGREES K )
C        PRS   = PRESSURE   ( ATMOSPHERES )
C        D     = ARRAY(4)   ( RATIO, 4 ELEMENTS )
C
C     OUTPUT:    ( DOUBLE PREC. )
C
C        XMOFR = ARRAY(14)  ( MOLE FRACTIONS, 14 SPECIES )
C        ISENT = ERROR CODE:
C             0 = NO ERROR
C             1 = TEMP TOO HIGH
C             2 = TEMP TOO LOW
C             3 = ( UNUSED )
C             4 = TOO MANY ITERATIONS, RESULTS DOUBTFUL, LOOK UP NU
C             5 = TOO MANY ITERATIONS
C             6 = THERE ARE NO GASES PRESENT
C             7 = CHECK IF THERE ARE ENOUGH SPECIES
C             8 = TOO MANY TRIES FOR T
C
C     AUTHOR:  DAN DANTZER      LATEST REVISION 12/14/72
C     ADAPTED FOR USE WITH HPCHEM BY TOM MIKUS: CURRENT TO 5/23/74
C
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      EQUIVALENCE ( ITOTSP, M       )
      EQUIVALENCE ( ITOTSP, M1      )
      EQUIVALENCE ( NELEM , N       )
      EQUIVALENCE ( G(1,1), CMN(1)  )
C
      DIMENSION D(1), XMOFR(1)
       DIMENSION A(4,14), ZL(14,8)
      DIMENSION ZL1(56), ZL2(56)
      DIMENSION K2(2)
      DIMENSION RTP(5)
C
C      FOLLOWING ARRAYS ARE 'NELEM' IN SIZE
C
      DIMENSION DD(4), XMU(4), XNJ(4), F(4), E(4,4)
C
```

```
C        FOLLOWING ARRAYS ARE 'NELEM' +2  = 'INXNSL'
C
      DIMENSION R(6), G(6,6)
C
C        FOLLOWING ARRAYS ARE 'ITOTSP'
C
      DIMENSION CMN(14), CP(14), CPT(14), X(14), XMAX(14)
      DIMENSION HORT(14), SR(14), C(14)
      DIMENSION XHORT(14)
C
      COMMON / HRPT / HORTSM,SMOHRT,XMU,RTP,SUMNI
C
C     NSAME  = INITIALIZATION FLAG
C     NELEM  = NR OF ELEMENTS INVOLVED
C     ITOTSP = TOTAL NR OF SPECIES INVOLVED
C
      DATA NSAME  /  0 /
      DATA NELEM  /  4 /
      DATA INXNSL /  6 /
      DATA ITOTSP / 14 /
C
      DATA DD,XNU,E,F / 28*0.0D0 /
      DATA  R, G  /  42 * 0.0D0 /
      DATA  A,        CP, CPT, X, XMAX  /  112 * 0.0D0 /
C   CMN IS NOT INITIALIZED WHEN IT LIES WITHIN ARRAY G
C
C     ARRAY ZL(K,J)  CONTAINS THE HI-TEMP DATA FOR EACH OF 14 SPECIES
C
C        K = SPECIES NR ( 1 - 14 )
C        J = DATA ( 1 - 8 EACH SPECIES )
C
C     DATA WAS TAKEN FROM ORIGINAL DATA SET ( CARDS), ARRANGED IN
C     ROW,COL (14,8),   BUT DATA STATEMENT INTERNALLY STORES
C     BY COL,ROW:  THEREFORE,  DATA MUST BE REVERSED FOR PROG EXEC.
C     ORIGINAL DATA ARRANGMENT MAINTAINED FOR CONVENIENCE IN MAKING
C     CHANGES TO SPECIES DATA.
C
C     NR OF CONTINUATION CARDS LIMITED TO 19
C     CONTINUATION COL #6 CONTAINS THE HEXIDECIMAL SPECIES NR
C
      DATA  ZL1  /
     1  9.3434439D 00, 2.9512196D 00,-6.7098366D-01, 5.0901942D-02,
     1 -4.1140777D-01,-6.9903498D 00, 6.2395554D 01, 2.3009987D 00,
     2  7.0995646D 00, 1.2759552D 00,-2.8774744D-01, 2.2356123D-02,
     2 -1.5986955D-01,-2.9023636D 01, 5.4823700D 01, 1.2890015D 00,
     3  1.1940331D 01, 2.0885811D 00,-4.7029203D-01, 3.7363116D-02,
     3 -5.8944768D-01,-9.9468796D 01, 6.2207169D 01, 2.3269949D 00,
     4  4.9679995D 00,-5.9678716D-13, 1.9345219D-13,-1.8732195D-14,
     4 -7.4194936D-14, 5.0619217D 01, 3.3404419D 01, 1.0119925D 00,
     5  5.6197815D 00, 1.9668446D 00,-3.8645178D-01, 2.7364515D-02,
     5  1.3418680D-01, 8.0923529D 00, 5.0777405D 01, 2.0489998D 00,
     6  5.5556803D 00, 1.7971914D 00,-2.8813416D-01, 1.9515470D-02,
     6  1.6118270D-01,-1.2590199D 00, 3.8126053D 01, 2.0239983D 00,
     7  6.1390944D 00, 4.6078291D 00,-9.3550094D-01, 6.6594975D-02,
     7  3.3580098D-02,-5.9687856D 01, 5.1456772D 01, 3.0519965D 00 /
      DATA  ZL2  /
     8  5.1632023D 00,-1.8977487D-01, 3.6921006D-02, 3.6241105D-03,
     8 -3.2718156D-02, 1.1134157D 02, 4.2733066D 01, 1.0359793D 00,
     9  7.5180626D 00, 1.0245209D 00,-2.3053735D-01, 1.7926671D-02,
     9 -1.9369543D-01, 1.8756821D 01, 5.8378296D 01, 2.0729971D 00,
```

```
     A  1.2123282D 01, 1.2564993D 00,-3.0112296D-01, 2.3658749D-02,
     A -6.2256289D-01, 2.3839598D 00, 6.8810959D 01, 3.1109982D 00,
     B  6.8077698D 00, 1.4534035D 00,-3.2898575D-01, 2.5610346D-02,
     B -1.1894619D-01,-2.4038353D 00, 5.3165161D 01, 2.0719986D 00,
     C  1.2365961D 01, 1.7261782D 00,-4.0528846D-01, 3.1418435D-02,
     C -5.8120877D-01, 1.4105570D 01, 6.4331467D 01, 3.1099997D 00,
     D  5.1006308D 00,-1.5177220D-01, 4.8953138D-02,-2.8814352D-03,
     D  8.9299418D-03, 5.8080948D 01, 4.4752548D 01, 1.0379944D 00,
     E  7.8658457D 00, 6.8837130D-01,-3.1944100D-02,-2.6870817D-03,
     F -2.0138729D-01,-2.9684544D 00, 5.7424637D 01, 2.0749989D 00 /
C
C
C
      IF(NSAME)2000,2000,2004
 2000 NSAME=1
      AP=1.98726D0
      ITMAX = 500
      ITW  = 400
      DIF = 15.0D0
      DIF1 = DIF
      T = 1.0D0
      TLUB = 6000.
         XN=N
      TOL1 = .01D0
      TOL3 = .00001D0
      TOL5 = 1.0D-5
      TOL6 = .1D0
      TOL7 = 10.0D0
C
C     ARRAY A(I,K)  CONTAINS NR OF ATOMS PER ELEMENT ( IN SPECIES )
C
C        I = ELEMENTS H, C, N, O RESPECTIVELY
C        K = SPECIES NR
C
      A(1,1)  = 1.
      A(1,4)  = 1.
      A(1,5)  = 1.
      A(1,6)  = 2.
      A(1,7)  = 2.
      A(2,1)  = 1.
      A(2,2)  = 1.
      A(2,3)  = 1.
      A(3,8)  = 1.
      A(3,9)  = 1.
      A(3,10) = 1.
      A(3,11) = 2.
      A(3,12) = 2.
      A(4,1)  = 1.
      A(4,2)  = 1.
      A(4,3)  = 2.
      A(4,5)  = 1.
      A(4,7)  = 1.
      A(4,9)  = 1.
      A(4,10) = 2.
      A(4,12) = 1.
      A(4,13) = 1.
      A(4,14) = 2.
C
C     LOAD DATA INTO SPECIES ARRAY  ZL
C
```

```
      II = 0
      DO 1050 K = 1,7
      I = K + 7
      DO 1050 J = 1, 8
      II = II + 1
      ZL(K,J) = ZL1(II)
 1050 ZL(I,J) = ZL2(II)
      DO 3010 I = 1,N
      XMU(I) = 0.0
 3010 CONTINUE
C
C
C     END OF ONE-TIME INITIALIZATION
C
 2004 IF ( TMP - 200.0 )  2112, 2112, 2355
 2355 CONTINUE
      IF ( TMP - TLUB ) 2012, 2012, 2009
 2009 ISENT=1
      GO TO 5000
 2112 ISENT=2
      GO TO 5000
 2012 CONTINUE
      TK  = TMP / 1.0D+3
      XLP = DLOG ( PRS )
C
C     START OF ORIGINAL 'HS' SUBROUTINE
C
       DO  5004  K10 =1, M
      IF ( ZL(K10,1) )  5003, 5002, 5003
 5002 HORT(K10) = 0.11111111D0
      SR  (K10) = -1.0D6
      GO TO 5004
 5003 HORT(K10) = (((( ZL(K10,4) * TK / 4.D0 + ZL(K10,3) / 3.0D0 ) *
     1     TK + ZL(K10,2) / 2.D0 ) * TK  + ZL(K10,1) ) * TK -
     2     ZL(K10,5) / TK + ZL(K10,6) ) / ( AR * TK )
      SR(K10) = ( ZL(K10,1) * DLOG(TK) + TK * ( ZL(K10,2) +
     1   ZL(K10,3) * 0.5D0 * TK + ZL(K10,4) * TK **2 / 3.D0 ) -
     2   ZL(K10,5) * 0.5D0 / TK ** 2 + ZL(K10,7) ) / AR
 5004 C(K10) = HORT(K10) - SR(K10) + XLP
C
C     END OF ORIGINAL 'HS' SUBROUTINE
C
      ISENT=0
        ITER=0
      ITTPDG=0
      TOL4 = 0.1D0
      YMAX = 0.
