SIMULATION STUDIES OF THE EFFECTS OF LEAN OPERATION, TURBOCHARGING AND HEAT TRANSFER ON SPARK IGNITION ENGINES

by

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ABSTRACT

A computer simulation is presented that predicts the efficiency, performance and nitric oxide emissions of a spark ignition engine. Predictions of the model for wide-open-throttle and turbocharged operation were verified through comparison with manufacturers' engine performance data. Simulation studies were performed to determined the effects of lean operation, turbocharging and heat transfer on the efficiency, performance and nitric oxide emissions of a spark ignition engine. The 5.7ℓ naturally aspirated and 3.8ℓ turbocharged and naturally aspirated engines were chosen for this study.

The cycle simulation studies of lean operation showed that the improvements in fuel consumption were the same for air and EGR at equal levels of mixture dilution. EGR, at the same dilution level as with air, produces much greater reduction in specific NO emissions. Further studies revealed that turbocharging significantly improves the efficiency and performance of a spark ignition engine. However, the bsNO emissions are higher for a turbocharged engine. Heat transfer reduction studies indicated that the changes in engine efficiency and performance may or may not be favorable depending upon the method employed to reduce heat loss. Increasing the thermal boundary layer resistance significantly improves efficiency and performance, where as heat loss reduction by using ceramic cylinder components adversely affects power as a result of decreased volumetric efficiency. It is anticipated that heat loss reduction through utilization of ceramic engine components coupled with a turbocharger may provide a feasible method to significantly improve the efficiency and performance of spark ignition engines.

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I. Introduction

During the past few years the growing concern over fuel conservation has prompted engine manufacturers to design toward more fuel efficient engines. Three particular areas of interest which have shown promise in improving enigne efficiency are: lean operation, turbocharging and reduction of heat transfer. However, to study experimentally these effects on engine efficiency can be a difficult task since engine operating conditions and combustion parameters are interrelated in very complicated ways. Therefore, the use of engine cycle simulations has proven to be successful as a tool to help quantify some of the trade-offs inherent in optimizing engine efficiency. This study presents the use of a cycle simulation to predict the effects of lean operation, turbocharging and heat transfer of spark ignition engines.

The cycle simulation presented is a thermodynamic, zero-dimensional model of a conventional spark ignition engine. The principles of thermodynamics in conjunction with energy and mass conservation are used to determine the conditions in the engine cylinder during compression, combustion and expansion. The mass flow through the intake and exhaust valves is modelled as quasi-steady, adiabatic nozzle flow. The cylinder contents during combustion are modelled as three separate zones: an unburned gas zone, an adiabatic core burned gas zone and a boundary layer

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The results of the model for wide-open-throttle and turbocharged operation were verified by comparison to manufacturers' performance data. Matching of the brake mean effective pressure and brake specific fuel consumption of the simulation to the manufacturers' data was used as the criteria for determining validity of the model. The results of the model for part-throttle operation had been previously verified (3).

A parametric investigation of the effects of lean operation, turbocharging and heat transfer on efficiency, power output, specific fuel consumption and specific NO emissions was then carried out. Three engine designs were chosen for this study, a 5.7ℓ naturally aspirated engine and the 3.8ℓ naturally aspirated and turbocharged engines, as they represent a large portion of the automotive market.

The following sections provide a description of the model and its validation at wide-open-throttle and turbocharged operation. A detailed explanation of the study methodology is given followed by the results of the simulation studies.

A listing of the simulation model is included in Appendix B .

II. Spark Ignition Engine Simulation

1. Model Description

Many of the component pieces of the engine cycle model have been described previously (1) - (3). The inputs to the calculation are: engine geometry, engine speed, intake mixture fuel-air equivalence ratio, exhaust gas recycle fraction, intake manifold pressure and temperature, exhaust manifold pressure, combustion chamber wall temperature, parameters which define the burning law. One-dimensional quasi-steady flow models are used for the intake and exhaust processes. The first law of thermodynamics is used to determine conditions in the engine cylinder during compression, combustion and expansion. Empirical correlations are used for heat transfer in conjunction with a simple boundary layer model.

The model - or cycle simulation - then predicts the following: mass flow rates through the engine, the cylinder pressure, unburned and burned mixture temperatures, heat transfer to the combustion chamber walls, work transfer to the piston, all as functions of crank angle during the cycle. An example of these outputs versus crank angle is shown in Fig. 1 . From this information, the indicated power, specific fuel consumption, efficiency, mean effective pressure and mean exhaust temperature, are then computed for the particular engine operating point.

The calculated cylinder pressure and burned gas temperature profiles, with the equivalence ratio and fuel composition, are used in parallel to compute the rate of formation and decomposition of nitric oxide (NO) in the burned gases through the combustion and expansion processes. In this manner, the engine exhaust NO concentration and specific emissions are obtained.

2. Basic Assumptions

The following assumptions were made in developing the cycle simulation model for a conventional spark-ignition engine.

1) The engine cylinder is treated as a variable volume plenum. The cylinder pressure is a function of time only.

2) The charge is assumed homogeneous during intake and compression. During combustion, three zones exist: an unburned zone, an adiabatic burned zone, and a boundary layer burned zone. Each zone is assumed to be uniform in composition and temperature.

3) The volume of gas where the fuel oxidation process occurs is assumed to be negligible.

4) It is assumed that the individual species in the gas mixture behave as ideal gases. The unburned gas is composed of a non-reacting mixture of air, fuel and residual gases. The burned gases are a mixture of reacting gases, assumed to be in chemical equilibrium. An approximate method for computing burned gas properties is used (4).

5) Quasi-steady, adiabatic and one-dimensional flow equations are used to predict mass flows past the valves. The intake and exhaust manifolds are treated as infinite plenums having specified pressure and temperature histories. When reversed flow past the intake valve occurs, a plug flow model is assumed (5).

6) Heat transfer is predicted with the correlations of Woschni which were developed for diesel engines and generally applied to spark-ignition engines (6).

7) The mass fraction burned as a function of crank angle is specified by a Wiebe function.

8) Nitric oxide emissions are calculated by using the extended Zeldovich kinetic scheme, with the steady state assumption for the N concentration and equilibrium values used for H, O, O_2 and OH concentrations in the adiabatic core (1). The sudden freezing assumption is used for calculating boundary layer NO. This assumes that the NO accompanying the mass transfer to the boundary layer is immediately frozen.

Most ot the above assumptions have been used previously in cycle simulations and have been shown valid under normal engine operating conditions.

3. Combustion Model

A three zone combustion model is used to describe the combustion process. The use of three zones -- an adiabatic burned gas zone, a boundary layer burned gas zone and an unburned gas zone -- resulted from the need to include the NO formation calculations in a realistic fashion. A schematic of the three zone combustion model is shown in Fig. 2 .

The mass fraction of the charge within the cylinder which has burned at a given crank angle is specified by a Wiebe function of the following form (7)

$$x = 1 - \exp\{-a[(\Theta - \Theta_o)/\Delta\Theta_b]\}^{m+1} \qquad (1)$$

where:

x = fraction of total mass in cylinder burned

a = efficiency parameter

m = form factor

Θ = crank angle

Θ_o = start of combustion

$\Delta\Theta_b$ = combustion duration

This formulation allows one flexibility in specifying the shape of the curve; the values in this study were determined by matching with experimental traces and were $a = 5$, $m = 2.2$.

Figure 3 shows the parameters which define the start and duration of the combustion process. Θ_o, the crank angle at start of combustion, must be specified as input. For $\Theta > \Theta_o$, the mass fraction burned is given by the Wiebe function, Eq. (1). The start of combustion is related to actual spark timing by an ignition delay, $\Delta\Theta_{id}$, as shown. This ignition delay differs from an empirical ignition delay often used, $\Delta\Theta^*_{id}$, which is the crank angle interval between spark and 10 percent mass fraction burned. Θ_o is usually related to start of combustion timing which gives maximum brake torque at constant inlet pressure.

The combustion duration $\Delta\Theta_b$, is also specified as an input. This is the crank angle interval from start of combustion to the 100 percent burned position of the curve in Fig. 3 . This combustion duration (0 to 100 percent) differs from the 10 to 90 percent burn duration $\Delta\Theta^*_b$ often used empirically.

The three energy equations used during combustion for the three zones are:

$$\dot{E}_u = -\dot{Q}_u - \dot{W}_u - \dot{m}_b h_u \qquad (2)$$

$$\dot{E}_a = -\dot{W}_a + \dot{m}_b h_u - \dot{m}_{bl} h_a \qquad (3)$$

$$\dot{E}_{bl} = -\dot{W}_{bl} - \dot{Q}_{bl} + \dot{m}_{bl} h_a \qquad (4)$$

where the subscripts u, a and bl refer to the unburned, adiabatic core and boundary layer zones. In addition, properties of an average burned gas zone ($m_{bl} + m_a$) are calculated.

The mass transfer rate of the unburned gas to the burned gas ($\dot{m}_b$) is determined by the derivative of the Wiebe function (7). The rate of mass transfer to the boundary layer is calculated through the simultaneous solution of the aforementioned three energy equations, conservation of mass, and the perfect gas law for each zone. An average boundary layer temperature is defined as

$$T_{bl} = (T_a - T_w) / \ln (T_a/T_w) \qquad (5)$$

where the subscripts bl, a and w refer to the boundary layer, adiabatic core and wall.

4. Heat Transfer Model

The heat transfer correlations of Woschni (6) have been used to model the heat transfer process. The convective heat transfer coefficient is expressed as:

$$h = .0136 \, (WP)^{.8} / (d^{.2} T^{.547}) \qquad (6)$$

h = convective heat transfer coefficient, $J/m^2 s\ K$

P = pressure, Pa

d = cylinder bore, m

T = temperature, K

W = mean gas velocity, m/s

where W =

2.28C	compression and expansion
6.18C	scavenging
$3.24E{-}3[(V_s T_i)/(P_i V_i)](P-P_m) + 2.28C$	combustion

C = mean piston speed, m/s

V_s = cylinder volume, m^3

V_i = instantaneous cylinder volume, m^3

T_i = instantaneous temperature, K

P_i = instantaneous pressure, Pa

P_m = pressure in the cylinder of corresponding motored engine, Pa

In the model, heat transfer occurs from both the unburned and burned gas mixtures to the boundary surfaces and not across the flame front. The surface area ratios of the burned and unburned mixtures exposed to heat transfer are calculated from the engine geometry.

$$A_b = (V_b/V_z)^{2/3} \quad (7)$$

$$A_u = (V_u/V_z)^{2/3} \quad (8)$$

A_b = surface area of the burned gas region

A_u = surface area of the unburned gas region

V_b = volume of the burned gas

V_u = volume of the unburned gas

V_z = instantaneous volume of the cylinder

The heat transfer equation is then expressed as:

$$\dot{Q}_j = h\Sigma A_c(T_j - T_c) \qquad (9)$$

where the subscript j refers to the unburned gas or burned gas and the subscript c refers to the component surface areas, ie. piston, cylinder walls, head, intake and exhaust valves.

The total rate of heat transfer is:

$$\dot{Q}_{total} = \dot{Q}_b + \dot{Q}_u \qquad (10)$$

5. Method of Solution

The basic simultaneous differential equations which must be integrated to analyze the engine cycle are:

(1) Intake, Compression and Exhaust Processes

(i) mass flow rate equations for intake and exhaust valves

(ii) energy conservation for the cylinder contents

(iii) Woschni's correlation for heat transfer to the walls

(2) Combustion and Expansion Processes

(i) energy conservation equations for unburned, adiabatic core and boundary layer systems

(ii) mass burn-rate equation

(iii) Woschni's correlation for heat transfer to the walls for the burned and unburned systems

(iv) equations for the rate of change of the mass of NO in the adiabatic core and boundary layer.

These equations are solved using a modified Euler predictor-corrector technique. This integration scheme is adequate for solving the thermodynamic system equations. The NO equations are solved using a fourth order predictor-corrector scheme. This added complexity is necessary for accurate integration of the governing equations for the NO since the NO kinetics are extremely temperature dependent.

For each calculation, a mean exhaust temperature is computed from the mass averaged enthalpy of the burned gas as it exits the cylinder. This mean exhaust temperature is used as an indicator of trends in hydrocarbon emissions. If $\overline{T}_{exh}$ decreases, less afterburning will occur; if $\overline{T}_{exh}$ increases, more afterburning will occur. The calculated values of $\overline{T}_{exh}$ are higher than typical measured exhaust temperatures. The calculated temperature corresponds to the valve seat location. Measured exhaust temperatures are lower because heat losses to the exhaust valve, in the exhaust port, and in the exhaust manifold occur.

The cycle simulation calculations deal only with the contents of the engine cylinder; thus only indicated quantities are computed. Since the simulation covers the complete four-stroke cycle, pumping work over the intake and exhaust strokes is determined. To obtain brake values of engine parameters, mechanical friction is calculated using the method proposed by Bishop (8).

III. Model Validation

1. Procedure

Experimental validation of this model for part-throttle operation is given by Heywood et. al. (3). However, in order to perform parametric studies to evaluate the performance of the 5.7ℓ naturally aspirated engine and the 3.8ℓ turbocharged engine, the model must first be validated at wide-open-throttle (W.O.T.) and turbocharged operation.

The simulation output was checked against W.O.T. performance data (G.M. Test Code #1 (18)) provided by Chevrolet and Buick. Tables 2 and 3 show the simulation test matrices for the model validation. Although most of the input operating parameters were provided by the manufacturers' data for this cycle simulation it was necessary to determine an ignition delay, $\Delta\Theta_{ig}$, to relate the crank angle for start of combustion to the actual engine spark timing and to determine a combustion duration, $\Delta\Theta_b$, for the given operating conditions. An outline of the procedure used to determine $\Delta\Theta_{ig}$ and $\Delta\Theta_b$ for the model validation studies is given in Appendix A. In the cases where equivalence ratio, ϕ, was varied the values of ϕ were estimated from carburetor flow data as given in Fig. 4 . The actual values of fmep used for determining predicted values of bmep are given in Table 4 .

2. Wide Open Throttle Performance

Figures 5 and 6 show the comparison between the brake mean effective pressures (bmep) and brake specific fuel consumption (bsfc) of the actual engine and the simulation output at W.O.T. Three studies were performed (Table 2): 1) equivalence ratio held constant, 2) equivalence ratio varied to account for the changing air-fuel ratio with engine speed and 3) equivalence ration held constant and bmep values obtained using actual fmep data instead of Bishop (8).

The results of matching the bmep values of the simulation to the engine data as given in Fig. 5 show a deviation of up to approximately 25 percent. However, in each of these studies, the results exhibited trends similar to those of the actual engine. The matching of the bsfc values of the simulation to the engine data also showed a deviation of up to 25 percent (Fig. 6).

To fully evaluate these results three sources of uncertainty must be identified: 1) experimental uncertainties of the data, 2) uncertainty in matching the simulation to the engine test conditions and 3) inadequacies of the model. Although the engine performance data provided by Chevrolet are those of a 5.7ℓ engine, and the geometries of the engine input parameters to the simulation (ie. valve lift, valve timing, wall thicknesses etc.) are those of the standard Chevrolet 350 CID engine, they are not known with certainty to be identical to those of the Chevrolet engine tested. In addition, some of the conditions of the engine test were not known and had to be estimated introducing some uncertainty into the data for this application. Thus, matching the simulation to the engine test conditions may have introduced some error as a result of the interdependcy of such parameters as inlet pressure, equivalence ratio, start of combustion timing and combustion duration. With these qualifications, the model gives sufficiently accurate predictions of trends and magnitudes to be useful for assessing the effects of engine performance at W.O.T.

3. Turbocharged Performance

Figures 7 and 8 show the comparison of the simulation output, bmep and bsfc, with the W.O.T. maximum performance of the 3.8ℓ turbocharged engine. Five studies were performed (Table 3): 1) MBT timing with constant ϕ, 2) retarded timing[1] with constant ϕ, 3) retarded timing, constant ϕ and $\Delta\Theta_b$ adjusted to correlate with the retarded timing, 4) retarded timing, ϕ adjusted to account for the changing air-fuel ratio with engine speed and $\Delta\Theta_b$ adjusted to correlate with the retarded timing and variation in equivalence ratio and 5) similar to study 4 with the exception that predicted brake mean effective pressures were obtained by using actual fmep data.

[1] Start of combustion timing was retarded at speeds of 2500 rpm and greater to match the engine spark advance curves.

Close agreement was obtained between the simulation output of bmep (Fig. 7) and the engine data for the first study using MBT timing up to approximately 2500 rpm. At this point, knock begins to occur in the engine due to the high inlet pressures. To prevent the occurrence of knock in the engine the spark timing is retarded approximately 8 degrees at 2500 rpm and then advanced from this point for the higher speeds. As a result, the simulation output with MBT timing exhibits a divergence from the engine data at speeds of 2500 rpm and greater. The subsequent studies in which spark timing, burn duration and equivalence ratio were adjusted to attempt to represent the actual engine performance improved the match with the test data to within a modest margin of error.

Figure 8 shows the comparison of the bsfc of the simulation with that of the turbocharged engine. The simulation output values fall up to 30 percent below the actual data. However, the results of study 4 (the dashed line) in which the timing, burn duration and equivalence ratio were adjusted to represent the actual enigne performance, exhibited trends similar to those of the engine data with closer matching.

Much of the error in matching the bsfc values may be due to the estimation of the equivalence ratio. The values of ϕ were estimated from the carburetor flow data (Fig. 4) for a naturally aspirated engine. It is known that in addition to retarded timing to deter knock, the turbocharged engine at maximum power output utilizes a richer mixture than a naturally aspirated engine at maximum power. Therefore, the use of the carburetor flow data may have resulted in an underestimation of ϕ over much of the performance range. In addition, the model assumes 100 percent of the fuel is burned. This is not true for the engine. With mixture nonuniformities and incomplete combustion much of the engine input fuel remains unburned resulting in high bsfc values.

Closer agreement of the engine data and the simulation output could be obtained for most of the performance range if much of the empiricism could be removed from determining the combustion parameters. For the purposes of this study the model sufficiently predicts the performance of turbocharged operation of an engine.

An additional model validation study was performed to examine the feasibility of simulating the turbocharged engine's performance over a range of loads at a constant speed. This was necessary to determine if accurate predictions of the turbocharged engine's performance could be made by calculating the input parameters (exhaust pressure and inlet temperature) from compressor and turbine maps rather than using the manufacturer's test data. An engine speed of 2000 rpm was selected for this study as 50 percent of the operating range (50% to 100% load) utilizes the turbocharging effects. The start of combustion timing was related to manufacturer's data and $\Delta\Theta_b$ determined by the correlations of Hires et. al. (14). The equivalence ratio ranged from stoichiometric to rich to accommodate the high load operating conditions. The intake pressures were taken from manufacturer's data. The predicted bmep values were determined through the use of Bishop and also by using actual fmep data. Details of the input parameters are given in Table 5 .

Figure 9 shows the comparison of the bmep values of the simulation output and the engine data. The results show a similar trend to the engine data though they are slightly high by almost a constant factor over the entire operating range. This constant factor of error suggests the effects of additional power drain due to the engine accessories. Therefore, the effects of such accessories as the generator, A.I.R. pump, power steering pump and fan were taken into account (19), which then reduced the margin of error to within approximately 10 percent.

The results of matching the bsfc values for this study are given in Fig. 10 . Close agreement was not obtained over much of the operating range, This again is probably due in part to the estimation of ϕ and $\Delta\Theta_b$ as discussed previously.

For the purposes of the parametric study the results of this study indicate the method of simulating the performance of the turbocharged engine by calculating the input parameters from the turbine and compressor maps is adequate.

IV. Simulation Studies of Lean Operation, Turbocharging and Heat Transfer

1. Engine Specifications

Parametric studies were performed to evaluate the efficiencies and emission characteristics of lean operation, turbocharging and heat transfer of spark ignition engines. A 5.7ℓ engine, with geometry similar to the Chevrolet 350 CID and Ford 351 CID engines, and the 3.8ℓ turbocharged and naturally aspirated engines were chosen for these studies as they represent a large portion of the automobile engines on the market today in the U.S. Detailed engine specifications are given in Table 1 . The following sections describe in detail the study methodology and results of the parametric studies.

2. Lean Operation

A. Study Methodology

It is well known that engine operation with a close-to-stoichiometric mixture of fuel and air has high NO emissions, and at part throttle, high pumping work losses. Lean engine operation - dilution of the fuel-air mixture with excess air - has been proposed and used to reduce the impact of both these problems. Lean engine operation, however, lowers exhaust temperatures and slows the combustion process. Hydrocarbon emissions control and misfire may therefore become major problems.

The proposed extensive use in the U.S. of a three-way catalyst system for simultaneous removal of HC, CO and NO in the exhaust system requires an alternative form of mixture dilution. Three-way catalysts are only effective on engine operation with stoichiometric mixtures. Engine NO emissions and pumping work with stoichiometric mixtures can be reduced with dilution with recycled exhaust gases. It is important therefore to compare the characteristics of engines at part-throttle operated with lean mixtures, with the characteristics when operated with stoichiometric mixtures with EGR.

The 5.7ℓ displacement production engine was used for this study. Since ordinary spark ignition engine operation encompasses a wide range of operating modes, e.g. idle, acceleration, deceleration and cruise, the results of a simulation study are most useful if engine speed and load are held fixed at selected values which are representative of common operating modes. For an appropriate vehicle with this size engine, a moderate vehicle acceleration point with engine speed of 1400 rpm and brake torque 149 Nm was chosen as the reference point. This corresponds to a brake mean effective pressure of 328 kPa. All calculations were done at this load-speed condition.

The burn duration was held constant at 60^{o} which is a representative combustion duration for this particular engine operating at the reference point. Combustion timing was always related to the timing which gave maximum brake torque. MBT start of combustion timing was determined from plots of imep vs θ_o and was found to be essentially independent of equivalence ratio and percent EGR for a given engine geometery, engine speed and burn duration. Details of the input parameters for this study are given in Table 6 .

B. Results

Figure 11 shows the effect of dilution with air, and with EGR for a stoichiometric mixture on bsfc and bsNO. The solid line shows the effect of leaning out the mixture with air (the numbers indicated in the figure are air-fuel ratio and, in brackets, the equivalence ratio); the dashed line shows the effect of EGR. At equivalent levels of dilution (e.g. 10 percent EGR and an equivalence ratio of .89) the fuel consumption is about 1 percent lower with air as diluent. This is due to the slightly lower specific heat ratio of the mixture with recycled exhaust. However, EGR is very much more effective with a stoichiometric mixture as a means of reducing NO emissions because it contains negligible oxygen.

At a given value of bsNO, lean operation always gives better fuel economy, primarily because much greater dilution with air is required to achieve the same bsNO reduction. For example, for a stoichiometric mixture bsNO = 10.7 gNO/kW-hr; a factor of three reduction is obtained with 10 percent EGR or with an equivalence ratio of 0.76 (an air-fuel ratio of 19.5-20). The fuel consumption with air as diluent is 6 percent better than with EGR. However, achieving good combustion characteristics with $\phi = 0.76$ is much more difficult than with $\phi = 1.0$ and 10 percent EGR, and the hydrocarbon emissions may well be higher.

Figure 12 shows that at equivalent levels of dilution, the mean exhaust temperature with EGR and air are essentially the same. At equal NO emission levels, the exhaust temperature with air dilution is significantly lower (~ 120 K). The implications for hydrocarbon emission control are complex, however; EGR, equivalence ratio, gas temperature during expansion and exhaust strokes, catalyst configuration (if any) as well as spark timing relative to optimum are all significant variables in the HC emission problem.

Experimental verification of the predictions in Fig. 11 is provided by the results of Nicholson (10) on a 4.2ℓ V-8 engine at constant speed and torque. The effects of EGR for a stoichiometric mixture, and air, on bsfc and bsNO until misfire occurred as determined from engine data are matched closely by the predictions of Fig. 11 and 12 (the load, speed and engine details are slightly different). The engine data on hydrocarbon emissions showed that minimum engine emissions occurred at about ϕ = .92 without EGR, and increased as the mixture was further leaned out. For the above comparison of EGR and air as diluents, at the same NO_x emission level (with 10 percent EGR at ϕ = 1.0, and without EGR at ϕ = .77) the HC emissions with the leaner mixture were about 20 percent higher.

3. Turbocharging

A. Study Methodology

In previous years, engine manufacturers' responses to desires for increased power and performance were to increase the displacement of the engines. However, increased displacement generally results in decreased fuel economy during part-throttle operation, thus making it an undesirable solution for today's engines. An alternative to the use of increased displacements for increased power is turbocharging.

Turbocharging is a means to provide, through the use of an exhaust gas driven compressor, greater air flow delivered to a given displacement engine by increasing the density of the incoming air-fuel charge. This increased air-fuel charge, when burned during combustion, is then realized as additional power output.

The turbocharger consists of two main assemblies; a turbine and a compressor. Exhaust gases from the engine, containing energy normally dissipated in the form of heat and pressure, expand across the turbine to near atmospheric pressure and are expelled through the vehicle's exhaust system. This exhaust gas energy is converted into mechanical work which, through a connecting shaft, drives the compressor. Thus an increased charge of air and fuel can be delivered to the engine through the utilization of waste gas energy without increased engine displacement. Therefore, it is important to compare the performance, efficiencies and emission characteristics of a larger displacement engine with a smaller displacement turbocharged engine at part-throttle and W.O.T.

This study was performed using the geometries of the 5.7ℓ naturally aspirated and the 3.8ℓ turbocharged engines (Table 7). To simulate a turbocharged engine, input parameters (inlet pressure and inlet temperature) were taken from the manufacturer's performance data. Turbine and compressor maps were used to check mass flow rates and speeds to assure comparable performance to the turbocharged engine. Combustion duration and equivalence ratio were held constant at 60° and 1.0 respectively. Indolene clear was chosen as the fuel with the properties for Indolene taken from LoRusso (17).

B. Results

Figure 13 shows the comparison of bsfc for the 3.8ℓ turbocharged engine and the 5.7ℓ naturally aspirated engine as a function of engine power at selected engine speeds. At any given power level the 3.8ℓ engine exhibits lower fuel consumption than the 5.7ℓ engine. Assuming a moderate vehicle acceleration point, brake power ≈ 40 kW and an engine speed of 2000 rpm, the reduction in fuel consumption for the smaller displacement engine is approximately 9%. At this point, the turbocharger is actually "idling" and rotating at relatively slow speeds. Therefore the turbocharged engine is performing essentially as a naturally aspirated engine, and the improvement in bsfc comes from the improved mechanical efficiency of the engine. As the demand for power is increased the turbocharger comes into effect and positive manifold pressures are realized. However, at low engine speeds such as 1200 rpm, the turbocharger has very little effect and therefore the maximum power the 3.8ℓ engine can develop is approximately 35% less than the 5.7ℓ engine. At higher speeds, where the turbocharger does have an appreciable affect on inlet pressure, these maximum power differences diminish, and as shown in Fig. 13, the maximum power outputs for both engines are equal at 3200 rpm.

A definite fuel economy gain for the 3.8ℓ turbocharged engine is shown in Fig. 13 for each power output point. In practice though, to achieve the high output power levels, for both engines, the incoming charge will richen. At these power levels, the turbocharged engine will also require an even richer mixture and retarded timing to deter knock. Figures 14 and 15 compare the actual engines' performances at maximum power output levels. The bmep levels of the 3.8ℓ turbocharged engine exceed those of the 5.7ℓ naturally aspirated engine as shown in Fig. 14. However, the bsfc values of the 3.8ℓ turbocharged engine as shown in Fig. 15 are higher, as expected, particularly at the higher speeds as a result of the richer mixtures to prevent knock. These extreme conditions would only be experienced in vehicle operation during periods of heavy acceleration or speeds above 110 kph. Therefore, the 3.8ℓ turbocharged engine is more efficient than the 5.7ℓ engine during normal vehicle operating speeds and loads.

Wallace (12) compared the in vehicle performance (a 4000 pound EPA inertia weight vehicle) of the 3.8ℓ turbocharged and the 5.7ℓ naturally aspirated engines. His work revealed that the 5.7ℓ provides an EPA fuel economy balue of 18 miles per gallon while the turbo 3.8ℓ improves this value to 19 miles per gallon.

Figure 16 shows the comparison of the bsNO emissions for the 3.8ℓ engine and the 5.7ℓ engine. The 3.8ℓ engine exhibits higher bsNO emissions than the 5.7ℓ engine at a given power output. This is due to the higher loads, and consequently, higher cylinder pressures and temperatures at which the 3.8ℓ engine must operate to produce the power equal to that of the 5.7ℓ engine.

4. Heat Transfer

A. Study Methodology

As an ever increasing importance is placed on fuel economy and emissions of internal combustion engines, automotive manufacturers are looking for ways in which to increase the thermal efficiency of engines. Heat balance studies conducted by Ament et.al. (15) on a 5.7ℓ engine have shown that for certain operating conditions as much as 80 percent of the fuel heat of combustion may be lost to the coolant and exhaust through radiation effects. Although, the laws of thermodynamics prove that much of this heat loss cannot be recovered as useful work, it has been shown that even a one percent improvement in the thermal efficiency of automotive engines could reduce fuel consumption by approximately 80,000 bbl/day (15). Therefore it is important to examine the reduction of heat loss in engines and its effects on performance, efficiency and emissions.

The 5.7ℓ and 3.8ℓ naturally aspirated engines were used for this study. A speed of 1200 rpm was selected as it is a representative mid-range operational speed for both engines. Combustion duration and equivalence ratio were held constant at 60° and 1.0 respectively. Combustion timing was always related to the timing which gave maximum brake torque.

The effects of the changes in heat transfer were examined by two methods: 1) by changing the resistance of the thermal boundary layer and 2) by changing the thermal resistance of the walls. The resistance of the thermal boundary layer was changed by multiplying the convective coefficient obtained from Woschni's correlation (Eq. 1) by a factor ranging from 1.25-0. This method permits one to examine the effects of uncertainty in heat transfer on the simulation predictions and to study the importance of combustion chamber surface area and gas motion, both of which affect heat transfer. The second method employed changing the thermal conductivity, k, of the components which make up the combustion chamber walls (piston, head and cylinder walls). A summarization of the input details for these methods is given in Table 8 .

B. Results

Figures 17, 18 and 19 exhibit the results of the first method for reducing heat transfer in which the resistance of the thermal boundary layer is increased. Figure 17 shows an approximate 17 percent increase in the brake output power and a 20 percent increase in the brake thermal efficiency when the heat transfer is reduced to zero. This gain in output power and efficiency does not represent the total heat loss energy. Figure 18 shows the effect of heat transfer reduction on the mean exhaust temperature. The exhaust temperature increases by approximately 32 percent which accounts for the remainder of the heat loss energy.

Figure 17 can be used to assess the effects of uncertainty in the heat transfer calculations. If a 25 percent error was involved in the heat transfer, the output power and efficiency values would only vary by approximately a factor of 5 percent which would not be significantly detrimental to the evaluation of predicted results obtained using this cycle simulation.

The effects of reduced heat transfer on bsNO emissions are given in Fig. 19 . Due to the evolution of higher temperatures as heat transfer is reduced the bsNO emissions increase. An approximate 15 percent increase in bsNO for both engines is shown to result from reducing heat transfer to zero.

Table 9 displays the results of the study in which heat transfer was reduced by changing the thermal conductivity of the components. The thermal conductivity of the components was reduced one at a time to a value of k = .001 BTU/ft-min-^{o}F to simulate adiabatic behavior. In run #5 the thermal conductivity of all the components was reduced to k = .001 BTU/ft-min-^{o}F to approximate an adiabatic engine.

The results in Table 9 reveal a slight increase in the thermal efficiency with reduced heat transfer in most cases, however, unlike the previous results, the output power decreases as the heat transfer is reduced. This reduction in output power results from a decrease in the volumetric efficiency as shown in Table 9 . The reduced thermal conductivity of the walls results in higher wall temperatures which heat the incoming charge reducing its density, and thus, decreasing volumetric efficiency. The increase in the temperature of the incoming charge also produces extremely high unburned gas temperatures as the mixture is compressed which would result in a severe knocking condition. In addition, with the high cylinder temperatures the bsNO emissions also increase.

These two studies of heat transfer reduction have shown drastically different results. The first study in which the thermal boundary layer resistance was increased, showed the possibility for positive gains in efficiency. However, the feasibility of applying this concept to an actual engine is questionable. Application of this method would require engine geometry designs which tend toward laminar boundary layer flow. Given the operating conditions of an engine this would prove to be a difficult task.

The second method in which an "ideal" ceramic was employed to reduce the thermal conductivity of the cylinder components exhibited only a slight increase in efficiency. Other aspects, such as decreased power output, decreased volumetric efficiency and extreme knocking conditions would suggest this method to be undesirable. The use of a turbocharger however, would increase the volumetric efficiency above that of the base condition and also utilize the higher exhaust gas temperatures for a further increase in efficiency. Under these conditions though, severe knock would exist. Again, this study was performed using an "ideal" ceramic. Actual ceramics, which do not have such favorable thermal resistivity properties, may not produce such an extreme operating environment and coupled with a turbocharger may provide a feasible and significant improvement in engine efficiency.

V. Conclusions

1. The predictions of the model for wide-open-throttle and turbocharged operation were verified by comparison to manufacturers' performance data. Error in matching the simulation output with the engine data can be attributed to three sources: 1) uncertainty of the engine operating conditions, 2) inadequacies of the model and 3) uncertainty in the empirical estimation of the combustion parameters.

2. Exhaust gas recycle as a mixture diluent acts similarly to air in its effect on specific fuel consumption and exhaust temperature.

3. A comparison of air and EGR at equal levels of mixture dilution shows that the improvements on fuel consumption and decreases in exhaust temperature that result from changing thermodynamic properties of the working fluid and reduced pumping work are the same. EGR, at the same dilution level, produces much greater reduction on specific NO emissions. At the same specific NO emissions levels, dilution with air gives better fuel consumption and lower exhaust temperatures because much greater dilution is required.