        DO    412   J=1,M1
        XMAX(J) = 1.0D10
        DO  412  I=1,N
        IF  (A(I,J))  412,412,413
  413   IF  (D(I)/A(I,J) -XMAX(J))  414,412,412
  414   XMAX(J)= D(I)/A(I,J)
  412   CONTINUE
         X0=0.0D0
        DO    90  I=1,N
   90    X0=X0+D(I)
      AVD = X0 / XN
         Y0=0.0D0
         DO   93  J=1,M
```

```
  93     Y0=Y0+ XMAX(J)
     X0= DMIN1(X0,Y0)
        X0=X0*1.05D0
       DO 825 J=1,M1
 825       XMAX(J)=XMAX(J)*1.05D0
C
C     CAUTION***   ASSUMPTION:  THAT EACH ELEMENT MOLE RATIO DIVIDED BY
C     THE SUM OF THE RATIOS WILL BE GREATER THAN 0.01:
C     IF = OR < 0.01. THEN MUST USE FOLLOWING ROUTINE:
C     I.E., REMOVE THE 'C' COMMENT FROM COL 1 FROM HERE TO LABEL 530 &
C        FROM LABEL 503 TO 475
C     NOTE:  ARRAY K2 IS DIMENSIONED (2)
C
C  SUM IS NOT DEFINED IN ORIGINAL PROGRAM
      SUM = 0.0
      DO 525 I = 1,N
 525  SUM = SUM + D(I)
C
        L1=0
         NGO5=1
      RATIO = .01D0
        DO  526   I=1,N
         IF (D(I)/SUM - RATIO )    527,527,526
 527      L1=L1+1
          K2(L1) =I
 526     CONTINUE
         NL= L1
         IF   (NL)  528,528,529
 528     NGO5 =1
         GO TO  530
 529     NGO5=2
 530        CONTINUE
C
C
       ITER4=0
          NGO6=1
          RH2=1.0D0
C
C     END OF ENTRY INITIALIZATION & CHECKING OF TEMPERATURE
C
C   BEGINNING OF MAIN PROGRAM LOOP
C
  99      NGO=1
          ITER2=0
        IF (ITER - 1)    473,473,474
 474  RH2=DSQRT(H2)
      RH2=DMIN1(RH2,1.0D0)
 473        NGO1=1
       DO   101  J=1,M1
        SUM= C(J)
       DO  1002 I=1,N
1002    SUM=SUM+ XMU(I)*A(I,J)
 101    CP(J)= SUM
       DO  1012  J=1,M1
1012    CPT(J)= CP(J)
       DO    1001  I=1,N
1001   DD(I)= D(I)
       L1= 0
         SUMEX=0.0D0
         DO  102  J=1,M
```

```
            J1=J
          IF  (CPT(J)+ 30.0D0) 420,420, 421
  421 XJ=DEXP(-CPT(J))
             SUMFX=SUMFX+XJ
  102     X(J)=XJ
           IF (SUMFX-1.0D0-TOL1*RH2)    103,103,107
  103     IF(SUMFX-1.0D0+TOL1*RH2)    112,104,104
  104    L1=1
         DO    106   I=1,N
          SUM=0.0
         DO    105   J=1,M
  105     SUM=SUM+ A(I,J)*X(J)
  106     F(I,1) = SUM
      YMAX = X0
      GO TO 123
  420       CPT1 = CPT(J1)
             DO  423     J=1,M
             J1= J
             CPT2 = CPT(J)-CPT1
             IF (CPT2 +30.0D0) 420,420,422
  422 X(J)  =DEXP(-CPT2)
  423        CONTINUE
  107    SUM=0.0D0
         DO  416    J=1,M
  416    SUM= SUM+ X(J)
         SUM= X0/SUM
         DO  108   J= 1,M
  108     X(J)=X(J)*SUM
          DO  109    I=1,N
           SUM= DD(I)
           DO 110   J=1,M
  110      SUM = SUM -A(I,J)*X(J)
  109      DD(I)= SUM
      GO TO 123
  112      DO    113  J=1,M
  113      X(J)= 0.0D0
  123   L=L1
C
C       L = 0 OR 1 ONLY
C
          IF  (L)    131,131, 200
  131      DO  132    I=1,N
  132     XNU(I)=-DD(I)
           GO TO 23
  430      DO 431   J=1,M1
            CMN(J)= 0.0D0
           DO 431   I=1,N
  431       CMN(J)=CMN(J)+XNU(I)*A(I,J)
               COMP=TOL5*TOL5/H2
           XNUD=0.0D0
           DO    432   I=1,N
  432      XNUD= XNUD+ XNU(I)*D(I)
  446         H= -XNUD
      ITTRDG=ITTRDG+1
      IF(ITTRDG-5000)2358,2358,2356
 2356 ISENT = 8
      GO TO 5000
 2358 CONTINUE
          DO  433    J=1,M1
  433     CPT(J)= CP(J)+ T*CMN(J)
```

```
          EXMIN=  1.0D10
          DO   510   J=1,M
           IF (CPT(J) - EXMIN)     511,510,510
 511 CONTINUE
           EXMIN= CPT(J)
 510       CONTINUE
           SUMEX =0.0D0
           DO    513   J=1,M
           IF(CPT(J)-EXMIN-DIF1)      517,517,516
 516        X(J)= 0.0D0
      GO TO 513
 517 X(J) =DEXP(EXMIN -CPT(J))
           SUMEX =SUMEX +X(J)
 513        CONTINUE
          IF   (EXMIN )    521,521 , 519
 519 IF(SUMEX*DEXP(-EXMIN)-1.0D0) 443,521,521
 521        PROD = X0 /SUMEX
            DO     522    J=1,M
 522       H= H+ PROD* X(J)*CMN(J)
 443        CONTINUE
         IF (H)  458,458,457
 457         T0=T
       H0= H
            GO TO (448,459) , NGO
 448     T= T+T
       IF (T - 1.0D15 ) 446, 446, 908
 908 ISENT = 7
     GO TO 5000
 458        T1=T
       NGO=2
 459 IF(DABS(H/H2)-TOL3) 453,453,460
 460        IF ((T1-T0)**2-COMP)    453,453,452
 452     T=0.5D0*(T0+T1)
       GO  TO  446
 453   DO  454  I=1,N
 454   XMU(I) = XMU(I) + T* XNU(I)
       GO TO  99
C
C      L = 1 AT THIS POINT
C
 200 SDUM = 0.0D0
      SUM = 0.0D0
     DO 2 I = 1, N
     SDUM = SDUM + F(I,1) * F(I,1)
   2  SUM =  SUM + F(I,1) * DD(I)
     E(1) = SUM / SDUM
     G(1,1) = 0.0D0
     Y1     = 0.0D0
     Z1     = 0.0D0
  71 SUM = E(1) + G(1,1) * Z1
     IF ( SUM )10, 10, 11
  10 Z1 = 0.0D0
     GO TO 8
  11 IF ( SUM - YMAX )  471, 471, 472
 472 Z1 = YMAX
     GO TO 8
 471 Z1 = SUM
   8 IF ( DABS( Z1 - Y1 ) - TOL3 )  15, 15, 13
  13 Y1 = Z1
     GO TO 71
```

```
   15 DO 16  I = 1, N
   16 XNU(I) = -DD(I) + F(I,1) * Z1
      DO 19  J = 1, M
   19 X(J) = X(J) * Z1
C
C     L = 0 OR 1 BELOW THIS POINT
C
   23      DO   24    I=1,N
      IF(DABS(XNU(I)) - TOL4 * AVD) 24,24,25
   24      CONTINUE
           NGO1=2
           GO TO 330
   25    GO TO (550,551), NGO6
  551        ITER4=ITER4+1
        IF (L)   550,550,814
  814  IF (ITER4-20)550,552,552
  552        ITER4=0
         NGO1=2
          GO TO 330
  550          H0=0.0D0
          DO 26 I=1,N
   26     H0=H0+XNU(I)**2
        H2= H0
          T0=0.0D0
          T=1.0D0
              GO   TO   330
C
C     SEE COMMENTS ABOVE ( LABEL 527 )
C
  503 CONTINUE
C
          GO TO (475,476),NGO5
  476 K = ITER - ( ITER / N ) * N
            IF   (K)    531,532,531
  532        K=N
  531         DO   540  L1=1,NL
        IF(K2(L1)-K)     540,541,540
  540           CONTINUE
           GO TO 475
  541 IF(DABS(XNU(K))-TOL5*D(K)) 475,475,542
  542 IF(DABS(XNU(K))-1.D-15)475,475,8000
 8000 SUM=XNU(K)
        DO 543 I=1,N
  543         XNU(I)=0.0D0
          XNU(K)=SUM
         H0=SUM*SUM
          DIF1=100.0D0
            H2=H0
           T0=0.0D0
          T=1.0D0
          GO TO 430
  475     DIF1=DIF
C
        GO TO 430
  330     ITER= ITER+1
         IF (ITER - ITW)    333,670,670
  670 ISENT = 4
      GO TO 5079
C
  333        GO TO (503,500) ,N3O1
```

```
C
  500       NTOT=N+1
          DO 820  I=1,N
  820       DD(I)=XMU(I)
            DO 821 J=1,M1
  821        CPT(J)=X(J)
              IF  (L)     727,727,502
  502          XBAR=Z1
      ITER2 = 1
  750 IF (XBAR) 727, 727, 701
  701     G(N+1,N+1)= 0.0D0
            DO    704  K=1,M
               SUM=- C(K)
          DO  705  I=1,N
  705 SUM=SUM-XMU(I)*A(I,K)
          IF   (SUM -30.0D0)425,727, 727
  425 X(K) = XBAR*DEXP(SUM)
  704     CONTINUE
            DO  706  I=1,N
             SUM=0.0D0
            DO  707  K=1,M
  707        SUM=SUM +A(I,K)*X(K)
             SUM=SUM/XBAR
             G(I,N+1) =SUM
             G(N+1,I) =SUM
            R(I) = D(I)-SUM*XBAR
           DO  706  J=1,N
               SUM= 0.0D0
           DO  709  K=1,M
  709        SUM=SUM - A(I,K)*A(J,K)*X(K)
  706         G(I,J)=SUM
              SUM=-XBAR
              DO    710  K=1,M
  710         SUM=SUM+X(K)
              R(N+1) =SUM/XBAR
         DO  728  I=1,N
     IF(DABS(R(I)) - TOL6*AVD) 728,728,727
  728    CONTINUE
         GO TO  730
  727    DO 903  I=1,N
     IF(DABS(XMU(I))-TOL5*D(I)) 903,903,801
  903       CONTINUE
          DO 822   I=1,N
  822       XMU(I)=DD(I)
         DO 823  J=1,M1
  823      X(J)=CPT(J)
     GO TO 5079
  801   TOL4=0.1D0*TOL4
         NG06=2
         H2=1.0D0
           GO  TO  99
  730 IPP=NXNSOL(INXNSL,NTOT,G,R)
      IF(IPP-2)8001,727,8001
 8001 ITER2=ITER2+1
            DO  465  I=1,N
      IF(DABS(R(I)) -TOL7) 465,465,727
  465     CONTINUE
         DO    731  I=1,NTOT
      IF(DABS(R(I)) - TOL5) 731, 731, 739
  731    CONTINUE
```

```
        GO TO   737
  733     DO  734  I=1,N
  734     XMU(I)= XMU(I)+R(I)
          XBAR =XBAR+ R(N+1)
      GO TO 750
  739       CONTINUE
          IF (ITER2- ITMAX)  733,740,740
  740 ISENT=5
      GO TO 5000
C
C        TEST IF  X(J)  NEGATIVE
C
  737     DO   470  J=1,M1
          IF  (X(J))    801,470,470
  470     CONTINUE
C
C    END OF MAIN PROGRAM LOOP
C
 5079 SUMNI =0.0D0
       DO  5010 I = 1, M
      SUMNI = SUMNI + X(I)
 5010 CONTINUE
         IF (SUMNI)  751, 752, 751
  752 ISENT=6
       GO TO 5000
  751 CONTINUE
       DO  5011 I = 1, M
 5011 XMOFR(I)   = X(I) / SUMNI
C
C      NOTE:          ROUTINE TO CHECK FOR A SINGULAR DERIVATIVE MATRIX
C      IN RTP & RPP ARRAYS HAS BEEN REMOVED.
C
C  ADDITIONAL CALCULATIONS REQUIRED BY HPCHEM:
C
      NP11 = N + 1
          DO 6000 I= 1,N
          DO 6000 J= 1,N
      G(I,J) = 0.0D0
          DO 6000 K= 1,M
      G(I,J) = G(I,J) - A(I,K)*A(J,K)* X(K)
 6000 CONTINUE
          DO 6001   I = 1,N
      G(I, NP11) = 0.0D0
      G(NP11, I) = 0.0D0
          DO 6002   K = 1,M
      G(I, NP11) = G(I, NP11) +  A(I,K)* X(K)
      G(NP11, I) = G(NP11, I) +  A(I,K)* X(K)
 6002 CONTINUE
      G(I, NP11) = G(I, NP11) / XBAR
      G(NP11, I) = G(NP11, I) / XBAR
 6001 CONTINUE
      G(NP11,NP11) = 0.0
      XBAR = SUMNI
      XHPRIM = 0.0
      HORTSM = 0.0
      DO 6010 I = 1,N
      RTP(I) = 0.0
 6010 CONTINUE
      DO 6030 K = 1,M
      XHPRIM = XHPRIM + X(K) * ( ((ZL(K,4)*TK + ZL(K,3))*TK + ZL(K,2))
```

```
     1                              * TK  +  ZL(K,1) + ZL(K,5)/(TK*TK)  )
      XHORT(K) = X(K) * HORT(K)
      HORTSM = HORTSM + XHORT(K)
      DO 6020 I = 1,N
      RTP(I) = RTP(I) - A(I,K) * XHORT(K)
 6020 CONTINUE
 6030 CONTINUE
      RTP(NP11) = HORTSM / XBAR
      NPL = N + L
      DO 6040 I = 1,NPL
      RTP(I) = RTP(I) / TMP
 6040 CONTINUE
      IPP = NXNSOL(INXNSL,NPL,G,RTP)
      CSUBP = 0.0
      DO 6060 K = 1,M
      RTPA = 0.0
      DO 6050 I = 1,N
      RTPA = RTPA + RTP(I) * A(I,K)
 6050 CONTINUE
      CSUBP = CSUBP + (HORT(K)/TMP - RTPA)*XHORT(K)
 6060 CONTINUE
      SMDHDT = XHPRIM + AR*TMP*(CSUBP + RTP(NP11)*HORTSM/SUMNI)
C
      RETURN
C
C     ERROR:  SET MOLE FRACTIONS TO 0.
C
 5000 DO 5100 I = 1, ITOTSP
 5100 XMOFR(I) = 0.
      RETURN
      END
```

```
      FUNCTION    NXNSOL(IM,IN,A,B)
CNXNSOL
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(2),B(2)
      INTEGER XROW
      XROW(K000FX,K001FX)=K001FX*M-M+K000FX
      M=IM
      N=IN
      N1=N-1
      DO 44  J=1,N1
      K=J
      J1=J+1
      JJ=XROW(J,J)
      WS1=DABS(A(JJ))
C     LOOP TO FIND LARGEST
      DO 11 L=J1,N
      LJ=XROW(L,J)
      WWS1=DABS(A(LJ))
      IF (WS1-WWS1) 12,11,11
   12 WS1=WWS1
      K=L
   11 CONTINUE
      IF (J-K) 13,31,31
C                             $ IF DIAG NOT LARGEST INTERCHANGE ROWS
   13 DO 26    L=1,N
      JL=XROW(J,L)
      KL=XROW(K,L)
      WS1=A(JL)
      A(JL)=A(KL)
 26   A(KL)=WS1
      WS1=B(J)
      B(J)=B(K)
      B(K)=WS1
 31   DO 33     L=J1,N
      JL= XROW(J,L)
      IF(A(JJ))33,54,33
 33   A(JL)= A(JL)/A(JJ)
      B(J)=B(J)/A(JJ)
      DO 43     L =1,N
      IF  (L -J) 37,43,37
 37   LJ = XROW(L  ,J)
 38   DO 41     L2=J1,N
      LL2= XROW(L  ,L2)
      JL2= XROW(J,L2)
 41   A(LL2) = A(LL2 )-A(LJ )*A(JL2)
      B(L) = B(L)-A(LJ)*B(J)
 43   CONTINUE
 44   CONTINUE
C       LAST COLUMN HAS NOT BEEN DONE YET
      NN= XROW(N,N)
      IF  (A(NN)) 46,54,46
   46 B(N)= B(N)/A(NN)
      DO 50 L=1,N1
      LN= XROW(L,N)
   50 B(L)= B(L)- A(LN)*B(N)
      NXNSOL=1
      RETURN
   54 NXNSOL=2
      RETURN
      END
```

```
-----C20049.DAT  RUN #28  JUL. 28 '77------
9.842    9.842    16.8275   12.7     57.29    2.46      1.
-20.     480.      200.     14.      335.     355.
16.5     9.0      14.45     10020.   64.4
0.0196   2000.    0.
650.     500.     700.      600.     650.
2.28     0.0032   1.6
34.      15.      2.        0.02227
3.65     0.08     0.35      0.80     0.012    0.0000065
0.1      0.22     200.      50.
4.57     1.625    2.95      1.625    1.       1.
7.       1.       3.
18
 9
0.       0.058    0.096     0.135    0.173    0.211     0.25     0.288
0.308    0.692    0.712     0.75     0.789    0.827     0.865    0.904
0.942    1.0
0.       0.029    0.096     0.304    0.544    0.755     0.911    0.991
1.0      1.0      0.991     0.911    0.755    0.544     0.304    0.096
0.029    0.0
0.0      0.05     0.1       0.15     0.2      0.25      0.3      0.35
0.4
0.0      0.08     0.135     0.19     0.25     0.3       0.35     0.41
0.47
18
10
0.       0.058    0.096     0.135    0.173    0.211     0.25     0.288
0.308    0.692    0.712     0.75     0.789    0.827     0.865    0.904
0.942    1.0
0.       0.029    0.096     0.304    0.544    0.755     0.911    0.991
1.0      1.0      0.991     0.911    0.755    0.544     0.304    0.096
0.029    0.0
0.0      0.05     0.1       0.15     0.2      0.25      0.3      0.35
0.4      0.46
0.0      0.15     0.25      0.35     0.44     0.52      0.57     0.61
0.63     0.65
 8
310.     1.
0.960    1.035    310.
2.       2.       2.        2.       2.
1.       1.       1.        1.
1.27     640.     0.5       540.
 0 420.
-10.     710.
 1
```

```
**CYCLE SIMULATION FOR DIRECT INJECTION ENGINE**   VERSION 1***
-----C20058.DAT  RUN #37  JUN. 28 '77------

                          TABLE OF INPUT DATA AND INITIAL ENGINE CONDITIONS
   *****************************************************************************************************
INITIAL JET SPEED
       VINIT=      9530.9CM/SEC
-------------------------------------------------------------------------------------------------------
      ENGINE GEOMETRY        *           TIMING            *         FUEL PROPERTIES          *   ESTIMATE TEMPERATURES
STROKE      =      9.842CM   *  INT.VAL.OPEN  =    -20.0DEG  *  ZM(NO. OF H)    =       16.5       *  PISTON TOP(TP) =       650.0K
CON.ROD     =      16.83CM   *  EXH.VAL.OPEN  =    480.0DEG  *  ZN(NO. OF C)    =        9.0       *  CYL.WALL(TW)   =       600.0K
BORE        =      9.842CM   *  INT.VAL.CLOSE =    200.0DEG  *  SAFC(STOICH.A/F)=       14.4       *  CYL.HEAD(TCYLH)=       650.0K
CLEAR.VOL. =      12.70CM**3 *  EXH.VAL.CLOSE =     14.0DEG  *  LOWER HEATING   =   10020. CAL/G*  INT.VALVE(TINV)=       500.0K
CUP VOL.    =      57.29CM**3 *  FUEL INJ.START=    330.0DEG  *  VAPORIZING HEAT =      64. CAL/G*  EXH.VALVE(TEXV)=       700.0K
                                FUEL INJ.END  =    360.0DEG  *  DENSITY         =   0.800G/CM**3*
-------------------------------------------------------------------------------------------------------
        INITIAL JET DATA               *          JET MIXING PARAMETER           *              PLUME MODEL
JET DIRECTION**                        * SWIRL RATIO AT BDC        =      3.650*RPM  * INITIAL PLUME RADIUS =    0.1000 CM    *
 ANGLE(VERTICAL)    =      34.00 DEG   * AIR ENTRAIN. PARAMETER                     * ENTRAIN. PARAMETER   =     0.220         *
 ANGLE(TANGENTIAL)=       15.00 DEG   *   ALPHA                   =       0.070     * LAM. FLAME SPEED     =    200.00 CM/SEC  *
JET RADIUS          =    0.02227 CM    *   BETA                    =       0.350     * SPARK PLUG LOCATION  =     50.00 DEG     *
JET LOCATION(R)     =      2.000 CM    * DENSITY OF SURROUD. GAS   =   0.01200 G/CC *        (FROM INJ. NOZZLE)
PISTON CUP RADIUS   =      2.460 CM    * SWIRL DECAY FACTOR        = 0.650E-05       * TAYLOR MICRO SCALE   =    0.0236 CM
-------------------------------------------------------------------------------------------------------
     ENGINE CONDITION        *      INTAKE CONDITIONS        *     COMPUT'NG INTERVALS     *        PRINT CONTROL
ENGINE SPEED  =   2000. RPM  * PRESSURE      =   0.960 ATA   * VALVE OVERLAP=   2.00 DEG   * VALVE OVERLAP=    1.00
FUEL AMOUNT   = 0.02970 G/SHOT* TEMPERATURE  =  310.00 K     * INTAKE       =   2.00 DEG   * INTAKE       =    1.00
EGR           =   0.0        * EQUI. R TIO   =   0.0         * COMPRESSION  =   2.00 DEG   * COMPRESSION  =    1.00
     AMBIENT CONDITIONS      *  EXHAUST CONDITIONS(ASSUME)   * COMBUSTION   =   3.75 DEG   * COMBUSTION   =    1.00
PRESSURE      =     1.00 ATA * PRESSURE      =    1.03 ATA   * EXPANSION    =   2.00 DEG   * EXPANSION    =    1.00
TEMPERATURE   =  310.00 K    * TEMPERATURE   =  786.00 K     * EXHAUST      =   2.00 DEG   * EXHAUST      =    1.00
                             * EQUI. RATIO   =   0.500       *
-------------------------------------------------------------------------------------------------------
       INTAKE VALVE          *      HEAT TRANS. AREA         *     HEAT TRANS. COEFF        *     INITIAL CONDITION
DIAMETER      =     4.570 CM * INTAKE VALVE =   16.403 CM**2*               (WOSCHNI'S EQ.) * CYL. PRESS.   =     1.27 ATA
LIFT          =     1.625 CM * EXHAUST VALVE=    6.835 CM**2* COHT          =  1.60000     * CYL. TEMP.    =    786.0 DEG
NUMBER        =       1.0    * PISTON TOP   =   57.066 CM**2* COHT1         =  2.28000     * CYL. EQUI.    =    0.500
      EXHAUST VALVE          * PISTON TOP   =   46.576 CM**2* COHT2         =  0.00320     * EXHAUST TEMP.=    786.0 DEG   *
DIAMETER      =     2.950 CM * CYL. HEAD    =   52.840 CM**2*
LIFT          =     1.625 CM * CYL. WALL    =       VARIABLE*
NUMBER        =       1.0    *
-------------------------------------------------------------------------------------------------------
      FRICTION LOSS          *
PISTON SKIRT =    7.000 CM   *
JOU. BEAR. COE=   1.000      *
NO. OF RINGS  =     3.0      *
-------------------------------------------------------------------------------------------------------
```

INTAKE VALVE--EFFECTIVE FLOW AREA VS. CRANK ANGLE

NORMALIZED CRANK ANKLE

0.0	0.058	0.096	0.135	0.173	0.211	0.250	0.288	0.308	0.692
0.712	0.750	0.789	0.827	0.865	0.904	0.942	1.000		

NORMALIZED EFFECTIVE FLOW AREA

0.0	0.000	0.005	0.044	0.132	0.240	0.345	0.409	0.417	0.417
0.409	0.345	0.240	0.132	0.044	0.005	0.000	0.0		

EXHAUST VALVE--EFFECTIVE FLOW AREA VS. CRANK ANGLE

NORMALIZED CRANK ANKLE

0.0	0.058	0.096	0.135	0.173	0.211	0.250	0.288	0.308	0.692
0.712	0.750	0.789	0.827	0.865	0.904	0.942	1.000		

NORMALIZED EFFECTIVE FLOW AREA

0.0	0.001	0.015	0.116	0.310	0.480	0.592	0.644	0.650	0.650
0.644	0.592	0.480	0.310	0.116	0.015	0.001	0.0		

INTAKE AND EXHAUST VALVE OPEN

OUTPUT DATA

THED DEG	P ATA	T K	V CM**3	WORK PS	CYL.MAS KG	HEAT TRANSFER CAL/A	CAL	AEFI CM**2	GWI G/S	AEFE CM**2	GWE G/S
-8.0	1.31	790.	75.	-0.00	0.043	-0.862E-02	-0.345E-01	0.01	-0.16	0.17	-2.99
-6.0	1.33	792.	73.	-0.00	0.043	-0.887E-02	-0.700E-01	0.03	-0.28	0.13	-2.47
-4.0	1.35	793.	71.	-0.00	0.043	-0.901E-02	-0.106E+00	0.05	-0.73	0.09	-1.85
-2.0	1.35	791.	70.	-0.00	0.042	-0.901E-02	-0.142E+00	0.08	-1.22	0.05	-1.17
0.0	1.34	788.	70.	-0.01	0.042	-0.886E-02	-0.177E+00	0.11	-1.69	0.02	-0.49
2.0	1.31	783.	70.	-0.00	0.041	-0.854E-02	-0.212E+00	0.21	-2.35	0.02	-0.30
4.0	1.25	773.	71.	-0.00	0.040	-0.793E-02	-0.243E+00	0.42	-5.27	0.01	-0.24
6.0	1.16	758.	73.	-0.00	0.039	-0.698E-02	-0.271E+00	0.63	-7.71	0.01	-0.16
8.0	1.06	741.	75.	-0.00	0.038	-0.583E-02	-0.295E+00	0.84	-8.55	0.01	-0.09
10.0	0.98	725.	77.	-0.00	0.037	-0.471E-02	-0.313E+00	1.09	-6.60	0.01	0.02
12.0	0.95	721.	81.	-0.00	0.037	-0.397E-02	-0.329E+00	1.59	3.43	0.00	0.04
14.0	0.95	724.	84.	-0.00	0.039	-0.407E-02	-0.346E+00	2.08	10.18	0.0	0.01

INTAKE VALVE OPEN

OUTPUT DATA

THEC DEG	P ATA	T K	V CM**3	WORK PS	CYL.MAS G	HEAT TRANSFER CAL/A	CAL	AEFI CM**2	GWI G/S
16.0	0.95	726.	89.	-0.00	0.041	-0.426E-02	-0.363E+00	2.57	11.68
18.0	0.95	727.	94.	-0.00	0.043	-0.445E-02	-0.381E+00	3.06	13.06
20.0	0.93	692.	99.	-0.01	0.047	-0.376E-02	-0.396E+00	3.66	22.59
22.0	0.92	653.	105.	-0.01	0.052	-0.190E-02	-0.403E+00	4.27	33.03
24.0	0.92	616.	111.	-0.01	0.059	0.416E-04	-0.403E+00	4.88	39.28
26.0	0.92	583.	118.	-0.01	0.066	0.195E-02	-0.395E+00	5.48	43.92
28.0	0.93	555.	126.	-0.01	0.074	0.378E-02	-0.390E+00	6.06	47.65
30.0	0.93	530.	134.	-0.01	0.083	0.551E-02	-0.358E+00	6.63	50.90
32.0	0.93	509.	142.	-0.01	0.092	0.716E-02	-0.329E+00	7.20	54.04
34.0	0.93	491.	151.	-0.01	0.101	0.871E-02	-0.295E+00	7.76	57.05
36.0	0.93	475.	161.	-0.02	0.111	0.102E-01	-0.254E+00	8.23	59.46
38.0	0.93	462.	170.	-0.02	0.121	0.115E-01	-0.208E+00	8.59	61.29
40.0	0.93	450.	190.	-0.02	0.132	0.128E-01	-0.156E+00	8.94	63.59
42.0	0.93	440.	191.	-0.02	0.143	0.141E-01	-0.100E+00	9.30	65.94
44.0	0.93	431.	202.	-0.02	0.154	0.153E-01	-0.390E-01	9.57	68.11
46.0	0.93	423.	213.	-0.02	0.166	0.164E-01	0.265E-01	9.65	69.36
48.0	0.93	415.	224.	-0.02	0.178	0.175E-01	0.956E-01	9.72	70.87
50.0	0.93	409.	236.	-0.03	0.190	0.186E-01	0.171E+00	9.72	72.26
52.0	0.93	403.	248.	-0.03	0.202	0.196E-01	0.249E+00	9.72	73.61
54.0	0.93	399.	261.	-0.03	0.214	0.206E-01	0.331E+00	9.72	74.95
56.0	0.93	393.	273.	-0.03	0.227	0.215E-01	0.418E+00	9.72	76.21
58.0	0.93	389.	286.	-0.03	0.240	0.225E-01	0.508E+00	9.72	77.35
60.0	0.93	385.	299.	-0.04	0.253	0.234E-01	0.601E+00	9.72	78.39
62.0	0.93	382.	312.	-0.04	0.266	0.243E-01	0.699E+00	9.72	79.30
64.0	0.92	379.	325.	-0.04	0.280	0.252E-01	0.800E+00	9.72	80.10
66.0	0.92	376.	339.	-0.04	0.293	0.261E-01	0.904E+00	9.72	80.79
68.0	0.92	374.	352.	-0.05	0.307	0.270E-01	0.101E+01	9.72	81.36
70.0	0.92	371.	366.	-0.05	0.320	0.278E-01	0.112E+01	9.72	81.82
72.0	0.92	369.	379.	-0.05	0.334	0.287E-01	0.124E+01	9.72	82.16
74.0	0.92	367.	393.	-0.05	0.348	0.295E-01	0.136E+01	9.72	82.40
76.0	0.92	365.	406.	-0.05	0.361	0.303E-01	0.148E+01	9.72	82.53
78.0	0.92	364.	420.	-0.06	0.375	0.311E-01	0.160E+01	9.72	82.55
80.0	0.92	362.	434.	-0.06	0.389	0.319E-01	0.173E+01	9.72	82.46