4. A 3.8ℓ turbocharged engine is capable of producing power greater than that of a 5.7ℓ naturally aspirated engine. The smaller displacement turbocharged engine is approximately 10 percent more fuel efficient under normal operating conditions, as it performs essentially as a naturally aspirated engine, and the improvement in bsfc comes from the improved mechanical efficiency.

5. The turbocharged engine utilizes richer mixtures than a naturally aspirated engine at high speeds and loads for increased power and to deter knock. As a result, under these extreme operating conditions the bsfc values of the 3.8ℓ turbocharged engine are higher than those of the 5.7ℓ naturally aspirated engine.

6. The 3.8ℓ turbocharged engine exhibited higher bsNO emissions than the 5.7ℓ engine at a given power output due to the higher loads, and consequently, higher cylinder pressures and temperatures at which the 3.8ℓ engine must operate to produce the power equal to that of the 5.7ℓ engine.

7. Brake output power, efficiency and exhaust temperature increased as a result of reducing the engine heat loss by increasing thermal boundary layer resistance. The feasibility of this method of heat loss reduction is questionable since it requires engine geometry designs which tend toward laminar boundary layer flow.

8. An error of ± 25 percent in the heat transfer would not be significantly detrimental to the evaluation of predicted results obtained using this cycle simulation.

9. The reduction of heat transfer by increasing the thermal resistance of the engine components results in decreased power output as a result of decreased volumetric efficiency. High wall temperatures heat the incoming charge, reducing its density and thereby decreasing volumetric efficiency. Increased inlet

temperatures also results in very high unburned gas temperatures during compression and therefore a severe knock condition would exist.

10. It is anticipated that the use of actual ceramics in an engine would not produce such extreme operating conditions and coupled with a turbocharger may provide a feasible and significant improvement in engine efficiency.

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Table 1

Engine Specifications

Dimensions	Engine 5.7ℓ N.A.	Engine 3.8ℓ N.A.	Engine 3.8ℓ Turbo
Bore (mm)	101.6	96.52	96.52
Stroke (mm)	88.4	86.36	86.36
Crank radius/con. rod length	.305	.285	.285
Compression ratio	8.1:1	8.0:1	8.0:1
Cylinder head area (excl. valves) /piston area	.91	.91	.91
Intake valve:			
diameter (mm)	50.8	41.3	41.3
max. valve lift (mm)	9.75	9.88	8.15
opens at	38 deg BTDC	41 deg BTDC	41 deg BTDC
closes at	92 deg ABDC	101 deg ABDC	81 deg ABDC
Exhaust valve:			
diameter (mm)	39.6	36.2	36.2
max. valve lift (mm)	10.3	9.45	9.45
opens at	92 deg ATDC	85 deg ATDC	85 deg ATDC
closes at	52 deg ATDC	61 deg ATDC	61 deg ATDC

Table 2 - 5.7ℓ W.O.T. Performance Simulation Test Matrix

Run #	RPM	S.O.C. (B.T.D.C.)	ϕ	$\Delta\Theta_b$	P_{in} psig	P_{ex} psig	T_{in} ^oF
A01	4400	-26.0	1.26	60^o	-.73	11.95	115.0
A02	4000	-25.0	1.26	58^o	-.67	11.31	115.0
A03	3000	-23.0	1.16	53^o	-.49	7.54	115.0
A04	2500	-20.0	1.13	50^o	-.41	4.99	115.0
A05	2000	-17.0	1.10	46^o	-.32	3.13	115.0
A06	1000	-10.0	1.14	37^o	-0.12	0.78	115.0
A07	4400	-26.0	1.10	60^o	-.73	11.95	115.0
A08	1000	-10.0	1.10	37^o	-.12	0.78	115.0
A09	2500	-20.0	1.10	50^o	-.41	4.99	115.0
A10	4000	-25.0	1.10	58^o	-.67	11.31	115.0
A11	3000	-23.0	1.10	53^o	-.49	7.54	115.0

Table 3 - 3.8ℓ Turbocharged Maximum Performance Simulation Test Matrix

Run #	RPM	S.O.C.	ϕ	$\Delta\Theta_b$	P_{in} psig	P_{ex} psig	T_{in} ^oF
A13	1200	-10	1.2	37	0.98	2.4	98.0
A14	1500	-13	1.2	40	1.96	3.5	103.5
A15	2000	-15	1.2	44	5.53	6.9	122.0
A16	2500	-18	1.2	48	9.50	12.2	159.0
A17	3000	-21	1.2	50	9.89	15.2	169.0
A18	3500	-24	1.2	53	9.99	17.3	178.0
A19	4000	-26	1.2	55	9.94	18.6	190.0
A20	4400	-27	1.2	57	9.89	19.0	200.0
A21	4400	-19	1.2	57	9.89	19.0	200.0
A22	4000	-18	1.2	55	9.94	18.6	190.0
A23	3500	-13	1.2	53	9.99	17.3	178.0
A24	3000	-10	1.2	50	9.89	15.2	169.0
A25	4400	-19	1.2	73	9.89	19.0	200.0
A26	4000	-18	1.2	71	9.94	18.6	190.0
A27	3500	-13	1.2	69	9.99	17.3	178.0
A28	3000	-10	1.2	66	9.89	15.2	169.0

Table 3 (con't)

Run #	RPM	S.O.C.	ϕ	$\Delta\Theta_b$	P_{in} psig	P_{ex} psig	T_{in} ^oF
A29	4400	-19	1.25	79	9.89	19.0	200.0
A30	4000	-18	1.25	76	9.94	18.6	190.0
A31	3500	-13	1.15	73	9.99	17.3	178.0
A32	3000	-10	1.15	70	9.89	15.2	169.0
A33	1200	-10	1.15	40	0.98	2.4	98.0
A34	1500	-13	1.15	43	1.96	3.5	103.5
A35	2000	-15	1.15	47	5.53	6.9	122.0
A36	2500	-15	1.15	65	9.50	12.2	159.0

Table 4 - Buick 3.8ℓ Fmep*

RPM	W.O.T. kPa	Closed Throttle kPa
800	22.5	67.4
1200	36.0	76.5
1600	49.5	90.1
2000	72.1	103.5
2400	90.1	117.0
2800	117.0	130.5
3200	144.0	144.0
3600	180.0	166.5
4000	198.0	180.0
4400	225.1	202.6

*G.M. Test Code #11

Table 5

Part Load 3.8ℓ Simulation Test Matrix

Run #	RPM	S.O.C.	$\Delta\Theta_b$	ϕ	P_{in} psig	P_{ex} psig	T_{in} ^oF
B01	2000	-32.0	94	1.00	-6.76	0.50	96.0
B02	2000	-26.0	63	1.10	-3.67	0.50	98.0
B03	2000	-20.0	50	1.10	-0.49	2.96	98.0
B04	2000	-18.0	47	1.10	1.76	5.25	105.0
B05	2000	-15.0	47	1.15	3.72	5.94	118.0

Table 6

Simulation Input Data for Lean Operation Studies
Base Condition

Equivalence ratio, ϕ	1.0
exhaust gas recycle, percent	0
Start of combustion timing, θ_o	22^{o}BTC
Combustion duration, $\Delta\Theta_b$	60^{o}
Speed, rev/min	1400
Fuel heating value, MJ/kg	44.4
Stoichiometric air-fuel ratio	15.1
Fuel molecular composition	C_8H_{18}
Inlet manifold pressure (gauge), kPa	-23.8
Inlet mixture temperature, K	319.4

Table 7 -Structure of Parametric Study for Comparison of the 3.8ℓ & 5.7ℓ Engines

Engine	RPM	S.O.C.	ϕ	$\Delta\Theta_b$	P_{in} psig	P_{ex} psig	T_{in} oF
3.8ℓ	1200	-21.0	1.0	60^o	-7.74 - 0.59	0.5 - 2.0	98.0 - 112.0
3.8ℓ	2000	-23.0	1.0	60^o	-6.76 - 5.53	0.5 - 6.9	98.0 - 122.0
3.8ℓ	3200	-25.0	1.0	60^o	-7.03 - 9.99	0.5 - 16.2	98.0 - 174.0
5.7ℓ	1200	-21.0	1.0	60^o	-7.74 - W.O.T.	0.5	98.0
5.7ℓ	2000	-23.0	1.0	60^o	-7.74 - W.O.T.	0.5	98.0
5.7ℓ	3200	-25.0	1.0	60^o	-7.74 - W.O.T.	0.5	98.0

Table 8

Simulation Input for Heat Transfer Studies

Method 1 - 3.8ℓ & 5.7ℓ Engines

Equivalence ratio	1.0
Speed, rev/min	1200
Combustion duration	60°
Inlet pressure	W.O.T.
S.O.C. timing	MBT
Heat transfer multiplier	1.25 - 0

Method 2 - 5.7ℓ Engine

Equivalence ratio	1.0
Speed, rev/min	1200
Combustion duration	60°
Inlet pressure	W.O.T.
S.O.C. timing	MBT

Thermal conductivity:

1) Base condition: k=0.560 BTU/ft-min-$^{\circ}$F (head, walls, valves)
   k=2.200 BTU/ft-min-$^{\circ}$F (piston)
2) Head: k=0.001 BTU/ft-min-$^{\circ}$F
3) Piston: k=0.001 BTU/ft-min-$^{\circ}$F
4) Cylinder wall: k=0.001 BTU/ft-min-$^{\circ}$F
5) All components: k=0.001 BTU/ft-min-$^{\circ}$F

Table 9

Results of Heat Transfer Study - Method 2

	Base Condition	Adiabatic Piston	Adiabatic Head	Adiabatic Cylinder	All Adiabatic
Heat Transfer (-)	.242	.208	.212	.184	.056
Power, kW	89.77	85.16	85.69	73.03	64.77
$\overline{T}_{exh}$, K	1235	1299	1292	1376	1604
η_{vol}, %	82.6	77.4	77.9	68.8	57.7
bsNO g/kW-hr	14.03	15.85	15.73	16.19	18.12
T_{wall}(max), K	409			1245	1373
T_u(max), K	836	922	914	1003	1242
T_{adiab}(max), K	2637	2681	2678	2716	2821
P_{max}, kPa	3783	3723	3738	3385	3176
imep, kPa	957	913	918	794	714
η_{th_i}	.352	.357	.357	.349	.366
bmep, kPa	871	826	831	708	628
$\eta_{th_{brake}}$	.320	.323	.323	.310	.323

Figure Captions

Fig. 1 Profiles of variables predicted by the simulation throughout the four-stroke engine cycle for a 5.7ℓ engine at Plotted against crank angle are: cylinder volume/clearance volume, inlet and exhaust valve lift, inlet and exhaust mass flow rates, cylinder pressure P, mass fraction burned x, unburned mixture temperature T_u, mean burned gas temperature $\overline{T}_b$, temperature of burned gas adiabatic core T_a, instantaneous heat transfer rate Q (normalized by the initial enthalpy of the fuel-air mixture within the cylinder), nitric oxide concentration NO, thermal boundary layer thickness δ_t (normalized by the cylinder bore B).

Fig. 2 Schematic of three zone combustion model. U denotes unburned gas zone, A denotes the adiabatic burned gas core, BL denotes the burned gas boundary layer.

Fig. 3 Schematic of mass fraction burned profile. Θ_s is spark timing, Θ_o is the start of combustion, $\Delta\Theta_{id}$ is the ignition delay and $\Delta\Theta_b$ is the combustion duration. $\Delta\Theta_{id}^*$ and $\Delta\Theta_b^*$ are the usual empirical definitions of ignition delay and combustion duration (0-10 percent and 10-90 percent burned respectively).

Fig. 4 Variation in equivalence ratio with engine speed at W.O.T. for a Rochester 4bbl carburetor using indolene.

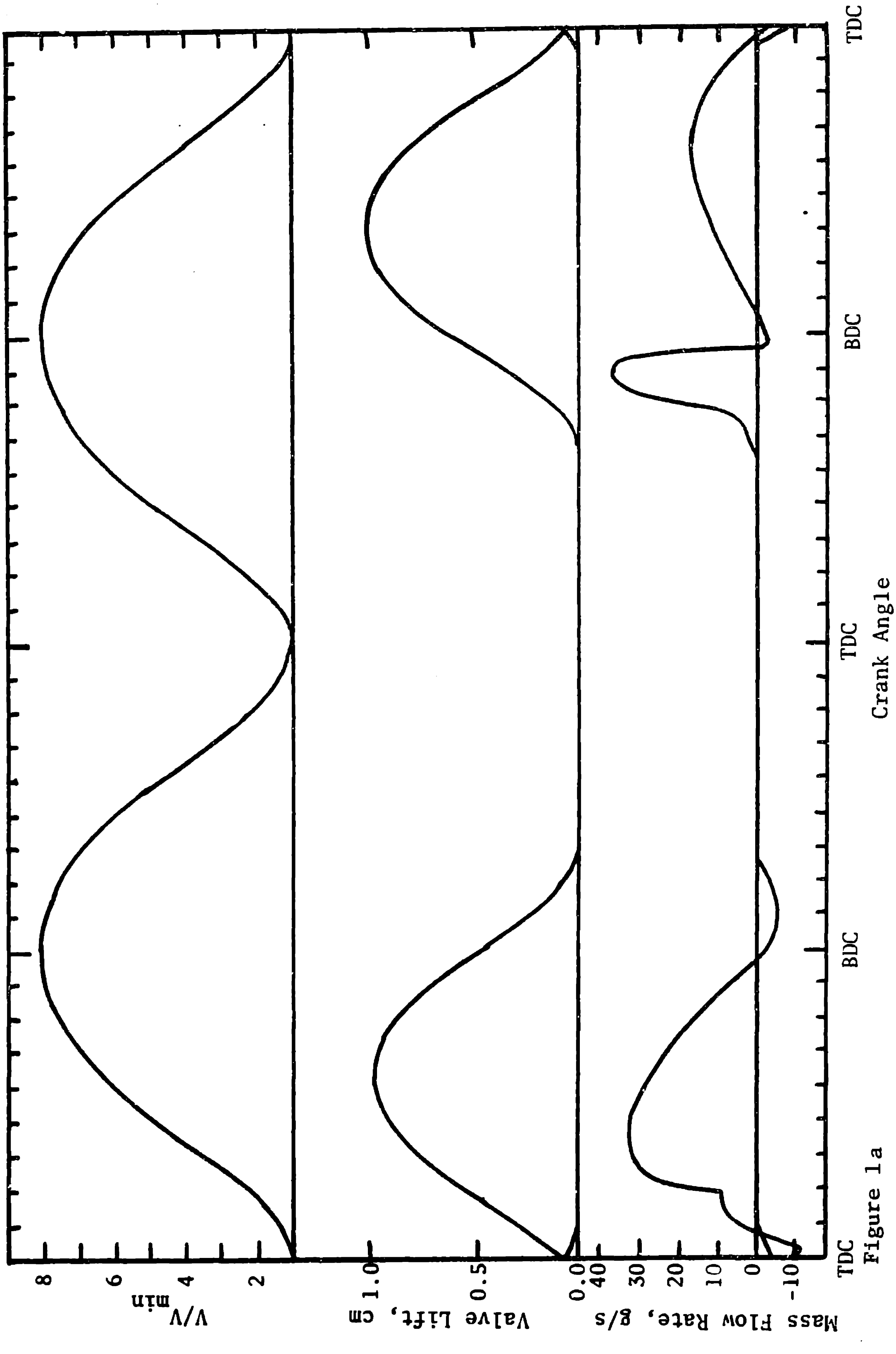
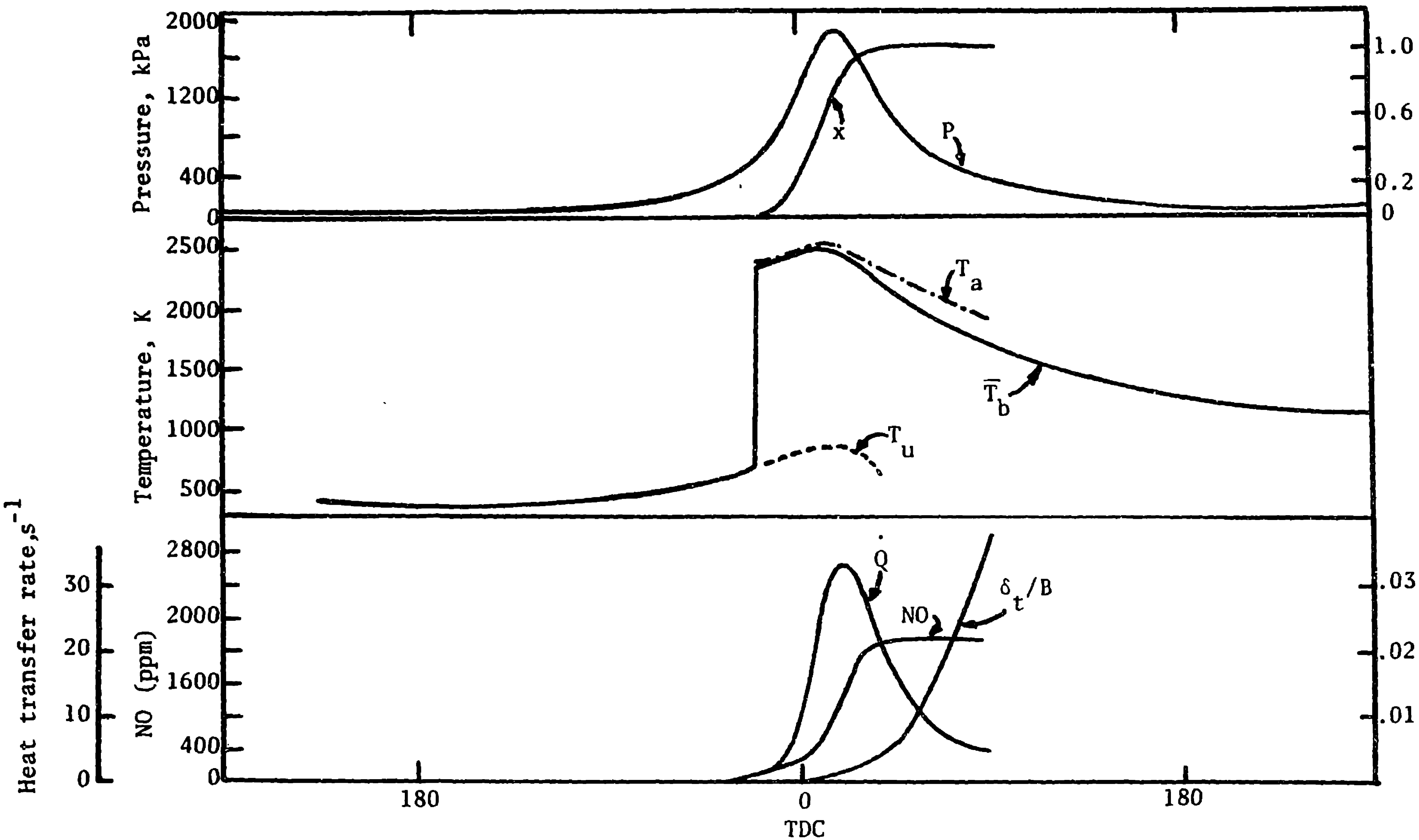

V/V$_{min}$
8
6
4
2
Valve Lift, cm
1.0
0.5
0.0
Mass Flow Rate, g/s
40
30
20
10
0
-10
TDC
BDC
TDC
BDC
TDC
Crank Angle

Figure 1a



Pressure, kPa
2000
1200
400
0
x
1.0
0.6
0.2
0
P
x
Temperature, K
2500
2000
1500
1000
500
Ta
Tb
Tu
Heat transfer rate, s-1
30
20
10
0
NO (ppm)
2800
2000
1600
400
0
(δt/B)
.03
.02
.01
Q
NO
δt/B
180
0
TDC
180
Crank Angle, deg.

Figure 1b

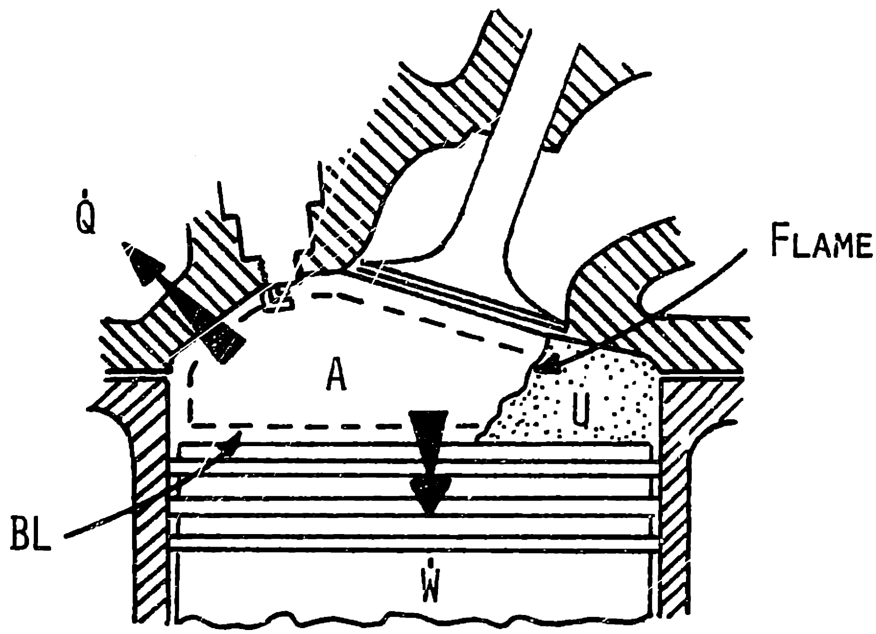


Figure 2.

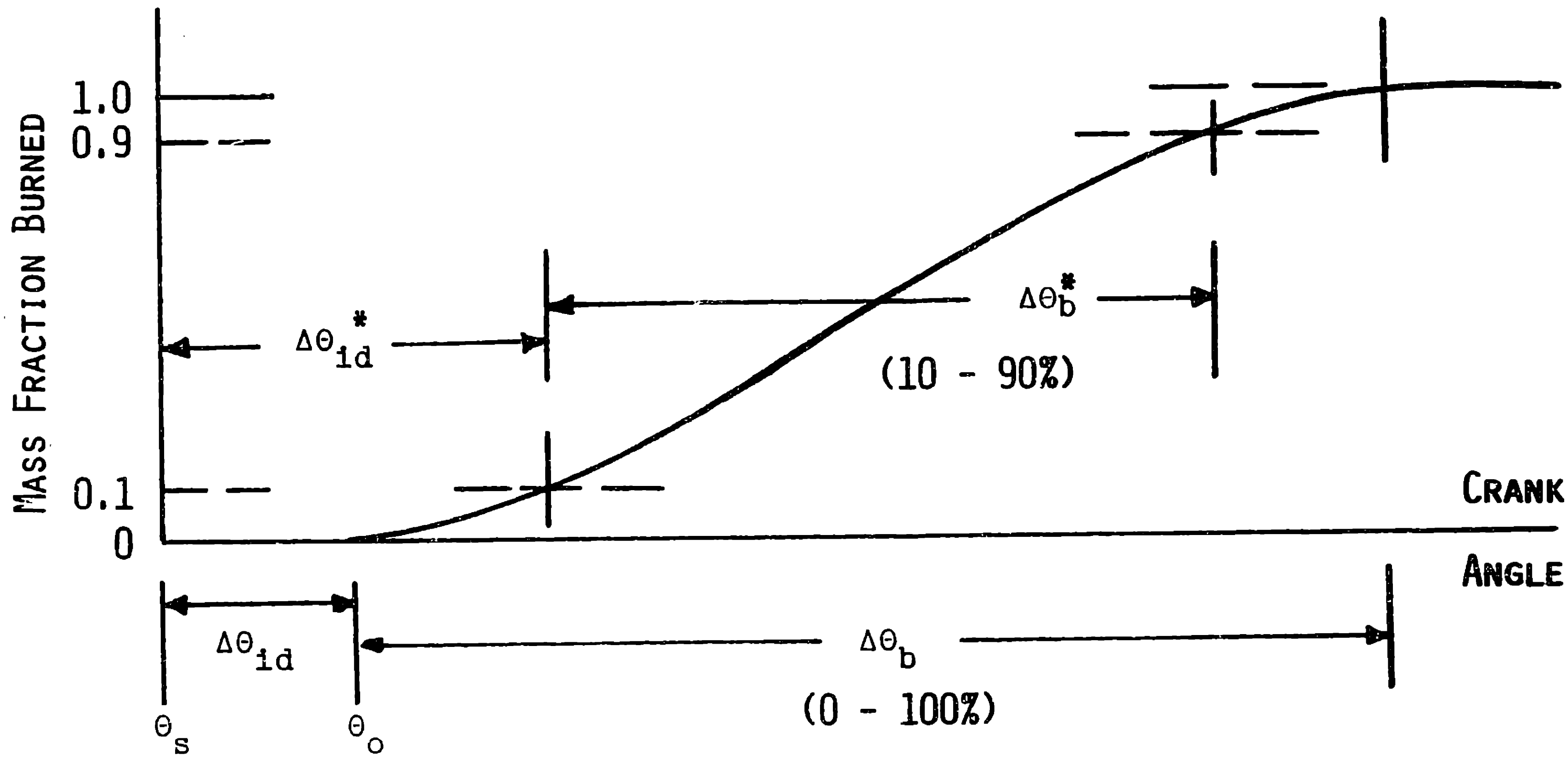

MASS FRACTION BURNED
1.0
0.9
0.1
0
CRANK
ANGLE
$\Delta\Theta_{id}^{*}$
$\Delta\Theta_{b}^{*}$
(10 - 90%)
$\Delta\Theta_{id}$
$\Delta\Theta_{b}$
(0 - 100%)
Θ_s
Θ_o

Figure 3.

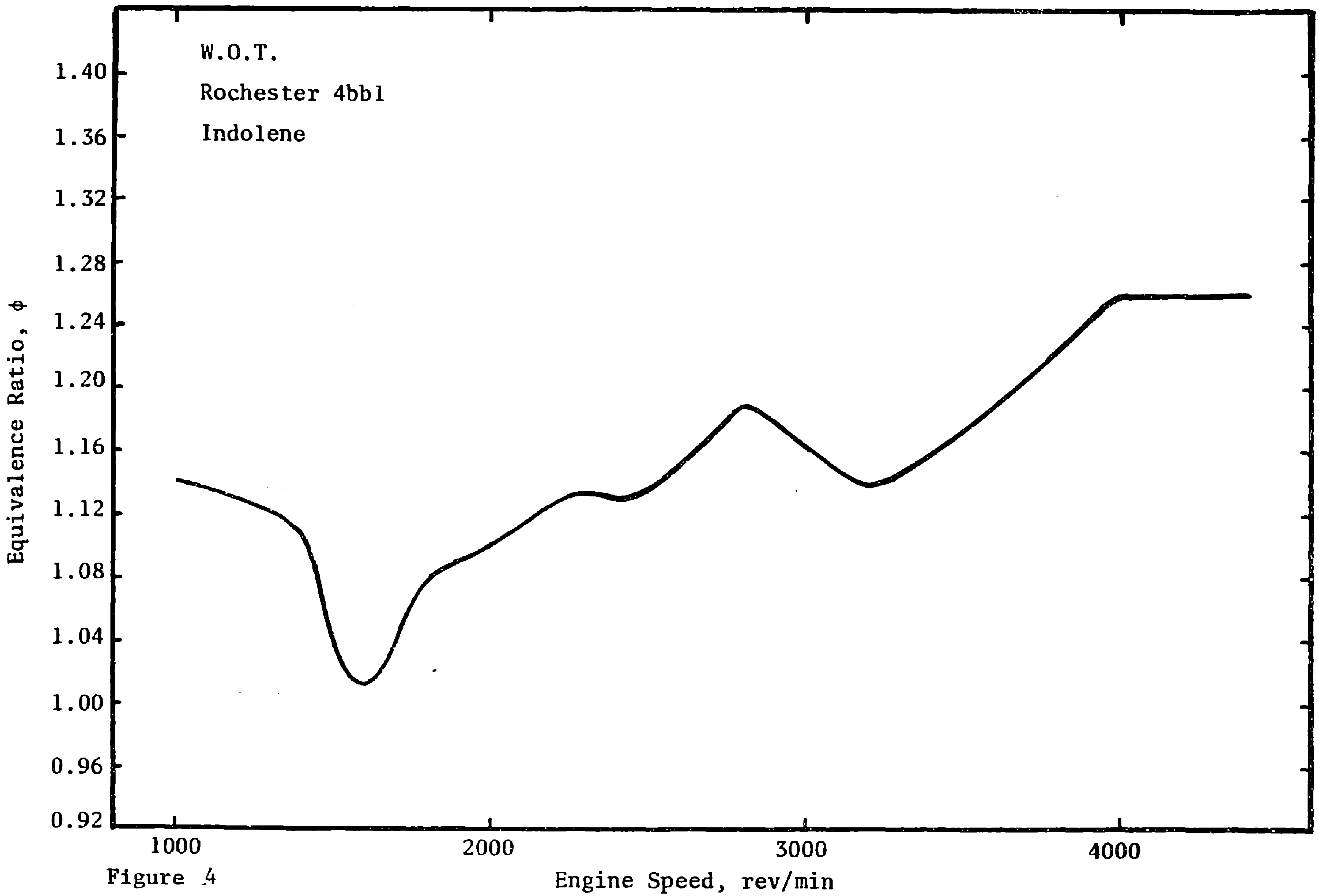

W.O.T.
Rochester 4bbl
Indolene
Equivalence Ratio, φ
1.40
1.36
1.32
1.28
1.24
1.20
1.16
1.12
1.08
1.04
1.00
0.96
0.92
1000
2000
3000
4000
Engine Speed, rev/min

Figure 4

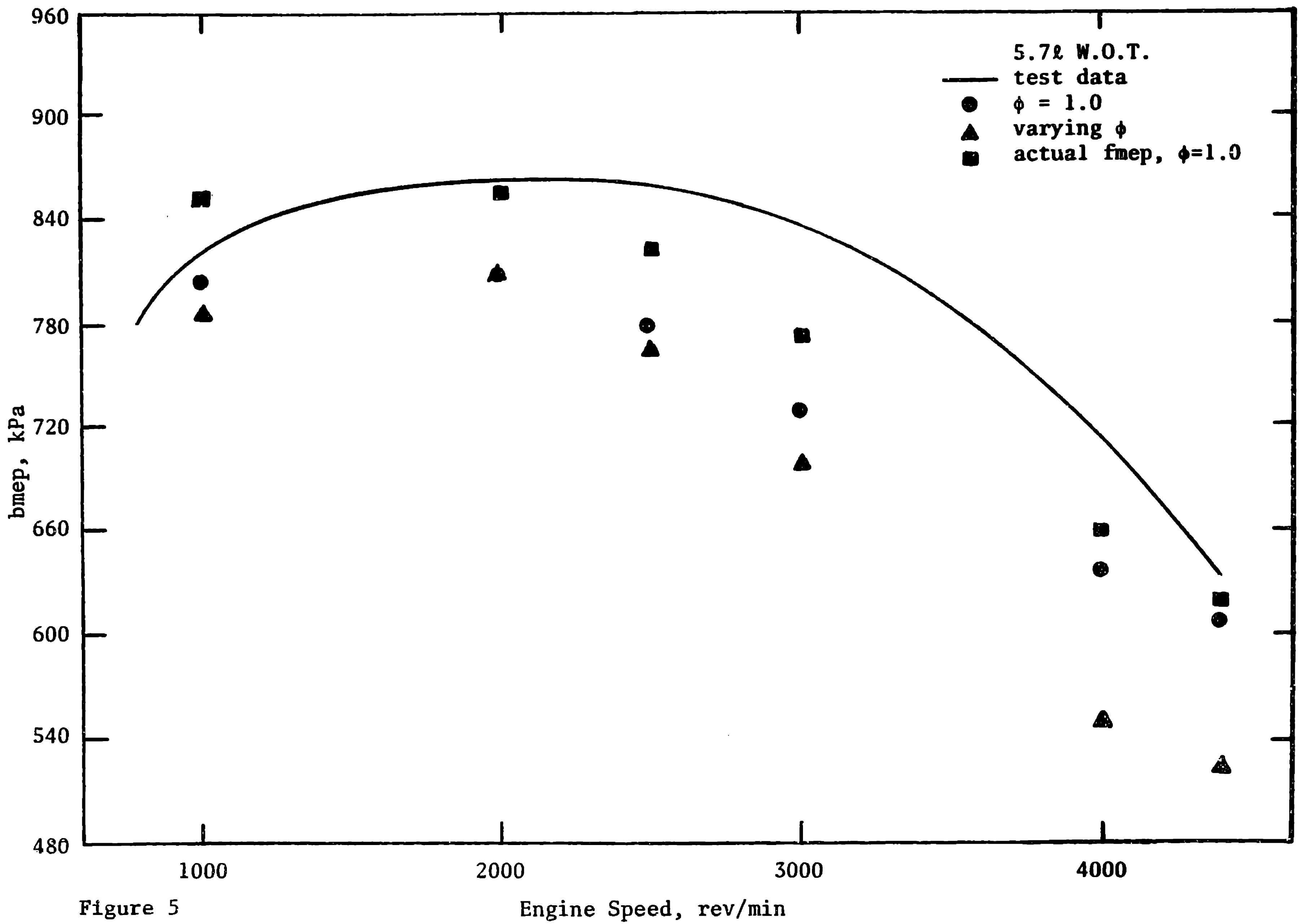

5.7ℓ W.O.T.
test data
ϕ = 1.0
varying ϕ
actual fmep, ϕ=1.0
960
900
840
780
720
660
600
540
480
bmep, kPa
1000
2000
3000
4000
Engine Speed, rev/min