82.0	0.92	361.	447.	-0.06	0.403	0.327E-01	0.186E+01	9.72	82.27
84.0	0.92	360.	461.	-0.06	0.416	0.335E-01	0.199E+01	9.72	81.98
86.0	0.92	359.	474.	-0.07	0.430	0.343E-01	0.213E+01	9.72	81.59
88.0	0.92	358.	487	-0.07	0.443	0.350E-01	0.227E+01	9.72	81.10
90.0	0.93	357.	500.	-0.07	0.457	0.357E-01	0.242E+01	9.72	80.50
92.0	0.93	356.	513.	-0.07	0.470	0.365E-01	0.256E+01	9.72	79.82
94.0	0.93	355.	526.	-0.08	0.483	0.372E-01	0.271E+01	9.72	79.03
96.0	0.93	355.	539.	-0.08	0.496	0.379E-01	0.286E+01	9.72	78.15
98.0	0.93	354.	551.	-0.08	0.509	0.385E-01	0.302E+01	9.72	77.18
100.0	0.93	353.	564.	-0.08	0.522	0.392E-01	0.317E+01	9.72	76.12
102.0	0.93	353.	576.	-0.08	0.534	0.399E-01	0.333E+01	9.72	74.97
104.0	0.93	353.	588.	-0.09	0.547	0.405E-01	0.349E+01	9.72	73.73
106.0	0.93	352.	599.	-0.09	0.559	0.411E-01	0.366E+01	9.72	72.40
108.0	0.93	352.	611.	-0.09	0.571	0.417E-01	0.382E+01	9.72	71.00
110.0	0.94	352.	622.	-0.09	0.582	0.423E-01	0.399E+01	9.72	69.51
112.0	0.94	351.	633.	-0.09	0.593	0.429E-01	0.417E+01	9.72	67.95
114.0	0.94	351.	643.	-0.09	0.604	0.434E-01	0.434E+01	9.72	66.31
116.0	0.94	351.	653.	-0.09	0.615	0.439E-01	0.451E+01	9.72	64.60
118.0	0.94	351.	664.	-0.10	0.626	0.444E-01	0.469E+01	9.72	62.82
120.0	0.94	351.	673.	-0.10	0.636	0.449E-01	0.487E+01	9.72	60.98
122.0	0.94	351.	683.	-0.10	0.646	0.454E-01	0.505E+01	9.72	59.07
124.0	0.94	351.	692.	-0.10	0.655	0.459E-01	0.524E+01	9.72	57.11
126.0	0.95	351.	701.	-0.10	0.664	0.463E-01	0.542E+01	9.72	55.10
128.0	0.95	351.	709.	-0.10	0.673	0.467E-01	0.561E+01	9.72	53.03

130.0	0.95	351.	718.	-0.10	0.682	0.471E-01	0.580E+01	9.72	50.91
132.0	0.95	351.	725.	-0.10	0.690	0.475E-01	0.599E+01	9.72	48.76
134.0	0.95	351.	733.	-0.10	0.698	0.478E-01	0.618E+01	9.65	46.43
136.0	0.95	352.	740.	-0.10	0.705	0.481E-01	0.637E+01	9.57	43.99
138.0	0.95	352.	747.	-0.11	0.712	0.484E-01	0.657E+01	9.30	41.40
140.0	0.95	352.	754.	-0.11	0.718	0.487E-01	0.676E+01	8.94	38.40
142.0	0.95	352.	760.	-0.11	0.724	0.490E-01	0.696E+01	8.59	35.78
144.0	0.95	352.	766.	-0.11	0.730	0.492E-01	0.715E+01	8.23	33.40
146.0	0.95	353.	772.	-0.11	0.735	0.494E-01	0.735E+01	7.76	31.09
148.0	0.95	353.	777.	-0.11	0.740	0.495E-01	0.755E+01	7.20	28.37
150.0	0.95	353.	782.	-0.11	0.744	0.498E-01	0.775E+01	6.63	25.68
152.0	0.95	353.	787.	-0.11	0.748	0.499E-01	0.795E+01	6.06	23.54
154.0	0.95	354.	791.	-0.11	0.751	0.500E-01	0.815E+01	5.48	21.28
156.0	0.95	354.	795.	-0.11	0.755	0.501E-01	0.835E+01	4.88	18.99
158.0	0.95	354.	799.	-0.11	0.757	0.502E-01	0.855E+01	4.27	16.72
160.0	0.95	355.	803.	-0.11	0.760	0.502E-01	0.875E+01	3.65	14.48
162.0	0.95	355.	806.	-0.11	0.762	0.503E-01	0.895E+01	3.06	12.26
164.0	0.95	356.	808.	-0.11	0.764	0.503E-01	0.915E+01	2.57	10.26
166.0	0.95	356.	811.	-0.11	0.765	0.503E-01	0.935E+01	2.08	8.42
168.0	0.95	357.	813.	-0.11	0.766	0.502E-01	0.955E+01	1.59	6.56
170.0	0.95	357.	815.	-0.11	0.767	0.502E-01	0.975E+01	1.09	4.72
172.0	0.95	358.	816.	-0.11	0.767	0.501E-01	0.995E+01	0.84	3.27
174.0	0.96	359.	817.	-0.11	0.768	0.501E-01	0.102E+02	0.63	2.40
176.0	0.96	359.	818.	-0.11	0.768	0.500E-01	0.104E+02	0.42	1.56
178.0	0.96	359.	819.	-0.11	0.768	0.499E-01	0.106E+02	0.21	0.80
180.0	0.96	360.	819.	-0.11	0.768	0.498E-01	0.108E+02	0.11	0.23
182.0	0.96	361.	819.	-0.11	0.768	0.497E-01	0.110E+02	0.08	-0.08
184.0	0.96	362.	818.	-0.11	0.768	0.495E-01	0.112E+02	0.05	-0.16
186.0	0.97	363.	817.	-0.11	0.768	0.494E-01	0.113E+02	0.03	-0.14
188.0	0.97	363.	816.	-0.11	0.768	0.493E-01	0.115E+02	0.01	-0.07
190.0	0.98	364.	815.	-0.11	0.768	0.491E-01	0.117E+02	0.01	-0.05
192.0	0.98	365.	813.	-0.11	0.768	0.490E-01	0.119E+02	0.01	-0.05
194.0	0.99	367.	811.	-0.11	0.768	0.488E-01	0.121E+02	0.01	-0.04
196.0	0.99	368.	808.	-0.11	0.768	0.487E-01	0.123E+02	0.00	-0.03
198.0	1.00	369.	806.	-0.11	0.768	0.485E-01	0.125E+02	0.00	-0.02
200.0	1.01	370.	803.	-0.11	0.768	0.483E-01	0.127E+02	0.0	-0.01

OVERALL EQUIVALENCE RATIO = 0.590
VOLUMETRIC EFFICIENCY= 0.855
CORRECT CHARGED AIR PHI = 0.031
INDUCED AIR AND RES. GAS NOX
PPM = 52.4 MASS = 0.418E-04G

COMPRESSION

OUTPUT DATA

THED DEG	P ATA	T K	V CM**3	WORK PS	CYL.MAS G	HEAT TRANSFER CAL/A	CAL	FSWR	S.RT *RPM
202.0	1.01	371.	799.	-0.11	0.768	0.482E-01	0.129E+02	0.999	3.65
204.0	1.02	373.	795.	-0.11	0.768	0.480E-01	0.131E+02	0.999	3.65
206.0	1.03	374.	791.	-0.11	0.768	0.478E-01	0.133E+02	0.998	3.65
208.0	1.04	376.	787.	-0.11	0.768	0.476E-01	0.135E+02	0.997	3.65
210.0	1.05	377.	792.	-0.11	0.768	0.473E-01	0.137E+02	0.997	3.65
212.0	1.06	379.	777.	-0.11	0.768	0.471E-01	0.139E+02	0.996	3.65
214.0	1.07	380.	772.	-0.12	0.768	0.469E-01	0.140E+02	0.996	3.65
216.0	1.09	382.	766.	-0.12	0.768	0.466E-01	0.142E+02	0.995	3.65
218.0	1.10	384.	760.	-0.12	0.768	0.464E-01	0.144E+02	0.994	3.65
220.0	1.12	386.	754.	-0.12	0.768	0.461E-01	0.146E+02	0.994	3.64
222.0	1.13	388.	747.	-0.12	0.768	0.459E-01	0.148E+02	0.993	3.64
224.0	1.15	390.	740.	-0.12	0.768	0.456E-01	0.150E+02	0.992	3.64
226.0	1.17	392.	733.	-0.13	0.768	0.453E-01	0.151E+02	0.992	3.64
228.0	1.18	394.	725	-0.13	0.768	0.450E-01	0.153E+02	0.991	3.64
230.0	1.20	396.	718.	-0.13	0.768	0.447E-01	0.155E+02	0.991	3.64
232.0	1.23	399.	709.	-0.14	0.768	0.444E-01	0.157E+02	0.990	3.64
234.0	1.25	401.	701.	-0.14	0.768	0.440E-01	0.159E+02	0.989	3.64
236.0	1.27	404.	692.	-0.15	0.768	0.437E-01	0.160E+02	0.989	3.64
238.0	1.30	406.	683.	-0.15	0.768	0.433E-01	0.162E+02	0.988	3.65
240.0	1.33	409.	673.	-0.16	0.768	0.430E-01	0.164E+02	0.987	3.65
242.0	1.35	412.	664.	-0.17	0.768	0.426E-01	0.166E+02	0.987	3.65
244.0	1.38	415.	653.	-0.17	0.768	0.422E-01	0.167E+02	0.986	3.65
246.0	1.42	418.	643.	-0.18	0.768	0.419E-01	0.169E+02	0.985	3.65
248.0	1.45	421.	633.	-0.19	0.768	0.413E-01	0.171E+02	0.985	3.65
250.0	1.49	424.	622.	-0.20	0.768	0.409E-01	0.172E+02	0.994	3.65
252.0	1.53	428.	611.	-0.22	0.768	0.404E-01	0.174E+02	0.984	3.66
254.0	1.57	431.	599.	-0.23	0.768	0.397E-01	0.175E+02	0.983	3.66
256.0	1.62	435.	588.	-0.25	0.768	0.394E-01	0.177E+02	0.982	3.66
258.0	1.66	439.	576.	-0.26	0.768	0.388E-01	0.179E+02	0.982	3.67
260.0	1.71	443.	564.	-0.28	0.768	0.383E-01	0.180E+02	0.981	3.67
262.0	1.77	447.	551.	-0.30	0.768	0.377E-01	0.182E+02	0.980	3.67
264.0	1.83	451.	539.	-0.32	0.768	0.370E-01	0.183E+02	0.980	3.68
266.0	1.89	456.	526.	-0.35	0.768	0.364E-01	0.184E+02	0.979	3.68
268.0	1.96	461.	513.	-0.37	0.768	0.357E-01	0.186E+02	0.978	3.69
270.0	2.03	466.	500.	-0.40	0.768	0.350E-01	0.187E+02	0.978	3.69
272.0	2.11	471.	487.	-0.43	0.768	0.342E-01	0.189E+02	0.977	3.70
274.0	2.19	476.	474.	-0.47	0.768	0.334E-01	0.190E+02	0.976	3.71
276.0	2.28	481.	461.	-0.50	0.768	0.325E-01	0.191E+02	0.976	3.71
278.0	2.38	487.	447.	-0.54	0.768	0.316E-01	0.193E+02	0.975	3.72
280.0	2.48	493.	434.	-0.59	0.768	0.307E-01	0.194E+02	0.975	3.73
282.0	2.59	499.	420.	-0.63	0.768	0.297E-01	0.195E+02	0.974	3.74
284.0	2.71	506.	406.	-0.68	0.768	0.286E-01	0.196E+02	0.973	3.75
286.0	2.85	512.	393.	-0.74	0.768	0.274E-01	0.197E+02	0.973	3.76
288.0	2.99	520.	379.	-0.80	0.768	0.261E-01	0.198E+02	0.972	3.78
290.0	3.14	527.	366.	-0.86	0.768	0.249E-01	0.199E+02	0.971	3.79
292.0	3.31	534.	352.	-0.92	0.768	0.234E-01	0.200E+02	0.970	3.81
294.0	3.49	542.	339.	-1.00	0.768	0.218E-01	0.201E+02	0.970	3.82
296.0	3.69	551.	325.	-1.07	0.768	0.202E-01	0.202E+02	0.969	3.84
298.0	3.91	559.	312.	-1.16	0.768	0.184E-01	0.203E+02	0.968	3.86
300.0	4.15	568.	299.	-1.24	0.768	0.165E-01	0.203E+02	0.968	3.88
302.0	4.40	577.	286.	-1.34	0.768	0.144E-01	0.204E+02	0.967	3.91
304.0	4.69	597.	273.	-1.44	0.768	0.122E-01	0.204E+02	0.966	3.94
306.0	5.00	597.	261.	-1.55	0.768	0.973E-02	0.205E+02	0.965	3.97
308.0	5.34	607.	248.	-1.66	0.768	0.706E-02	0.205E+02	0.965	4.00
310.0	5.71	618.	236.	-1.78	0.768	0.414E-02	0.205E+02	0.964	4.03
312.0	6.12	629.	224.	-1.91	0.768	0.945E-03	0.205E+02	0.963	4.07
314.0	6.57	641.	213.	-2.05	0.768	-0.257E-02	0.205E+02	0.962	4.12
316.0	7.06	653.	202.	-2.19	0.768	-0.644E-02	0.205E+02	0.961	4.17

318.0	7.60	665.	191.	-2.34	0.768	-0.107E-01	0.204E+02	0.961	4.23
320.0	8.20	678.	180.	-2.51	0.768	-0.154E-01	0.204E+02	0.960	4.29
322.0	8.86	691.	170.	-2.67	0.768	-0.207E-01	0.203E+02	0.959	4.36
324.0	9.58	705.	161.	-2.85	0.768	-0.264E-01	0.202E+02	0.958	4.44
326.0	10.37	719.	151.	-3.04	0.768	-0.329E-01	0.201E+02	0.957	4.52
328.0	11.24	733.	142.	-3.23	0.768	-0.400E-01	0.199E+02	0.956	4.62
330.0	12.19	748.	134.	-3.43	0.768	-0.479E-01	0.197E+02	0.955	4.74

COMBUSTION AND EXPANSION

OUTPUT DATA

THED NUM **		PRESS T.AV K	BTEM K	PS B.RT	FSWIR MASS MG	PMAS MG	S.RT BMAS MG	PPM V CM**3	EQUI	WNO CP CAL/G	ENTH CAL/G	PPM PPM	WNO G*10**6	JET LOCATIONS R(CM)	Z(CM)	DEG	RJET CM	C.ANG DEG	H.T. CAL