Figure 5

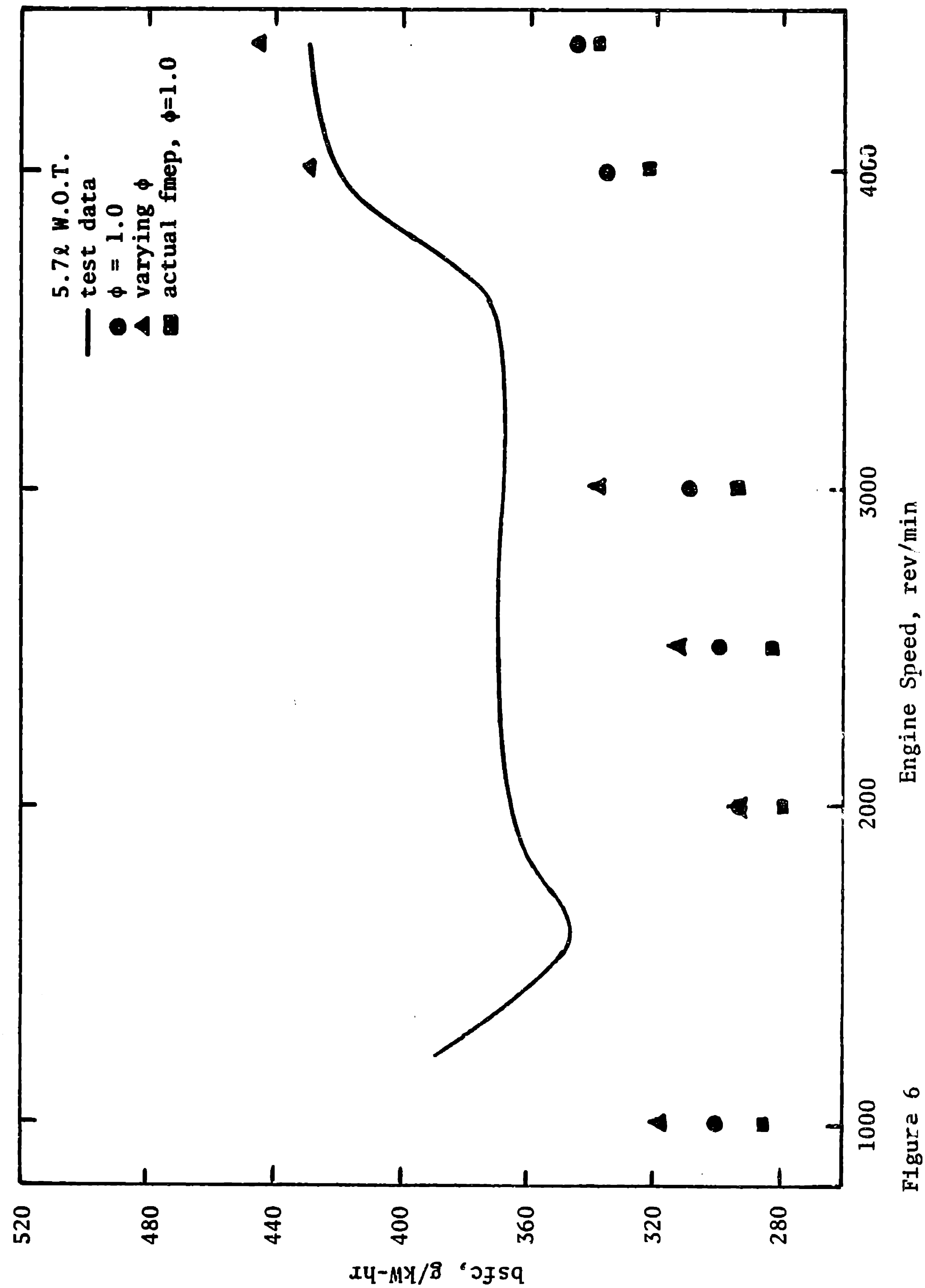
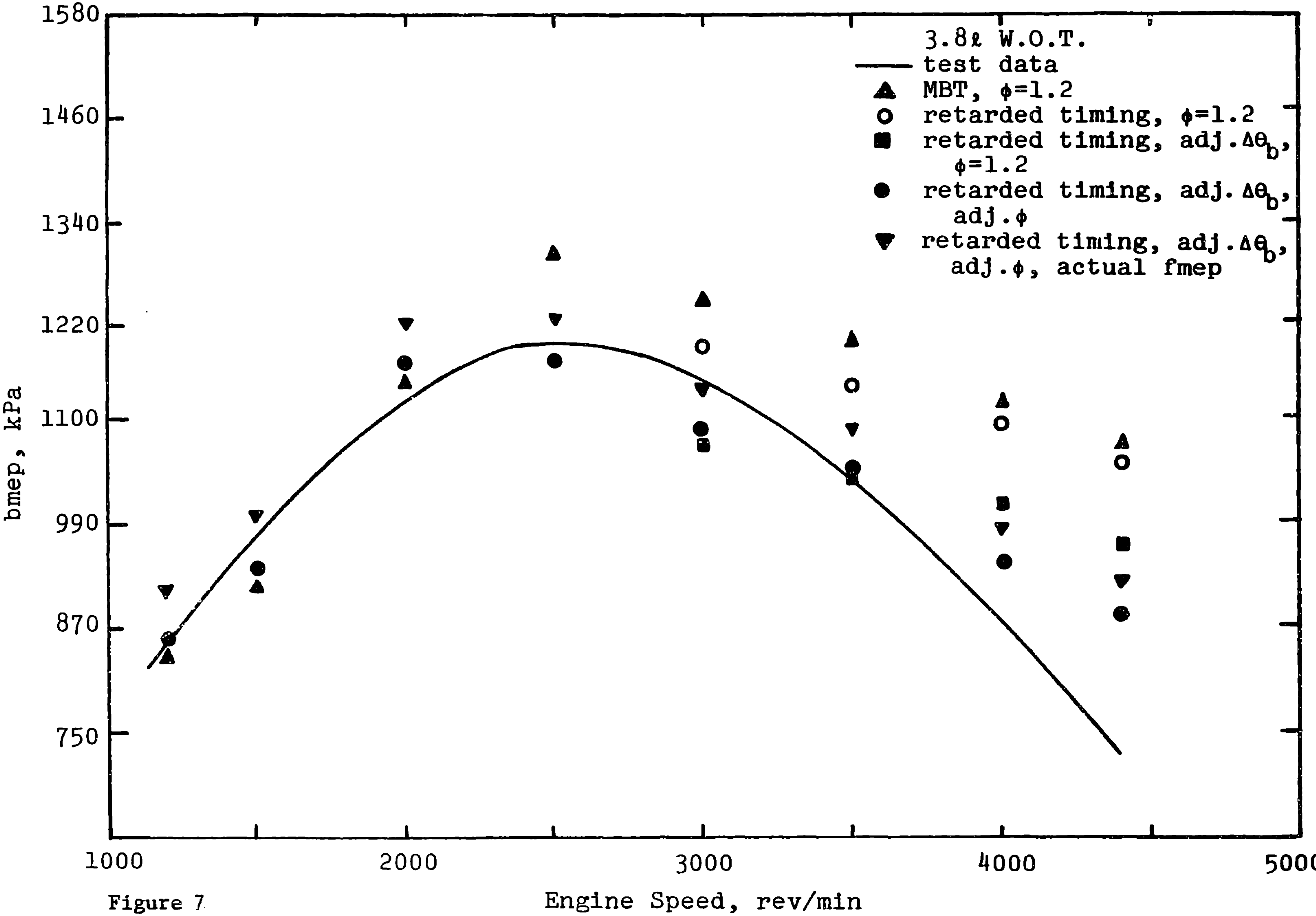

5.7ℓ W.O.T.
test data
φ = 1.0
varying φ
actual fmep, φ=1.0
520
480
440
400
360
320
280
bsfc, g/kW-hr
1000
2000
3000
4000
Engine Speed, rev/min

Figure 6



1580
1460
1340
1220
1100
990
870
750
bmep, kPa
1000
2000
3000
4000
5000
Engine Speed, rev/min
3.8ℓ W.O.T.
test data
MBT, ϕ=1.2
retarded timing, ϕ=1.2
retarded timing, adj.Δθb, ϕ=1.2
retarded timing, adj.Δθb, adj.ϕ
retarded timing, adj.Δθb, adj.ϕ, actual fmep

Figure 7

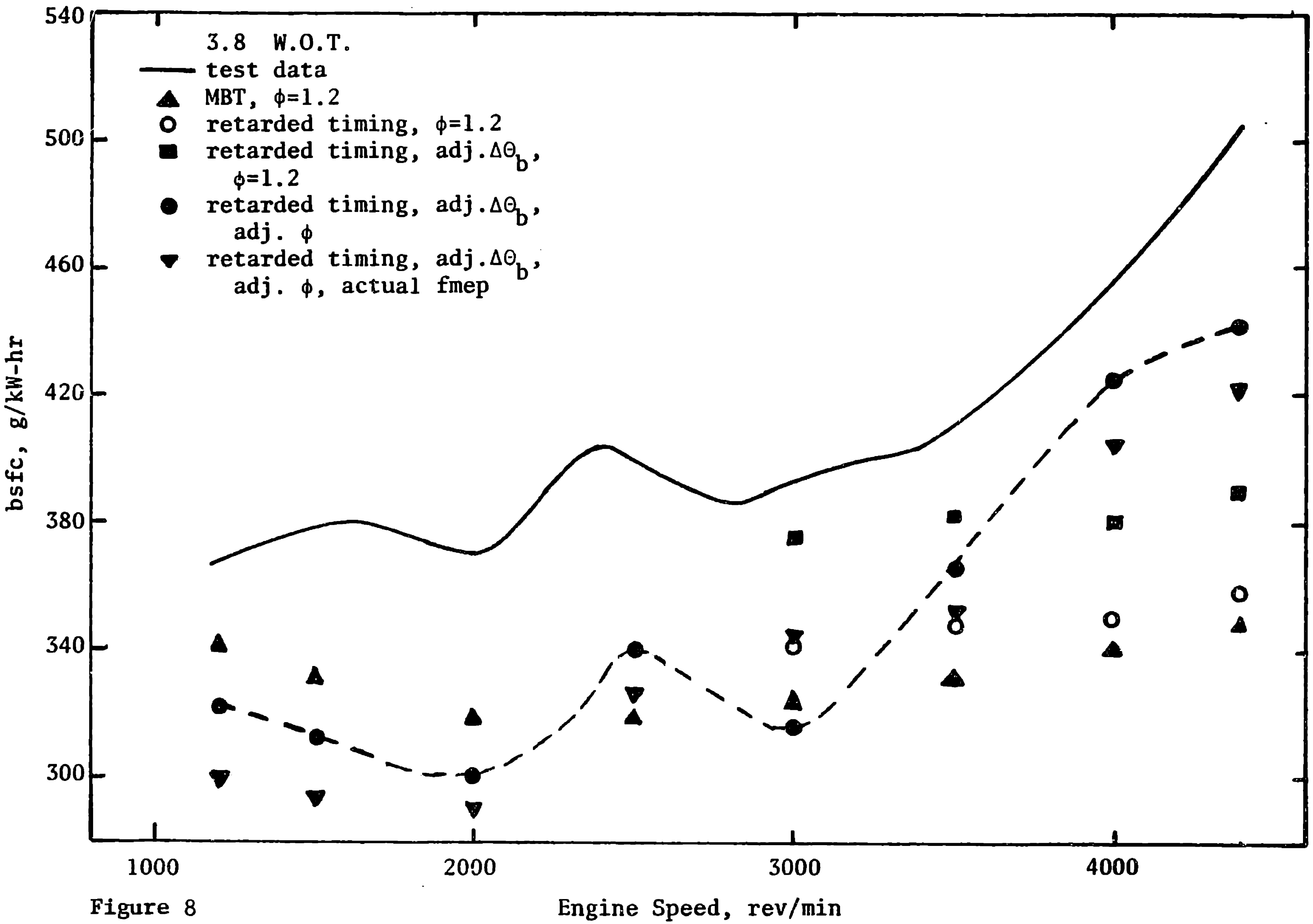
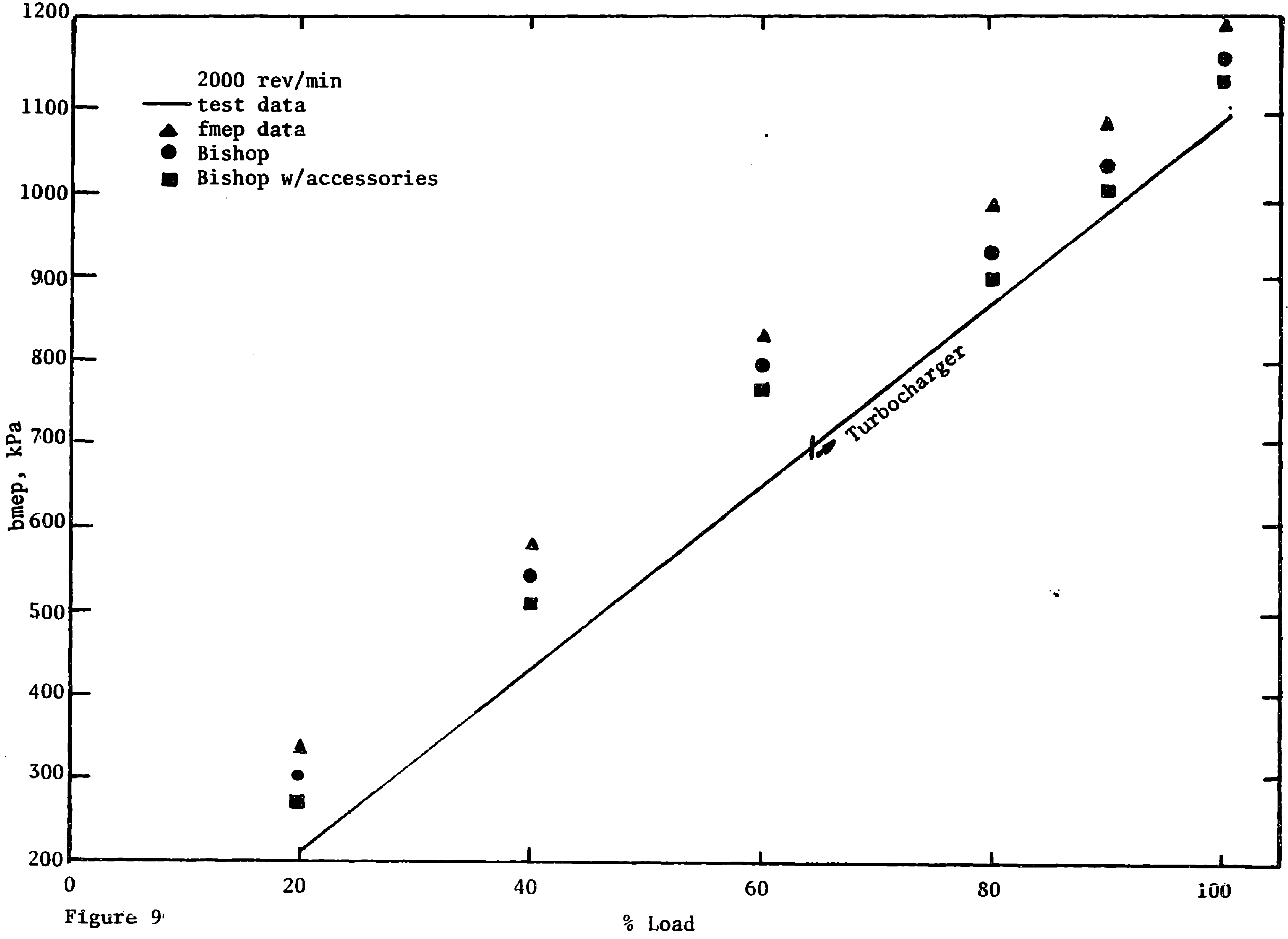

3.8 W.O.T.
test data
MBT, ϕ=1.2
retarded timing, ϕ=1.2
retarded timing, adj.ΔΘb, ϕ=1.2
retarded timing, adj.ΔΘb, adj. ϕ
retarded timing, adj.ΔΘb, adj. ϕ, actual fmep
540
500
460
420
380
340
300
bsfc, g/kW-hr
1000
2000
3000
4000
Engine Speed, rev/min

Figure 8


2000 rev/min
test data
fmep data
Bishop
Bishop w/accessories
Turbocharger
bmep, kPa
1200
1100
1000
900
800
700
600
500
400
300
200
0
20
40
60
80
100
% Load
Figure 9

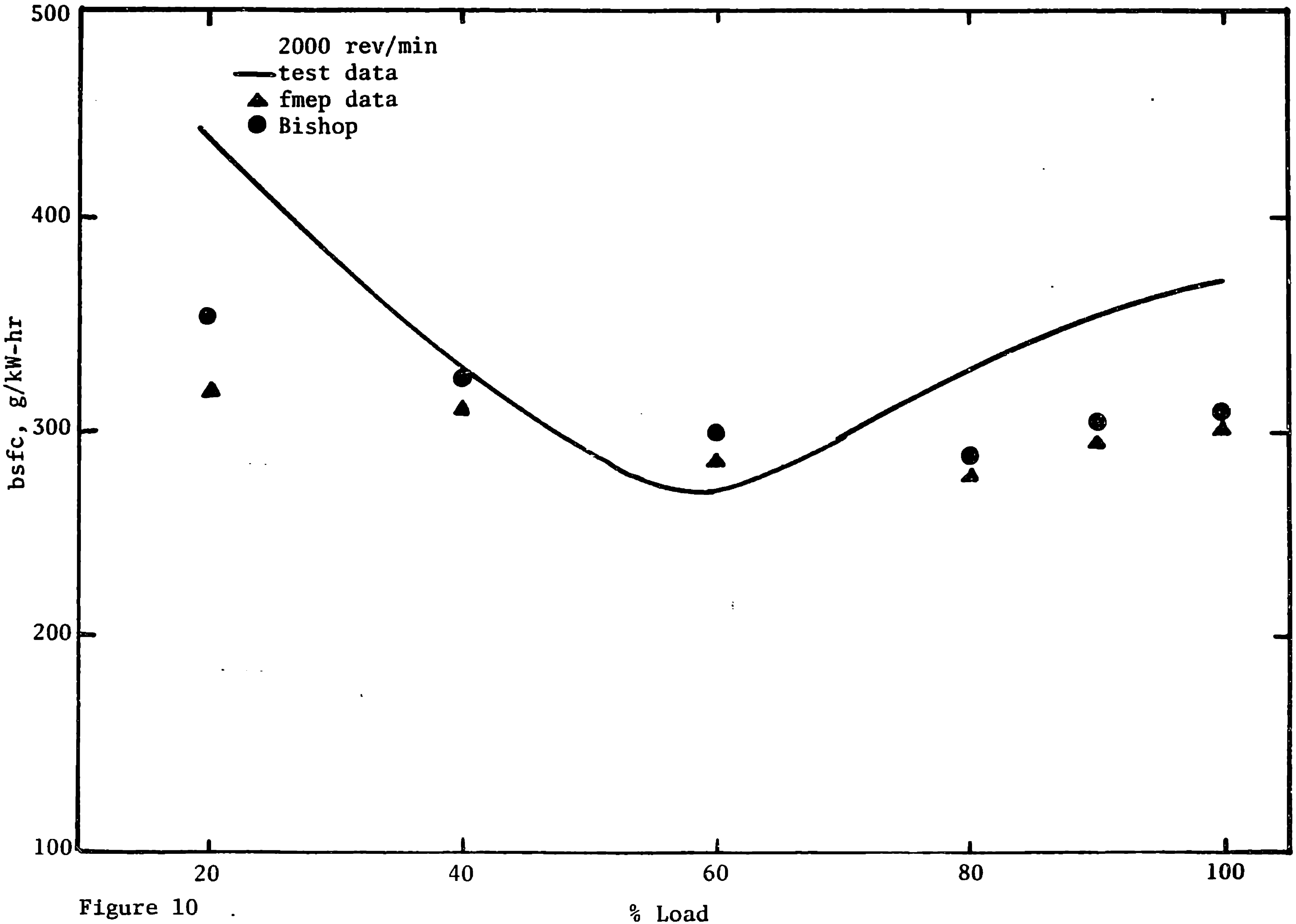
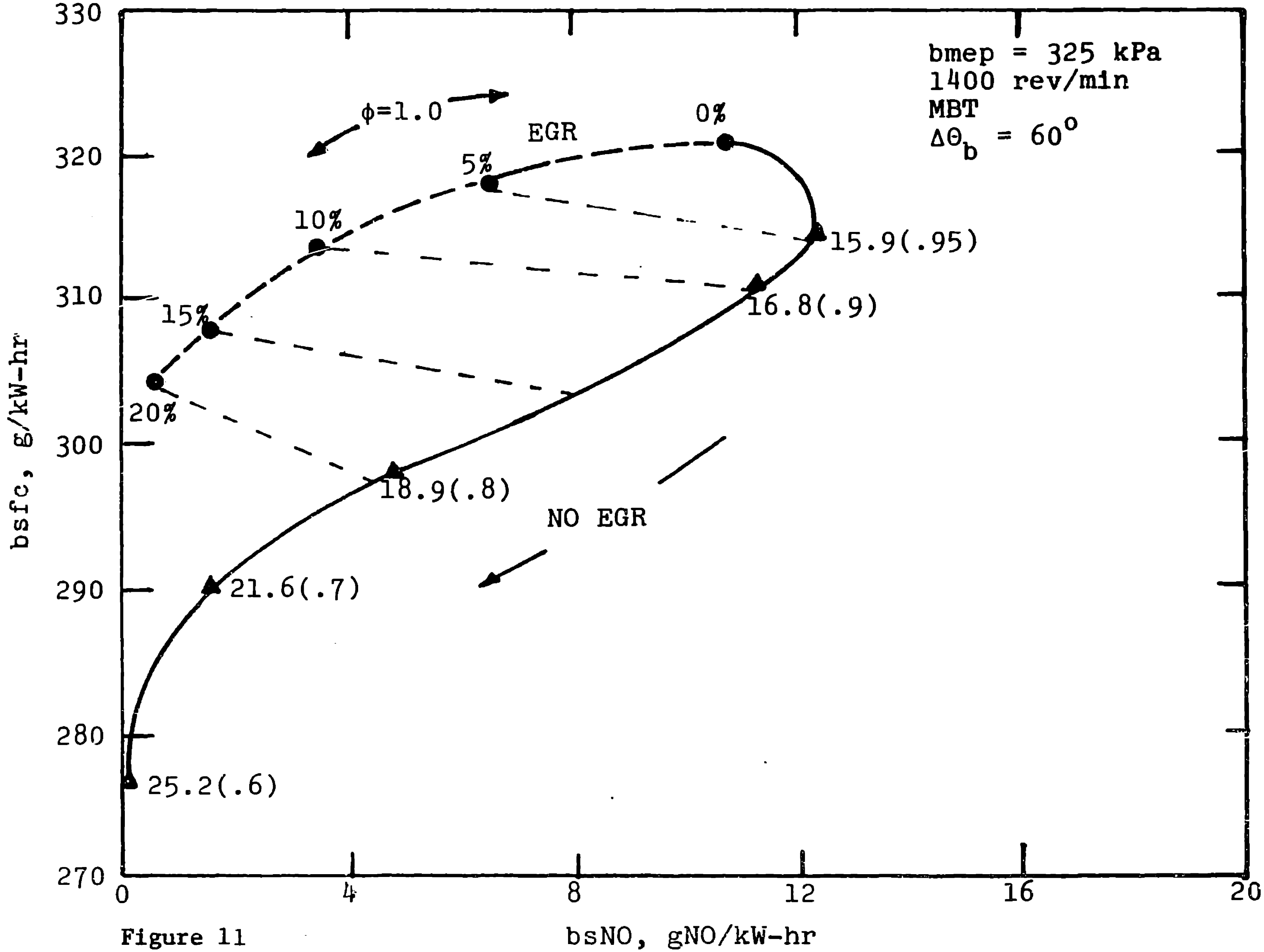

2000 rev/min
test data
fmep data
Bishop
500
400
300
200
100
bsfc, g/kW-hr
20
40
60
80
100
% Load

Figure 10



bmep = 325 kPa
1400 rev/min
MBT
ΔΘb = 60°
φ=1.0
EGR
0%
5%
10%
15%
20%
15.9(.95)
16.8(.9)
18.9(.8)
21.6(.7)
25.2(.6)
NO EGR
330
320
310
300
290
280
270
0
4
8
12
16
20
bsfc, g/kW-hr
bsNO, gNO/kW-hr

Figure 11

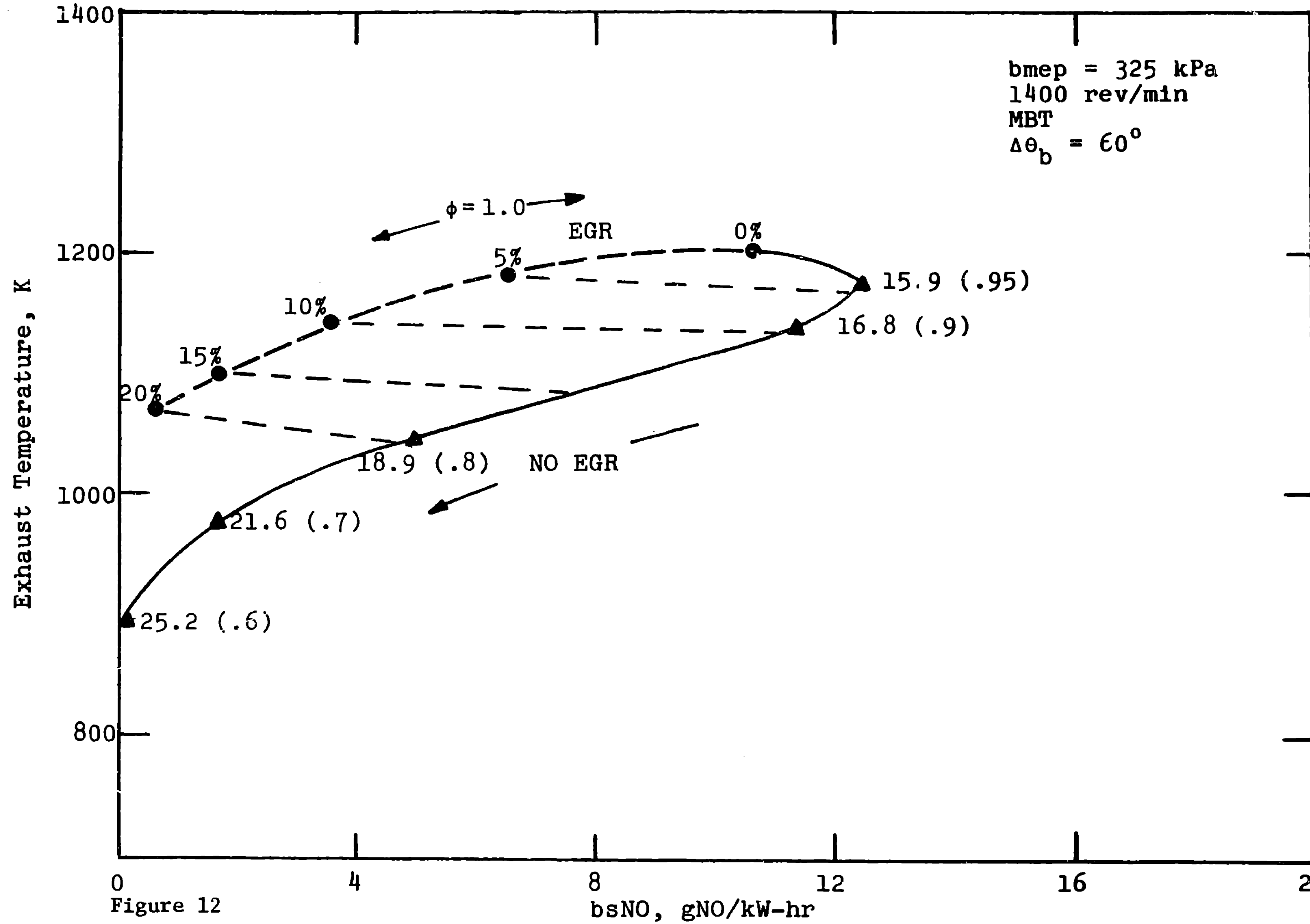

bmep = 325 kPa
1400 rev/min
MBT
Δθb = 60°
φ = 1.0
EGR
0%
5%
10%
15%
20%
15.9 (.95)
16.8 (.9)
18.9 (.8)
21.6 (.7)
25.2 (.6)
NO EGR
Exhaust Temperature, K
1400
1200
1000
800
0
4
8
12
16
20
bsNO, gNO/kW-hr

Figure 12

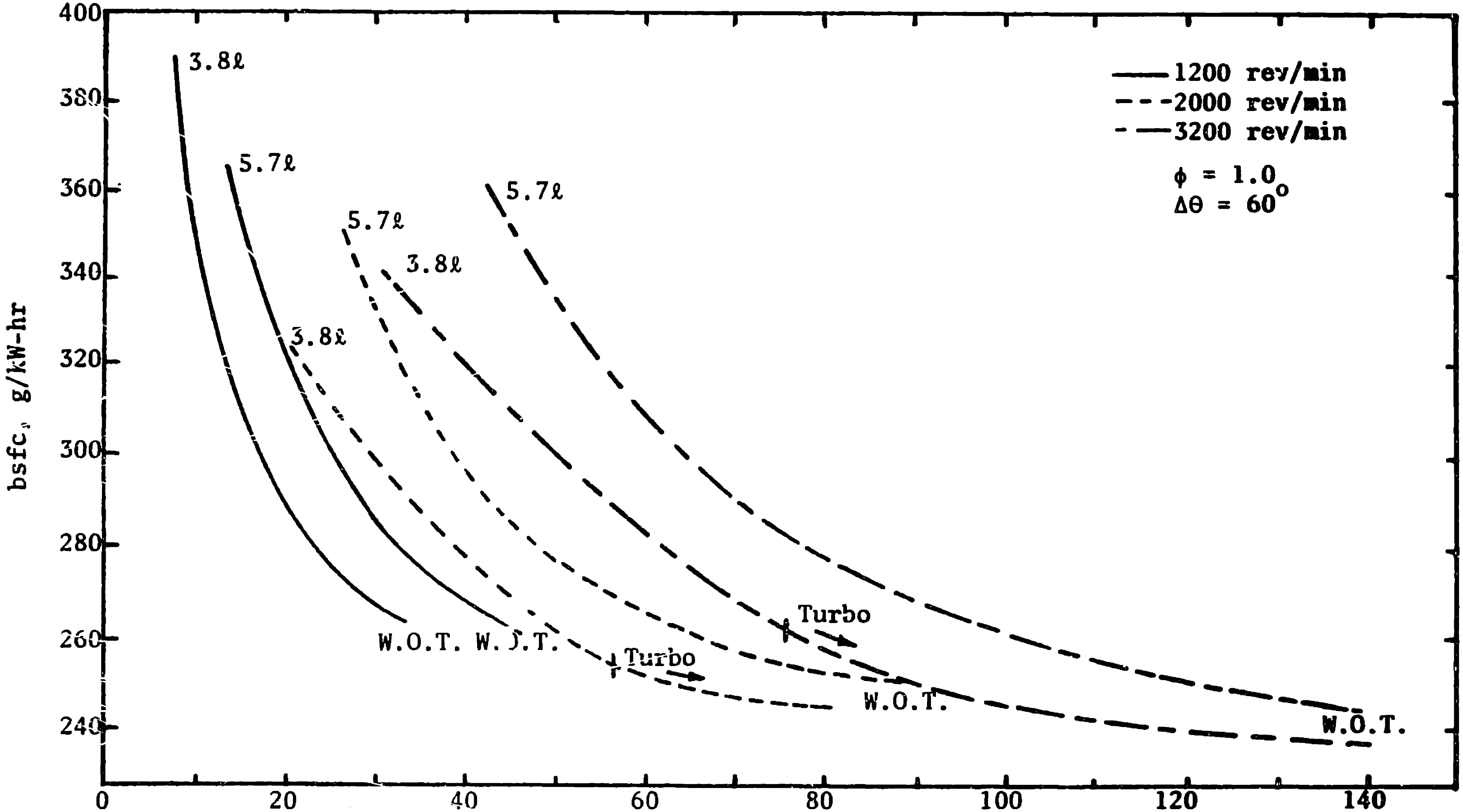

1200 rev/min
2000 rev/min
3200 rev/min
ϕ = 1.0
Δθ = 60°
3.8ℓ
5.7ℓ
5.7ℓ
3.8ℓ
5.7ℓ
3.8ℓ
W.O.T.
Turbo
Turbo
W.O.T.
W.O.T.
bsfc, g/kW-hr
400
380
360
340
320
300
280
260
240
0
20
40
60
80
100
120
140
Brake Power, kW