333.7 PRESS.= 14.27 PS= -3.8 FSWIR= 0.953 S.RT= 5.146 SUM.H.REJ=0.192E+02																			
TOTAL				0.0				119.35	0.59			52.	42.						-0.62E-01
1	1	777.			758.6			117.31	0.03	0.267	193.8	52.	41.						-0.23E+00
2	1	777.	777.	0.0	13.2	0.0	0.0	2.03	5.69	0.432	193.8	48.	0.52	2.0	1.15	32.	0.463	0.	0.0
337.5 PRESS.= 16.61 PS= -4.2 FSWIR= 0.950 S.RT= 5.506 SUM.H.REJ=0.186E+02																			
TOTAL				-0.002				106.53	0.59			52.	42.						-0.83E-01
1	1	805.			742.1			102.19	0.03	0.268	201.4	52.	40.						-0.31E+00
2	2	737.	-192.	-0.012	20.1	1.8	1.5	2.51	3.32	0.349	178.5	31.	0.89	2.2	1.77	55.	0.783	137.	-0.13E-02
3	1	805.	805.	0.0	13.4	0.0	0.0	1.81	5.59	0.433	201.4	48.	0.53	2.0	1.16	33.	0.463	0.	0.0
341.2 PRESS.= 19.31 PS= -4.7 FSWIR= 0.948 S.RT= 5.953 SUM.H.REJ=0.178E+02																			
TOTAL				0.001				95.52	0.59			51.	42.						-0.11E+00
1	1	834.			717.9			88.01	0.03	0.269	209.1	52.	39.						-0.40E+00
2	2	903.	1214.	0.019	27.0	6.3	5.7	3.56	2.34	0.337	235.7	37.	1.27	2.4	2.22	74.	1.131	170.	-0.34E-02
3	2	770.	-88.	-0.012	20.7	1.8	1.5	2.30	3.20	0.349	187.7	31.	0.92	2.2	1.77	57.	0.790	138.	-0.20E-02
4	1	834.	834.	0.0	13.7	0.0	0.0	1.64	5.40	0.433	209.1	48.	0.55	2.0	1.15	34.	0.467	0.	0.0
345.0 PRESS.= 22.66 PS= -5.1 FSWIR= 0.945 S.RT= 6.491 SUM.H.REJ=0.167E+02																			
TOTAL				0.017				86.42	0.59			50.	42.						-0.14E+00
1	1	865.			685.3			74.25	0.03	0.271	217.3	52.	37.						-0.52E+00
2	2	1245.	1830.	0.123	34.2	14.7	13.7	5.29	1.80	0.347	353.7	41.	1.66	2.4	2.57	92.	1.367	177.	-0.99E-02
3	2	950.	1314.	0.024	27.9	6.6	6.0	3.26	2.25	0.337	247.9	37.	1.32	2.4	2.22	76.	1.122	168.	-0.49E-02
4	2	807.	61.	-0.011	21.5	1.9	1.6	2.11	3.06	0.348	196.6	32.	0.97	2.2	1.75	58.	0.798	138.	-0.30E-02
5	1	865.	865.	0.0	14.2	0.0	0.0	1.49	5.14	0.431	217.3	48.	0.57	2.0	1.14	34.	0.476	0.	0.0
349.7 PRESS.= 27.32 PS= -5.4 FSWIR= 0.941 S.RT= 7.098 SUM.H.REJ=0.153E+02																			
TOTAL				0.067				79.27	0.59			50.	42.						-0.20E+00
1	1	901.			643.4			60.27	0.03	0.272	227.3	52.	35.						-0.68E+00
2	2	1462.	2281.	0.374	41.8	29.8	28.0	8.03	1.44	0.351	570.0	44.	2.06	2.3	2.85	111.	1.420	170.	-0.23E-01
3	2	1321.	1929.	0.140	35.4	16.0	14.9	4.77	1.73	0.348	378.3	41.	1.72	2.4	2.56	96.	1.314	172.	-0.13E-01
4	2	1006.	1437.	0.030	28.9	7.0	6.3	2.94	2.17	0.338	267.3	38.	1.37	2.3	2.19	79.	1.105	166.	-0.71E-02
5	2	851.	252.	-0.009	22.4	2.0	1.7	1.91	2.91	0.348	212.1	33.	1.01	2.2	1.72	60.	0.807	138.	-0.44E-02
6	1	901.	901.	0.0	14.9	0.0	0.0	1.33	4.85	0.429	227.3	49.	0.61	2.0	1.12	35.	0.487	24.	-0.11E-02
352.5 PRESS.= 34.40 PS= -5.8 FSWIR= 0.936 S.RT= 7.694 SUM.H.REJ=0.132E+02																			
TOTAL				0.142				74.12	0.59			50.	42.						-0.28E+00
1	1	948.			591.2			46.24	0.03	0.274	240.0	52.	32.						-0.93E+00
2	3	2325.	2325.	0.632	50.3	41.8	41.8	9.58	1.18	0.356	732.8	48.	2.60	2.1	3.06	134.	1.341	148.	-0.39E-01
3	3	2138.	2138.	0.491	43.4	35.4	35.2	7.53	1.38	0.354	666.5	44.	2.15	2.2	2.83	117.	1.320	159.	-0.32E-01
4	3	1745.	1745.	0.277	36.7	28.9	27.6	5.14	1.66	0.357	528.0	42.	1.79	2.3	2.52	100.	1.250	165.	-0.23E-01
5	2	1247.	1590.	0.089	30.0	18.3	15.8	2.98	2.08	0.356	352.8	38.	1.43	2.3	2.14	83.	1.083	162.	-0.13E-01
6	2	823.	486.	-0.026	23.3	7.8	6.3	1.51	2.78	0.343	197.5	34.	1.06	2.2	1.67	62.	0.813	138.	-0.57E-02
7	1	948.	948.	0.0	15.5	0.0	0.0	1.14	4.58	0.427	240.0	49.	0.64	2.0	1.08	36.	0.500	42.	-0.26E-02
356.2 PRESS.= 41.54 PS= -6.0 FSWIR= 0.931 S.RT= 8.140 SUM.H.REJ=0.102E+02																			
TOTAL				0.314				71.02	0.59			75.	63.						-0.39E+00
1	1	933.			529.5			35.60	0.03	0.276	249.9	52.	29.						-0.12E+01
2	3	2532.	2532.	0.830	58.9	50.3	50.3	10.11	1.00	0.477	814.2	385.	23.71	1.8	3.24	164.	1.263	120.	-0.52E-01
3	3	2403.	2403.	0.674	51.9	43.4	43.4	8.38	1.15	0.365	760.6	56.	3.09	2.0	3.05	144.	1.240	133.	-0.49E-01
4	3	2219.	2219.	0.516	44.9	36.7	36.7	6.61	1.34	0.354	696.5	45.	2.22	2.1	2.79	125.	1.230	147.	-0.43E-01
5	3	1978.	1978.	0.362	37.3	30.0	30.0	4.93	1.61	0.359	615.4	42.	1.85	2.2	2.46	106.	1.189	158.	-0.34E-01
6	3	1470.	1470.	0.148	31.0	23.3	23.1	2.97	2.00	0.361	429.8	39.	1.48	2.3	2.07	87.	1.062	159.	-0.20E-01
7	2	898.	691.	-0.019	24.1	8.3	6.7	1.39	2.67	0.345	221.3	34.	1.11	2.2	1.60	65.	0.820	139.	-0.92E-02
8	1	953.	953.	0.0	16.1	0.0	0.0	1.01	4.36	0.425	249.8	49.	0.68	2.0	1.04	37.	0.513	55.	-0.46E-02

360.0 PRESS.= 47.53 PS= -6.1 FSWIR= 0.925 S.RT= 8.275 SUM.H.REJ=0.656E+01

TOTAL				0.464				69.99	0.59			284.	241.					-0.49E+00
1	1	1005.			463.3			27.80	0.03	0.277	255.7	52.	25.					-0.15E+01
2	3	2630.	2630.	0.973	65.3	58.9	58.9	10.18	0.90	0.478	861.0	2293.	156.40	1.7	3.40	202.	1.281	111.-0.65E-01
3	3	2584.	2584.	0.867	59.5	51.9	51.9	9.03	0.99	0.488	835.6	765.	47.67	1.8	3.23	179.	1.215	111.-0.59E-01
4	3	2457.	2457.	0.706	52.7	44.8	44.8	7.53	1.13	0.376	781.7	73.	4.09	1.9	3.01	155.	1.179	121.-0.56E-01
5	3	2272.	2272.	0.546	45.5	37.8	37.8	5.96	1.32	0.354	720.4	45.	2.26	2.1	2.73	133.	1.166	139.-0.52E-01
6	3	2046.	2046.	0.386	38.5	31.0	31.0	4.49	1.58	0.359	637.6	43.	1.88	2.2	2.38	112.	1.151	154.-0.44E-01
7	3	1553.	1553.	0.168	31.7	24.1	23.9	2.77	1.95	0.362	456.8	39.	1.52	2.3	1.98	90.	1.054	159.-0.26E-01
8	2	956.	843.	-0.012	24.7	8.6	7.0	1.32	2.59	0.346	239.3	35.	1.14	2.2	1.52	66.	0.832	142.-0.13E-01
9	1	1005.	1005.	0.0	16.6	0.0	0.0	0.93	4.22	0.423	255.7	49.	0.70	2.0	0.99	37.	0.525	66.-0.68E-02

363.7 PRESS.= 51.36 PS= -6.0 FSWIR= 0.919 S.RT= 8.035 SUM.H.REJ=0.231E+01

TOTAL				0.589				71.02	0.59			616.	524.					-0.57E+00
1	1	1010.			410.4			22.91	0.03	0.277	257.1	52.	22.					-0.17E+01
2	3	2560.	2560.	0.986	71.1	65.3	65.3	9.99	0.83	0.424	829.7	3297.	244.12	1.9	3.54	238.	1.501	139.-0.93E-01
3	3	2639.	2638.	0.972	64.6	59.5	59.5	9.26	0.91	0.480	862.0	2712.	183.00	1.9	3.40	217.	1.328	125.-0.82E-01
4	3	2624.	2624.	0.885	58.6	52.7	52.7	8.28	1.01	0.499	853.3	1029.	63.22	1.8	3.21	192.	1.219	117.-0.70E-01
5	3	2486.	2486.	0.723	52.2	45.5	45.5	6.92	1.14	0.378	797.3	84.	4.65	1.9	2.95	166.	1.162	122.-0.63E-01
6	3	2319.	2319.	0.562	45.2	38.5	38.5	5.53	1.33	0.356	735.1	45.	2.25	2.1	2.64	140.	1.154	139.-0.60E-01
7	3	2097.	2097.	0.403	38.6	31.7	31.7	4.22	1.57	0.359	653.3	42.	1.88	2.2	2.28	116.	1.155	157.-0.51E-01
8	3	1608.	1608.	0.184	32.1	24.7	24.5	2.67	1.93	0.362	474.5	40.	1.54	2.3	1.87	92.	1.075	163.-0.31E-01
9	2	993.	952.	-0.005	25.0	8.6	7.0	1.28	2.55	0.347	251.2	35.	1.16	2.2	1.44	67.	0.854	148.-0.16E-01

367.5 PRESS.= 52.91 PS= -5.7 FSWIR= 0.913 S.RT= 7.505 SUM.H.REJ=-.227E+01

TOTAL				0.713				74.12	0.59			882.	744.					-0.61E+00
1	1	1001.			357.7			19.22	0.03	0.277	254.7	52.	19.					-0.17E+01
2	3	2419.	2419.	1.000	80.2	71.1	71.1	10.33	0.73	0.367	774.3	3254.	271.29	2.3	3.68	265.	1.928	167.-0.11E+00
3	3	2504.	2504.	0.985	72.8	64.6	64.6	9.61	0.81	0.400	803.4	3117.	236.11	2.2	3.56	247.	1.701	160.-0.10E+00
4	3	2607.	2607.	0.961	64.6	58.6	58.6	8.80	0.91	0.466	844.9	2409.	162.37	2.1	3.39	226.	1.466	148.-0.96E-01
5	3	2619.	2619.	0.874	57.0	52.2	52.2	7.73	1.04	0.481	852.8	752.	45.05	2.0	3.16	201.	1.280	136.-0.82E-01
6	3	2504.	2504.	0.719	50.6	45.2	45.2	6.49	1.18	0.374	801.9	83.	4.51	2.0	2.87	172.	1.202	136.-0.71E-01
7	3	2345.	2345.	0.566	44.3	38.6	38.6	5.25	1.35	0.357	741.9	45.	2.20	2.2	2.53	144.	1.200	151.-0.66E-01
8	3	2123.	2123.	0.412	38.4	32.1	32.1	4.09	1.58	0.360	660.8	42.	1.87	2.3	2.15	118.	1.213	167.-0.56E-01
9	3	1630.	1630.	0.191	32.2	25.0	24.8	2.62	1.92	0.363	480.9	40.	1.55	2.4	1.75	92.	1.127	171.-0.34E-01

371.2 PRESS.= 51.57 PS= -5.1 FSWIR= 0.908 S.RT= 6.852 SUM.H.REJ=-.680E+01

TOTAL				0.807				79.27	0.59			1037.	870.					-0.60E+00
1	1	978.			303.9			16.36	0.04	0.276	248.3	52.	17.					-0.16E+01
2	3	2278.	2278.	1.000	97.8	80.2	80.2	10.92	0.67	0.341	724.5	3045.	277.46	2.4	3.81	286.	2.253	178.-0.10E+00
3	3	2345.	2345.	1.000	81.9	72.8	72.8	10.39	0.72	0.353	743.8	2917.	248.31	2.5	3.70	270.	2.138	179.-0.11E+00
4	3	2453.	2453.	0.991	73.9	64.6	64.6	9.71	0.80	0.384	780.1	2541.	195.07	2.4	3.56	252.	1.912	176.-0.11E+00
5	3	2557.	2557.	0.949	64.2	57.0	57.0	8.72	0.92	0.450	823.6	1569.	105.02	2.3	3.35	230.	1.626	167.-0.10E+00
6	3	2573.	2573.	0.841	55.5	50.6	50.6	7.51	1.07	0.440	829.2	350.	20.47	2.2	3.08	203.	1.392	156.-0.87E-01
7	3	2481.	2481.	0.700	49.0	44.3	44.3	6.31	1.22	0.367	791.2	65.	3.47	2.2	2.76	173.	1.296	156.-0.76E-01
8	3	2335.	2335.	0.562	43.5	38.4	38.4	5.23	1.38	0.358	736.6	44.	2.14	2.3	2.39	143.	1.308	168.-0.69E-01
9	3	2116.	2116.	0.414	38.2	32.2	32.1	4.14	1.59	0.360	656.9	42.	1.86	2.5	2.01	116.	1.317	179.-0.57E-01

375.0 PRESS.= 48.01 PS= -4.3 FSWIR= 0.904 S.RT= 6.213 SUM.H.REJ=-.109E+02

TOTAL				0.872				86.42	0.59			1140.	953.					-0.55E+00
1	1	944.			263.0			14.66	0.03	0.274	239.0	52.	14.					-0.14E+01