Figure 13

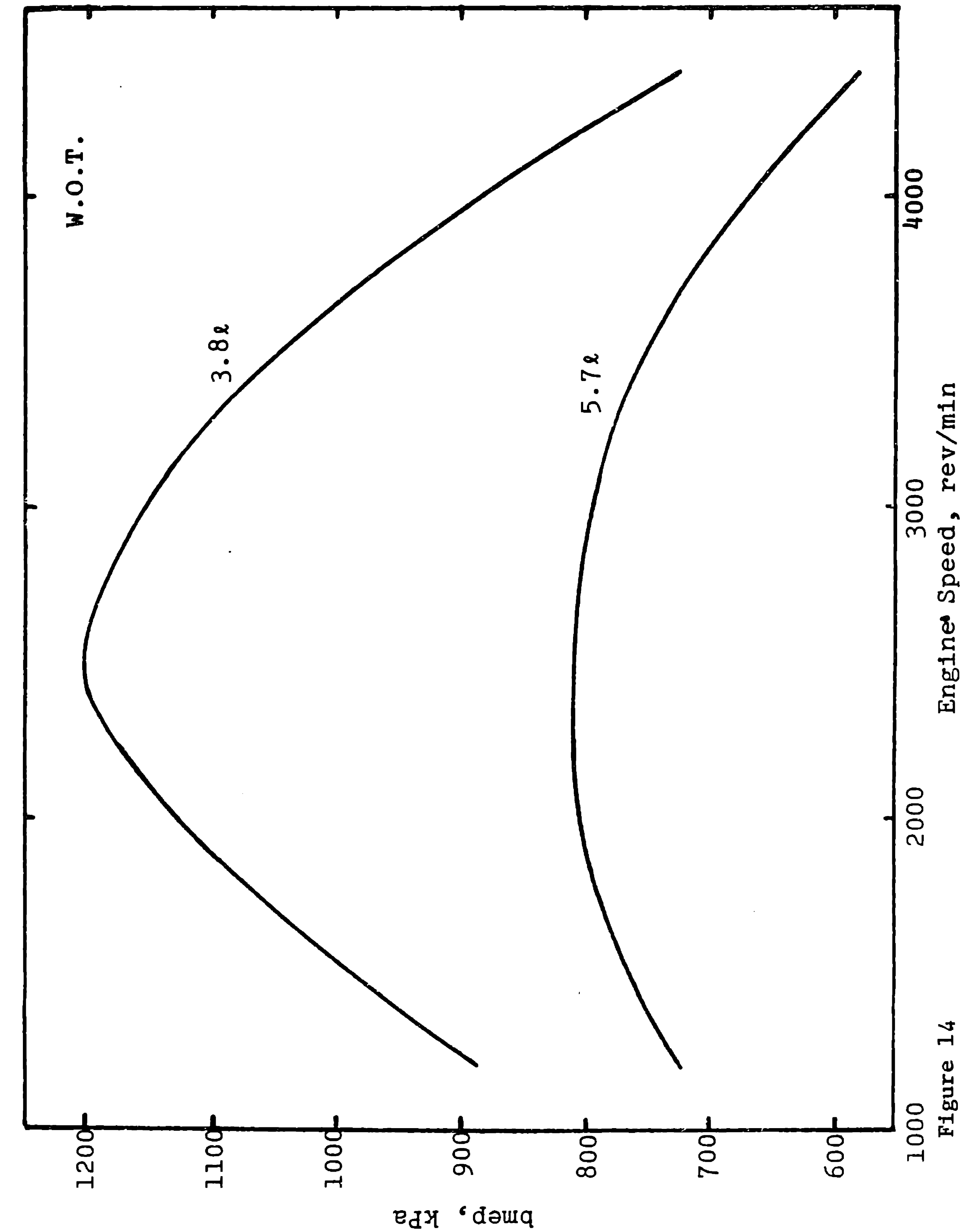

W.O.T.
3.8ℓ
5.7ℓ
1200
1100
1000
900
800
700
600
bmep, kPa
1000
2000
3000
4000
Engine Speed, rev/min

Figure 14

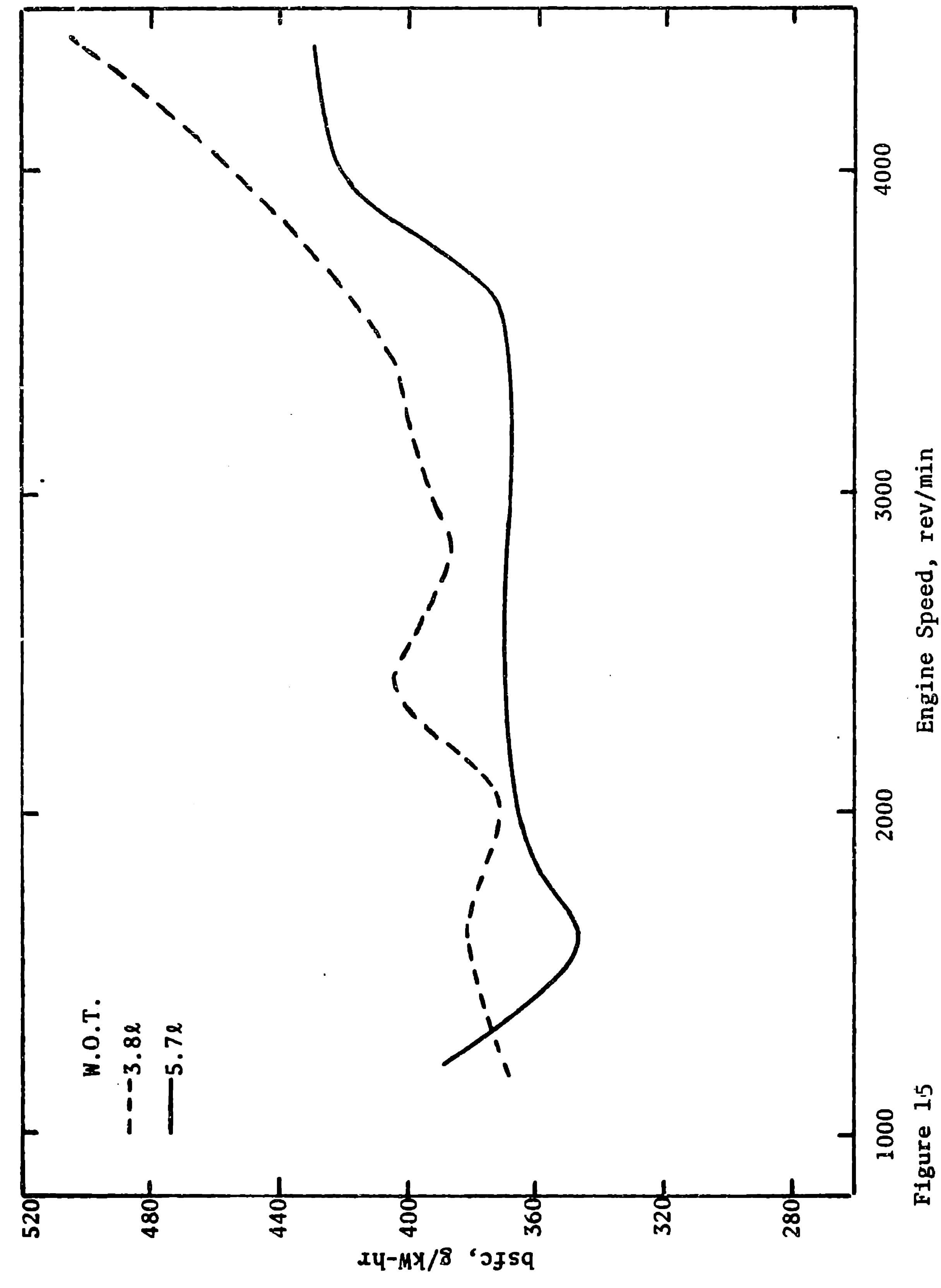
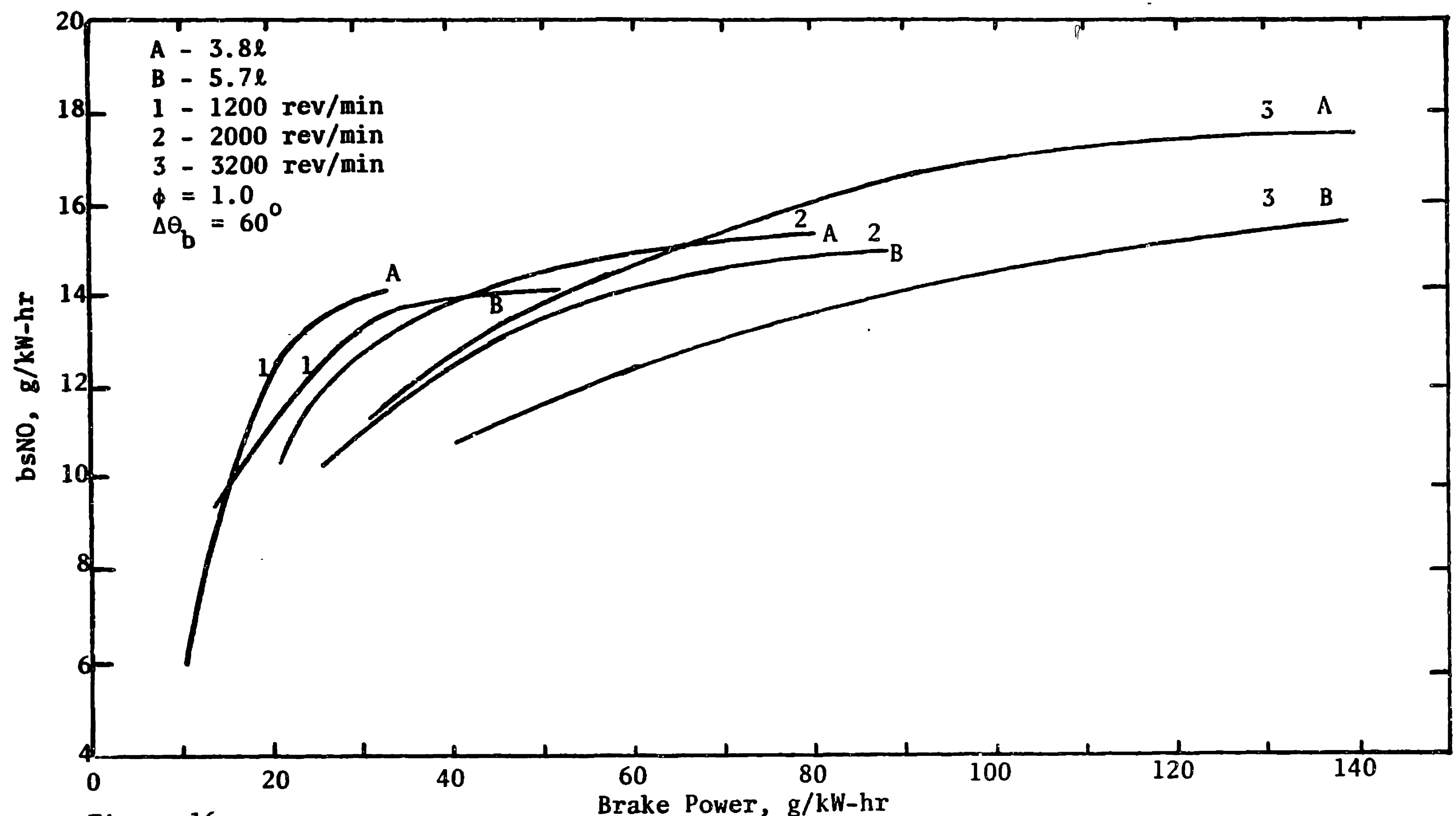

W.O.T.
3.8ℓ
5.7ℓ
520
480
440
400
360
320
280
bsfc, g/kW-hr
1000
2000
3000
4000
Engine Speed, rev/min

Figure 15



A - 3.8ℓ
B - 5.7ℓ
1 - 1200 rev/min
2 - 2000 rev/min
3 - 3200 rev/min
ϕ = 1.0
Δθb = 60°
bsNO, g/kW-hr
Brake Power, g/kW-hr
0
20
40
60
80
100
120
140
4
6
8
10
12
14
16
18
20
1
1
A
B
2
A
2
B
3
A
3
B

Figure 16

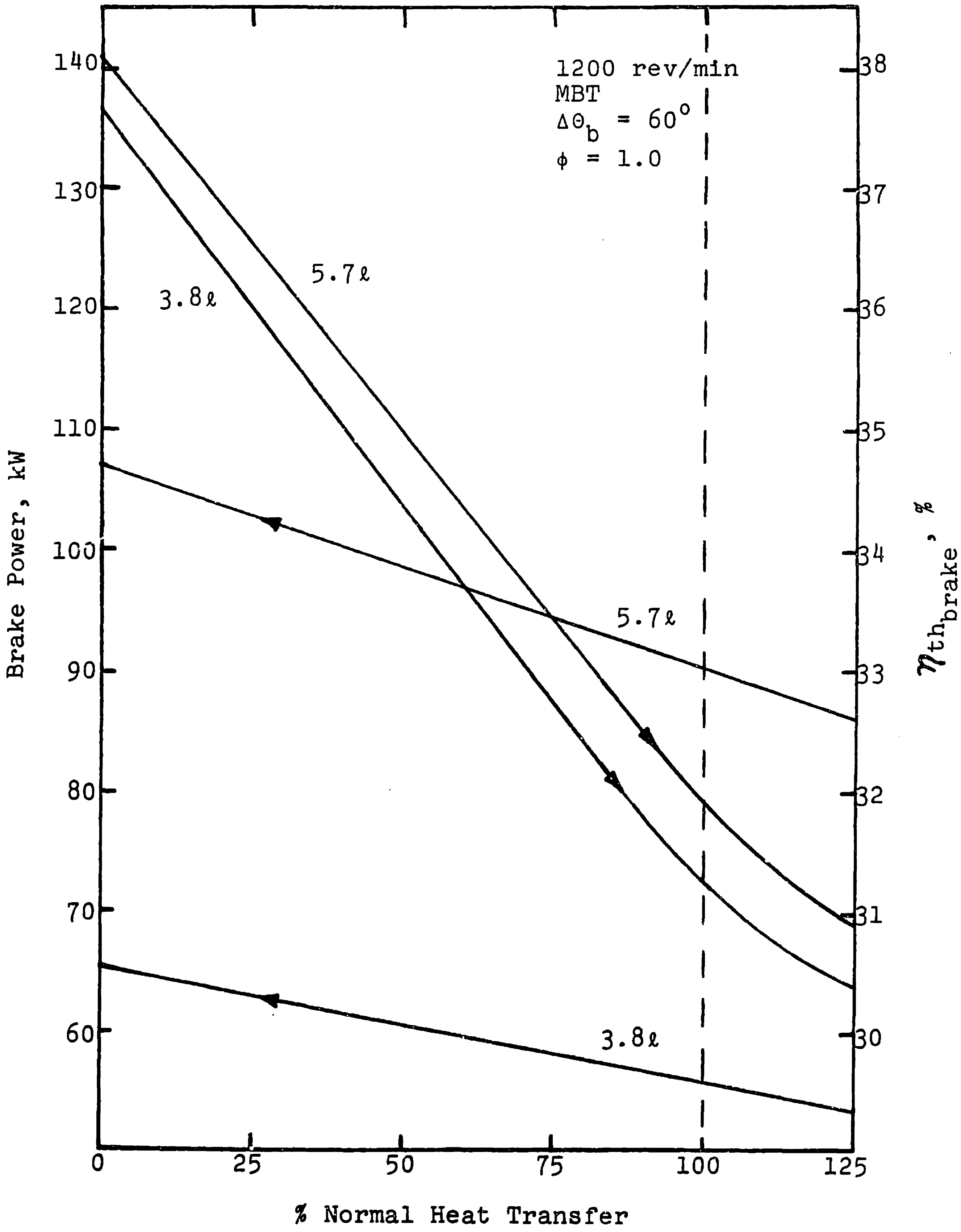

1200 rev/min
MBT
$\Delta\Theta_b = 60^\circ$
$\phi = 1.0$
5.7ℓ
3.8ℓ
5.7ℓ
3.8ℓ
Brake Power, kW
$\eta_{th_{brake}}$, %
140
130
120
110
100
90
80
70
60
38
37
36
35
34
33
32
31
30
0
25
50
75
100
125
% Normal Heat Transfer

Figure 17

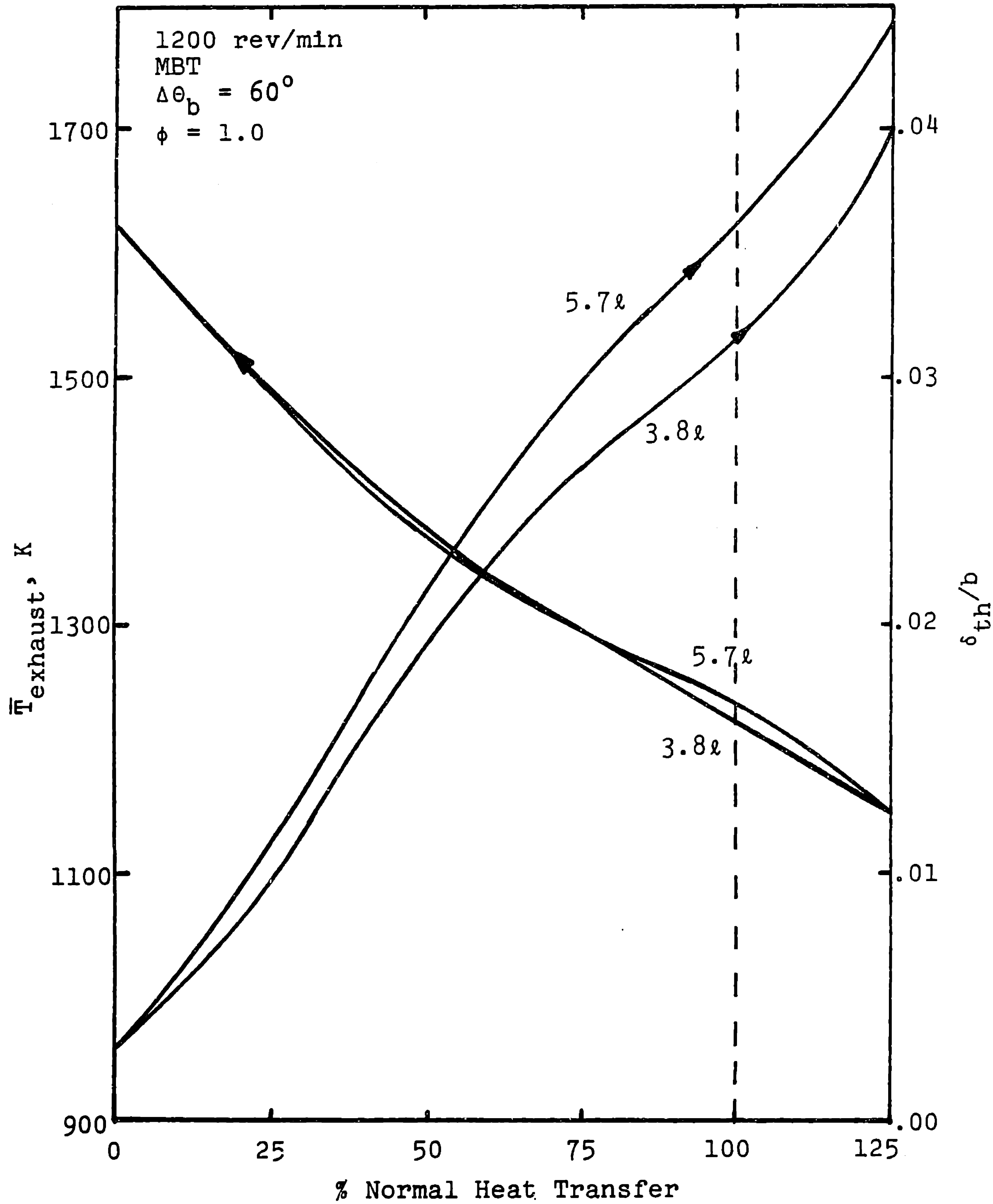

1200 rev/min
MBT
$\Delta\Theta_b = 60^\circ$
$\phi = 1.0$
1700
1500
1300
1100
900
$\bar{T}_{exhaust}$, K
.04
.03
.02
.01
.00
δ_{th}/b
5.7ℓ
3.8ℓ
5.7ℓ
3.8ℓ
0
25
50
75
100
125
% Normal Heat Transfer

Figure 18

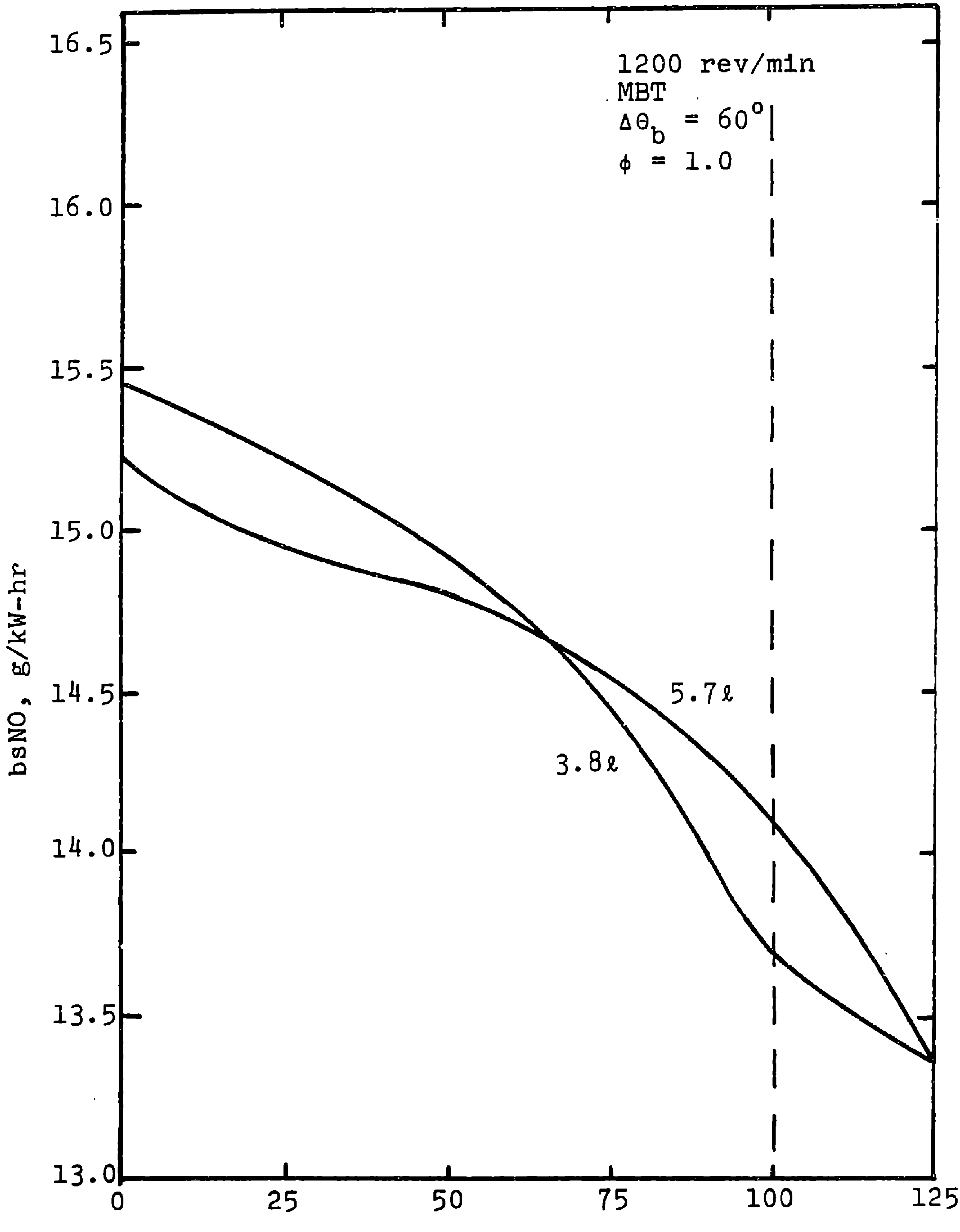

1200 rev/min
MBT
$\Delta\theta_b = 60^o$
$\phi = 1.0$
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
bsNO, g/kW-hr
5.7ℓ
3.8ℓ
0
25
50
75
100
125
% Normal Heat Transfer

Figure 19

APPENDIX A

Correlations For Determining Ignition Delay And Combustion Duration

An important characteristic of the use of the cycle simulation presented is that the details of the combustion process must be supplied as input. These details are provided in the form of a Wiebe function (Eq. 1) described on page 15 . The efficiency parameter, a, and the form factor, m, were determined experimentally by LoRusso (17). The parameters of combustion duration, $\Delta\Theta_b$, and start of combustion timing, Θ_o, vary with varing modes of engine operation. Therefore, to match experimental data these parameters must be determined for each different engine operating point. Start of combustion timing is related to actual engine spark timing through as ignition delay period, $\Delta\Theta_{ig}$:

$$\Theta_s = \Theta_o - \Delta\Theta_{ig} \tag{11}$$

Hires et. al. (14) performed parametric studies based on the geometry of a 6.6ℓ engine to determine the effects of a wide range of spark advances, engine speeds, equivalence ratios, EGR and loads on combustion duration and ignition delay. Values of $\Delta\Theta_{ig}$ and $\Delta\Theta_b$ for the model validation studies were taken from Hires et. al.'s parametric studies. Then through correlations for $\Delta\Theta_{ig}$ and $\Delta\Theta_b$ derived by Hires et. al. and geometric assumptions the values of $\Delta\Theta_{ig}$ and $\Delta\Theta_b$ were scaled to correspond to the smaller 5.7ℓ and 3.8ℓ engines.

The correlation developed by Hires et. al. for determining $\Delta\Theta_{ig}$ is:

$$\Delta\Theta_{ig} \propto (S_p \nu)^{1/3} (h/S_\ell)^{2/3} \quad (12)$$

where

S_p = piston speed

ν = kinematic viscosity

h = instantaneous chamber height

S_ℓ = laminar flame speed

From basic engine principles it can be shown that

$$S_p \propto L\ RPM \quad (13)$$

and

$$h \propto L \quad (14)$$

where L is the stroke.

Equations (12) through (14) can be combined to yield:

$$\Delta\Theta_{ig} \propto (L RPM \nu)^{1/3} (L/S_\ell)^{2/3} \quad (15)$$

The residual fraction within the engine has a significant effect on the laminar flame speed. Hires et. al. have shown that for intake pressures near atmospheric (W.O.T.) and greater that the residual fraction is small and nearly constant. Therefore, laminar flame speed would not vary significantly for W.O.T. and turbocharged operation. In addition, it is assumed that the viscosity would be similar for different size engines under the same operating conditions. With these considerations Eq. (15) reduces to

$$\Delta\Theta_{ig} \propto L(RPM)^{1/3} \tag{16}$$

The correlation Hires et. al. derived for determining $\Delta\Theta_b$ is given as:

$$\Delta\Theta_b \propto (b/h^*)\,(S_p\nu^*)^{1/3}\,(h_i/S_\ell^*)^{2/3} \tag{17}$$

where

b = bore

h_i = instantaneous chamber height

$*$ = values at 50% mass fraction burned

Combining equations (13), (14) and (17) yields:

$$\Delta\Theta_b \propto b(RPM\nu^*)^{1/3}\,(1/S_\ell^*)^{2/3} \tag{18}$$

Again, making the same aforementioned assumptions concerning laminar flame speed and viscosity, Eq. (18) reduces to