2	3	2199.	2199.	1.000	91.7	87.8	87.7	11.68	0.65	0.334	697.9	2969.	279.61	2.5	3.93	306.	2.339	180.-0.92E-01
3	3	2246.	2246.	1.000	85.0	81.9	81.9	11.19	0.68	0.340	709.6	2825.	251.99	2.4	3.38	290.	2.188	177.-0.91E-01
4	3	2332.	2332.	1.000	79.3	73.9	73.8	10.63	0.74	0.354	735.8	2483.	204.59	2.4	3.38	272.	2.084	179.-0.90E-01
5	3	2446.	2446.	0.996	71.5	64.2	64.2	9.96	0.82	0.389	777.0	1789.	132.95	2.5	3.39	251.	1.950	180.-0.91E-01
6	3	2522.	2522.	0.934	62.7	55.5	55.5	8.91	0.94	0.449	805.7	859.	56.14	2.5	3.28	220.	1.761	180.-0.95E-01
7	3	2511.	2511.	0.806	53.9	49.0	49.0	7.53	1.10	0.399	802.3	142.	8.09	2.4	2.97	199.	1.517	173.-0.84E-01
8	3	2434.	2434.	0.681	47.9	43.5	43.5	6.44	1.25	0.361	772.0	53.	2.75	2.4	2.60	168.	1.438	174.-0.75E-01
9	3	2326.	2326.	0.557	42.9	38.2	38.2	5.44	1.40	0.357	725.0	44.	2.10	2.5	2.22	139.	1.415	180.-0.66E-01

378.7 PRESS.= 43.57 PS= -3.4 FSWIR= 0.901 S.RT= 5.657 SUM.H.REJ=-.145E+02

TOTAL				0.919				95.52	0.59			1224.	1019.					-0.47E+00
1	1	905.			236.2			13.93	0.03	0.273	228.3	52.	13.					-0.12E+01
2	3	2121.	2121.	1.000	92.9	90.7	90.7	12.74	0.63	0.330	672.0	2906.	280.35	2.4	4.06	325.	2.304	176.-0.82E-01
3	3	2151.	2151.	1.000	89.1	85.9	85.9	12.27	0.66	0.333	677.7	2736.	253.08	2.3	3.47	311.	2.119	172.-0.[illegible]E-01
4	3	2250.	2250.	1.000	81.5	79.3	79.3	11.63	0.72	0.343	707.1	2457.	207.90	2.4	3.48	293.	2.043	175.-0.79E-01

5	3	2389.	2389.	1.000	72.5	71.5	71.5	10.88	0.81	0.376	755.3	1952.	146.97	2.4	3.49	273.	1.950	178.-0.81E-01
6	3	2480.	2480.	0.996	66.9	62.7	62.7	10.32	0.88	0.417	787.4	1246.	86.77	2.5	3.47	249.	1.845	180.-0.80E-01
7	3	2502.	2502.	0.909	59.4	53.9	53.9	9.12	1.00	0.463	798.3	393.	24.38	2.5	3.16	222.	1.699	180.-0.79E-01
8	3	2460.	2460.	0.781	52.4	47.9	47.9	7.85	1.13	0.376	781.5	78.	4.37	2.5	2.80	191.	1.582	180.-0.72E-01
9	3	2385.	2385.	0.667	47.1	42.9	42.9	6.81	1.27	0.358	753.4	48.	2.45	2.5	2.42	162.	1.494	180.-0.66E-01

380.7 PRESS.= 41.27 PS= -2.9 FSWIR= 0.899 S.RT= 5.402 SUM.H.REJ=-.162E+02

TOTAL				0.950				101.16	0.59			1270.	1057.					-0.42E+00
1	1	884.			223.8			13.62	0.03	0.272	222.7	52.	12.					-0.53E+00
2	3	2073.	2073.	0.999	94.5	92.9	92.8	13.37	0.62	0.328	656.3	2860.	280.59	2.4	4.13	336.	2.285	174.-0.40E-01
3	3	2101.	2101.	0.998	90.7	89.1	89.0	12.87	0.65	0.330	661.1	2691.	253.40	2.3	3.51	323.	2.113	169.-0.39E-01
4	3	2206.	2206.	0.999	82.6	81.5	81.4	12.20	0.71	0.339	692.1	2436.	208.88	2.3	3.53	304.	2.043	173.-0.39E-01
5	3	2353.	2353.	0.999	73.1	72.5	72.4	11.41	0.81	0.368	741.9	1999.	151.73	2.4	3.54	284.	1.950	178.-0.40E-01
6	3	2446.	2446.	0.997	67.6	66.9	66.7	10.85	0.87	0.405	773.5	1392.	97.78	2.5	3.57	260.	1.849	180.-0.39E-01
7	3	2524.	2524.	0.977	61.8	59.4	59.1	10.10	0.96	0.461	808.4	628.	40.47	2.5	3.26	234.	1.739	180.-0.40E-01
8	3	2537.	2537.	0.874	54.7	52.4	52.2	8.92	1.09	0.423	812.2	149.	8.61	2.5	2.90	203.	1.624	180.-0.37E-01
9	3	2487.	2487.	0.758	49.2	47.1	46.8	7.84	1.21	0.371	790.4	60.	3.19	2.5	2.52	174.	1.535	180.-0.35E-01

382.7 PRESS.= 38.64 PS= -2.4 FSWIR= 0.898 S.RT= 5.174 SUM.H.REJ=-.177E+02

TOTAL				0.964				107.33	0.59			1304.	1083.					-0.38E+00
1	1	862.			209.5			13.27	0.03	0.271	216.7	52.	11.					-0.47E+00
2	3	2021.	2021.	0.999	96.2	94.5	94.4	14.18	0.61	0.326	639.2	2810.	280.74	2.3	4.20	348.	2.285	173.-0.37E-01
3	3	2052.	2052.	0.999	92.2	90.7	90.6	13.65	0.64	0.328	645.0	2649.	253.58	2.3	3.56	336.	2.113	169.-0.36E-01
4	3	2169.	2170.	0.999	83.7	82.6	82.5	12.92	0.70	0.336	676.4	2410.	209.41	2.3	3.58	316.	2.043	173.-0.36E-01
5	3	2307.	2307.	1.000	74.0	73.1	73.0	12.10	0.80	0.359	725.3	2011.	154.46	2.4	3.59	295.	1.974	179.-0.37E-01
6	3	2374.	2374.	0.999	70.0	67.6	67.5	11.65	0.84	0.380	745.5	1421.	103.29	2.5	3.66	271.	1.888	180.-0.37E-01
7	3	2466.	2466.	0.988	64.1	61.8	61.6	10.94	0.92	0.429	782.6	767.	51.17	2.5	3.36	246.	1.779	180.-0.38E-01
8	3	2525.	2525.	0.918	56.9	54.7	54.6	9.88	1.04	0.456	807.1	247.	14.79	2.5	3.00	215.	1.665	180.-0.36E-01
9	3	2494.	2494.	0.808	51.3	49.2	49.1	8.76	1.16	0.382	793.1	79.	4.33	2.5	2.61	186.	1.576	180.-0.34E-01

384.7 PRESS.= 36.06 PS= -1.8 FSWIR= 0.896 S.RT= 4.973 SUM.H.REJ=-.191E+02

TOTAL				0.975				114.01	0.59			1328.	1102.					-0.34E+00
1	1	840.			194.3			12.86	0.03	0.270	210.8	52.	11.					-0.41E+00
2	3	1966.	1966.	0.999	98.2	96.2	96.1	15.08	0.60	0.324	621.4	2755.	280.87	2.3	4.28	359.	2.292	172.-0.34E-01
3	3	1999.	1999.	0.999	93.9	92.2	92.1	14.52	0.63	0.326	627.7	2602.	253.71	2.3	3.61	348.	2.159	171.-0.34E-01
4	3	2107.	2107.	0.999	85.1	83.7	83.6	13.74	0.69	0.333	659.0	2374.	209.70	2.4	3.63	328.	2.084	175.-0.34E-01
5	3	2252.	2252.	0.999	75.3	74.0	73.9	12.88	0.78	0.350	705.5	1993.	155.85	2.5	3.65	306.	2.007	180.-0.34E-01
6	3	2302.	2302.	0.998	72.1	70.0	69.8	12.47	0.82	0.362	718.8	1414.	105.80	2.5	3.74	283.	1.922	180.-0.34E-01
7	3	2405.	2405.	0.998	66.4	64.1	64.0	11.85	0.89	0.401	757.5	833.	57.54	2.5	3.45	258.	1.819	180.-0.35E-01
8	3	2501.	2501.	0.954	59.1	56.9	56.8	10.89	1.00	0.471	795.9	363.	22.43	2.5	3.09	227.	1.705	180.-0.34E-01
9	3	2488.	2488.	0.853	53.4	51.3	51.2	9.74	1.11	0.396	790.6	103.	5.86	2.5	2.70	198.	1.616	180.-0.32E-01

386.7 PRESS.= 33.55 PS= -1.3 FSWIR= 0.895 S.RT= 4.795 SUM.H.REJ=-.203E+02

TOTAL				0.983				121.19	0.59			1345.	1115.					-0.31E+00
1	1	818.			177.8			12.31	0.03	0.269	204.8	52.	10.					-0.36E+00
2	3	1908.	1908.	0.999	100.4	98.2	98.1	16.09	0.59	0.322	602.8	2695.	281.00	2.3	4.35	371.	2.337	173.-0.32E-01
3	3	1938.	1938.	0.999	96.3	93.9	93.8	15.51	0.61	0.324	608.0	2540.	253.85	2.4	3.66	360.	2.249	174.-0.32E-01
4	3	2047.	2047.	0.999	87.0	85.1	85.0	14.67	0.68	0.330	639.0	2324.	209.88	2.4	3.66	339.	2.161	178.-0.31E-01
5	3	2193.	2193.	0.999	76.8	75.3	75.3	13.75	0.77	0.343	685.2	1963.	156.53	2.5	3.70	317.	2.030	180.-0.32E-01
6	3	2232.	2232.	0.999	74.2	72.1	72.0	13.37	0.79	0.350	693.8	1389.	106.93	2.5	3.83	294.	1.957	180.-0.31E-01
7	3	2329.	2329.	0.998	68.7	66.4	66.3	12.76	0.86	0.375	728.2	848.	60.54	2.5	3.54	270.	1.858	180.-0.33E-01
8	3	2459.	2459.	0.975	61.3	59.1	59.0	11.93	0.96	0.449	776.4	457.	29.19	2.5	3.18	239.	1.745	180.-0.32E-01
9	3	2476.	2476.	0.895	55.4	53.4	53.3	10.82	1.07	0.418	785.9	136.	7.91	2.5	2.79	210.	1.655	180.-0.31E-01

388.7 PRESS.= 31.17 PS= -0.7 FSWIR= 0.894 S.RT= 4.637 SUM.H.REJ=-.214E+02

TOTAL				0.990				128.87	0.59			1357.	1125.					-0.27E+00
1	1	797.			160.0			11.61	0.03	0.268	199.1	52.	9.					-0.31E+00
2	3	1848.	1848.	0.999	103.0	100.4	100.3	17.20	0.57	0.321	583.2	2628.	281.14	2.4	4.42	382.	2.417	176.-0.29E-01
3	3	1871.	1871.	0.999	99.2	96.3	96.1	16.61	0.59	0.322	586.4	2465.	254.02	2.4	3.71	371.	2.380	179.-0.29E-01
4	3	1984.	1984.	0.999	89.2	87.0	86.9	15.69	0.66	0.327	618.4	2268.	210.03	2.5	3.73	349.	2.235	180.-0.28E-01
5	3	2135.	2135.	0.999	78.3	76.8	76.7	14.69	0.75	0.338	665.4	1930.	156.87	2.5	3.75	329.	2.054	180.-0.29E-01
6	3	2163.	2163.	0.999	76.2	74.2	74.1	14.34	0.77	0.341	669.9	1358.	107.44	2.5	3.90	305.	1.991	180.-0.29E-01
7	3	2254.	2254.	0.998	71.0	68.7	68.6	13.73	0.83	0.358	700.7	840.	61.87	2.5	3.62	281.	1.897	180.-0.30E-01
8	3	2411.	2411.	0.992	63.5	61.3	61.2	13.04	0.93	0.421	755.6	518.	34.22	2.5	3.27	251.	1.785	180.-0.30E-01
9	3	2459.	2459.	0.933	57.4	55.4	55.3	11.98	1.03	0.447	778.7	178.	10.70	2.5	2.87	221.	1.694	180.-0.29E-01

390.7 PRESS.= 28.93 PS= -0.2 FSWIR= 0.893 S.RT= 4.498 SUM.H.REJ=-.223E+02

TOTAL				0.994				137.01	0.59			1366.	1132.					-0.24E+00
1	1	776.			143.3			10.91	0.03	0.266	193.4	52.	8.					-0.26E+00
2	3	1784.	1794.	0.999	105.1	103.0	102.9	19.43	0.56	0.319	563.0	2554.	281.31	2.5	4.50	393.	2.528	179.-0.27E-01
3	3	1817.	1817.	0.999	101.3	99.2	99.1	17.75	0.58	0.321	569.0	2415.	254.13	2.5	3.76	381.	2.427	180.-0.26E-01
4	3	1932.	1932.	0.999	90.7	89.2	89.1	16.75	0.65	0.325	601.5	2231.	210.12	2.5	3.78	360.	2.258	180.-0.26E-01
5	3	2077.	2077.	0.999	79.8	78.3	78.2	15.70	0.74	0.334	646.1	1895.	157.06	2.5	3.80	340.	2.078	180.-0.27E-01
6	3	2096.	2096.	0.999	78.3	76.2	76.1	15.37	0.75	0.336	647.1	1325.	107.71	2.5	3.98	316.	2.025	180.-0.27E-01
7	3	2190.	2190.	0.998	73.2	71.0	70.9	14.76	0.80	0.346	674.7	822.	62.47	2.5	3.71	293.	1.936	180.-0.28E-01
8	3	2347.	2347.	0.999	65.6	63.5	63.4	14.13	0.90	0.393	729.6	544.	37.07	2.5	3.35	262.	1.824	180.-0.28E-01
9	3	2434.	2434.	0.965	59.4	57.4	57.3	13.22	1.00	0.456	767.2	227.	14.07	2.5	2.95	233.	1.732	180.-0.27E-01

392.7 PRESS.= 26.82 PS= 0.3 FSWIR= 0.892 S.RT= 4.376 SUM.H.REJ=-.232E+02

TOTAL				0.997				145.62	0.59			1371.	1136.					-0.21E+00
1	1	755.			127.1			10.16	0.03	0.265	187.9	52.	7.					-0.22E+00
2	3	1722.	1722.	0.999	109.3	106.1	105.9	19.77	0.54	0.317	543.1	2480.	281.48	2.5	4.16	403.	2.596	180.-0.25E-01
3	3	1771.	1771.	0.999	102.9	101.3	101.2	18.96	0.57	0.320	554.3	2378.	254.2	2.5	3.81	391.	2.449	180.-0.24E-01