$$\Delta\Theta_b \propto b(RPM)^{1/3} \qquad (19)$$

Equations (16) and (19) were the correlations used to scale the values of $\Delta\Theta_{ig}$ and $\Delta\Theta_b$ taken from the parametric studies to correspond to the smaller 5.7ℓ and 3.8ℓ engines.

```
MEMBER NAME  MAIN
C
C
C    MAIN CALLING PROGRAM
      INTEGER CD, PRI, DSI,DSO,V,C,P1,P2,T,TP,Z
      COMMON/EVAP/RGGZS(8)    ,IVERD(8)
      COMMON /TITLE/ NA(60)
      COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
     1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
      CD = 5
      PRI = 6
      DSI = 11
      V = 0
C
C    WRITE DUMMY RECORD ON TEMPORARY OUTPUT FILES FOR EOF
C
      REWIND 12
      REWIND 13
      WRITE ( 12, 71 )
      WRITE ( 13, 71 )
   71 FORMAT ( '     DUMMY RECORD FOR EOF' )
C
C    READ DATA CARDS & BUILD DISK DATA SET
C
C    REWIND INPUT DATA SET FOR MULTI-STEP JOBS
C
      REWIND DSI
C
  100 READ  ( CD, 101, END=210 )   ( NA(I), I = 1, 20 )
      WRITE (DSI, 101 )            ( NA(I), I = 1, 20 )
  101 FORMAT (  20A4 )
      GO TO 100
C
C    D.S. EXISTS, LOAD DATA INTO COMMON
C
  210 REWIND DSI
```

```
 1000 CONTINUE
      CALL REED
      CALL CONVR
      CALL CALC
      GO TO 1000
      STOP
      END
```

```
MEMBER NAME  COMP
      SUBROUTINE COMP(TH,T1,T2,G,N,*)
C CRITERIA FOR CONVERGENCE AND PRECISION
C GETESTET 5.8.69
      DIMENSION TH(N),T1(N),T2(N)
      INTEGER G(N)
      IF(ABS(TH(N)-T1(N)).LE.ABS(T1(N)-T2(N))-.01)GOTO 20
      IF(ABS(1.-T2(N)/T1(N)).GE..0001)GOTO40
      G(N)=0
      GOTO 50
   40 G(N)=-1
      TH(N)=T1(N)
      T1(N)=T2(N)
      GOTO 50
   20 RETURN 1
   50 RETURN
      END
```

```
MEMBER NAME  CONPM
      SUBROUTINE CONPM(D1,D2,G,N)
C CRITERIA FOR CONVERGENCE AND PRECISION
      DIMENSION D1(N),D2(N)
      INTEGER G(N)
      IF(ABS(1.-D1(N)/D2(N)).GE.0.0001) GO TO 40
      G(N)=0
      GO TO 50
   40 G(N)=-1
      D1(N)=D2(N)
   50 RETURN
      END
```

```
MEMBER NAME  CANOX
      SUBROUTINE CANOX (N,PZ,GGZ,DR)
C SEPTNO CRBELIB NAME
C CALCULATION OF NOX IN BURNED CYLINDER CONTENTS
      COMMON /FUEL/SLB,CE,LAV,RB,ML,MBR,MRG,VERDD,Q(3,7)
     1/GEOM/D,H,LA,EPS,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI1,
     2XC,FK,VH,TAKT
     3/MASS/MO,M1,MO,ME,MA,MEA,MEE
      COMMON /CNOX/TZU(8),TZUS(8),TZB(8),TZBS(8),NNOU(8),
     1NNOB(8),DNOOUI(8),DNOOU(8),DNOOBI(8),NNOT(8),
     2DNOOB(8),  FBURN,ITEST(8),NRP, BS   , FNNOTS, FBURNS
      COMMON /OUTP/ CNOPPM(8)
      COMMON /ORG/NEUIN(8),PP,CO,DBV,VERD
      COMMON /STEPS/DPHI
      COMMON/CONCO/XCO,TMOLCO
      COMMON /COMB/AV,MV,PHIVA(8),VD
      COMMON/APROP/DEL,PSI
      COMMON/PHICHI/CHI
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,QLOWER
      COMMON/ADIAB/TADBS(8),TADB(8),XMA,XMB,VADB,VBL,RADB,RMEAN
      REAL*8 TBULK,GPZ,DEQIB,XMOFR
      DIMENSION PZ(8),VB(8),TZ(8),TU(8),GGZ(8),ITES1(8),
     2YBM3(8),YBN(8),YPBM2(8),YBM2(8),YPBM1(8),YPBN(8),YBM1(8),
     4YBNP1(8),FBURNS(8),YPBNP1(8),FNNOTS(8),TWX(8)
      REAL LAV,ML,MBR,MRG,MV,MO(8),M1(8),MO,ME(8),MA(8),
     1MEA(8),MEE(8),M1B,NNOU,NNOB,NNOT,INNOT(8),MSTAR
      REAL NNOE,NNE
      INTEGER PP(8),CO(8),DBV(8)
      DIMENSION DEQIB(4),XMOFR(14)
      LOGICAL VERD
      IF(XMA.LE.0.0001*MO*MO(N)) GO TO 5432
      IF(ITEST(N).EQ.1)GO TO 112
      ITEST(N)=1
      ITES1(N)=0
      DNORP1=0.0
      DNORN=0.0
```

```
      DNORM1=0.0
      DNORM2=0.0
      IF(PP(N).GT.1) GO  TO  360
      FBURNS(N)=0.1E-10
      INNOT(N)=0.3E-20
      FNNOTS(N)=0.1E-20
      NNOU(N)=INNOT(N)
      NNOB(N)=0.0
      NNOT(N)=0.0
      GOTO 361
  360 CONTINUE
      INNOT(N)=(1.-GGZ(N))*FNNOTS(N)
      FBURNS(N)=0.1E-10
      NNOU(N)=INNOT(N)
      NNOB(N)=0.0
      NNOT(N)=0.0
  361 CONTINUE
      CNOPPM(N)=0.0
      DNOBL=0.
      BLNO=0.
      XMBS=0.
      GOTO 260
  112 CONTINUE
      DNORP1=(FBURN-FBURNS(N))*INNOT(N)
      IF(FBURN.LE.0.1E-10)GOTO 260
      G=PZ(N)
      PZ(N)=G*9.8692*10.**(-6.)
      M1B=XMA
      GPZ=PZ(N)
      WMOZ=8314.7/RADB
      TBULK=TADB(N)
      VB1MQ=(XMA*1.0E+06*RADB*TADB(N))/G
      VBOUND=(M1B-MSTAR)*RQ*TMEAN/G
      XHY=HY/CX
      XOZ=OZ/CX
      XNW=ENW/CX
```

```
      XWHY=LAV*(1.+XHY/4.-XOZ/2.)
      DEQIB(1)=XHY
      DEQIB(2)=1.
      DEQIB(4)=XOZ+2.*XWHY
      DEQIB(3)=XNW+2.*3.764*XWHY
      IF(TADB(N).LT.1800.) GO TO 701
      CALL PTCHEM(TBULK,GPZ,DEQIB,XMOFR,ISENT)
      IF(ISENT.GT.0) GO TO 6666
      GO TO 6668
 6666 WRITE(6,6667)ISENT
 6667 FORMAT(5X,'ERROR IN EQUILIBRIUM PROGRAM ',I6 )
      GO TO 6668
  701 DO 711 KEQ=1,14
  711 XMOFR(KEQ)=1.0E-10
 6668 XCO=XMOFR(2)
      PZ(N)=G
      TOTMOL=(XMA)*RADB/8314.7*1000.
      NNOE=XMOFR(9)*TOTMOL
      NNE=XMOFR(8)*TOTMOL
      D1BE=1.9857*TBULK
      RK1FB=7.6E+13*EXP(-75456./D1BE)
      RK1RB=1.60E+13
      IF(TADB(N).LT.1800.) RK1RB=0.0
      RK2FB=(6.4E+09)*TBULK*EXP(-6255./D1BE)
      RK2RB=1.5E+09*TBULK*EXP(-38721./D1BE)
      RK3FB=0.
      RKOH=4.1E+13
      XSS=RK1RB*XMOFR(9)/(RK2FB*XMOFR(14)+RKOH*XMOFR(5))
      CAPL=XSS
      IF(ITES1(N).GT.3)GOTO 254
      IF(NNOB(N).LE.0.)   NNOB(N)=1.0E-15*TOTMOL
      ALPHA1=NNOB(N)/NNOE
      TER1=2.*RK1RB*NNE*NNOE/VB1MQ*(1.-ALPHA1**2.)
      TER2=1.+ALPHA1*CAPL
      DNOOB(N)=TER1/(0.10472*DR*TER2)
      DNOBL=(XMB-XMBS)*TOTMOL/XMA*NNOB(N)/DPHI
```

```
      NNOB(N)=NNOB(N)+DNOOB(N)*DPHI
      NNOB(N)=NNOB(N)+DNORP1-DNOBL*DPHI
      NNOU(N)=NNOU(N)-DNORP1
      BLNO=BLNO+DNOBL*DPHI
      IF(ITES1(N).GT.0)GO TO 250
      ITES1(N)=ITES1(N)+1
      YBM3(N)=NNOB(N)
      DNORN=DNORP1
      XBLM3=BLNO
      GO TO 255
  250 CONTINUE
      IF(ITES1(N).GT.1)GO TO 251
      ITES1(N)=ITES1(N)+1
      YBM2(N)=NNOB(N)
      YPBM2(N)=DNOOB(N)
      XBLM2=BLNO
      XPBLM2=DNOBL
      DNORM1=DNORN
      DNORN=DNORP1
      GO TO 255
  251 CONTINUE
      IF(ITES1(N).GT.2)GO TO 252
      ITES1(N)=ITES1(N)+1
      YPBM1(N)=DNOOB(N)
      YBM1(N)=NNOB(N)
      XBLM1=BLNO
      XPBLM1=DNOBL
      DNORM2=DNORM1
      DNORM1=DNORN
      DNORN=DNORP1
      GO TO 255
  252 CONTINUE
      IF(ITES1(N).GT.3)GO TO 253
      ITES1(N)=ITES1(N)+1
      YPBN(N)=DNOOB(N)
      YBN(N)=NNOB(N)
```

```
      XPBLN=DNOBL
      XBLN=BLNO
      DNORM2=DNORM1
      DNORM1=DNORN
      DNORN=DNORP1
  253 CONTINUE
  254 CONTINUE
      YBNP1(N)=(4.*DPHI/3.)*(2.*YPBM2(N)-YPBM1(N)+2.*YPBN(N))+YBM3(N)
      YBNP1(N)=YBNP1(N)+DNORP1+DNORN+DNORM1+DNORM2
      IF(YBNP1(N).LE.0.)   YBNP1(N)=1.0E-15*TOTMOL
      XBLNP1=(4.*DPHI/3.)*(2.*XPBLM2-XPBLM1+2.*XPBLN)+XBLM3
      IF(XBLNP1.LE.0.000000) XBLNP1=1.0E-15*TOTMOL
      ALPHA1=YBNP1(N)/NNOE
      TER1=2.*RK1RB*NNE*NNOE/VB1MQ*(1.-ALPHA1**2.)
      TER2=1.+ALPHA1*CAPL
      YPBNP1(N)=TER1/(0.10472*DR*TER2)-DNOBL
      NNOU(N)=NNOU(N)-DNORP1
      NNOB(N)=YBM1(N)+(DPHI/3.)*(YPBM1(N)+4.*YPBN(N)+YPBNP1(N))
      NNOB(N)=NNOB(N)+DNORP1+DNORN
      XPNP1=(XMB-XMBS)*NNOB(N)*TOTMOL/XMA/DPHI
      DNOBL=XPNP1
      BLNO=XBLM1+DPHI/3.*(XPBLM1+4.*XPBLN+XPNP1)
      IF(NNOB(N).LE.0.)   NNOB(N)=1.0E-15*TOTMOL
      ALPHA1=NNOB(N)/NNOE
      TER1=2.*RK1RB*NNE*NNOE/VB1MQ*(1.-ALPHA1**2.)
      TER2=1.+ALPHA1*CAPL
      DNOUB(N)=TER1/(0.10472*DR*TER2)-DNOBL
  255 CONTINUE
      NNOT(N)=NNOB(N)+NNOU(N)+BLNO
      CNOPPM(N)=(NNOT(N)*0.30E+08)/(M1(N)*MO)
      CNOPPM(N)=CNOPPM(N)*(WMOZ/30.)
      CNOPPM(N)=CNOPPM(N)*1.0E-03
      IF(ITES1(N).LE.3)GOTO 260
      DNORM2=DNORM1
      DNORM1=DNORN
      DNORN=DNORP1
```

```
      DNOOBI(N)=YPBNP1(N)
      YBM3(N)=YBM2(N)
      YBM2(N)=YBM1(N)
      YPBM2(N)=YPBM1(N)
      YBM1(N)=YBN(N)
      YPBM1(N)=YPBN(N)
      YBN(N)=NNOB(N)
      YPBN(N)=DNOOB(N)
      XBLM3=XBLM2
      XBLM2=XBLM1
      XPBLM2=XPBLM1
      XBLM1=XBLN
      XPBLM1=XPBLN
      XBLN=BLNO
      XPBLN=DNOBL
      TMOLCO=XCO*TOTMOL
      FNNOTS(N)=NNOT(N)
      FBURNS(N)=FBURN
  260 CONTINUE
 5432 CONTINUE
      XMBS=XMB
      RETURN
      END
```

```
MEMBER NAME  HEATR2
      SUBROUTINE HEATR(DB,PIN,PINS,PS,A3S,TWX)
C EVALUATION OF CYLINDERSTATE, INLET AND EXHAUST CLOSED
C NEW VERSION , NOVEMBER 70
C
      INTEGER PP(8),CO(8),DBV(8),TPZ
C
      REAL LGU, LGB, KU, MAB, MAU, MMAB, MVB, MTB, MTU
     1,MPZ(2,8),MQWB(2,8),MQWU(2,8),KB
      REAL LGRG(8),LAVS,MT(2,8),MLGZ(2,8),MBGZ(2,8),MLZ(8),LGZ(8),
     1LGZS(8),KZ(8),MQW(2,8),MBA(2,8),          B(8),BS(8)
     2,LGE2(8)
      REAL LAND,LANW,LANK,LANEV,LANAV,LAV,ML,MBR,MRG,MV,LA,M0(8),M1(8),
     1MO,ME(8),MA(8),MEA(8),MEE(8),MB    ,MGZ(8),MTA(2,8)
C
      COMMON/HEATC/LGU (8),LGB (8),KU (8),MVB (2,8),MTB (2,8),MTU (2,8)
     1,KB (8),BGU (8),RGGU (8),BGB (8), CVB (8), CVU (8),HU (8)
     2,RU (8),HB (8),UB (8),RG (8),RGGB (8),MB   (8)
      COMMON/EVAP/RGGZS(8),IVERD(8)
      COMMON /CONTRL/ CD, PHI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
     1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
      COMMON/SCCOMB/PZ,TZ,TZS,TZ2,RZ,HZ,UZ,KZ,MT,LGZ,LGZS,BGZ,BGZS,RGGZ
     1,GGZ,PHIZ,MQW,I,N,LGRG,RU2,TEE2,LGE2,BGE2,GGE2,PZS
      COMMON/HTREL/TZM,TZMS,ALFAM,ALFAMS,BO,DB,      LAVS,DU1,DU2,DUDTZ,
     1AI,AIS,QW,QWS,MLGZ,MBGZ,MLZ,HG,   KONV,B,BS,MBA,MPZ,TPZ,ETAU,
     2AM,AMS,TB,TU,VB,VU,MQWB,MQWU,TBS,TUS,TZV
      COMMON /EKONTR/BB,TREF1(8),TREF2(8),PREF1(8),PREF2(8)
      COMMON /HTR/TD,TKD,DD,ALD,LAND,TW,TKW,DW,ALW,LANW,TK,TKK,DK,ALK,LA
     1NK,TEV,TKEV,DEV,ALEV,LANEV,TAV,TKAV,DAV,ALAV,LANAV,FDFK,WF,ZETA
     2/FUEL/SLB,CE,LAV,RB,ML,MBR,MRG,VERDD,Q(3,7)
     3/COMB/AV,MV,PHIVA(8),VD
     4/GEOM/D,H,LA,EPS,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI,
     5XC,FK,VH,TAKT
     6/ORG/NEUIN(8),PP,CO,DBV,VERD
     7/MASS/M0,M1,MO,ME,MA,MEA,MEE
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,
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```
     1 QLOWER
      COMMON/APROP/DEL,PSI
      COMMON/PHICHI/CHI
      COMMON/ADIAB/TAS,TA,XMA,XMB,VA,VBL,RA,RM
C
      LOGICAL VERD,ANALY
C
      DIMENSION HG(8),                              TB(8),TBS(8),TU(8),TUS(8)
     1,VB(8),VU(8),                             UU(8)
     2          ,PZS(8),TZV(8)
      DIMENSION PZ(8),TZ(8),TZS(8),TZ2(8),TZM(8),TZMS(8),ALFAM(8),
     1ALFAMS(8),B0(8),DB(8),RZ(8),HZ(8),UZ(8),DU1(8),DU2(8),GGZ(8),
     2DUDTZ(8),AI(8),AIS(8),QW(8),QWS(8),BGZ(8),BGZS(8),RGGZ(8),PHIZ(8)
     3,RU2(8),TEE2(8),BGE2(8),GGE2(8),AM(8),AMS(8),TA(8),TAS(8),TWX(8)
C
      ANALY=.FALSE.
      VERD=.TRUE.
      IF(PHI.GT.PHIVA(N)+TAKT*PP(N))GOTO 8
  211 CONTINUE
      RESFRK=1.-GGZ(N)
      CALL GPROP(TZ(N),PZ(N),LAV,DEL,PSI,RESFRK,HZ(N),UZ(N),CSUPZ,
     1CSUTZ,RHOZ,DRHOTZ,DRHOPZ,DH1Z,RZ(N),KZ(N))
      TB(N)=TZ(N)
      TU(N)=TZ(N)
      VB(N)=0.
      VU(N)=VZ(N)
      TZV(N)=TZ(N)
      IF(VERD)GOTO 9
      IF(IVERD(N).EQ.0)GOTO 9
      IVERD(N)=0
      MO(N)=M1(N)+B0(N)/MO
      CALL GPROP(380.,PZ(N),.01,DEL,PSI,0.,H1,UFU,H2,H3,H4,H5,H6,H7,H8,H
     19)
      UMIX=UZ(N)*M1(N)*MO+B0(N)*(UFU-RB)
      LGZ(N)=LGZ(N)*M1(N)/MO(N)
      BGZ(N)=(BGZ(N)*M1(N)*MO+B0(N))/(MO(N)*MO)
```

```
      RGGZ(N)=1.-LGZ(N)-BGZ(N)
      CALL NTEMP1(UMIX,MO(N),MO,TZ(N),LGZ(N),BGZ(N),LAV,PZ(N))
      RESFRK=1.-GGZ(N)
      CALL GPROP(TZ(N),PZ(N),LAV,DEL,PSI,RESFRK,HZ(N),UZ(N),CSUPZ,
     1CSUTZ,RHOZ,DRHOTZ,DRHOPZ,DH1Z,RZ(N),KZ(N))
      PZ(N)=MO(N)*MO*RZ(N)*TZ(N)/VZ(N)
      PZS(N)=PZ(N)
      TZS(N)=TZ(N)
      LGZS(N)=LGZ(N)
      BGZS(N)=BGZ(N)
      RGGZS(N)=RGGZ(N)
    9 MBGZ(I,N)=0.
      MLGZ(I,N)=0.
      MB(N)=0.
      GOTO 17
    8 IF(PHI.GT.PHIVA(N)+VD+TAKT*PP(N))GOTO 16
      IF(.NOT.ANALY)B(N)=0.
      IF(.NOT.ANALY)BS(N)=0.
      IF(PP(N).EQ.NCY.AND.TPZ.NE.0)ANALY=.TRUE.
      IF(ANALY)GOTO 200
      IF(HG(N).LT.0)GOTO 210
      HG(N)=-1.
      BGU(N)=BGZ(N)
      LGU(N)=LGZ(N)
      RGGU(N)=1.-BGU(N)-LGU(N)
      BGB(N)=BGU(N)-BO(N)*LAVS/(MO(N)*MO)
      LGB(N)=LGU(N)-BO(N)*LAVS*SLB/(MO(N)*MO)
      RGGB(N)=1.-BGB(N)-LGB(N)
      IK=0
      RESFRK=1.-GGZ(N)
      CALL GPROP(TZ(N),PZ(N),LAV,DEL,PSI,RESFRK,HZ(N),UZ(N),
     1CSUPZ,CSUTZ,RHOZ,DRHOTZ,DRHOPZ,DH1Z,RZ(N),KZ(N))
      HSTAR=HZ(N)
      TSTAR=2200.
 1234 CALL GPROP(TSTAR,PZ(N),LAV,DEL,PSI,1.,H1,U1,
     1CSUP1,CSUT1,RHO1,DRHOT1,DRHOP1,DH11,R1,G1)
```

```
      TSTARN=TSTAR-(H1-HSTAR)/CSUP1
      ERROR=ABS(TSTARN-TSTAR)
      IK=IK+1
      IF(IK.GT.100)  RETURN
      TSTAR=TSTARN
      IF(ERROR.GT.1.)  GO TO 1234
      TB(N)=TSTAR
      TBS(N)=TB(N)
      TU(N)=TZ(N)
      TUS(N)=TU(N)
      TA(N)=TZ(N)+30.
      TAS(N)=TA(N)
      MTA(1,N)=0.
      MTA(2,N)=0.
      VB(N)=.0
      MTB(1,N)=.0
      MTU(1,N)=.0
      MPZ(1,N)=.0
      MTB(2,N)=.0
      MTU(2,N)=.0
      MPZ(2,N)=.0
  210 CONTINUE
      IF(TA(N).GE.3000.)  TA(N)=3000.
      IF(TA(N).LE.TB(N))  TA(N)=TB(N)+50.
      TMEAN=(TA(N)-TWX(N))/ALOG(TA(N)/TWX(N))
      RESFRK=1.
      CALL GPROP(TB(N),PZ(N),LAV,DEL,PSI,RESFRK,HB(N),UB(N),CSUPB,
     1CSUTB,RHOB,DRHOTB,DRHOPB,DH1B,RG(N),KB(N))
      CALL GPROP(TA(N),PZ(N),LAV,DEL,PSI,RESFRK,HA,UA,CSUPA,
     1CSUTA,RHOA,DRHOTA,DRHOPA,DH1A,RA,GAMA)
      CALL GPROP(TMEAN,PZ(N),LAV,DEL,PSI,RESFRK,HM,UM,CSUPM,
     1CSUTM,RHOM,DRHOTM,DRHOPM,DH1M,RM,GAMM)
      RESFRK=1.-GGZ(N)
      CALL GPROP(TU(N),PZ(N),LAV,DEL,PSI,RESFRK,HU(N),UU(N),CSUPU,CSUTU,
     1RHOU,DRHOTU,DRHOPU,DH1U,RU(N),KU(N))
      BB=BO(N)*(1.-EXP(-AV*((PHI-PHIVA(N)-TAKT*PP(N))/VD)**(MV+1.)))
```

```
      IF(BB.LE.0.)GOTO 211
      MB(N)=AV*(MV+1.)*((PHI-PHIVA(N)-TAKT*PP(N))/VD)**MV*EXP(-AV*
     1((PHI-PHIVA(N)-TAKT*PP(N))/VD)**(MV+1.))/VD*LAVS
      MAB=BB*MO(N)*MO/(BO(N)      *ETAU)
      MAU=MO(N)*MO-MAB
      IF(MAU.LE.1.0E-5*MO*MO(N))MAU=1.0E-5*MO*MO(N)
      MMAB=MB(N)*MO(N)*MO/(1.*ETAU)
      DMU=-MMAB
      XMA=MAB*(RG(N)*TB(N)-RM*TMEAN)/(RA*TA(N)-RM*TMEAN)
      IF(XMA.GE.MAB) XMA=0.99MMAB
      IF(XMA.LE.0.) XMA=0.99*MAB
      XMB=MAB-XMA
      IF(XMB.LE.0.) XMB=MAB*.01
C     THIS IS THE UPDATED VERSION OF THE ENERGY EQUATIONS
C     THE FOLLOWING VARIABLES ARE SET UP TO SOLVE FOR TB AND
C     TU AS WELL AS THE CYLINDER PRESSURE
      AB=MAB*(CSUPB+1./RHOB*DRHOTB/DRHOPB-CSUTB/DRHOPB*DRHOTB)
      AU=MAU*(CSUPU+1./RHOU*DRHOTU/DRHOPU-CSUTU/DRHOPU*DRHOTU)
      AA=XMA*(CSUPA+1./RHOA*DRHOTA/DRHOPA-CSUTA/DRHOPA*DRHOTA)
      AMM=XMB*(CSUPM+1./RHOM*DRHOTM/DRHOPM-CSUTM/DRHOPM*DRHOTM)
      BZB=(1.-RHOB*CSUTB)/DRHOPB
      BZU=(1.-RHOU*CSUTU)/DRHOPU
      BA=(1.-RHOA*CSUTA)/DRHOPA
      BM=(1.-RHOM*CSUTM)/DRHOPM
      CB=BZB*RHOB
      CU=BZU*RHOU
      CA=BA*RHOA
      CM=BM*RHOM
      VB(N)=MAB*RG(N)*TB(N)/PZ(N)
      VU(N)=MAU*RU(N)*TU(N)/PZ(N)
      VA=XMA*RA*TA(N)/PZ(N)
      VBL=XMB*RM*TMEAN/PZ(N)
C     ADD TERM TO CALCULATE  VARIABLES IN ADIABATIC CORE AND
C     BOUNDARY LAYER
      ALPHA=(ALOG(TA(N)/TWX(N))-(1.-TWX(N)/TA(N)))/(ALOG(TA(N)/TWX(N))
     1**2.)
```

```
      XCON=1./ALPHA
      ZETA1=XCON*AA*CM/AMM+CA
      ZETA2=XCON*AA*(HM-BM-HA)/AMM-BA
      ZETA3=(HA-BA-HU(N))
      DA=1./RHOA*DRHOPA
      DM=1./RHOM*DRHOPM
      EA=1./RHOA*DRHOTA
      EM=1./RHOM*DRHOTM
      BETA1=DA/DM/(VB(N)-VA)+1./VA+EM*DA*CA/DM/AA/XCON-CA*EA/AA
      BETA2=-DA/DM*(1./XMB+BA*EM/XCON/AA)-1./(XMA)+BA*EA/AA
      BETA3=DA*EM/DM/AA/XCON*(HA-BA-HU(N))-EA/AA*(HA-BA-HU(N))
     1-1./XMA
      QUAN1=RHOB/RHOU*DRHOPU/DRHOPB
      DUM1=1./VU(N)+QUAN1*(1./VB(N)-(CB/AB*DRHOTB/RHOB))
     1-1./RHOU*DRHOTU*CU/AU
      IF(BB/BO(N).LE.0.005)  MQWB(I,N)=0.
      DUM2=1./AB*(HU(N)*MMAB-(HB(N)-BZB)*MMAB-MQWB(I,N))
      DUM3=1./AU*(-HU(N)*MMAB+(HU(N)-BZU)*MMAB-MQWU(I,N))
      DUM4=1./RHOU*DRHOTU*CU/AU
      TERM1=MMAB*(QUAN1/MAB+1./MAU)
      TERM2=PHIZ(N)*(1./VU(N)-DUM4)
      TERM3=1./RHOU*DRHOTU*DUM3-QUAN1*DUM2*DRHOTB/RHOB
      MVB(I,N)=(TERM1+TERM2+TERM3)/DUM1
      BETA4=DA/DM*MVB(I,N)/VBL
      ZETA4=XCON*AA/AMM*(CM*MVB(I,N)+MQWB(I,N))
      DMBL=(DMU*(BETA1*ZETA3-BETA3*ZETA1)+BETA1*ZETA4-BETA4*ZETA1)
     1/(ZETA1*BETA2-BETA1*ZETA2)
      DVA=(DMBL*BETA2+BETA3*DMU+BETA4)/BETA1
      MTA(I,N)=1./AA*((HA-BA-HU(N))*DMU-BA*DMBL-CA*DVA)
      MTB(I,N)=DUM2-CB/AB*MVB(I,N)
      MTU(I,N)=DUM3-CU/AU*(PHIZ(N)-MVB(I,N))
      MPZ(I,N)=RHOU/DRHOPU*(-(PHIZ(N)-MVB(I,N))/VU(N)-MMAB/MAU-1./RHOU
     1*DRHOTU*MTU(I,N))
      IF(BB/BO(N).LE.0.005)  GO TO 901
      CALL INTEG(TBS    ,TB    ,MTB,I,N,DPHI)
      IF(TB(N).GT.2900.)TB(N)=2900.
```

```
      CALL INTEG(TUS    ,TU    ,MTU,I,N,DPHI)
      CALL INTEG(TAS,TA,MTA,I,N,DPHI)
  901 CALL INTEG(PZS    ,PZ    ,MPZ,I,N,DPHI)
      IF(BB/BO(N).GT.0.005) GO TO 902
      IKK=0
      RESPRK=1.-GGZ(N)
      CALL GPROP(TU(N),PZ(N),LAV,DEL,PSI,RESPRK,HU(N),UZ(N),
     1CSUPZ,CSUTZ,RHOZ,DRHOTZ,DRHOPZ,DH1Z,RU(N),KU(N))
      HSTAR=HU(N)
      TSTAR=2200.
 1235 CALL GPROP(TSTAR,PZ(N),LAV,DEL,PSI,1.,H1,U1,
     1CSUP1,CSUT1,RHO1,DRHO1,DRHOP1,DH11,R1,G1)
      TSTARN=TSTAR-(H1-HSTAR)/CSUP1
      ERROR=ABS(TSTARN-TSTAR)
      IKK=IKK+1
      IF(IKK.GT.100) RETURN
      TSTAR=TSTARN
      IF(ERROR.GT.1.) GO TO 1235
      TB(N)=TSTAR
      TA(N)=TB(N)
      VB(N)=MAB/RHO1
      VU(N)=VZ(N)-VB(N)
      MAU=MO(N)*MO-MAB
      RHOU=MAU/VU(N)
      TU(N)=PZ(N)/RHOU/RU(N)
  902 CONTINUE
C     UPDATE ALL  THE VARIABLES
      IF(TA(N).GE.3000.) TA(N)=3000.
      IF(TA(N).LE.TB(N)) TA(N)=TB(N)+50.
      CALL GPROP(TB(N),PZ(N),LAV,DEL,PSI,1.,HB(N),UB(N),CSUPB,
     1CSUTB,RHOB,DRHOTB,DRHOPB,DH1B,RG(N),KB(N))
      CALL GPROP(TA(N),PZ(N),LAV,DEL,PSI,1.,HA,UA,CSUPA,
     1CSUTA,RHOA,DRHOTA,DRHOPA,DH1A,RA,GAMA)
      TMEAN=(TA(N)-TWX(N))/ALOG(TA(N)/TWX(N))
      CALL GPROP(TMEAN,PZ(N),LAV,DEL,PSI,1.,HM,UM,CSUPM,
     1CSUTM,RHOM,DRHOTM,DRHOPM,DH1M,RM,GAMM)
```

```
      XMA=MAB*(RG(N)*TB(N)-RM*TMEAN)/(RA*TA(N)-TMEAN*RM)
      XMB=MAB-XMA
      IF(XMA.LE.0.)XMA=MAB*0.99
      IF(XMB.LE.0.) XMB=MAB*0.01
      VA=RA*TA(N)*XMA/PZ(N)
      VBL=RM*TMEAN*XMB/PZ(N)
C     END OF UPDATE
      LGZ(N)=LGB(N)
      BGZ(N)=BGB(N)
      RGGZ(N)=1.-LGB(N)-BGB(N)
      TZ(N)=TB(N)
      TZV(N)=(MAB*TB(N)+MAU*TU(N))/(MO(N)*MO)
      GOTO 201
   16 IF(ANALY)GOTO 200
  200 CONTINUE
      MB(N)=0.
      MLGZ(I,N)=0.
      MBGZ(I,N)=0.
      RESFRK=1.
      TMEAN=(TA(N)-TWX(N))/ALOG(TA(N)/TWX(N))
      CALL GPROP(TA(N),PZ(N),LAV,DEL,PSI,RESFRK,HA,UA,CSUPA,
     1CSUTA,RHOA,DRHOTA,DRHOPA,DH1A,RA,GAMA)
      CALL GPROP(TMEAN,PZ(N),LAV,DEL,PSI,RESFRK,HM,UM,CSUPM,
     1CSUTM,RHOM,DRHOTM,DRHOPM,DH1M,RM,GAMM)
      CALL GPROP(TZ(N),PZ(N),LAV,DEL,PSI,RESFRK,HZ(N),UZ(N),CSUPZ,
     1CSUTZ,RHOZ,DRHOTZ,DRHOPZ,DH1,RZ(N),KZ(N))
      XMA=MO*MO(N)*(RZ(N)*TZ(N)-RM*TMEAN)/(RA*TA(N)-RM*TMEAN)
      IF(XMA.LE.0.) XMA=.0001*MAB
      XMB=MO*MO(N)-XMA
      VA=XMA*RA*TA(N)/PZ(N)
      VBL=XMB*RM*TMEAN/PZ(N)
      AA=XMA*(CSUPA+1./RHOA*DRHOTA/DRHOPA-CSUTA/DRHOPA*DRHOTA)
      AMM=XMB*(CSUPM+1./RHOM*DRHOTM/DRHOPM-CSUTM/DRHOPM*DRHOTM)
      BM=(1.-RHOM*CSUTM)/DRHOPM
      BA=(1.-RHOA*CSUTA)/DRHOPA
      CA=BA*RHOA
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      CM=BM*RHOM
      DA=DRHOPA/RHOA
      DM=DRHOPM/RHOM
      EA=DRHOTA/RHOA
      EM=DRHOTM/RHOM
      ALPHA=(ALOG(TA(N)/TWX(N))-(1.-TWX(N)/TA(N)))/(ALOG(TA(N)/TWX(N)
     1)**2.)
      BMM=HA-HM+BM
      X1=-(ALPHA*AMM*BA+BMM*AA)/(ALPHA*AMM*CA+AA*CM)
      X2=ALPHA*AMM*AA/(ALPHA*CA*AMM+AA*CM)*(CM/ALPHA/AMM*PHIZ(N)+
     1MQW(I,N)/ALPHA/AMM)
      YN1=(1./VA-EA*CA/AA+DA/DM*(1./(VZ(N)-VA)-EM/AMM*CM))
      YD1=(-1./XMA+EA*BA/AA-DA/DM*(1./XMB-EM*BMM/AMM))
      Y1=YN1/YD1
      YN2=DA/DM*(PHIZ(N)*(-1./(VZ(N)-VA)+EM*CM/AMM)+EM/AMM*MQW(I,N))
      Y2=YN2/YD1
      DMBL=(Y1*X2+Y2)/(1.-Y1*X1)
      DVA=X1*DMBL+X2
      MTA(I,N)=1./AA*(-BA*DMBL-CA*DVA)
      CALL INTEG(TAS,TA,MTA,I,N,DPHI)
   17 AUU=MO(N)*MO*(CSUPZ+1./RHOZ*DRHOTZ/DRHOPZ-CSUTZ/DRHOPZ*DRHOTZ)
      BZZ=(1.-RHOZ*CSUTZ)/DRHOPZ
      CZ=BZZ*RHOZ
      MT(I,N)=1./AUU*(-MQW(I,N)-CZ*PHIZ(N))
      IF(PHI.GT.PHIVA(N)+VD+TAKT*PP(N).AND.PHI-DPHI.LT.PHIVA(N)+VD+
     1TAKT*PP(N))MT(1,N)=MT(2,N)
      MPZ(I,N)=RHOZ/DRHOPZ*(-PHIZ(N)/VZ(N)-DRHOTZ/RHOZ*MT(I,N))
      CALL NEWT(TZS,TZ,TZ2,MT,I,N,CO,DPHI)
      CALL CPRESS(PZ,TZ,RZ,I,N)
C     CALL INTEG(PZS,PZ,MPZ,I,N,DPHI)
      IF(HG(N).GT.-1)GO TO 300
      TMEAN=(TA(N)-TWX(N))/ALOG(TA(N)/TWX(N))
      CALL GPROP(TA(N),PZ(N),LAV,DEL,PSI,1.,HA,UA,CSUPA,
     1CSUTA,RHOA,DRHOTA,DRHOPA,DH1A,RA,GAMA)
      CALL GPROP(TMEAN,PZ(N),LAV,DEL,PSI,1.,HM,UM,CSUPM,
     1CSUTM,RHOM,DRHOTM,DRHOPM,DH1M,RM,GAMM)
```

```
      CALL  GPROP(TZ(N),PZ(N),LAV,DEL,PSI,1.,HZ(N),UZ(N),CSUPZ,
     1CSUTZ,RHOZ,DRHOTZ,DRHOPZ,DH1,RZ(N),KZ(N))
      XMA=MO(N)*MO*(RZ(N)*TZ(N)-RM*TMEAN)/(RA*TA(N)-RM*TMEAN)
      XMB=MO*MO(N)-XMA
      VA=XMA*RA*TA(N)/PZ(N)
      VBL=XMB*RM*TMEAN/PZ(N)
  300 CONTINUE
      IF(.NOT.ANALY)GOTO 201
  202 CALL  INTEG(BS,B,MBA,I,N,DPHI)
      TZ(N)=PZ(N)*VZ(N)/(MO(N)*MO*RZ(N))
  201 RETURN
      END
```

```
MEMBER NAME  REED
      SUBROUTINE REED
C
C     READ ENGINE DATA SET INTO COMMON AFTER CHECKING FOR VALID PASSWORD
C
      INTEGER CD, PRI, DSI,DSO,V,C,P1,P2, PR
      INTEGER T, TP, Z, TEX, TIN, VERG
C
      REAL LAND,LANW,LANK,LANEV,LANAV,LA,MO(8),M1(8),MO,ME(8),MA(8),
     1MEA(8),MEE(8),LAV,ML,MBR,MRG,MV,MU0E,MU1E,MU2E,MU3E,MU0A,MU1A,