4	3	1882.	1882.	0.999	92.3	90.7	90.6	17.89	0.64	0.324	585.2	2194.	210.21	2.5	3.83	370.	2.281	180.-0.24E-01
5	3	2021.	2021.	0.999	81.4	79.8	79.8	16.79	0.72	0.331	627.4	1861.	157.10	2.5	3.85	351.	2.103	180.-0.25E-01
6	3	2031.	2031.	0.999	80.4	78.3	78.2	16.49	0.73	0.332	625.4	1293.	107.88	2.5	4.05	327.	2.059	180.-0.24E-01
7	3	2109.	2109.	0.999	75.4	73.2	73.1	15.86	0.78	0.338	650.1	802.	62.77	2.5	3.79	305.	1.974	180.-0.25E-01
8	3	2274.	2274.	0.998	67.7	65.6	65.5	15.24	0.87	0.370	701.8	546.	38.42	2.5	3.43	274.	1.862	180.-0.26E-01
9	3	2392.	2392.	0.983	61.4	59.4	59.3	14.48	0.96	0.433	748.4	266.	16.98	2.5	3.03	245.	1.770	180.-0.25E-01

394.7 PRESS.= 24.87 PS= 0.8 FSWIR= 0.891 S.RT= 4.267 SUM.H.REJ=-.239E+02

TOTAL				0.999				154.67	0.59			1374.	1139.					-0.18E+00
1	1	735.			111.0			9.31	0.03	0.264	182.7	52.	6.					-0.18E+00
2	3	1664.	1664.	0.999	112.4	109.3	109.2	21.19	0.52	0.316	524.6	2412.	281.65	2.5	4.27	413.	2.639	180.-0.22E-01
3	3	1726.	1726.	0.999	104.5	102.9	102.8	20.23	0.55	0.318	540.0	2343.	254.31	2.5	3.86	402.	2.472	180.-0.22E-01
4	3	1833.	1833.	0.999	93.8	92.3	92.2	19.11	0.64	0.323	569.3	2158.	210.30	2.5	3.89	381.	2.305	180.-0.22E-01
5	3	1966.	1966.	0.999	82.9	81.4	81.3	17.95	0.71	0.329	609.4	1828.	157.28	2.5	3.90	361.	2.128	180.-0.23E-01
6	3	1968.	1968.	0.999	82.4	80.4	80.3	17.67	0.71	0.329	604.8	1263.	108.01	2.5	4.13	338.	2.093	180.-0.22E-01
7	3	2040.	2040.	0.999	77.6	75.4	75.3	17.03	0.76	0.334	627.1	781.	62.95	2.5	3.87	316.	2.011	180.-0.23E-01
8	3	2202.	2202.	0.998	69.8	67.7	67.6	16.41	0.84	0.354	675.7	539.	39.06	2.5	3.51	285.	1.900	180.-0.24E-01
9	3	2344.	2344.	0.998	63.3	61.4	61.3	15.79	0.93	0.407	728.2	290.	19.08	2.5	3.11	256.	1.807	180.-0.24E-01

396.7 PRESS.= 23.06 PS= 1.3 FSWIR= 0.890 S.RT= 4.170 SUM.H.REJ=-.245E+02

TOTAL				0.999				164.14	0.59			1376.	1140.					-0.16E+00
1	1	716.			94.9			8.37	0.03	0.263	177.6	52.	5.					-0.15E+00
2	3	1608.	1608.	0.999	115.5	112.4	112.3	22.70	0.51	0.314	507.2	2349.	281.82	2.5	4.37	423.	2.682	180.-0.20E-01
3	3	1682.	1682.	0.999	106.1	104.5	104.5	21.60	0.56	0.317	526.0	2308.	254.39	2.5	3.90	412.	2.495	180.-0.20E-01
4	3	1785.	1785.	0.999	95.4	93.8	93.8	20.41	0.62	0.321	553.9	2124.	210.38	2.5	3.93	391.	2.328	180.-0.20E-01
5	3	1913.	1913.	0.999	84.5	82.9	82.8	19.19	0.70	0.327	591.9	1795.	157.37	2.5	3.95	372.	2.153	180.-0.21E-01
6	3	1904.	1904.	0.999	84.4	82.4	82.3	18.93	0.70	0.327	585.2	1234.	108.13	2.5	4.20	349.	2.127	180.-0.20E-01
7	3	1974.	1974.	0.999	79.8	77.6	77.5	18.28	0.74	0.330	605.2	762.	63.09	2.5	3.94	327.	2.048	180.-0.21E-01
8	3	2132.	2132.	0.999	71.9	69.8	69.7	17.64	0.82	0.344	651.1	528.	39.38	2.5	3.59	297.	1.937	180.-0.22E-01
9	3	2276.	2276.	0.999	65.3	63.3	63.3	17.04	0.90	0.381	701.5	298.	20.18	2.5	3.18	268.	1.844	180.-0.22E-01

398.7 PRESS.= 21.39 PS= 1.8 FSWIR= 0.890 S.RT= 4.084 SUM.H.REJ=-.250E+02

TOTAL				0.999				174.02	0.59			1377.	1140.					-0.13E+00
1	1	697.			79.0			7.31	0.03	0.262	172.7	52.	4.					-0.12E+00
2	3	1556.	1556.	0.999	118.6	115.5	115.4	24.29	0.50	0.313	490.8	2290.	281.99	2.5	4.48	433.	2.724	180.-0.18E-01
3	3	1640.	1640.	0.999	107.8	106.1	106.1	23.03	0.55	0.316	512.5	2274.	254.48	2.5	3.95	422.	2.518	180.-0.18E-01
4	3	1739.	1739.	0.999	97.0	95.4	95.3	21.78	0.61	0.320	539.1	2090.	210.47	2.5	3.98	401.	2.352	180.-0.18E-01
5	3	1862.	1862.	0.999	86.0	84.5	84.4	20.50	0.69	0.325	575.2	1763.	157.46	2.5	3.99	383.	2.178	180.-0.19E-01
6	3	1851.	1851.	0.999	86.4	84.4	84.3	20.27	0.68	0.325	566.6	1206.	108.24	2.5	4.27	360.	2.160	180.-0.19E-01
7	3	1912.	1912.	0.999	82.0	79.8	79.7	19.59	0.72	0.328	584.7	743.	63.22	2.5	4.02	339.	2.085	180.-0.20E-01
8	3	2064.	2064.	0.999	73.9	71.9	71.8	18.93	0.80	0.337	628.0	516.	39.57	2.5	3.66	308.	1.974	180.-0.20E-01
9	3	2207.	2207.	0.999	67.2	65.3	65.2	19.33	0.88	0.362	675.9	297.	20.74	2.5	3.25	279.	1.880	180.-0.20E-01

400.7 PRESS.= 19.89 PS= 2.2 FSWIR= 0.889 S.RT= 4.007 SUM.H.REJ=-.255E+02

TOTAL				0.999				184.29	0.59			1377.	1141.					-0.11E+00
1	1	680.			63.2			5.13	0.03	0.261	168.1	52.	3.					-0.88E-01
2	3	1507.	1507.	0.999	121.6	118.6	118.4	25.96	0.49	0.311	475.5	2235.	282.15	2.5	4.57	443.	2.765	180.-0.17E-01
3	3	1599.	1599.	0.999	109.4	107.8	107.7	24.53	0.54	0.315	499.5	2241.	254.57	2.5	4.00	433.	2.541	180.-0.17E-01
4	3	1695.	1695.	0.999	98.6	97.0	96.9	23.22	0.60	0.319	524.9	2057.	210.56	2.5	4.03	412.	2.376	180.-0.17E-01

5	3	1813.	1813.	0.999	87.6	86.0	85.9	21.97	0.67	0.324	559.2	1733.	157.54	2.5	4.04	394.	2.203	180.-0.17E-01
6	3	1797.	1797.	0.999	88.4	86.4	86.3	21.67	0.67	0.323	549.1	1180.	108.35	2.5	4.33	370.	2.193	180.-0.17E-01
7	3	1953.	1953.	0.999	84.1	82.0	81.9	20.97	0.70	0.326	565.4	725.	63.33	2.5	4.09	350.	2.121	180.-0.18E-01
8	3	1999.	1999.	0.999	76.0	73.9	73.8	20.28	0.77	0.333	606.4	504.	39.71	2.5	3.73	319.	2.011	180.-0.18E-01
9	3	2139.	2139.	0.999	69.1	67.2	67.1	19.67	0.85	0.349	652.0	293.	21.03	2.5	3.32	290.	1.916	180.-0.19E-01

EXPANSION PROCESS IS CALCULATED AS ONE ELEMENT

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PRESSURE          =   19.88ATA
AV. TEMPERATURE   =   1663.9K DEG
AV. EQUI. RATIO   =   0.590
AV. ENTHALPY      =   515.11CAL/G
TOTAL MASS        =   0.7978G
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EXHAUST NOX*

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NOX CONCN.   =   1377.0PPM
TOTAL MASS   =   0.173E-01G
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THEC DEG	P ATA	T K	V CM**3	WORK PS	CYL.MAS G	HEAT TRANSFER CAL/A	CAL	FSWR	S.RT *RPM
402.7	18.47	1636.	195.	2.63	0.798	-0.500E+00	-0.275E+02	0.888	4.01
404.7	17.20	1609.	206.	3.04	0.798	-0.470E+00	-0.294E+02	0.887	3.94
406.7	16.04	1593.	217.	3.43	0.798	-0.443E+00	-0.312E+02	0.887	3.88
408.7	14.99	1558.	229.	3.81	0.798	-0.419E+00	-0.328E+02	0.886	3.82
410.7	14.03	1534.	241.	4.17	0.798	-0.396E+00	-0.344E+02	0.885	3.77
412.7	13.15	1511.	253.	4.51	0.798	-0.376E+00	-0.359E+02	0.885	3.73
414.7	12.36	1489.	265.	4.83	0.798	-0.357E+00	-0.373E+02	0.884	3.68
416.7	11.63	1468.	278.	5.14	0.798	-0.340E+00	-0.387E+02	0.883	3.65
418.7	10.96	1448.	291.	5.43	0.798	-0.324E+00	-0.400E+02	0.883	3.61
420.7	10.35	1427.	304.	5.71	0.798	-0.310E+00	-0.412E+02	0.882	3.58
422.7	9.79	1410.	317.	5.98	0.798	-0.297E+00	-0.424E+02	0.881	3.55
424.7	9.28	1392.	330.	6.23	0.798	-0.284E+00	-0.436E+02	0.881	3.53
426.7	8.81	1375.	344.	6.47	0.798	-0.273E+00	-0.447E+02	0.880	3.50
428.7	8.38	1359.	357.	6.70	0.798	-0.263E+00	-0.457E+02	0.880	3.48
430.7	7.98	1343.	371.	6.91	0.798	-0.253E+00	-0.467E+02	0.879	3.46
432.7	7.61	1328.	384.	7.12	0.798	-0.244E+00	-0.477E+02	0.879	3.44
434.7	7.27	1314.	398.	7.31	0.798	-0.235E+00	-0.486E+02	0.878	3.42
436.7	6.95	1300.	412.	7.50	0.798	-0.228E+00	-0.495E+02	0.877	3.40
438.7	6.66	1286.	425.	7.67	0.798	-0.220E+00	-0.504E+02	0.877	3.39
440.7	6.39	1274.	439.	7.94	0.798	-0.213E+00	-0.513E+02	0.876	3.37
442.7	6.14	1261.	452.	8.00	0.798	-0.207E+00	-0.521E+02	0.876	3.36
444.7	5.91	1250.	466.	8.15	0.798	-0.201E+00	-0.529E+02	0.875	3.35
446.7	5.69	1238.	479.	8.29	0.798	-0.196E+00	-0.537E+02	0.875	3.33
448.7	5.49	1227.	492.	8.42	0.798	-0.190E+00	-0.545E+02	0.874	3.32
450.7	5.30	1217.	505.	8.55	0.798	-0.185E+00	-0.552E+02	0.874	3.31
452.7	5.13	1207.	518.	8.67	0.798	-0.181E+00	-0.559E+02	0.873	3.30
454.7	4.96	1197.	531.	8.79	0.798	-0.176E+00	-0.566E+02	0.873	3.29
456.7	4.81	1188.	544.	8.90	0.798	-0.172E+00	-0.573E+02	0.872	3.28
458.7	4.67	1179.	556.	9.00	0.790	-0.168E+00	-0.580E+02	0.872	3.28
460.7	4.53	1170.	568.	9.10	0.798	-0.164E+00	-0.586E+02	0.871	3.27
462.7	4.41	1162.	580.	9.19	0.798	-0.161E+00	-0.593E+02	0.871	3.26
464.7	4.29	1154.	592.	9.28	0.798	-0.158E+00	-0.599E+02	0.870	3.25
466.7	4.18	1147.	603.	9.36	0.798	-0.155E+00	-0.605E+02	0.870	3.24
468.7	4.08	1137.	615.	9.44	0.798	-0.152E+00	-0.611E+02	0.869	3.24
470.7	3.98	1132.	625.	9.51	0.798	-0.149E+00	-0.617E+02	0.869	3.23
472.7	3.89	1126.	637.	9.58	0.798	-0.146E+00	-0.623E+02	0.868	3.23
474.7	3.81	1119.	647.	9.55	0.798	-0.144E+00	-0.629E+02	0.868	3.22
476.7	3.73	1113.	657.	9.71	0.798	-0.141E+00	-0.635E+02	0.867	3.21
478.7	3.65	1107.	667.	9.77	0.798	-0.139E+00	-0.640E+02	0.867	3.21
480.0	3.61	1103.	673.	9.81	0.798	-0.137E+00	-0.644E+02	0.866	3.20

EXHAUST VALVE OPEN

OUTPUT DATA

THED DEG	P ATA	T K	V CM**3	WORK PS	CYL.MAS G	HEAT TRANSFER CAL/A	CAL	AEFE CM**2	GWE G/S
482.0	3.54	1098.	683.	9.86	0.798	-0.127E+00	-0.649E+02	0.00	-0.06
484.0	3.48	1092.	692.	9.91	0.798	-0.125E+00	-0.654E+02	0.01	-0.18
486.0	3.42	1087.	701.	9.96	0.798	-0.123E+00	-0.659E+02	0.01	-0.30
488.0	3.36	1082.	709.	10.01	0.798	-0.121E+00	-0.663E+02	0.01	-0.42
490.0	3.31	1078.	718.	10.05	0.798	-0.120E+00	-0.668E+02	0.01	-0.53
492.0	3.26	1073.	725.	10.09	0.797	-0.118E+00	-0.673E+02	0.02	-0.63
494.0	3.21	1069.	733.	10.13	0.797	-0.117E+00	-0.678E+02	0.02	-0.74
496.0	3.16	1065.	740.	10.16	0.797	-0.115E+00	-0.682E+02	0.05	-1.15
498.0	3.12	1060.	747.	10.20	0.797	-0.114E+00	-0.687E+02	0.09	-2.69
500.0	3.08	1056.	754.	10.23	0.796	-0.113E+00	-0.691E+02	0.13	-4.30
502.0	3.04	1052.	760.	10.26	0.795	-0.111E+00	-0.696E+02	0.17	-5.87
504.0	3.00	1049.	766	10.28	0.794	-0.110E+00	-0.700E+02	0.22	-7.[illegible]
506.0	2.96	1045.	772.	10.31	0.792	-0.109E+00	-0.705E+02	0.47	-1[illegible].25
508.0	2.91	1040.	777.	10.33	0.788	-0.107E+00	-0.709E+02	0.78	-23.11
510.0	2.86	1035.	782.	10.35	0.782	-0.105E+00	-0.713E+02	1.09	-33.92
512.0	2.80	1029.	787.	10.37	0.775	-0.103E+00	-0.717E+02	1.39	-44.31
514.0	2.73	1023.	791.	10.39	0.766	-0.100E+00	-0.721E+02	1.70	-54.22
516.0	2.66	1017.	795.	10.40	0.755	-0.976E-01	-0.725E+02	2.26	-67.46
518.0	2.58	1009.	799.	10.42	0.740	-0.944E-01	-0.729E+02	2.87	-85.75
520.0	2.49	1000.	803.	10.43	0.723	-0.906E-01	-0.732E+02	3.47	-102.86
522.0	2.39	990.	806.	10.44	0.703	-0.864E-01	-0.736E+02	4.08	-118.37
524.0	2.28	980.	808.	10.45	0.681	-0.818E-01	-0.739E+02	4.68	-132.14
526.0	2.17	968.	811.	10.45	0.658	-0.770E-01	-0.742E+02	5.21	-142.99
528.0	2.05	956.	813.	10.46	0.632	-0.720E-01	-0.745E+02	5.74	-151.15
530.0	1.94	943.	815.	10.46	0.606	-0.670E-01	-0.748E+02	6.27	-157.73
532.0	1.82	930.	816.	10.46	0.579	-0.619E-01	-0.750E+02	6.80	-162.68
534.0	1.70	916.	817.	10.47	0.551	-0.568E-01	-0.753E+02	7.29	-165.24
536.0	1.59	902.	818.	10.47	0.524	-0.519E-01	-0.755E+02	7.64	-162.64
538.0	1.49	888.	819.	10.47	0.498	-0.472E-01	-0.757E+02	7.98	-156.54
540.0	1.39	874.	819.	10.47	0.474	-0.429E-01	-0.758E+02	8.32	-148.26
542.0	1.31	861.	819.	10.47	0.451	-0.390E-01	-0.760E+02	8.66	-137.63
544.0	1.23	849.	818.	10.47	0.430	-0.355E-01	-0.761E+02	8.96	-124.39
546.0	1.17	838.	817.	10.47	0.412	-0.325E-01	-0.763E+02	9.12	-107.27
548.0	1.11	829.	816.	10.47	0.397	-0.300E-01	-0.764E+02	9.28	-87.93
550.0	1.07	822.	815.	10.47	0.386	-0.281E-01	-0.765E+02	9.45	-67.28
552.0	1.05	817.	813.	10.47	0.378	-0.267E-01	-0.766E+02	9.61	-45.67
554.0	1.04	814.	811.	10.47	0.375	-0.259E-01	-0.767E+02	9.72	-22.98
556.0	1.04	814.	808.	10.47	0.374	-0.255E-01	-0.768E+02	9.75	-5.01
558.0	1.04	813.	806.	10.47	0.373	-0.254E-01	-0.769E+02	9.79	-7.20
560.0	1.04	813.	803.	10.47	0.371	-0.253E-01	-0.770E+02	9.79	-7.33
562.0	1.04	813.	799.	10.47	0.370	-0.251E-01	-0.771E+02	9.79	-8.14
564.0	1.04	812.	795.	10.46	0.369	-0.250E-01	-0.772E+02	9.79	-8.94
566.0	1.04	812.	791.	10.46	0.367	-0.249E-01	-0.773E+02	9.79	-9.83
568.0	1.04	811.	787.	10.46	0.365	-0.247E-01	-0.774E+02	9.79	-10.82
570.0	1.04	811.	782.	10.46	0.363	-0.246E-01	-0.775E+02	9.79	-12.56
572.0	1.04	810.	777.	10.46	0.361	-0.244E-01	-0.776E+02	9.79	-13.45
574.0	1.04	810.	772.	10.46	0.358	-0.242E-01	-0.777E+02	9.79	-13.74
576.0	1.04	809.	766.	10.46	0.356	-0.241E-01	-0.778E+02	9.79	-14.31
578.0	1.04	809.	760.	10.46	0.354	-0.239E-01	-0.779E+02	9.79	-15.08
580.0	1.04	808.	754.	10.46	0.351	-0.237E-01	-0.780E+02	9.79	-15.93
582.0	1.04	808.	747.	10.46	0.348	-0.235E-01	-0.781E+02	9.79	-16.82
584.0	1.04	807.	740.	10.46	0.345	-0.233E-01	-0.782E+02	9.79	-17.72
586.0	1.04	807.	733.	10.46	0.342	-0.231E-01	-0.783E+02	9.79	-18.62
588.0	1.04	807.	725.	10.46	0.339	-0.229E-01	-0.783E+02	9.79	-19.52
590.0	1.04	806.	718.	10.46	0.335	-0.227E-01	-0.784E+02	9.79	-20.42
592.0	1.04	806.	709.	10.46	0.332	-0.225E-01	-0.785E+02	9.79	-21.31
594.0	1.04	805.	701.	10.46	0.328	-0.222E-01	-0.786E+02	9.79	-22.20

596.0	1.04	805.	692.	10.46	0.324	-0.220E-01	-0.787E+02	9.79	-23.09
598.0	1.04	805.	683.	10.46	0.320	-0.218E-01	-0.788E+02	9.79	-23.96
600.0	1.04	804.	673.	10.45	0.316	-0.215E-01	-0.789E+02	9.79	-24.84
602.0	1.04	804.	664.	10.45	0.312	-0.213E-01	-0.790E+02	9.79	-25.70
604.0	1.04	804.	653.	10.45	0.307	-0.210E-01	-0.790E+02	9.79	-26.55
606.0	1.04	803.	643.	10.45	0.303	-0.208E-01	-0.791E+02	9.79	-27.39
608.0	1.04	803.	633.	10.45	0.298	-0.205E-01	-0.792E+02	9.79	-28.22
610.0	1.04	802.	622.	10.45	0.293	-0.202E-01	-0.793E+02	9.79	-29.03
612.0	1.05	802.	611.	10.45	0.288	-0.199E-01	-0.794E+02	9.79	-29.82
614.0	1.05	802.	599.	10.45	0.283	-0.197E-01	-0.795E+02	9.79	-30.59
616.0	1.05	801.	588.	10.45	0.278	-0.194E-01	-0.795E+02	9.79	-31.35
618.0	1.05	801.	576.	10.44	0.273	-0.191E-01	-0.796E+02	9.79	-32.07
620.0	1.05	800.	564.	10.44	0.267	-0.188E-01	-0.797E+02	9.79	-32.77
622.0	1.05	800.	551.	10.44	0.262	-0.185E-01	-0.798E+02	9.79	-33.45
624.0	1.05	800.	539.	10.44	0.256	-0.182E-01	-0.798E+02	9.79	-34.09
626.0	1.05	799.	526.	10.44	0.250	-0.179E-01	-0.799E+02	9.79	-34.70
628.0	1.05	799.	513.	10.44	0.244	-0.176E-01	-0.800E+02	9.79	-35.27
630.0	1.05	798.	500.	10.44	0.238	-0.172E-01	-0.800E+02	9.79	-35.80
632.0	1.05	798.	487.	10.44	0.232	-0.169E-01	-0.801E+02	9.79	-36.29
634.0	1.05	797.	474.	10.43	0.226	-0.166E-01	-0.802E+02	9.79	-36.74
636.0	1.05	797.	461.	10.43	0.220	-0.163E-01	-0.802E+02	9.79	-37.14
638.0	1.05	795.	447.	10.43	0.214	-0.160E-01	-0.803E+02	9.79	-37.49
640.0	1.05	796.	434.	10.43	0.207	-0.156E-01	-0.804E+02	9.79	-37.78
642.0	1.05	795.	420.	10.43	0.201	-0.153E-01	-0.804E+02	9.79	-38.03
644.0	1.05	795.	406.	10.43	0.195	-0.150E-01	-0.805E+02	9.79	-38.21
646.0	1.05	794.	393.	10.42	0.188	-0.146E-01	-0.805E+02	9.79	-38.34
648.0	1.05	794.	379.	10.42	0.182	-0.143E-01	-0.806E+02	9.79	-38.41
650.0	1.05	793.	366.	10.42	0.176	-0.140E-01	-0.807E+02	9.79	-38.41
652.0	1.05	793.	352.	10.42	0.169	-0.137E-01	-0.807E+02	9.79	-38.34
654.0	1.05	792.	339.	10.42	0.163	-0.133E-01	-0.808E+02	9.79	-38.21
656.0	1.05	792.	325.	10.42	0.156	-0.130E-01	-0.808E+02	9.79	-38.01
658.0	1.05	791.	312.	10.42	0.150	-0.127E-01	-0.809E+02	9.75	-37.70
660.0	1.05	790.	299.	10.41	0.144	-0.124E-01	-0.809E+02	9.72	-37.35
662.0	1.05	790.	286.	10.41	0.138	-0.121E-01	-0.810E+02	9.61	-36.89
664.0	1.05	789.	273.	10.41	0.132	-0.118E-01	-0.810E+02	9.45	-36.26
666.0	1.05	789.	261.	10.41	0.126	-0.115E-01	-0.811E+02	9.28	-35.72
668.0	1.05	788.	248.	10.41	0.120	-0.112E-01	-0.811E+02	9.12	-35.13
670.0	1.05	787.	236.	10.41	0.114	-0.109E-01	-0.811E+02	8.96	-34.48
672.0	1.05	787.	224.	10.41	0.109	-0.106E-01	-0.812E+02	8.66	-33.61
674.0	1.05	786.	213.	10.40	0.103	-0.104E-01	-0.812E+02	8.32	-32.69
676.0	1.05	785.	202.	10.40	0.098	-0.101E-01	-0.813E+02	7.98	-31.83
678.0	1.05	785.	191.	10.40	0.093	-0.988E-02	-0.813E+02	7.64	-30.92
680.0	1.05	784.	180.	10.40	0.088	-0.966E-02	-0.813E+02	7.29	-29.95
682.0	1.05	783.	170.	10.40	0.083	-0.944E-02	-0.814E+02	6.80	-28.74
684.0	1.05	783.	161.	10.40	0.078	-0.925E-02	-0.814E+02	6.27	-27.49
686.0	1.06	782.	151	10.40	0.074	-0.907E-02	-0.815E+02	5.74	-26.29
688.0	1.06	782.	142.	10.40	0.070	-0.891E-02	-0.815E+02	5.21	-25.02
690.0	1.06	781.	134.	10.39	0.066	-0.877E-02	-0.815E+02	4.68	-23.69
692.0	1.06	781.	126.	10.39	0.062	-0.865E-02	-0.816E+02	4.08	-22.16
694.0	1.07	781.	118.	10.39	0.059	-0.857E-02	-0.816E+02	3.47	-20.51
696.0	1.08	781.	111.	10.39	0.056	-0.852E-02	-0.816E+02	2.87	-18.75
698.0	1.09	781.	105.	10.39	0.053	-0.853E-02	-0.817E+02	2.26	-16.76
700.0	1.10	782.	99.	10.39	0.050	-0.862E-02	-0.817E+02	1.70	-14.46
702.0	1.12	784.	94.	10.39	0.048	-0.877E-02	-0.817E+02	1.39	-12.87
704.0	1.13	785.	89.	10.39	0.046	-0.896E-02	-0.818E+02	1.09	-11.41
706.0	1.15	787.	84.	10.38	0.045	-0.920E-02	-0.818E+02	0.78	-9.41
708.0	1.19	790.	81.	10.38	0.044	-0.953E-02	-0.818E+02	0.47	-6.94
710.0	1.22	793.	77.	10.38	0.043	-0.100E-01	-0.819E+02	0.22	-4.02

EXHAUST TEMPERATURE= 811.9KDEG

*PREDICTION OF THE FRICTION LOSS**

MISC. AND PUMPS= 77.682G/CM**2

CAM GEAR = 101.310G/CM**2

BEARING = 140.845G/CM**2

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BLOWBY            =      43.481G/CM**2
VISCOUS PISTON    =     366.137G/CM**2
RING TENSION      =     115.044G/CM**2
RING GAS PRESS    =       7.335G/CM**2
------------------------------------------------------
TOTAL LOSS        =     851.834G/CM**2


     PIMEP=  -67.65G/CM**2     PSIN=   -0.11HP
      PEMEP=  345.27G/CM**2     PSEX=    0.57HP

     AIMEP=   6240.G/CM**2     IHP=   10.38HP     AISFC=  171.64G/IHP.HR

      BMEP=   5388.G/CM**2     BHP=    8.96HP      BSFC=  198.78G/BHP.HR

     HEAT REJECTION=    CAL/MIN
     TOTAL H. REJ   =0.8189E+05
     CYL. LINER     =0.2051E+05
     PISTON TOP     =0.1673E+05
     PISTON CUP     =0.2095E+05
     CYL. HEAD      =0.1517E+05
     INT. VALVE     =0.7223E+04
     EXH. VALVE     =0.1322E+04

   HEAT REJ./FUEL    =      0.277

     PEAK CYL PRESS=      52.0AT367.5DEG. CA
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