     2MU2A,MU3A
      REAL LDEL,LDIL
C
      COMMON /TITLE/ NA(60)
      COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
     1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
      COMMON /INPUTP/ INPUTT
      COMMON /HTR/TD,TKD,DD,ALD,LAND,TW,TKW,DW,ALW,LANW,TK,TKK,DK,ALK,
     1LANK,TEV,TKEV,DEV,ALEV,LANEV,TAV,TKAV,DAV,ALAV,LANAV,FDFK,WF,ZETA
     2/GEOM/D,H,LA,EPS,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI,
     3XC,PK,VH,TAKT
     6/FUEL/SLB,CE,LAV,RB,ML,MBR,MRG,VERDD,Q(3,7)
     7/COMB/AV,MV,PHIVA(8),VD
     8/OPD/PO,TO,PE,TE,PA,PB,DR,PEO,TEO,FEO,VER
     9/SC/MU0E,MU1E,MU2E,MU3E,FER,MU0A,MU1A,MU2A,MU3A,FAR
      COMMON/VALVE/PHIOEX,PHIOIN,PHICEX,PHICIN,SAEX,R1EX,R2EX,R3EX,R4EX,
     1RAREX,SAIN,R1IN,R2IN,R3IN,R4IN,RARIN
     3/VARIA/FAV,FEV,LE,LI,TEX,TIN,TWU,VERG,LDEL,CDEL,LDIL,CDIL, FEL ,
     4 FAL,PHIL,PHILP,PEL,PAL,REZ,CN
      COMMON/VALASH/ VLASH
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,QLOWER
C       THIS  INPUT ROUTINE ISMODIFIED FOR USE WITH M.MARTINS
C        SUBROUTINES FOR GAS PROPERTIES
C
      DIMENSION PE(8), TE(8), PA(8), PHIL(320), FEL(320), FAL(320),
     1 PEL(300), PAL(300), PHILP(300),
```

```
     2  LDEL(20), CDEL(20), LDIL(20), CDIL(20)
      DIMENSION KEYA(160,10), KDATE(2)
      DATA NBLK / '    ' /
      DATA MKEY / '{   ' /
C    MKEY CONTAINS A SPECIAL CODE & IS NOT PRINTED
C    IF CODE IS REQUIRED, SEE SPECIAL PROGRAMS DEPT
C   PASSWORD PROTECTION DELETED
C
C    PR IS USED LOCALLY FOR PRINTER
C
      PR = PRI
C     NKU = 29
C
C    REWIND FOR MULTI-STEP JOBS
C    READ CLOCK FUNCTION TO GET CURRENT DATE & SAVE IN DKEY FILE
C
C     REWIND NKU
      KDATE(2) = NBLK
      XZERO = 0.
C
C    FIRST 16 DATA CARDS ARE REQUIRED
C
C    READ TITLE, 2 COMMENT, AND 1 CONTROL CARDS
C
      READ (DSI, 7011, END=7990)  ( NA(II), II = 1, 60 )
 7011 FORMAT ( 20A4 )
      READ ( DSI, 7017, END=7990 )  V, C, P1, P2, NDAT1, NDAT2,
     1 T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O, IKEY1, IKEY2
 7017 FORMAT ( 4I1, 4X, 2A4, 4X, 5I2, 2X, 4I2, 10X, 2F6.2 , 2A4 )
      INPUTT = T
C
C    CK FOR VALID PASSWORD
C
C    READ FILE INTO ARRAY FOR CHECKING AND UPDATE OF COUNTER
C    IF 1ST RECORD IS SPECIAL MKEY CODE, CK IF PASSWORD IS REQUIRED
C        KEYA(1,4) = 0 PASSWORD IS  REQUIRED
```

```
C          KEYA(1,4) = 1 PASSWORD NOT REQUIRED
C
C      READ (NKU, 7019, END=7990, ERR=7980 )  (KEYA( 1,II), II = 1, 10 )
C7019 FORMAT ( 3A4, I4, 6A4 )
C      IF (KEYA(1,2) .NE. MKEY )  GO TO 7021
C      IF (KEYA(1,4) .EQ. 1    )  GO TO 7040
C
C     PASSWORD REQUIRED
C
C7021 IF (IKEY1 .EQ. NBLK )  GO TO 7986
C      DO 7022 LL = 2, 160
C7022 READ (NKU, 7019, END=7024, ERR=7980 )  (KEYA(LL,II), II = 1, 10 )
C7024 LL = LL -1
C      DO 7028 KK = 1, LL
C      IF (KEYA(KK,2) .NE. IKEY1 )  GO TO 7028
C      IF (KEYA(KK,3) .NE. IKEY2 )  GO TO 7028
C      IF (KEYA(KK,1) .EQ. MKEY  )  GO TO 7034
C7028 CONTINUE
C
C     PASSWORD NOT FOUND
C
C      WRITE (PRI, 7031 ) IKEY1, IKEY2
C7031 FORMAT ( // 10X, 2A4, '  PASSWORD NOT VALID' )
C      STOP
C
C     PASSWORD IS VALID, INCREMENT COUNTER & REPLACE FILE
C     SAVE CURRENT ENGINE NAME FROM USER'S ENGINE DATA
C
C7034 KEYA(KK,4) = KEYA(KK,4) + 1
C      REWIND NKU
C      KEYA(KK,5) = KDATE(1)
C      KEYA(KK,6) = KDATE(2)
C      KEYA(KK,7) = NA(1)
C      KEYA(KK,8) = NA(2)
C
C      DO 7036 KK = 1, LL
```

```
C7036 WRITE (NKU, 7019 )                              (KEYA(KK,II), II = 1, 10 )
C     REWIND NKU
C     WRITE (PRI, 7037 )
C7037 FORMAT ( /// 10X, 'PASSWORD VALID' )
C
C    CHECK IF CALC = YES = 1
C
 7040 IF ( C .LT. 1 ) STOP
C
C    READ DETAILED ENGINE DATA
C
      FREQ=2.34127E17
      ORDER=1.5922
      ACTV=80.0535
      TSUBC=6430.43
      ENW=0.0
      READ (DSI, 7121)  D, H, LA, EPS, FAR, FER, DD, DW, DK, DAV, DEV,
     1 PHIOEX,PHIOIN,PHICEX,PHICIN,FAV,FEV,FDFK, LE,LI,TEX,TIN,
     2 SAEX,R1EX,R2EX,R3EX,R4EX,RAREX,SAIN,R1IN,R2IN,R3IN,R4IN,RARIN,
     3 MUOA, MU1A, MU2A, MU3A, MUOE, MU1E, MU2E, MU3E, VLASH,VLASH2,
     4 WF, TWU, ALD, ALW, ALK, ALAV, ALEV,
     5 LAND, LANW, LANK, LANAV, LANEV, TKD, TKW, TKK, TKAV, TKEV,
     6 CE, SLB,  MBR, MRG,CX,HY,OZ,ENW
 7121 FORMAT ( 11F6.3, / 7F6.1, 4I4, / 12F6.3, / 10F6.3, / 7F6.2, /
     1  10F6.3, / 4F8.1,4F8.2  )
      QLOWER=CE*5.5595E-04
C
 7130 READ (DSI, 7131)   ( AF(II), II = 1, 6 )
 7131 FORMAT ( 6E11.4 )
C
      READ (DSI, 7137)  PHIVA(1), VD, MV, AV, XLAV, PO,TO,PB,DR
 7137 FORMAT ( 9F7.2  )
      LAV=1./XLAV
C
      READ (DSI, 7139, END=7990)    PE(1), TE(1), PA(1), REZ, CN
 7139 FORMAT ( 10F6.3 )
```

```
C
      IF ( LE.GT.0 ) READ (DSI, 7141)  ( LDEL(L), CDEL(L), L = 1, LE )
      IF ( LI.GT.0 ) READ (DSI, 7141)  ( LDIL(L), CDIL(L), L = 1, LI )
 7141 FORMAT (  10F7.4 )
C
      IF ( T .NE. 0 ) GO TO 7260
      PHIL(1) = PHICIN - 720.
      FEL(1) = 0.
      FAL(1) = 0.
      IH = TEX +1
      PHIPR = PHIOEX - PHIL(1)
      DAE = PHIOIN - PHIOEX
      READ (DSI, 7151, END=7990)  (FAL(L), L = 2, IH )
 7151 FORMAT (  8F9.6 )
C
      DO 715 L = 2, IH
      PHIL(L) = PHIL(1) + PHIPR + ( 2 * L -4 )
      FAL(L)=FAL(L)-VLASH2
      IF(FAL(L).LT.0.) FAL(L)=0.
      FAL(L) = FAL(L) * RAREX
  715 FEL(L) = 0.
      IH1 = ( DAE + .001 ) / 2. +2.
      IH2 = ( 720. - PHIPR + .001 ) / 2. +2.
      READ ( DSI, 7151, END=7990 )  ( FEL(L), L = IH1, IH2 )
      DO 717 L = IH1, IH2
      PHIL(L) = PHIL(2) + ( 2 * L - 4 )
      FEL(L)=FEL(L)-VLASH
      IF(FEL(L).LT.0.) FEL(L)=0.
      FEL(L) = FEL(L) * RARIN
      IF ( L .GT. IH )  FAL(L) = 0.
  717 CONTINUE
      T = IH2
      GO TO 7400
C
 7260 READ (DSI, 7261)  (PHIL(L),  FAL(L),  FEL(L), L = 1, T )
 7261 FORMAT ( 12F6.3 )
```

```
C
 7400 IF ( TP .EQ. 0) GO TO 7600
      READ (DSI, 7411)   (PHILP(L), PAL(L),  PEL(L), L = 1, TP)
 7411 FORMAT ( 12F6.2 )
C
C     LAST SETS OF DATA ARE PROGRAM VERSION DEPENDENT
C     STARTS WITH DATA 'OPC2'  (SEE CALC)
C
C
C     PRINT INPUT DATA REPORT, THUS FAR
C
 7600 NPAGE = 1
      WRITE (PR, 7711 )  NDAT1, NDAT2, (NA(I), I = 1, 20),
     1  KDATE(1), KDATE(2), NPAGE,
     2  V,C,P1,P2, (NA(J), J = 21, 60 )
 7711 FORMAT ( 1H1 /// 10X, 2A4, 7X, 20A4,  5X,A4,A1,T120, 'PAGE', I4,
     1  // 10X, 'VERSION', I2  / 10X, 'CALC', I2, 4X, 'PLOT1', I2,
     2  4X, 'PLOT2' , I2 , 2( / 10X, 20A4 ) )
      WRITE (PR, 7717 ) INPUTT,TP,Z,NCY,NCYO,K1, K2, K3, K4, DPHIO, O
 7717 FORMAT ( /// 6X, 'CONTRL', 7X, 'NT', 6X, 'NTP', 5X, 'NCYL', 5X,
     1  'NCYC', 5X, 'NCYO', 6X, 'K1', 7X, 'K2', 7X, 'K3', 7X, 'K4',
     2  6X, 'DPHIO', 6X, 'O' , /  95X, 2( 3X, 'DEG.CA' ) , /
     3  13X, 2( 6X, I2 ), 7( 7X, I2 ), F12.2, F8.1 )
C
      WRITE (PR, 7721)  D, H, LA, EPS, FAR, FER, DD, DW, DK, DAV, DEV,
     1 PHIOEX,PHIOIN,PHICEX,PHICIN,FAV,FEV,FDFK, LE,LI,TEX,TIN,
     2 SAEX,R1EX,R2EX,R3EX,R4EX,RAREX,SAIN,R1IN,R2IN,R3IN,R4IN,RARIN
 7721 FORMAT ( / 6X, 'EGEOM', 8X, 'B', 8X, 'S', 7X, 'LA', 7X, 'CR', 6X,
     1  'APEX     APIN      DELH      DELCL     DELP      DELEX     DELIN',
     2 / 18X, 'IN.', 6X, 'IN.', 22X, 'SQ.IN.    SQ.IN.', 5X, 5('IN.',6X),
     3 / 13X, 3F9.3, F9.2, 7F9.3,
     4 // 6X, 'VALVE1', 5X, 'PHIOEX   PHIOIN   PHICEX   PHICIN',
     5    4X, 'AEX      AIN      AH/AP     NCEX      NCIN',
     6    5X, 'NEX      NIN', / 14X, 4( 3X, 'DEG.CA'), 2( 3X,'SQ.IN.'),
     7 / 13X, 4F9.1, 3F9.3, I8, 3I9,
     8 // 6X, 'VALVE2', 6X, 'SAEX     R1EX     R2EX     R3EX     R4EX',
```

```
     9 4X,'RAREX      SAIN     R1IN     R2IN     R3IN     R4IN    RARIN',
     A /  3X, 2( 15X, 'DEG.     IN.',  3( 6X, 'IN.' )),
     B / 13X,     2( F9.1, 5F9.3))
C
      WRITE (PR, 7727)   MU0A, MU1A, MU2A, MU3A, MU0E, MU1E, MU2E, MU3E,
     2 VLASH,VLASH2,
     4 WF, TWU, ALD, ALW, ALK, ALAV, ALEV,
     5 LAND, LANW, LANK, LANAV, LANEV, TKD, TKW, TKK, TKAV, TKEV,
     6 CE, SLB,  MBK, MRG,CX,HY,OZ,ENW
 7727 FORMAT ( / 6X, 'VFLOWC      FC0EX     FC1EX     FC2EX     FC3EX',
     1                        4X, 'FC0IN     FC1IN     FC2IN     FC3IN    VLA
     1SHI    VLASHE',
     2 // 13X, 10F9.3,
     3 //  6X, 'HTRANS1   MULTHTR   TDISTR     ALFH     ALFCL',
     4      5X, 'ALFP     ALFEX     ALFIN',
     5 /  35X, '----------BTU/SQ.FT.-DEG.F-MIN.----------',
     6 /  13X,  7F9.2,
     7 //  6X, 'HTRANS2      LANH     LANCL     LANP     LANEX     LANIN',
     8      5X, 'TCH       TCCL      TCP       TCEX      TCIN',
     9 /  17X, '-----------BTU/FT.-DEG.F-MIN.-----------',
     A           5( 4X, 'DEG.F' ),
     B /  13X, 5F9.3, 5F9.1,
     C //  6X, 'FUEL', 8X, 'CV        SA/F      MFUEL',
     D      4X, 'MEXPR' ,5X, 'CX' ,7X, 'HY' ,7X, 'OZ',7X, 'ENW',
     E /  16X, 'BTU/LB.' ,  9X, 2( 2X, 'LB/MOLE' ),
     F /  13X, F9.0, F8.1,  1X,   2F9.1,4F9.2)
C
      NPAGE = NPAGE +1
      WRITE (PR, 7731) NPAGE, ( AF(KK), KK = 1, 6)
 7731 FORMAT (1H1,// T120,'PAGE',I4,//6X,'GPROP',
     1  5X, 'COEFF. FOR SPEC. ENTH       A(1)',
     2  8X,'A(2)',8X, 'A(3)', 8X, 'A(4)', 8X,'A(5)',8X,'A(6)',
     3 / 16X, 'FUEL', 18X, 6E12.3)
C
      WRITE (PR, 7737) PHIVA(1), VD, MV, AV, XLAV, PO, TO, PB, DR
 7737 FORMAT ( // 6X, 'OPC1', 7X, 'PHISC     CD     MWIEBE  AWIEBE',
```

```
     1  3X, 'EXAIRM    PREF      TREF      PBARO     RPM',
     2 / 13X, 2( 3X, 'DEG.CA' ), 31X, 'PSIG      DEG.F    IN.HG',
     3 / 11X, 2F10.1, F8.2, 2F9.2, F10.2, F9.1, F9.2, F10.1  )
C
      WRITE (PRI,7739)    PE(1), TE(1), PA(1), REZ, CN
 7739 FORMAT (  // 6X, 'OPC2', 8X, 'PIN       TIN       PEX       REC',
     1  5X, 'CNTEX',
     2 / 18X, 'PSIG     DEG.F     PSIG',
     3 / 13X, F9.2, F9.1, F9.2, 2F9.3 )
C
      IF ( LE .GT. 0) WRITE (PR, 7741)  ( LDEL(L), CDEL(L), L = 1, LE )
 7741 FORMAT ( /// 6X, 'DISCOEFF', 7X, 5( 6X, 'LIFT   CD' ),
     1 // 16X, 'EXHAUST',5(F8.4,F7.3), 4(/ 23X, 5(F8.4,F7.3)))
C
      IF ( LI .GT. 0) WRITE (PR, 7743)  ( LDIL(L), CDIL(L), L = 1, LI )
 7743 FORMAT (
     1 // 16X, 'INTAKE ',5(F8.4,F7.3), 4(/ 23X, 5(F8.4,F7.3)))
C
      NPAGE = NPAGE +1
      WRITE (PR, 7747) NPAGE
 7747 FORMAT ( 1H1, // T120, 'PAGE', I4 )
C
      IF ( T .NE. 0 ) GO TO 7760
      WRITE (PR, 7751 )   ( FAL(L), L = 2, IH )
 7751 FORMAT ( // 6X, 'VLIFTEX   EXHAUST CAM LIFT (IN.), ',
     1                 'ALL 1 DEG. CAM ANGLE',
     2 // (14X, 8F10.6))
C
      WRITE (PR, 7753 )   ( FEL(L), L = IH1, IH2 )
 7753 FORMAT ( // 6X, 'VLIFTIN   INTAKE  CAM LIFT (IN.), ',
     1                 'ALL 1 DEG. CAM ANGLE',
     2 // (14X, 8F10.6))
      GO TO 7780
C
 7760 WRITE (PR, 7761)  (PHIL(L),  FAL(L),  FEL(L), L = 1, T )
 7761 FORMAT ( /// 6X, 'VAREA', 7X, 3( 'PHI     VAEX     VAIN', 9X),
```

```
     1 / 10X, 3( 7X, 'DEG.CA  SQ.IN.   SQ.IN.' ),
     2 / ( 9X, 3(F13.1, F8.3, F9.3)))
C
 7780 IF ( TP .EQ. 0 ) GO TO 7800
      WRITE (PR, 7783) (PHILP(L), PAL(L), PEL(L), L = 1, TP )
 7783 FORMAT ( /// 6X, 'PRESSFL', 5X, 3( 'PHI      PEX      PIN', 9X ),
     1 / 10X, 3( 7X, 'DEG.CA    PSIG     PSIG' ),
     2 ( / 10X, 3( F12.1, 2F9.2 )))
C
 7800 RETURN
C
 7980 WRITE (PRI, 7981 )
 7981 FORMAT ( // 10X, 'ERROR IN READING PASSWORD FILE' )
      STOP
 7986 WRITE ( PRI, 7987 )
 7987 FORMAT ( // 10X, 'NO PASSWORD' )
      STOP
 7990 WRITE (PR, 7991)
 7991 FORMAT ( // 10X, 'UNEXPECTED EOF' )
      STOP
      END
```

```
MEMBER NAME  INTEG
      SUBROUTINE INTEG(FS,F,M,I,N,DPHI)
C INTEGRATION
C GETESTET 1.8.69
      DIMENSION FS(N),F(N)
      REAL M(2,N)
      IF(I-1)10,10,20
   10 F(N)=FS(N)+M(1,N)*DPHI
      GOTO 30
   20 F(N)=FS(N)+(M(1,N)+(I-1)*M(I,N))*DPHI/I
   30 RETURN
      END
```

```
MEMBER NAME  LINPO
      SUBROUTINE LINPO(X,XL,FL,NXL,F)
C LINEAR INTERPOLATION
      DIMENSION XL(NXL),FL(NXL)
      M=NXL-1
      DO 1 N=1,M
      IF(X.LE.XL(N+1))GOTO 2
    1 CONTINUE
    2 DST=XL(N+1)-XL(N)
      F=FL(N)+(FL(N+1)-FL(N))/DST*(X-XL(N))
      RETURN
      END
```

```
MEMBER NAME  MFR
      SUBROUTINE MFR(MM,PO,TO,P1,WR,FR,FV,MUO,MU1,MU2,MU3,K,GK,DR,MO,
     1I,N)
C EVALUATION OF MASS FLOW RATE
C GETESTET 6.8.69
      DIMENSION PO(8),TO(8),P1(8),WR(8),       FV(8),GK(8),P(8)
      REAL MUO,MU1,MU2,MU3,K(8),MO,MM(2,8),MU
      P(N)=PO(N)
      PI=P1(N)/PO(N)
      PIK=(2./(K(N)+1.))**(K(N)/(K(N)-1.))
      IF(PO(N).LT.P1(N)) GOTO 10
      MU=MUO+MU1/PI
      IF(MU.GT.MU2) MU=MU2
      FEFF=FV(N)*MU
      IF(PI.LE.PIK) PI=PIK
      GO TO 20
   10 FEFF=-MU3*FV(N)
      P(N)=P1(N)
      IF(PI.LE.1./PIK) GOTO 30
      PI=PIK
      GOTO 20
   30 PI=1./PI
   20 WP=SQRT(2.*K(N)/(K(N)-1.)*GK(N)*TO(N)*(1.-PI**((K(N)-1.)/K(N))))
      WR(N)=FEFF/FR    *WP
      PSI=PI**(1./K(N))*SQRT(2.*K(N)/(K(N)-1.)*(1.-PI**((K(N)-1.)/K(N)))
     1)
      MM(I,N)=FEFF*PSI*P  (N)*9.55/(MO*DR*SQRT(GK(N)*TO(N)))
      RETURN
      END
```

```
MEMBER NAME  MFRP
      SUBROUTINE MFRP(MM,P1,P2,PREF,TREF,T1T,WR,FR,FV,MU0,MU1,MU2,MU3,
     1K,GK,DR,MO,I,N)
C EVALUATION OF MASS FLOW RATE, MEASURED PIPE PRESSURE
      DIMENSION WR(N),FV(N),GK(N)
      REAL MM(2,N),MU0,MU1,MU2,MU3,K(N),MO,MU
      PI=P2/P1
      MU=MU0+MU1/PI
      FI=FV(N)*MU/FR
      IF(FI.GT.1.) FI=1.
      WZ=2./(K(N)-1.)*(PI**(-(K(N)-1.)/K(N))-1.)
      WN=1./(FI*FI)*PI**(-2./K(N))-1.
      ARG=WZ/WN
      IF(ARG.LT.0.)ARG=0.
      W=SQRT(ARG)
      A2=SQRT(K(N)*GK(N)*TREF)*(P2/PREF)**((K(N)-1.)/(2.*K(N)))
      RO=P1/(GK(N)*TREF*(P1/PREF)**((K(N)-1.)/K(N)))
      MM(I,N)=W*A2*RO*FR*9.55/(MO*DR)
      WR(N)=W*A2
      T1T=TREF*(P1/PREF)**((K(N)-1.)/K(N))+(W*A2)*(W*A2)*(K(N)-1.)/
     1(2.*K(N)*GK(N))
      RETURN
      END
```

```
MEMBER NAME  MTEMP
      SUBROUTINE MTEMP(SENT,MA,MO,TAM,LGA,BGA,LAV,PAM)
C AVERAGE EXHAUST GAS TEMPERATURE
      REAL MA,MO,LGA,KAM,LAV
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,
     1 QLOWER
      COMMON/APROP/DEL,PSI
      COMMON/PHICHI/CHI
      TAM=700.
      RGGA=1.-LGA-BGA
   10 CALL GPROP(TAM,PAM,LAV,DEL,PSI,1.,HAM,UAM,CAMP,CAMT,RHOA,DRHOTA,
     1DRHOPA,DHA,RAM,KAM)
      IF(ABS((HAM-SENT/(MA*MO))/HAM).LT..001)GOTO 20
      TAM=TAM+(SENT/(MA*MO)-HAM)*(KAM-1.)/(RAM*KAM)
      GO TO 10
   20 RETURN
      END
```

```
MEMBER NAME  MTEMP1
      SUBROUTINE MTEMP1(SENT,MA,MO,TAM,LGA,BGA,LAV,PAM)
C AVERAGE CYLINDERTEMPERATURE AFTER EVAPORIZATION OF FUEL
      PEAL MA,MO,LGA,KAM,LAV
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,
     1 QLOWER
      COMMON/APROP/DEL,PSI
      COMMON/PHICHI/CHI
      TAM=500.
      RGGA=1.-LGA-BGA
      RESFRK=0.
   10 CALL APROP(TAM,PAM,LAV,DEL,PSI,RESFRK,HAM,UAM,CAMP,CAMT,
     1 RHOA,DRHOTA,DRHOPA,DHA,RAM,KAM)
      IF(ABS((UAM-SENT/(MA*MO))/UAM).LT..001)GOTO 20
      TAM=TAM+(SENT/(MA*MO)-UAM)*(KAM-1.)/(RAM)
      GO TO 10
   20 RETURN
      END
```

```
MEMBER NAME  NEWT
      SUBROUTINE NEWT(FS,F,F1,M,I,N,PR,DPHI)
C EVALUATION OF NEW TEMPERATURE
C GETESTET 1.8.69
      DIMENSION FS(N),F(N),F1(N)
      REAL M(2,N)
      INTEGER PR(N)
      CALL INTEG(FS,F,M,I,N,DPHI)
      IF(PR(N).EQ.0.AND.I.EQ.2) F(N)=(F(N)+F1(N))/2.
      RETURN
      END
```

```
MEMBER NAME  VA
      SUBROUTINE VA(VHUB,SA,R,R1,R2,VFMAX,VF)
C EVALUATION OF VALVE AREA
      IF(VHUB-(R-R1)/(SIN(SA)*COS(SA)))1,2,2
    1 VF=3.14*VHUB*COS(SA)*(2.*R-VHUB*COS(SA)*SIN(SA))
      GOTO 10
    2 IF(VHUB-(R2-R1)/(SIN(SA)*COS(SA)))3,4,4
    3 VF=3.14*VHUB*COS(SA)*(2.*R1+VHUB*COS(SA)*SIN(SA))
      GOTO 10
    4 VF=3.14*(R1+R2)*SQRT(VHUB**2.-2.*VHUB*(R2-R1)*TAN(SA)+(R2-R1)**2.
     1*(1.+(TAN(SA))**2.))
   10 IF(VF.GT.VFMAX) VF= VFMAX
      RETURN
      END
```

```
MEMBER NAME  WTEMP
      SUBROUTINE WTEMP1(TWO,TKO,DO,ALO,LAO,TZM,ALFAM,N,TAKT)
C EVALUATION OF WALLTEMPERATURES
C GETESTET 30.7.69
      DIMENSION TZM(N),ALFAM(N)
      REAL LAO
      TWO=(TZM(N)*ALFAM(N)*(DO/LAO+1./ALO)+TKO)/(ALFAM(N)*(DO/LAO+1.
     1/ALO)+1.)
      RETURN
      END
```

```
MEMBER NAME  WTEMP2
      SUBROUTINE WTEMP2(TWO,TKO,DO,ALO,LAO,TZM,ALFAM,N,AM)
C GETESTET 12.8.69
      DIMENSION TZM(N),ALFAM(N),AM(N)
      REAL LAO
      TWO=(TZM(N)/AM(N)*(DO/LAO+1./ALO)+TKO)/(ALFAM(N)/AM(N)*(DO/LAO+1.
     1/ALO)+1.)
      RETURN
      END
```

```
MEMBER NAME  CPRESS
      SUBROUTINE CPRESS(PZ,TZ,RZ,I,N)
C EVALUATION OF CYLINDERPRESSURE
C GETESTET 1.8.69
      COMMON/HYP/CRR,BO,SO,CRL,CR,EX,ARG,X1W,X2W,PHI1
      COMMON /MASS/MO,M1,MO,ME,MA,MEA,MEE/GEOM/D,H,LA,EPS,PHIO(8),DAE,
     1PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI,XC,FK,VH,TAKT
      DIMENSION PZ(N),TZ(N),RZ(N)
      REAL MO(8),M1(8),MO,ME (8),MA(8),MEA(8),MEE(8),LA
      IF(I.EQ.2)GOTO 20
      PZ(N)=(MO(N)+ME(N)+MEE(N)-MA(N)-MEA(N))*MO*RZ(N)*TZ(N)/((XC+H/2.
     1*(1.-COS(PHIX(N)+DPHI)+LA/2.*SIN(PHIX(N)+DPHI)*SIN(PHIX(N)+DPHI)))
     2*FK)
      GOTO 30
   20 PZ(N)=(MO(N)+ME(N)+MEE(N)-MEA(N)-MA(N))*MO*RZ(N)*TZ(N)/VZ(N)
   30 RETURN
      END
```

```
MEMBER NAME  GASEX
      SUBROUTINE  GASEX(PE,TE,PA,DR,REZ)
C GAS EXCHANGE
      COMMON/RUCK2/LGEE(8),BGEE(8),RGGEE(8)
      COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
     1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
      COMMON/SCCOMB/PZ,TZ,TZS,TZ2,RZ,HZ,UZ,KZ,MT,LGZ,LGZS,BGZ,BGZS,RGGZ
     1,GGZ,PHIZ,MQW,I,N,LGRG,RU2,TEE2,LGE2,BGE2,GGE2,PZS
      COMMON/SC1/    MGZ,GGZS,BGZO,PES,TEE,LGE,BGE,RGGE,GGE,RE,HE,UE,KE
     1,FE,WER,TAR,LGAR,BGAR,RGGAR,GGAR,RAR,HAR,UAR,KAR,FA,WAR      ,MES
     2,MAS,UA,MEES,MEAS,EEIN,EEINS,EAUS,EAUSS,MEZ,MEZS,MAZ,MAZS,ER,AR
     3,FMFRO,FMFRI,PREF,TREF
      DIMENSION PZ(8),PZS(8),TZ(8),TZS(8),TZ2(8),BGZ(8),BGZS(8),RGGZ(8),
     1GGZ(8),GGZS(8),BGZO(8),RZ(8),HZ(8),UZ(8),PE(8),PES(8),TE(8),
     2TEE(8),BGE(8),RGGE(8),GGE(8),RE(8),HE(8),UE(8),FE(8),WER(8),PA(8),
     3TAR(8),BGAR(8),RGGAR(8),GGAR(8),RAR(8),HAR(8),UAR(8),FA(8),WAR(8)
     4,PHIZ(8),EEIN(8),EAUS(8),EAUSS(8),EEINS(8),ER(8),AR(8),UA(8)
      REAL LGZ(8),LGZS(8),MGZ(8),KZ(8),LGE(8),KE(8),LGAR(8),KAR(8),
     1LGRG(8),MES(8),MAS(8),MEES(8),MEAS(8),MQW(2,8),MT(2,8)
     2,MEZ(8),MEZS(8),MAZ(8),MAZS(8)
      COMMON /EKONTR/BB,TREF1(8),TREF2(8),PREF1(8),PREF2(8)
      COMMON /FUEL/SLB,CE,LAV,RB,ML,MBR,MRG,VERDD,Q(3,7)
     1/GEOM/D,H,LA,EPS,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI,
     2XC,FK,VH,TAKT
     3/ORG/NEUIN(8),PP,CO,DBV,VERD
     4/MASS/MO,M1,MO,ME,MA,MEA,MEE
     5/SC/MUOE,MU1E,MU2E,MU3E,FER,MUOA,MU1A,MU2A,MU3A,FAR
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,
     1QLOWER
      COMMON/APROP/DEL,PSI
      COMMON/PHICHI/CHI
      REAL LAV,ML,MBR,MRG,LA,MO(8),M1(8),MO,ME(8),MA(8),MEA(8),MEE(8),
     1MUOE,MU1E,MU2E,MU3E,MUOA,MU1A,MU2A,MU3A
     2,LGE2(8)
      INTEGER PP(8),CO(8),DBV(8)
      LOGICAL VERD
```

```
      DIMENSION DU1(8),DU2(8),DU3(8),DU4(8),DUDTZ(8),DUDTE(8),HEE(8),
     1REE(8),HMMEA(2,8),DUDTAR(8), DUDTEE(8),UEE(8)
     2,RU2(8),TEE2(8),BGE2(8),GGE2(8)
      REAL LGEE
      REAL KEE(8),MMA(2,8),MMEA(2,8),MME(2,8),MMEE(2,8),MZ(8),MLGZ(2,8),
     1MBGZ(2,8),MGGZ(2,8)
     2,MEEIN(2,8),MEAUS(2,8)
C     THIS IS A GAS EXCHANGE PROGRAM FOR A SINGLE CYLINDER
C     ENGINE
C     THE FIRST STEP IS TO DETERMINE THE PROPERTIES OF THE GASES
C     IN THE CYLINDER
      RESFRK=1.-GGZ(N)
      CALL GPROP(TZ(N),PZ(N),LAV,DEL,PSI,RESFRK,HZ(N),UZ(N),
     1CSUBPZ,CSUBTZ,RHOZ,DRHOTZ,DRHOPZ,DH1,RZ(N),KZ(N))
C     CALCULATE SOME QUANTITIES USED IN THE ENERGY EQUATION THAT
C     ARE FUNCTIONS OF ONLY THE CYLINDER STATE
      GGER=1.-REZ
      QUAN1=(1.-RHOZ*CSUBTZ)/DRHOPZ
      QUAN2=RHOZ*QUAN1
      QUANZ=HZ(N)-QUAN1
C     FIRST CONSIDER THE EXHAUST MASS FLOWS AND DETERMINE IF THE
C     FLOW IS INTO THE CYLINDER OR INTO THE EXHAUST. STAEMENT 1
C     REFERS TO INFLOW AND STATEMENT 2 REFERS TO OUTFLOW.
      IF(PZ(N)-PA(N))1,2,2
    1 RESFRK=1.-GGAR(N)
      CALL GPROP(TAR(N),PA(N),LAV,DEL,PSI,RESFRK,HAR(N),UAR(N)
     1,CSUPA,CSUTA,RHOA,DRHOTA,DRHOPA,DH111,RAR(N),KAR(N))
      CALL MFR(MMA,PZ,TAR,PA,WAR,FAR,FA,MUOA,MU1A,MU2A,MU3A,KAR,RAR,
     1DR,MO,I,N)
      AT=(HAR(N)-QUANZ)*MMA(I,N)*MO
      MEAUS(I,N)=HAR(N)*MMA(I,N)*MO
      GOTO 3
    2 CALL MFR(MMA,PZ,TZ,PA,WAR,FAR,FA,MUOA,MU1A,MU2A,MU3A,KZ,RZ,DR,MO,I
     1,N)
      AT=(HZ(N)-QUANZ)*MMA(I,N)*MO
      MEAUS(I,N)=HZ(N)*MMA(I,N)*MO
```

```
    3 MZ(N)=MO(N)+ME(N)+MEE(N)-MEA(N)-MA(N)
      CALL INTEG(MAS,MA,MMA,I,N,DPHI)
      FMFRO=MMA(I,N)
      IF(PES(N).LE.PZS(N)) GOTO 4
      IF(PHI+DPHI*(1 -I).GE.PHIO(N)+DAE+PHIPR+TAKT*PP(N)) GOTO 7
      FE(N)=.0
C     THIS SECTION REFERS TO BACKFLOW INTO THE INTAKE SYSTEM
C     AND MMEA ISDM/DT FOR FLOW INTO THE INTAKE FROM THE CYLINDER
    4 CONTINUE
      CALL MFR(MMEA,PE,TZ,PZ,WER,FER,FE,MU0E,MU1E,MU2E,MU3E,KZ,RZ,DR,MO,
     1I,N)
      FMFRI=MMEA(I,1)
      ET=(HZ(N)-QUANZ)*MMEA(I,N)*MO
      MEEIN(I,N)=HZ(N)*MMEA(I,N)*MO
      HMMEA(I,N)=-MMEA(I,N)
      CALL INTEG(MEAS,MEA,HMMEA,I,N,DPHI)
      IF(PZ(N).GE.PA(N)) GOTO 5
      MGGZ(I,N)=-(GGAR(N)-GGZ(N))*MMA(I,N)/MZ(N)
      CALL INTEG(GGZS,GGZ,MGGZ,I,N,DPHI)
      GOTO 6
    5 MGGZ(I,N)=.0
    6 GGE(N)=GGZ(N)
      LGEE(N)=LGZ(N)
      BGEE(N)=BGZ(N)
      RGGEE(N)=1.-LGZ(N)-BGZ(N)
      TEE(N)=TZ(N)
      GOTO 15
    7 IF(MEAS(N)-MEES(N).LE..0) GOTO 10
C     BACKFLOW COMPENSATION TEE IS EQUAL TO THE LAST TZ THAT WENT INTO
C     THE INTAKE BEFORE FLOW INTO THE CYLINDER BEGINS
C     THIS SECTION TREATS THE RESIDUALS IN THE INLET AS BULK FLOW
C     AND ALL THE GASES THAT ARE RETURNED INTO THE CYLINDER FOLLOW THE
C     ORDER IN WHICH THEY LEFT. THAT IS THE RESIDUALS ARE NOT
C     ALLOWED TO MIX
   40 RESFRK=1.-GGE(N)
      CALL GPROP(TEE(N),PE(N),LAV,DEL,PSI,RESFRK,HEE(N),UEE(N),CSUPEE
```

```
     1,CSUTEE,RHOEE,DRHOTE,DRHOPE,DH1EE,REE(N),KEE(N))
      IF(MEAS(N).GE.MEES(N))GOTO 42
      IF(K2.LT.0.OR.K4.LT.0)GOTO 41
   42 CALL MFR(MMEE,PE,TEE,PZ,WER,FER,FE,MU0E,MU1E,MU2E,MU3E,KEE,REE,
     1DR,MO,I,N)
      GOTO 45
   41 CALL MFRP(MMEE,PE(N),PZ(N),PREF2(N),TREF2(N),TEE(N),WER,FER
     1,FE,MU0E,MU1E,MU2E,MU3E,KEE,REE,DR,MO,I,N)
      RESFRK=1.-GGE(N)
      CALL GPROP(TEE(N),PE(N),LAV,DEL,PSI,RESFRK,HEE(N),UEE(N),CSUPEE,
     1CSUTEE,RHOEE,DRHOTE,DRHOPE,DHIE,REE(N),KEE(N))
   45 FMFRI=MMEE(I,1)
      ET=(HEE(N)-QUANZ)*MMEE(I,N)*MO
      MEEIN(I,N)=HEE(N)*MMEE(I,N)*MO
      CALL INTEG(MEES,MEE,MMEE,I,N,DPHI)
      IF(PZ(N).LT.PA(N)) GOTO 8
      MGGZ(I,N)=(GGE(N)-GGZ(N))*MMEE(I,N)/MZ(N)
      GOTO 9
    8 MGGZ(I,N)=((GGE(N)-GGZ(N))*MMEE(I,N)-(GGAR(N)-GGZ(N))*MMA(I,N))/MZ
     1(N)
    9 CALL INTEG(GGZS,GGZ,MGGZ,I,N,DPHI)
      GOTO 15
C VOLLKOMMENE MISCHUNG
   10 IF(RU2(N).EQ.0)GOTO 37
      IF(MEES(N)-MEAS(N)-RU2(N).LT.0)GOTO 38
      MEE(N)=MEES(N)-RU2(N)
      MEES(N)=MEE(N)
      ME(N)=RU2(N)
      MES(N)=RU2(N)
      RU2(N)=.0
      GOTO 37
   38 TEE(N)=TEE2(N)
      GGE(N)=GGE2(N)
      LGEE(N)=LGE2(N)
      BGEE(N)=BGE2(N)
      RGGEE(N)=1.-LGE2(N)-BGE2(N)
```

```
      GOTO 40
   37 RESFRK=1.-GGER
      CALL GPROP(TE(N),PE(N),LAV,DEL,PSI,RESFRK,HE(N),UE(N),CSUPE,
     1CSUTE,RHOE,DRHOTE,DRHOPE,DH1E,RE(N),KE(N))
      IF(K2.LT.0.OR.K4.LT.0) GO TO 33
      CALL MFR(MME,PE,TE,PZ,WER,FER,FE,MUOE,MU1E,MU2E,MU3E,KE,RE,DR,MO,
     1I,N)
      GOTO 34
   33 CONTINUE
      CALL MFRP(MME,PE(N),PZ(N),PREF,TREF,TE(N),WER,FER,FE,MUOE,MU1E
     1,MU2E,MU3E,KE,RE,DR,MO,I,N)
   34 FMFRI=MME(I,1)
      RESFRK=1.-GGER
      CALL GPROP(TE(N),PE(N),LAV,DEL,PSI,RESFRK,HE(N),UE(N),CSUPE,
     1CSUTE,RHOE,DRHOTE,DRHOPE,DH1E,RE(N),KE(N))
      ET=(HE(N)-QUANZ)*MME(I,N)*MO
      MEEIN(I,N)=HE(N)*MME(I,N)*MO
      CALL INTEG(MES,ME,MME,I,N,DPHI)
      TEE2(N)=TZ(N)
      TREF2(N)=TZ(N)
      PREF2(N)=PZ(N)
      IF(PZ(N).GE.PA(N)) GOTO 13
      MGGZ(I,N)=((GGER-GGZ(N))*MME(I,N)-(GGAR(N)-GGZ(N))*MMA(I,N))/MZ(N)
      GOTO 14
   13 MGGZ(I,N)=(GGER-GGZ(N))*MME(I,N)/MZ(N)
   14 CALL INTEG(GGZS,GGZ,MGGZ,I,N,DPHI)
   15 IF(VERD) GOTO 16
      MLGZ(I,N)=MGGZ(I,N)*(1.-LGRG(N))
      GOTO 17
   16 MLGZ(I,N)=MGGZ(I,N)*(LAV*SLB/(1.+LAV*SLB)-LGRG(N))
   17 IF(LAV-1)18,19,19
   19 IF(VERD) GOTO 20
      MBGZ(I,N)=.0
      GOTO 22
   20 MBGZ(I,N)=MGGZ(I,N)/(1.+LAV*SLB)
      GOTO 22
```

```
   18 IF(VERD) GOTO 21
      MBGZ(I,N)=-BGZO(N)*MGGZ(I,N)
      GOTO 22
   21 MBGZ(I,N)=MGGZ(I,N)/(1.+LAV*SLB)-BGZO(N)*MGGZ(I,N)
   22 CONTINUE
C     CALCULATE THE CHANGE IN TEMPERATURE IN THE CYLINDER
      QUANDT=MZ(N)*MO*(CSUBPZ+1./RHOZ*DRHOTZ/DRHOPZ-CSUBTZ/DRHOPZ
     1*DRHOTZ)
      MT(I,N)=1./QUANDT*(-MZ(N)*MO*DH1*MGGZ(I,N)+(ET-AT)-MQW(I,N)
     1-QUAN2*PHIZ(N))
      CALL NEWT(TZS,TZ,TZ2,MT,I,N,CO,DPHI)
      CALL CPRESS(PZ,TZ,RZ,I,N)
      MGZ(N)=GGZ(N)*MZ(N)
      CALL INTEG(LGZS,LGZ,MLGZ,I,N,DPHI)
      CALL INTEG(BGZS,BGZ,MBGZ,I,N,DPHI)
      RGGZ(N)=1.-LGZ(N)-BGZ(N)
      IF(PZ(N).LT.PA(N)) GOTO 23
      LGAR(N)=LGZ(N)
      TAR(N)= TZ(N)
      GGAR(N)=GGZ(N)
      RGGAR(N)=RGGZ(N)
      BGAR(N)=BGZ(N)
   23 CALL INTEG(EEINS,EEIN,MEEIN,I,N,DPHI)
      CALL INTEG(EAUSS,EAUS,MEAUS,I,N,DPHI)
      RETURN
      END
```

```
MEMBER NAME  CLDPRD
C******************* VERSION 2.1 *** 1/10 76 ***************************
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 CLDPK (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)
C
      LOGICAL RICH,LEAN
      DIMENSION A(6,6,2),X(6)
      DIMENSION A1(36),A2(36)
      DIMENSION TABLE(7)
      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 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,.06669498,.0335801,-56.62588,
     2  7.099556,1.275957,-.2877457,.022356,-.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,-.1189462,-.331835/
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```
      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/
      DATA TABLE /-1.,1.,1.,-1.,0.,0.,0./
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
      DCDT = 0.
      GO TO 20
   10 Z = 1000./T
      K = EXP(2.743 + Z*(-1.761 + Z*(-1.611 + Z*.2803)))
      DKDT = -K*Z*(-1.761 + Z*(-3.222 + Z*.9049))/T
      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)
      DCDT = -DKDT*(C*C + (2.*(PHI - 1.) + EPS*PHI)*C - GAMMA/K)
      DCDT = DCDT/(2.*ALPHA*C + BETA)
```

```
      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.
      CSUBP = 0.
      CSUBT = 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    CSUBP  =  CSUBP  +  TCP*X(J) + 1000.*TH*DCDT*TABLE(J)
      ENTHLP = ENTHLP/MBAR
      CSUBP = CSUBP/MBAR
C
C        NOW CALCULATE RHO AND ITS PARTIAL DERIVATIVES
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```
C        USING PERFECT GAS LAW
C
      RHO = .012187*MBAR*P/T
      DRHODT = -RHO/T
      DRHODP = RHO/P
C
C        ALL DONE
      RETURN
      END
```

```
MEMBER NAME  HPROD
C****************** VERSION 2.0 *** 1/08/76 ***************************
C
C     SUBROUTINE HPROD
C
C     PURPOSE:
C        TO CALCULATE THE PROPERTIES OF THE PRODUCTS OF HYDROCARBON-
C        AIR COMBUSTION AS A FUNCTION OF TEMPERATURE AND PRESSURE,
C        USING AN APPROXIMATE CORRECTION FOR DISSOCIATION.
C        H AND RHO ARE CALCULATED AS FUNCTIONS OF P, T, AND PHI.
C        THE PARTIAL DERIVATIVES OF H AND RHO WITH RESPECT TO
C        P AND T ARE ALSO CALCULATED
C
C     USAGE:
C        CALL HPROD (P, T, PHI, DEL, PSI, H, CP, CT, 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        H      - SPECIFIC ENTHALPY OF THE PRODUCTS (KCAL/G)
C        CP     - PARTIAL DERIVATIVE OF H WITH RESPECT TO T AT CONSTANT
C                  P AND PHI   (CAL/G-DEG K)
C        CT     - PARTIAL DERIVATIVE OF H WITH RESPECT TO P AT CONSTANT
C                  T AND PHI   (CC/G)
C        RHO    - DENSITY OF THE PRODUCTS     (G/CC)
C        DRHODT- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO T AT
C                  CONSTANT P AND PHI   (G/CC-DEG K)
C        DRHODP- PARTIAL DERIVATIVE OF RHO WITH RESPECT TO P AT
C                  CONSTANT T AND PHI   (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) MULTIPLY ATM-CC BY .0242173 TO CONVERT TO CAL
C        3) MODIFIED VERSION OF MIKE MARTIN'S PROGRAM BPROP1
C        4) COLIN FERGUSON 253-5348
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED:
C        CLDPRD
C
C     METHOD:
C        SEE MARTIN & HEYWOOD 'APPROXIMATE RELATIONSHIPS FOR THE THERMO-
C        DYNAMIC PROPERTIES OF HYDROCARBON-AIR COMBUSTION PRODUCTS'
C
C
C
C***********************************************************************
C
      SUBROUTINE HPROD (P, T, PHI, DEL, PSI, H, CP, CT, RHO, DRHODT,
     *                   DRHODP)
      LOGICAL RICH, LEAN, NOTHOT, NOTWRM, NOTCLD
      REAL MCP, MWT, K1, K2
C
C     INITIALIZE PARAMETERS USED IN THE CALCULATION
C
      DATA R, ROVER2 / 1.9869, .99345 /, PSCALE /2.42173E-2 /
      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 CLDPRD (P,T,PHI,DEL,PSI,H,CP,CT,RHO,DRHODT,DRHODP,IER)
      RETURN
C
C     CALCULATE EQUILIBRIUM CONSTANTS FOR DISSOCIATION (EQS. 3.9 & 3.10)
C     (NOTE THAT THESE HAVE UNITS ATM**(.5) )
C
    5 K1 = 5.819E-6 * EXP(.9674*EPS + 35810./T)
      K2 = 2.961E-5 * EXP(2.593*EPS + 28980./T)
C
C     CALCULATE A, X, Y, & U AS IN EQS. 5.24, 3.6, 5.25, 3.7, 2.18,
C        2.19, & 3.8
C
      C5 = 2.- EPS + PSI
      A  = ( C5/(4.*P*K1*K1*EPS) )**(.33333333)
C
      C6 = EPS + 2.*C5
      X  = A*EPS*(3.*C5 + C6*A)/(3.*(1.+ 2.*A)*C5 + 2.*C6*A*A)
C
      Z = ABS((1.- PHI)/X)
      IF (LEAN)  Y = X/SQRT(1.+ .666667*Z + 1.333333*(1.-PHI))
      IF (RICH)  Y = X/(1.+.6666667*Z +.3333333*Z*Z -.6666667*(PHI-1.))
      U = C5*(EPS - 2.*X)/(4.*K1*K2*P*X)
C
C     CALCULATE THE ENTHALPY OF FORMATION FOR THIS APPROXIMATE
C     COMPOSITION AS IN EQS. 3.21, 3.22, & 5.7
C     ALSO GET THE COEFFICIENTS FOR T & TV TERMS IN 3.15 USING 5.3 & 5.4
C
      HF   = 1000.*((121.5 + 29.59*EPS)*Y + 117.5*U)
      HF   = HF + (20372.*EPS - 114942.)*PHI
      C1   = 7.*PSI + 5.*Y + 3.*U
      C2   = 2.*(PSI - 3.*Y - U)
C
      IF (LEAN)  GO TO 10
```

```
C          RICH CASE
      HF = HF + 1000.*(134.39 - 6.5/EPS)*(PHI - 1.)
      C1 = 2. + 2.*(7.- 4.*EPS)*PHI + C1
      C2 = 8. + 2.*(2.- 3.*EPS)*PHI + C2
      GO TO 20
C            LEAN CASE
   10 C1 = 7. +    (9.- 8.*EPS)*PHI + C1
      C2 = 2. + 2.*(5.- 3.*EPS)*PHI + C2
C
C     ADD IN TRANSLATIONAL,VIBRATIONAL, AND ROTATIONAL TERMS TO GET
C     TOTAL ENTHALPY, USING EQS. 3.16, 5.6, 3.11, & 3.15
C
   20 TV = (3256.- 2400.*EPS + 300.*PSI)/(1.- .5*EPS + .09*PSI)
      EXPTVT= EXP(TV/T)
      TVTIL = TV/( EXPTVT - 1.)
      MCP   = (8.*EPS + 4.)*PHI + 32. + 28.*PSI
C
      H     = .001*ROVER2*(C1*T + C2*TVTIL + HF)/MCP
C
C     CALCULATE AVERAGE MOLECULAR WEIGHT, AND GET DENSITY BY
C     USING THE PERFECT GAS LAW - EQS 3.12, 3.13, & 3.14
C
      IF (LEAN)  MWT = MCP/(1. + (1.- EPS)*PHI + PSI + Y + U)
      IF (RICH)  MWT = MCP/(     (2.- EPS)*PHI + PSI + Y + U)
      RHO = MWT*P*PSCALE/(R*T)
C
C     GET PARTIAL DERIVATIVES IF DESIRED
C
C     THE FOLLOWING USES IN ORDER EQS. 5.8, 5.9, 5.32, 5.31, 5.30,
C     5.29, 5.28, & 5.26
C
      C3 = (121.5 + 29.59*EPS)*1000.
      C4 = 1.175E5
C
      DUDTPX = 64790.*U/(T*T)
      DUDPTX = -U/P
```

```
      DUDXPT = -U*EPS/(X*(EPS - 2.*X))
C
      DADTP = 23873.*A/(T*T)
      DADPT = -A/(3.*P)
C
      T5 = 3.*C5
      DXDA = T5*EPS*(T5 + 2.*C6*A)/(T5*(1. + 2.*A) + 2.*C6*A*A)**2
C
C     FOLLOWING USES EQS. 5.23, 5.19-5.22, 5.18-5.14, 5.12, & 5.13
C
      IF (LEAN) DYDX = (Y*Y*Y)/(X*X*X) * (1.+ Z + 1.333333*(1.-PHI))
      IF (RICH) DYDX = (Y*Y)/(X*X)*(1.+ 4.*Z/3. + Z*Z - 2.*(PHI-1.)/3.)
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
      DTVDTP = (TVTIL*TVTIL)/(T*T)*EXPTVT
C
C     FOLLOWING USES EQS.  5.10, & 5.11
C
C
      CP = ROVER2/MCP*(C1 + T*DC1DTP + C2*DTVDTP + TVTIL*DC2DTP
     *                     + DHFDTP )
      CT = ROVER2/MCP*(T*DC1DPT + TVTIL*DC2DPT + DHFDPT)*PSCALE
C
C     FOLLOWING USES EQS. 5.46,  5.35-5.37, 5.33, & 5.34
C
```

```
      IF (LEAN) D = 1. + (1.- EPS)*PHI + PSI + Y + U
      IF (RICH) D =      (2.- EPS)*PHI + PSI + Y + U
      G     = -MCP/(D*D)
      DMDTP = G*(DYDTP + DUDTP)
      DMDPT = G*(DYDPT + DUDPT)
C
      DRHODT = PSCALE*P*(DMDTP - MWT/T)/(R*T)
      DRHODP = PSCALE*(MWT + P*DMDPT)/(R*T)
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) RETURN
C
      CALL CLDPRD (P,T,PHI,DEL,PSI,TH,TCP,TCT,TRHO,TDRT,TDRP,IER)
      W1 = (T - TCOLD)/(THOT - TCOLD)
      W2 = 1.0 - W1
C
      H   = W1*H   + W2*TH
      RHO = W1*RHO + W2*TRHO
      CP  = W1*CP  + W2*TCP
      CT  = W1*CT  + W2*TCT
      DRHODT = W1*DRHODT + W2*TDRT
      DRHODP = W1*DRHODP + W2*TDRP
C
      RETURN
      END
```

```
MEMBER NAME  GPROP
C THIS IS A SUBROUTINE TO CALCULATE GAS PROPERTIES USING M.MARTINS
C  PROGRAMS FOR UNBURNED AND BURNED  GASES
      SUBROUTINE GPROP(T,P,LAV,DEL,PSI,RESPRK,ENTHLP,ENERGY,
     1CSUBP,CSUBT,RHO,DRHODT,DRHODP,DH1,GASCON,GAMMA)
      REAL LAV
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,
     1QLOWER
      COMMON/PHICHI/CHI
      PHI=1./LAV
      PATM=P*9.8692*10.**(-6.)
      IF(RESPRK.LT.0.99) GO TO 100
      IF(RESPRK.GT.0.99) GO TO 200
C CALL M MARTIN PROGRAMS
  100 CALL UPROP(PATM,T,PHI,DEL,PSI,RESPRK,ENTHLP,CSUBP,CSUBT,
     1RHO,DRHODT,DRHODP,CHI)
      GO TO 1000
  200  CALL HPROD(PATM,T,CHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,
     1DRHODT,DRHODP)
 1000 CONTINUE
      CALL UPROP(PATM,T,PHI,DEL1,PSI1,1.,H2,D1,D2,R2,D4,D5,D6)
      CALL UPROP(PATM,T,PHI,DEL2,PSI2,0.,H1,D1,D2,R1,D4,D5,D6)
      Q1=RHO*(R2-R1)/(R1*R2)
      DH1=H1-H2
C CONVERT TO SI UNITS
      DH1=DH1*10.**3.*4.184*10**3.
C CHANGE ALL UNITS TO SI UNITS
      RHO=RHO*10.**3.
      CSUBP=CSUBP*4.184*10.**3.
      ENTHLP=ENTHLP*10.**3.*4.184*10.**3.
      DRHODT=DRHODT*10.**3.
      DRHODP=DRHODP*10.**3.*9.68692*10.**(-6.)
      GASCON=P/RHO/T
      CSUBT=CSUBT*10.**(-3)
      GAMMA=CSUBP/(CSUBP-GASCON)
      ENERGY=ENTHLP-P/RHO
```

```
DH1=DH1-(1.-RHO*CSUBT)*Q1/DRHODP
RETURN
END
```

```
MEMBER NAME  UPROP
C****************** VERSION 2.0 *** 1/10/76 ***************************
C
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        FREQ   - FREQUENCY FACTOR <(CC/G)**(ORDER - 1) PER SEC>
C        ORDER - REACTION ORDER
C        ACTV   - ACTIVATION ENERGY (KCAL/GMOLE)
```

```
C        TSUBC - CHARACTERISTIC TEMPERATURE OF NONADIABTIC FLAME (DEG K)
C        ENW   - AVEARGE 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      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 (C:02 RATIO DIVIDED
C                BY THE CHEMICALLY CORRECT C:02 RATIO)
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)   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 WRITEUP
C
C*****************************************************************************
      SUBROUTINE UPROP(P,T,PHI,DEL,PSI,RESPRK,ENTHLP,CSUBP,CSUBT,RHO,
```

```
C DRHODT,DRHODP,CHI)
 COMMON /FUEL1/ AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,QLOWER
 LOGICAL RICH,LEAN
 DIMENSION A(6,7,2),X(7)
 DIMENSION A1(42),A2(42),TABLE(7)
 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 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,.06669498,.0335801,-56.62588,
2  7.099556,1.275957,-.2877457,.022356,-.1598696,-27.73464,
4  7.865847,.6883719,-.031944,-.00268708,-.2013873,-.893455,
5  6.807771,1.453404,-.328985,.02561035,-.1189462,-.331835,
6  6*0.0/
 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,
$  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) = 3.76 + EPS*PHI*W/2.
```

```
      X(7) = PCTNEW * EPS*PHI/CX
C
C        CONVERT COMPOSITION TO MOLE FRACTIONS AND CALCULATE AVERAGE
C        MOLECULAR WEIGHT
C
      IF (LEAN) TMOLES = 3.76 + (1. + EPS*PHI/CX)*PCTNEW
     +                   + (1. + (1.- EPS)*PHI + EPS*PHI*(Z + W/2.))*PCTRES
      IF (RICH) TMOLES = 3.76 + (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.*3.76
      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 = (3.76 + EPS*PHI*W/2.)/(1. + EPS*Z*PHI/2.)
      CHI = PHI*(1. + EPS*Z/2.)/(1. + EPS*Z*PHI/2.)
C
C        ALL DONE
      RETURN
      END
```

```
MEMBER NAME  PTCHEM
      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           'H2O2', '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
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)
C
C      FOLLOWING ARRAYS ARE 'NELEM' IN SIZE
C
      DIMENSION DD(4), XMU(4), XNU(4), E(4), F(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)
C
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, XMU, XNU, E, F  /  32 * 0. /
      DATA  R, G  /  42 * 0. /
      DATA  A, CMN, CP, CPT, X, XMAX  /  126 * 0. /
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,-6.7088366D-01, 5.0901942D-02,
     1 -4.1140777D-01,-6.9903498D 00, 6.2395554D 01, 2.3009987D 00,
     2  7.0995646D 00, 1.2759562D 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, 1.7871914D 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,-9.3560094D-01, 6.6694975D-02,
     7  3.3580098D-02,-5.9687866D 01, 5.1456772D 01, 3.0619965D 00 /
      DATA  ZL2  /
     8  5.1632023D 00,-1.8977487D-01, 3.6921006D-02, 3.6241105D-03,
     8 -3.2718156D-02, 1.1134157D 02, 4.2783066D 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, 6.8837190D-01,-3.1944100D-02,-2.6870817D-03,
     E -2.0138729D-01,-2.9684544D 00, 5.7424637D 01, 2.0749989D 00 /
C
C
C
      IF(NSAME)2000,2000,2004
 2000 NSAME=1
      AE=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)
C
C
C     END OF ONE-TIME INITIALIZATION
C
 2004 IF ( TMP - 700.0 )  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
```

```
      ITTRDG=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          L1=0
C           NGO5=1
C     RATIO = .01D0
C        DO  526   I=1,N
C         IF (D(I)/SUM - RATIO )     527,527,526
C 527      L1=L1+1
C          K2(L1) =I
```

```
C 526      CONTINUE
C          NL= L1
C          IF  (NL)  528,528,529
C 528      NGO5 =1
C          GO TO  530
C 529      NGO5=2
C 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))
          SUMEX=SUMEX+XJ
102    X(J)=XJ
        IF (SUMEX-1.0D0-TOL1*RH2)    103,103,107
103    IF(SUMEX-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
C          GO TO (475,476),NGO5
C 476 K = ITER - ( ITER / N ) * N
C             IF  (K)   531,532,531
C 532           K=N
C 531         DO  540  L1=1,NL
C          IF(K2(L1)-K)    540,541,540
C 540             CONTINUE
C           GO TO 475
C 541 IF(DABS(XNU(K))-TOL5*D(K)) 475,475,542
C 542 IF(DABS(XNU(K))-1.D-15)475,475,8000
C8000 SUM=XNU(K)
C       DO 543 I=1,N
C 543         XNU(I)=0.0D0
C          XNU(K)=SUM
C         H0=SUM*SUM
C          DIF1=100.0D0
C             H2=H0
C            T0=0.0D0
C          T=1.0D0
C          GO TO 430
C 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) ,NGO1
C
```

```
500        NTOT=N+L
      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(XNU(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
          NGO6=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
      RETURN
C
C     ERROR:  SET MOLE FRACTIONS TO 0.
C
 5000 DO 5100 I = 1, ITOTSP
 5100 XMOFR(I) = 0.
      RETURN
      END
```

```
MEMBER NAME  NXNSOL
      FUNCTION    NXNSOL(IM,IN,A,B)
CNXNSOL
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(2),B(2)
      INTEGER XROW
      XROW(K000PX,K001PX)=K001PX*M-M+K000PX
      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=J,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
```

```
MEMBER NAME  CONVR
      SUBROUTINE CONVR
C
C
      INTEGER PP(9),CO(8),DBV(8)
      INTEGER T,Z,VERG,Y,SUMG,AVS,GZ(8),GE(8),TEX,TIN,TP     ,TPZ
C
      REAL NNOU,NNOB,NNOT
      REAL KS1(8)
      REAL LAND,LANW,LANK,LANEV,LANAV,LA,MO(8),M1(8),MO,ME(8),MA(8),
     1MEA(8),MEE(8),LAV,ML,MBR,MRG,MV,MUOE,MU1E,MU2E,MU3E,MUOA,MU1A,
     2MU2A,MU3A
      REAL MLZ(8),LGZ(8),LGZS(8),MT(2,8),MLGZ(2,8),MBGZ(2,8),KO,LGRG(8),
     1MEZ(8),LAVS,LGE(8),LGA(8),MGGZ(2,8),MEZS(8),MES(8),MAS(8),MEES(8),
     2MEAS(8),LGES(8),LGAS(8),MAI(2,8),MGZ(8),MQW(2,8)
     3,KZ(8),KE(8),KA(8)  ,MMEO(2,8),MMA2(2,8),MBA(2,8),MPZ(2,8)
     4,MAZ(8),MAZS(8),MEO(8),MEOS(8),MA2(8),MA2S(8),MO1(8),MO2(8)
     5,KEO(8),LGAR(8),KAR(8),LGARS(8),MTE(2,8),MTA(2,8)
     6,LGE2(8),M1B,M1U
      REAL MQWB(2,8),MQWU(2,8)
      REAL LDEL,LDIL
C   PUT C'S ON ALL CARDS NOT IN ORIGINAL MEINRAD VERSION
C  C  REAL MAUX,MOUTCA,MOUTPA,MINAC,MINAP,MRESAC  C  C  C  C  C  C  C
C  C  REAL MVPC  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C
C  C  COMMON/AUXIPT/TAUX,PAUX,MAUX,EAIRA,DMAUX,MOUTCA,MINAC,MRESAC  C
C    1,SMOPA,SMINAP,SMOCA,SMINAC,RMAUX,XAA,XFA,XSBPA,VAUX,TWAUXC  C  C
C  C  COMMON/AUXPLE/TPLE,PPLE,EPLE,AREAV,AREAO,XAP,XFP,XSBPP,JBKFL,C
C    1MINAP,MOUTPA,QAUX,SUMQ,SRMCYL,VELOR,VELV,SBKPL2,SBKPLC  C  C  C
      COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
     1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
      COMMON/SCCOMB/PZ,TZ,TZS,TZ2,RZ,HZ,UZ,KZ,MT,LGZ,LGZS,BGZ,BGZS,RGGZ
     1,GGZ,PHIZ,MQW,I,N,LGRG,RU2,TEE2,LGE2,BGE2,GGE2,PZS
      COMMON/HTREL/TZM,TZMS,ALFAM,ALFAMS,BO,DB,      LAVS,DU1,DU2,DUDTZ,
     1AI,AIS,QW,QWS,MLGZ,MBGZ,MLZ,HG,    KONV,B,BS,MBA,MPZ,TPZ,ETAU,
     2AM,AMS,TB,TU,VB,VU,MQWB,MQWU,TBS,TUS,TZV
      COMMON /HTR/TD,TKD,DD,ALD,LAND,TW,TKW,DW,ALW,LANW,TK,TKK,DK,ALK,
```

```
     1LANK,TEV,TKEV,DEV,ALEV,LANEV,TAV,TKAV,DAV,ALAV,LANAV,FDFK,WF,ZETA
     2/GEOM/D,H,LA,EPS,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI,
     3XC,FK,VH,TAKT
     6/FUEL/SLB,CE,LAV,RB,ML,MBR,MRG,VERDD,Q(3,7)
     7/COMB/AV,MV,PHIVA(8),VD
     8/OPD/PO,TO,PE,TE,PA,PB,DR,PEO,TEO,FEO,VER
     9/SC/MUOE,MU1E,MU2E,MU3E,FER,MUOA,MU1A,MU2A,MU3A,FAR
      COMMON/VALVE/PHIOEX,PHIOIN,PHICEX,PHICIN,SAEX,R1EX,R2EX,R3EX,R4EX,
     1RAREX,SAIN,R1IN,R2IN,R3IN,R4IN,RARIN
     3/VARIA/FAV,FEV,LE,LI,TEX,TIN,TWU,VERG,LDEL,CDEL,LDIL,CDIL, FEL ,
     4 FAL,PHIL,PHILP,PEL,PAL,REZ,CN
      COMMON /OUTP/ CNOPPM(8)
C C   COMMON/DICHRG/CDINT,CDCOMP,CDCOMBC  C  C  C  C  C  C  C  C  C  C
C C   COMMON/HRLPRE/VDP,MVP,AVPC  C  C  C  C  C  C  C  C  C  C  C  C
C
      LOGICAL VERD,EIN,AUS
C
      DIMENSION PZ(8),PZS(8),TZ(8),TZS(8),TZ2(8),TZ3(8),TZH(8),TZM(8),
     1TZMS(8),ALFAM(8),ALFAMS(8),BO(8),DB(8),RZ(8),HZ(8),UZ(8),
     2DU1(8),DU2(8),DUDTZ(8),AI(8),AIS(8),QW(8),QWS(8),BGZ(8),BGZS(8),
     3RGGZ(8),X(8),PE(8),TE(8),PA(8),PHIL(320),FEL(320),FAL(320),
     FPEL(300),PAL(300),PHILP(300),PZL(50),PHIPZ(50),
     4         WER(8),WAR(8),GGZ(8),BGE(8),BGZO(8),TEE(8),TA(8),RGGE(8),
     5RGGA(8),BGA(8),TES(8),TEH(8),PES(8),GGZS(8),RGGZS(8),TAS(8),TEES(8
     6),BGES(8),BGAS(8),RGGES(8),RGGAS(8),GGES(8),GGE(8),GGAS(8),GGA(8),
     7TE3(8),TE2(8),PHIZ(8),TWX(8),FE(8),FA(8),ALFA(8)
     8,RE(8),HE(8),UE(8),RA(8),HA(8),UA(8)
     9,EEIN(8),EEINS(8),EAUS(8),EAUSS(8),FELL(300),FALL(300)
     A,ER(8),AR(8),PEO(8),TEO(8),FEO(8),VER(8),PA2(8),TA2(8),FA2(8)
     B,VAE(8),TAR(8),BGAR(8),RGGAR(8),RAR(8),HAR(8),UAR(8),GGAR(8)
     C,TARS(8),BGARS(8),RGGARS(8),GGARS(8),WRH(1)
     D,DUDTEO(8),HEO(8),UEO(8),REO(8),DU3(8),DU4(8),DUDTA(8)
     E,PAS(8),ERO(8),AR2(8),RGA(8),DUDTE(8),B(8),BS(8)
     F,RU2(8),BGE2(8),TEE2(8),GGE2(8)
      DIMENSION EO(1),EOS(1),AEO(2,1)
      DIMENSION LDEL(20),CDEL(20),CDE(300),LDIL(20),CDIL(20),CDI(300)
```

```
      DIMENSION AA(8),AM(8),AMS(8)
      DIMENSION TB(8),TU(8),VB(8),VU(8),TBS(8),TUS(8),TZV(8)
      DIMENSION PS1(8),TS1(8),VSS1(8),TZVS(3),HG(8)
C  C  DIMENSION DMAUX(2),QAUX(2),MOUTCA(2),MOUTPA(2),MINAP(2),MINAC(2)
C
C
      DO 200 II = 1, 8
  200 CNOPPM(II) = 0.
      VERG=-1
      U=.017453848
      UDP=1./14.5*100000.
      UT=.5555
      UL=.0254
      UFI=.0006452
      ULE=17.57
      UFF=.0929
      UDI=25.4/750.5*100000.
      UALF=ULE/UFF/UT
      ULF=.3048
      ULAN=ULE/ULF/UT
      UEN=1055.
      UMA=.4536
      D=D*UL
      H=H*UL
      FER=FER*UFI
      FAR=FAR*UFI
      DD=DD*UL
      DW=DW*UL
      DK=DK*UL
      DEV=DEV*UL
      DAV=DAV*UL
      FAV=FAV*UFI
      FEV=FEV*UFI
      R1EX=R1EX*UL
      R2EX=R2EX*UL
      R3EX=R3EX*UL
```

```
      R4EX=R4EX*UL
      R1IN=R1IN*UL
      R2IN=R2IN*UL
      R3IN=R3IN*UL
      R4IN=R4IN*UL
      PHIO(1)=(PHICIN-720.)*U
      PHIPR=PHIOEX*U-PHIO(1)
      DAE=(PHIOIN-PHIOEX)*U
      SAEX=SAEX*U
      SAIN=SAIN*U
      ALD =ALD*UALF
      ALW =ALW*UALF
      ALK =ALK*UALF
      ALEV=ALEV*UALF
      ALAV=ALAV*UALF
      LAND=LAND*ULAN
      LANW=LANW*ULAN
      LANK=LANK*ULAN
      LANEV=LANEV*ULAN
      LANAV=LANAV*ULAN
      TKD=(TKD-32.)*UT+273.
      TKW=(TKW-32.)*UT+273.
      TKK=(TKK-32.)*UT+273.
      TKEV=(TKEV-32.)*UT+273.
      TKAV=(TKAV-32.)*UT+273.
C   C TPLE=(TPLE-32.)*UT+273.C  C  C  C  C  C  C  C  C  C  C  C  C  C
C   C TWAUX=(TWAUX-32.)*UT+273.C  C  C  C  C  C  C  C  C  C  C  C  C
C   C PPLE=PPLE*UDP+PB*UDIC  C  C  C  C  C  C  C  C  C  C  C  C  C  C
C   C AREAO=AREAO*UFIC  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C
C   C VAUX=VAUX*UFI*.0254C  C  C  C  C  C  C  C  C  C  C  C  C  C
      CE=CE*UEN/UMA
      RB=193.
      RB=RB*UEN/UMA
      PHIVA(1)=PHIVA(1)*U
      VD=VD*U
C   C VDP=VDP*UC  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C  C
```

```
      PB=PB*UDI
      PO=PO*UDP+PB
      TO=(TO-32.)*UT+273.
      TZM(1)=1000.
      ALPAM(1)=160.
      TAKT=4.*3.1415926
      IF(TEX.GT.0)GOTO 20
      DO 10 L=1,T
      PHIL(L)=PHIL(L)*U
      IF(LE.GT.0)GOTO 50
      FEL(L)=FEL(L)*UFI
      FAL(L)=FAL(L)*UFI
C  C  AUXV(L)=AUXV(L)*UFIC  C  C  C  C  C  C  C  C  C  C  C  C  C  C
      GOTO 10
   50 FEL(L)=FEL(L)*UL
      FAL(L)=FAL(L)*UL
   10 CONTINUE
      GOTO 30
   20 DO 40 L=1,T
      PHIL(L)=PHIL(L)*U
      FEL(L)=FEL(L)*UL
   40 FAL(L)=FAL(L)*UL
   30 RETURN
      END
```

```
MEMBER NAME  CALC
      SUBROUTINE CALC
C
C MULTICYLINDER SPARK IGNITION ENGINE WITH INTAKE- AND EXHAUST MANIFOLD
C PROGRAM ICEM-HRF, INCLUDING GENERATION OF HEAT RELEASE FUNCTION
C
C
      INTEGER CD, PRI, DSI,DSO,V,C,P1,P2
      INTEGER PP(8),CO(8),DBV(8)
      INTEGER T,Z,VERG,Y,SUMG,AVS,GZ(8),GE(8),TEK,TIN,TP    ,TPZ
C
      REAL LGU ,LGB ,KU ,MVB ,MTB ,MTU ,KB ,MB
      REAL LGEE
      REAL NNOU,NNOB,NNOT
      REAL KS1(8)
      REAL LAND,LANW,LANK,LANEV,LANAV,LA,MO(8),M1(8),MO,ME(8),MA(8),
     1MEA(8),MEE(8),LAV,ML,MBR,MRG,MV,MUOE,MU1E,MU2E,MU3E,MUOA,MU1A,
     2MU2A,MU3A
      REAL MLZ(8),LGZ(8),LGZS(8),MT(2,8),MLGZ(2,8),MBGZ(2,8),KO,LGRG(8),
     1MEZ(8),LAVS,LGE(8),LGA(8),MGGZ(2,8),MEZS(8),MES(8),MAS(8),MEES(8),
     2MEAS(8),LGES(8),LGAS(8),MAI(2,8),MGZ(8),MQW(2,8)
     3,KZ(8),KE(8),KA(8)  ,MMEO(2,8),MMA2(2,8),MBA(2,8),MPZ(2,8)
     4,MAZ(8),MAZS(8),MEO(8),MEOS(8),MA2(8),MA2S(8),MO1(8),MO2(8)
     5,KEO(8),LGAR(8),KAR(8),LGARS(8),MTE(2,8),MTA(2,8)
     6,LGE2(8),M1B,M1U
      REAL MQWB(2,8),MQWU(2,8)
      REAL LDEL,LDIL
C
      COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,OZ,
     1QLOWER
      COMMON/HEATC/LGU  (8),LGB  (8),KU  (8),MVB  (2,8),MTB  (2,8),MTU  (2,8)
     1,KB  (8),BGU  (8),RGGU  (8),BGB  (8), CVB  (8), CVU  (8),HU  (8)
     2,KU  (8),HB  (8),UB  (8),RG  (8),RGGB  (8),MB    (8)
      COMMON/RUCK2/LGEE(8),BGEE(8),RGGEE(8)
      COMMON /TITLE/ NA(60)
      COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
```

```
1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
 COMMON /INPUTP/ INPUTT
 COMMON /CNOX/TZU (8),TZUS (8),TZB (8),TZBS(8),NNOU (8),
1NNOB (8),DNOOUI (8),DNOOU(8),DNOOBI (8),NNOT (8),
2DNOOB(8),   FBURN,ITEST (8),NRP, BSDUM, FNNOTS, FBURNS
 COMMON /STEPS/DPHINO
 COMMON/HYP/CRR,BO,SO,CRL,CR,EX,ARG,X1W,X2W,PHI1
 COMMON/SCCOMB/PZ,TZ,TZS,TZ2,RZ,HZ,UZ,KZ,MT,LGZ,LGZS,BGZ,BGZS,RGGZ
1,GGZ,PHIZ,MQW,I,N,LGRG,RU2,TEE2,LGE2,BGE2,GGE2,PZS
 COMMON/HTREL/TZM,TZMS,ALFAM,ALFAMS,BO,DB,      LAVS,DU1,DU2,DUDTZ,
1AI,AIS,QW,QWS,MLGZ,MBGZ,MLZ,HG,    KONV,B,BS,MBA,MPZ,TPZ,ETAU,
2AM,AMS,TB,TU,VB,VU,MQWB,MQWU,TBS,TUS,TZV
 COMMON/SC1/    MGZ,GGZS,BGZO,PES,TEE,LGE,BGE,RGGE,GGE,RE,HE,UE,KE
1,FE,WER,TAR,LGAR,BGAR,RGGAR,GGAR,RAR,HAR,UAR,KAR,FA,WAR      ,MES
2,MAS,UA,MEES,MEAS,EEIN,EEINS,EAUS,EAUSS,MEZ,MEZS,MAZ,MAZS,ER,AR
3,FMFRO,FMFRI,PREF,TREF
 COMMON /EKONTR/BB,TREF1(8),TREF2(8),PREF1(8),PREF2(8)
 COMMON /HTR/TD,TKD,DD,ALD,LAND,TW,TKW,DW,ALW,LANW,TK,TKK,DK,ALK,
1LANK,TEV,TKEV,DEV,ALEV,LANEV,TAV,TKAV,DAV,ALAV,LANAV,FDFK,WF,ZETA
2/GEOM/D,H,LA,EPS,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI,
3XC,FK,VH,TAKT
4/ORG/NEUIN(8),PP,CO,DBV,                          VERD
5/MASS/MO,M1,MO,ME,MA,MEA,MEE
6/FUEL/SLB,CE,LAV,KB,ML,MBR,MRG,VERDD,Q(3,7)
7/COMB/AV,MV,PHIVA(8),VD
8/OPD/PO,TO,PE,TE,PA,PB,DR,PEO,TEO,FEO,VER
9/SC/MUOE,MU1E,MU2E,MU3E,FER,MUOA,MU1A,MU2A,MU3A,FAR
 COMMON/VALVE/PHIOEX,PHIOIN,PHICEX,PHICIN,SAEX,R1EX,R2EX,R3EX,R4EX,
1RAREX,SAIN,R1IN,R2IN,R3IN,R4IN,RARIN
2/OUTP/CNOPPM(8)
3/VARIA/FAV,FEV,LE,LI,TEX,TIN,TWU,VERG,LDEL,CDEL,LDIL,CDIL, FEL ,
4 FAL,PHIL,PHILP,PEL,PAL,REZ,CN
 COMMON/EVAP/RGGZS    ,IVERD(8)
 COMMON/CONCO/XCO,TMOLCO
  COMMON/PLOTR/PPLOT(720),VPLOT(720),CAPLOT(720),V4PLOT(720)
1  ,V5PLOT(720),IPV
```

```
      COMMON/APROP/DEL,PSI
      COMMON/PHICHI/CHI
      COMMON/ADIAB/TADBS(8),TADB(8),XMA,XMB,VADB,VBL,RADB,RBL
C
      LOGICAL VERD,EIN,AUS
C
      DIMENSION PZ(8),PZS(8),TZ(8),TZS(8),TZ2(8),TZ3(8),TZH(8),TZM(8),
     1TZMS(8),ALFAM(8),ALFAMS(8),BO(8),DB(8),RZ(8),HZ(8),UZ(8),
     2DU1(8),DU2(8),DUDTZ(8),AI(8),AIS(8),QW(8),QWS(8),BGZ(8),BGZS(8),
     3RGGZ(8),X(8),PE(8),TE(8),PA(8),PHIL(320),FEL(320),FAL(320),
     FPEL(300),PAL(300),PHILP(300),PZL(50),PHIPZ(50),
     4          WER(8),WAR(8),GGZ(8),BGE(8),BGZO(8),TEE(8),TA(8),RGGE(8),
     5RGGA(8),BGA(8),TES(8),TEH(8),PES(8),GGZS(8),RGGZS(8),TAS(8),TEES(8
     6),BGES(8),BGAS(8),RGGES(8),RGGAS(8),GGES(8),GGE(8),GGAS(8),GGA(8),
     7TE3(8),TE2(8),PHIZ(8),TWX(8),FE(8),FA(8),ALFA(8)
     8,RE(8),HE(8),UE(8),RA(8),HA(8),UA(8)
     9,EEIN(8),EEINS(8),EAUS(8),EAUSS(8),FELL(300),FALL(300)
     A,ER(8),AR(8),PEO(8),TEO(8),FEO(8),VER(8),PA2(8),TA2(8),FA2(8)
     B,VAR(8),TAR(8),BGAR(8),RGGAR(8),RAR(8),HAR(8),UAR(8),GGAR(8)
     C,TARS(8),BGARS(8),RGGARS(8),GGARS(8),WRH(1)
     D,DUDTEO(8),HEO(8),UEO(8),REO(8),DU3(8),DU4(8),DUDTA(8)
     E,PAS(8),ERO(8),AR2(8),RGA(8),DUDTE(8),B(8),BS(8)
     F,RU2(8),BGE2(8),TEE2(8),GGE2(8)
      DIMENSION EO(1),EOS(1),AEO(2,1)
      DIMENSION LDEL(20),CDEL(20),CDE(300),LDIL(20),CDIL(20),CDI(300)
      DIMENSION AA(8),AM(8),AMS(8)
      DIMENSION TB(8),TU(8),VB(8),VU(8),TBS(8),TUS(8),TZV(8)
      DIMENSION PS1(8),TS1(8),VSS1(8),TZVS(8),HG(8)
      DIMENSION  FNNOTS(8), FBURNS(8), TAM(8)
       DIMENSION HQW(2,8),HWS(8),HW(8)
C
C     INITIALIZATION
C
      DSO = 13
      NVER = 1
      HTRANS=1.
```

```
      IPV=0
C
C     CK FOR CORRECT PROG VERSION (NVER) AGAINST
C     THE ENGINE INPUT DATA SET VERSION (V)
C
      IF ( V .NE. NVER )  GO TO 8980
C
C     READ LAST DATA, FORMAT DEPENDS ON PROGRAM VERSION (CALC)
C
C     NO ADDITIONAL DATA REQUIRED FOR VER1, BASIC
C
C
C    COMPLETE THE INPUT DATA REPORT
C
      WRITE (PRI,7897)
 7897 FORMAT ( /// 10X, 'END OF INPUT DATA' )
C
C     REWIND & RELEASE BUFFERS
C     REWIND DSI
C
      UDP=1./14.5*100000.
      UT=.5555
      PE(1)=PE(1)*UDP+PB
      PA(1)=PA(1)*UDP+PB
      TE(1)=(TE(1)-32.)*UT+273.
      PZ(1)=2.*PE(1)
      TZ(1)=1.5*TE(1)
      TEFC=TE(1)
      IF(VERG)1,2,2
    1 VERD=.TRUE.
      GOTO 3
    2 VERD=.FALSE.
    3 CONTINUE
      U=.017453848
      PHI=PHIO(1)
      PHIEND=PHIO(1)+NCY*TAKT+10.*U
```

```
      DPHIO=DPHIO*U
      PP(1)=0
      O=O*U
            DO 1111 N=1,Z
               NNOT(N)=0.0
               NNOB(N)=0.0
               NNOU(N)=0.0
               ITEST(N)=0
               HW(N)=0.
1111        CONTINUE
               IPCTL=10
               TPHINO=PHI
               DPHINO=DPHIO
      PHIV=PHI
      XC=H/(EPS-1.)
      FK=.7853*D*D
      VH=H*FK
      KO=9.55/(H*DR)
      MO=PO*VH/(287.*TO)
      FRH   =1.
      LGA(1)=.0
      BGA(1)=.0
      RGGA(1)=1.
      EO(1)=0.
      IF(TEX.EQ.0)GOTO 560
      DO 561 L=1,T
      XH=FEL(L)/(2.*R2IN)
      IF(LI.GT.0)CALL LINPO(XH,LDIL,CDIL,LI,CDI(L))
      CALL VA(FEL(L),SAIN,R3IN,R1IN,R4IN,FEV,FEL(L))
      IF(LI.GT.0) FEL(L)=FEL(L)*CDI(L)
      XH=FAL(L)/(2.*R2EX)
      IF(LE.GT.0)CALL LINPO(XH,LDEL,CDEL,LE,CDE(L))
      CALL VA(FAL(L),SAEX,R3EX,R1EX,R4EX,FAV,FAL(L))
      IF(LE.GT.0) FAL(L)=FAL(L)*CDE(L)
  561 CONTINUE
      GO TO 563
```

```
560 DO 562 L=1,T
    XH=FEL(L)/(2.*R2IN)
    IF(LI.GT.0) CALL LINPO(XH,LDIL,CDIL,LI,CDI(L))
    IF(LI.GT.0) FEL(L)=CDI(L)*R2IN*R2IN*3.141593
    XH=FAL(L)/(2.*R2EX)
    IF(LE.GT.0) CALL LINPO(XH,LDEL,CDEL,LE,CDE(L))
    IF(LE.GT.0) FAL(L)=CDE(L)*R2EX*R2EX*3.141593
562 CONTINUE
563 CONTINUE
    FEV=3.1416*R2IN*R2IN
    FAV=3.1416*R2EX*R2EX
    IF (TP.EQ.0) GO TO 564
    DO 565 L=1,TP
    PHILP(L)=PHILP(L)*U
    IF (K2.LT.0.OR.K4.LT.0) PEL(L)=PEL(L)*UDP+PB
    IF (K3.LT.0.OR.K4.LT.0) PAL(L)=PAL(L)*UDP+PB
565 CONTINUE
564 CONTINUE
    N=1
    CALL WTEMP1(TD,TKD,DD,ALD,LAND,TZM,ALFAM,N,TAKT)
    CALL WTEMP1(TW,TKW,DW,ALW,LANW,TZM,ALFAM,N,TAKT)
    CALL WTEMP1(TK,TKK,DK,ALK,LANK,TZM,ALFAM,N,TAKT)
    CALL WTEMP1(TEV,TKEV,DEV,ALEV,LANEV,TZM,ALFAM,N,TAKT)
    CALL WTEMP1(TAV,TKAV,DAV,ALAV,LANAV,TZM,ALFAM,N,TAKT)
    DO 15 N=1,Z
    X(N)=.0
    PHIO(N)=PHIO(1)+X(N)
    PHIVA(N)=PHIVA(1)+X(N)
    PHIX(N)=PHI-X(N)
    TZM(N)=.0
    ALFAM(N)=.0
    AM(N)=0.
    GGE(N)=1.
    GGZ(N)=1.
    GGAE(N)=.0
    BESPRK=0.0
```

```
      IF(.NOT.VERD)GOTO 17
      BGZ(N)=1./(1.+LAV*SLB)
      RGGZ(N)=0.
      LGZ(N)=1.-BGZ(N)
      GOTO 18
   17 BGZ(N)=0.
      RGGZ(N)=0.
      LGZ(N)=1.
   18 CALL GPROP(TZ(N),PZ(N),LAV,DEL,PSI,RESPRK,HZ(N),UZ(N),CSUBPZ
     1,CSUBTZ,RHOZ,DRHOTZ,DRHOPZ,DH1,RZ(N),KZ(N))
      VZ(N)=(XC+H/2.*(1.-COS(PHIX(N))+LA/2.*SIN(PHIX(N))*SIN(PHIX(N))))
     1*FK
      M1(N)=VZ(N)*PZ(N)/(RZ(N)*TZ(N)*MO)
      IF(N.GT.1)MO(N)=M1(N)
      BO(N)=GGZ(N)*M1(N)*MO/(1.+LAV*SLB)
      IF(.NOT.VERD)BO(N)=BO(N)*(1.+LAV*SLB)/(LAV*SLB)
      LGRG(N)=0.
      WER(N)=0.
      WAR(N)=0.
      ME(N)=0.
      MEE(N)=0.
      MA(N)=0.
      MEA(N)=0.
      MEZ(N)=0.
      MAZ(N)=0.
      MEO(N)=.0
      MA2(N)=.0
      QW(N)=0.
      AI(N)=.0
      VB(N)=0.000001*VZ(N)
      XCO=0.
      TMOLCO=0.
      EEIN(N)=0.
      EAUS(N)=0.
      B(N)=0.
      BS(N)=0.
```

```
      DBV(N)=1
      TADBS(N)=TZ(N)
      TADB(N)=TZ(N)
      NEUIN(N)=0
      IF(N.GT.1)NEUIN(N)=-1
      LGAR(N)=LGZ(N)
      TAR(N)=  TZ(N)
      GGAR(N)=GGZ(N)
      RGGAR(N)=RGGZ(N)
      BGAR(N)=BGZ(N)
   15 CONTINUE
      PREF=PE(1)
      TREF=TE(1)
      N=1
      GGER=1.-REZ
      TE(N)=TEFC*GGER+(1.-GGER)*394.
      IF(VERD)GOTO 11
      IF(LAV-1.)550,550,551
  550 LGE(N)=GGER
      BGE(N)=(1.-GGER)*(1.-LAV)/(1.+LAV*SLB)
      GOTO 552
  551 BGE(N)=.0
      LGE(N)=GGER+(1.-GGER)*SLB*(LAV-1.)/(1.+LAV*SLB)
      GOTO 552
   11 IF(LAV-1.)553,553,554
  553 LGE(N)=GGER*LAV*SLB/(1.+LAV*SLB)
      BGE(N)=GGER/(1.+LAV*SLB)+(1.-GGER)*(1.-LAV)/(1.+LAV*SLB)
      GOTO 552
  554 LGE(N)=GGER*LAV*SLB/(1.+LAV*SLB)+(1.-GGER)*SLB*(LAV-1.)/(1.+LAV
     1*SLB)
      BGE(N)=GGER/(1.+LAV*SLB)
  552 RGGE(N)=1.-LGE(N)-BGE(N)
      CALL GPROP(TE(N),PE(N),LAV,DEL,PSI,1.0,HE(N),UE(N),CSUBPE,
     1CSUBTE,RHOE,DRHOTE,DRHOPE,DHEE,RE(N),KE(N))
  182 I=1
      PHINK=PHI
```

```
      BB=0.
      IF(LAV-1.) 19,20,20
   19 LAVS=LAV
      GOTO 21
   20 LAVS=1.
   21 CONTINUE
      FMPRO=.0
      FMPRI=0.
      INPC=-1
      EIN=.TRUE.
      AUS=.FALSE.
      ETAU=1.-EXP(-AV)
      XCO=0.
      ICYLA=0
C
C
C
C STEUERTEIL
C
  102 IF(PHI.GE.PHIEND)  GO TO 101
      IF(PHI.LT.PHINK)   GOTO 103
      SUMG=0
      KONV=0
      DPHI=DPHIO
  103 DO 107 N=1,Z
      IF(PHI.LT.PHIO(N))  GOTO 109
      PP(N)=INT((PHI-PHIO(N))/TAKT)
      GOTO 107
  109 PP(N)=-1
  107 CONTINUE
      DO 110 N=1,Z
      PHIX(N)=PHI-X(N)
      VZ(N)=(XC+H/2.*(1.-COS(PHIX(N))+LA/2.*SIN(PHIX(N))*SIN(PHIX(N))))
     1*FK
      PHIZ(N)=H/2.*FK*(SIN(PHIX(N))+LA*SIN(PHIX(N))*COS(PHIX(N)))
      TWX(N)=TW*(XC+H)/(VZ(N)/FK*TWU)*(1.-EXP(-TWU*(VZ(N)/FK)/(XC+H)))
```

```
      LGRG(N)=LGZ(N)
      EEIN(N)=0.
      EAUS(N)=0.
      NEUIN(N)=0
      IF(LAV.LT.1.)  GOTO 129
      BGZ(N)=0.
  129 RGGZ(N)=1.-LGZ(N)-BGZ(N)
      BGZO(N)=BGZ(N)
      TEE(N)=TZ(N)
      TAR(N)=TZ(N)
      DBV(N)=1
      WER(N)=0.
      WAR(N)=0.
      LGAR(N)=LGZ(N)
      RGGAR(N)=RGGZ(N)
      BGAR(N)=0.
      MGGZ(I,N)=0.
      LGA(N)=LGZ(N)
      BGA(N)=BGZ(N)
      RGGA(N)=1.-LGZ(N)-BGZ(N)
  110 CONTINUE
      IF(I.EQ.2)  GOTO 150
            IF(PHI.LT.TPHINO+DPHIO-0.0001)GOTO 1002
            TPHINO=PHI
         DO 1002 N=1,Z
      IF(PP(N).LE.0)GO TO 1002
              IF(DBV(N).GT.0)GOTO 1002
            IF(CO(N).EQ.1)GOTO 1000
      NNOU(N)=0.0
      NNOB(N)=0.0
      NNOT(N)=0.0
      ITEST(N)=0
      GOTO 1002
 1000       CONTINUE
            TZU(N)=TU(N)
            TZUS(N)=TUS(N)
```

```
          TZB(N)=TB(N)
          TZBS(N)=TBS(N)
          IF(PHI.GT.PHIVA(N)+TAKT*PP(N))GOTO 1003
      FBURN=0.1E-10
         GOTO 1005
 1003 CONTINUE
          IF(PHI.GT.PHIVA(N)+TAKT*PP(N)+VD)GOTO 1004
          FBURN=(1.-EXP(-AV*((PHI-PHIVA(N)-TAKT*PP(N))/VD)**(MV+1.)))
         GOTO 1005
 1004 CONTINUE
      FBURN=(0.1E+1)-(0.1E-10)
 1005 CONTINUE
          IF(FBURN.LE.0.999)GOTO 2012
             TZB(N)=TZ(N)
             TZBS(N)=TZS(N)
             TZV(N)=TZ(N)
             TZVS(N)=TZS(N)
 2012   CONTINUE
        AREAC=(2.*PK+(XC+H/2.*(1.-COS(PHIX(N))+LA/2.*SIN(PHIX(N))*
     1SIN(PHIX(N))))*3.1416*D)*10.76
      CALL CANOX(N,PZ,GGZ,DR)
      IF(NPRINT.EQ.0)GOTO 1300
      NPRINT=0
      IF(IPCTL.LT.5)GOTO 1310
      IPCTL=0
 1310 CONTINUE
      IPCTL=IPCTL+1
      OPZN=PZ(N)*.00001
 1300 CONTINUE
 1002 CONTINUE
  490 CONTINUE
      DO 132 N=1,Z
          TZVS(N)=TZV(N)
      TBS(N)=TB(N)
      TUS(N)=TU(N)
      EOS(1)=EO(1)
```

```
TADBS(N)=TADB(N)
PZS(N)=PZ(N)
TZS(N)=TZ(N)
AIS(N)=AI(N)
RGGARS(N)=RGGAR(N)
LGARS(N)=LGAR(N)
TES(N)=TE(N)
TZH(N)=0.
TEH(N)=0.
PES(N)=PE(N)
GE(N)=0
ICYLA=0
GZ(N)=0
QWS(N)=QW(N)
HWS(N)=HW(N)
ALFAMS(N)=ALFAM(N)
TZMS(N)=TZM(N)
AMS(N)=AM(N)
GGZS(N)=GGZ(N)
LGZS(N)=LGZ(N)
BGZS(N)=BGZ(N)
MEZS(N)=MEZ(N)
MA2S(N)=MA2(N)
MEOS(N)=MEO(N)
MAZS(N)=MAZ(N)
RGGZS(N)=RGGZ(N)
TAS(N)=TA(N)
PAS(N)=PA(N)
BS(N)=B(N)
IF(CO(N).EQ.1) GOTO 132
TARS(N)=TAR(N)
TEES(N)=TEE(N)
MES(N)=ME(N)
MAS(N)=MA(N)
MEAS(N)=MEA(N)
MEES(N)=MEE(N)
```

```
      BGES(N)=BGE(N)
      BGARS(N)=BGAR(N)
      RGGES(N)=RGGE(N)
      LGES(N)=LGE(N)
      GGES(N)=GGE(N)
      GGARS(N)=GGAR(N)
      EEINS(N)=EEIN(N)
      EAUSS(N)=EAUS(N)
  132 CONTINUE
      PHIS=PHI
  150 N=1
      DO 134 N=1,Z
      HE(N)=HE(1)
      UE(N)=UE(1)
      RE(N)=RE(1)
      KE(N)=KE(1)
      ER(N)=.0
      AR(N)=.0
C DREITEILIGER ANSATZ WOSCHNI
      C1=2.28
      C2=6.18
      C3=3.24E-03
      CK=H*DR/30.
      IF(CO(N).EQ.-1)GOTO 625
      IF(CO(N).EQ.1)GO TO 626
      W=C2*CK
      GOTO 627
  626 IF(PHI  -(PHIVA(N)+TAKT*PP(N)))628,629,629
  628 W=C1*CK
      PS1(N)=PZ(N)
      TS1(N)=TZ(N)
      KS1(N)=KZ(N)
      VSS1(N)=VZ(N)
      GOTO 627
  629 PNF=PS1(N)*(VSS1(N)/VZ(N))**KS1(N)
      W=  C3*(H+XC)*FK*TS1(N)*(PZ(N)-PNF)/(PS1(N)*VSS1(N))   +C1*CK
```

```
627 ALFA(N)=.035*3.65E-04*(W*PZ(N)/(287.*5.71E-07))**.8*D**(-.2)
   1*TZ(N)**(-.547)
    ALFA(N)=ALFA(N)*WF
    MQW(I,N)=ALFA(N)*9.55/DR*(FK*(TZ(N)-TK)+FK*(TZ(N)-TD)*FDFK
   1+4.*VZ(N)/D*(TZ(N)-TWX(N))+FEV*(TZ(N)-TEV)+FAV*(TZ(N)-TAV))
     HQW(I,N)=MQW(I,N)
625 CONTINUE
    IF(PHI.GT.PHIVA(N)+TAKT*PP(N).AND.PHI.LE.PHIVA(N)+VD+TAKT*PP(N))
   1GOTO 620
    GOTO 621
620 IF(VB(N).LT..0)VB(N)=0.
    ARB=(VB(N)/VZ(N))**.66
    ARU=(VU(N)/VZ(N))**.66
    MQWB(I,N)=MQW(I,N)*ARB
    MQWU(I,N)=ALFA(N)*(TU(N)/TZ(N))**(-.547)*9.55/DR*(FK*(TU(N)-TK)
   1+FK*(TU(N)-TD)*FDFK+4.*VZ(N)/D*(TU(N)-TWX(N))+FEV*(TU(N)-TEV)
   2+FAV*(TU(N)-TAV))*ARU
    MQW(I,N)=MQWB(I,N)+MQWU(I,N)
    HQW(I,N)=MQWB(I,N)
621 CONTINUE
    HTRANS=MQW(I,N)*DR/9.55
     IF(PHI.GT.PHIVA(N)+VD+TAKT*PP(N))  HQW(I,N)=MQW(I,N)
    MAI(I,N)=PZ(N)*PHIZ(N)
    IF(CO(N))134,158,157
158 CALL GASEX(PE,TE,PA,DR,REZ)
          ITEST(N)=0
    GOTO 134
157 IF(I.EQ.1.AND.KONV.EQ.0.AND.PHI+DPHIO.GE.PHIVA(N)+TAKT*PP(N)
   1.AND.PHI.LE.PHIVA(N)+TAKT*PP(N)+DPHIO)  GOTO 135
    GOTO 136
135 DPHI=DPHIO/20.
136 IF(DBV(N).EQ.0)GOTO 400
    IF(N.GT.1)  GO TO 4
    IF(PHI.LE.PHIO(N))GOTO 8100
    CALL WTEMP2(TD,TKD,DD,ALD,LAND,TZM,ALFAM,N,AM)
    CALL WTEMP2(TW,TKW,DW,ALW,LANW,TZM,ALFAM,N,AM)
```

```
      CALL WTEMP2(TK,TKK,DK,ALK,LANK,TZM,ALFAM,N,AM)
      CALL WTEMP2(TEV,TKEV,DEV,ALEV,LANEV,TZM,ALFAM,N,AM)
      CALL WTEMP2(TAV,TKAV,DAV,ALAV,LANAV,TZM,ALFAM,N,AM)
      A1=AI(N)/(BO(N)*CE)
      A2=QW(N)/(BO(N)*CE)
      A3=AI(N)*.00001/VH*14.5
      A4=AI(N)*DR/120000.*1.341
      A5=BO(N)*3600000/1.341*2.2046/AI(N)
      A6=MO*2.2046
      A7=BO(N)*2.2046
      A8=TD/UT
      A9=TW/UT
      A10=TK/UT
      A11=TEV/UT
      A12=TAV/UT
      A1A=A1*(AI(N)-QUAI2)/AI(N)
      A4A=A4*(AI(N)-QUAI2)/AI(N)
      A5A=A5*AI(N)/(AI(N)-QUAI2)
      A4B=QUAI2*DR/120000.*1.341
      A3A=A3*(AI(N)-QUAI2)/AI(N)
      A3B=QUAI2*.00001/VH*14.5
      A16=TMOLCO*28.*DR*30./A4
      A16A=TMOLCO*28.*DR*30./A4A
      IF(VERD)A13=MGZ(N)*MO*DR*30.*2.2046*(1.-1./(1.+LAV*SLB))
      IF(.NOT.VERD)A13=MGZ(N)*MO*DR*30.*2.2046
C
      CALL MTEMP(EAUS(1),MA(1),MO,TAM(1),LGA(1),BGA(1),LAV,PA(1))
      A14=NNOT(1)*30.*DR*30./A4
      A14A=A14*A4/A4A
      A15 = TAM(1) / UT
      TREZ=TAM(1)-CN*(TAM(1)-394.)
      TE(1)=GGER*TEFC+(1.-GGER)*TREZ
      TES(N)=TE(N)
      RESPRK=1.-GGER
      CALL GPROP(TE(N),PE(N),LAV,DEL,PSI,RESPRK,HE(N),UE(N),CSUBPE
     1,CSUBTE,RHOE,DRHOTE,DRHOPE,DHEE,RE(N),KE(N))
```

```
C CHECK RECIRCULATION
      CO(N)=9
C
C     END OF CYCLE
C         CO(N) = 9
C
      IDR = DR
      XLAV1=1./LAV
      WRITE (DSO, 8701 ) N, CO(N), IDR, A1, A2, A3, A4, A5,
     1 XLAV1, A4B, A3B, A13, A16, A14, A15, A1A, A3A
 8701 FORMAT ( 4X, 2I2, I5, 7X, 14F10.3 )
      WRITE ( DSO, 8707 )  A6, A7, A5A, A14A, A4A, A16A
 8707 FORMAT ( 20X, 2E10.3,4F10.3)
      CO(1)=1
      IF(PP(1).GT.NCY-NCYO)CALL REPORT
C
C     CHECK IF ALL DONE
C
      IF(PP(1).EQ.NCY)GOTO 101
      GOTO 8100
C
C     BEGINNING OF NEW CYCLE, SWITCH OUTPUT DATA SET NR.
C
 8100 IF ( DSO - 12 ) 8101, 8101, 8104
 8101 DSO = 13
      GO TO 8110
 8104 DSO = 12
C
C     WRITE HEADING ON NEXT DATA SET
C
 8110 REWIND DSO
      NCYCLE = PP(1) +1
      IPV=0
      WRITE ( DSO, 8121 )  (NA(II), II = 1, 60 )
 8121 FORMAT ( 20A4 )
      WRITE ( DSO, 8131 )  V, C, P1, P2, NDAT1, NDAT2,
```

```
    1  INPUTT, TP, Z, NCYCLE
8131 FORMAT ( 4I1, 4X, 2A4, 4X, 4I2 )
   4 ALFAMS(N)=0.
     TZMS(N)=0.
     AMS(N)=0.
     M1(N)= PZ(N)*VZ(N)/(RZ(N)*TZ(N)*MO)
     RU2(N)=MEA(N)-MEE(N)
     BGE2(N)=BGZ(N)
     LGE2(N)=LGZ(N)
     GGE2(N)=GGZ(N)
     IF(RU2(N).LT.0.)RU2(N)=0.
     IF(.NOT.VERD)GOTO 6
     MO(N)=M1(N)
   6 BO(N)=GGZ(N)*M1(N)*MO/(1.+LAV*SLB)
     IF(.NOT.VERD)BO(N)=BO(N)*(1.+LAV*SLB)/(LAV*SLB)
     AIS(N)=0.
     QWS(N)=0.
      HWS(N)=0.
     MLGZ(I,N)=0.
     DBV(N)=0
     ME(N)=0.
     MA(N)=0.
     MEE(N)=0.
     MEA(N)=0.
     MLZ(N)=LGZ(N)*M1(N)
     HG(N)=0.
 400 CALL HEATR(DR,PE(1),PES(1),PZS(1),A3S,TWX)
     IF(TZ(N).LT.0.)TZ(N)=TU(N)
     IF(TB(N).LT.0.)TB(N)=TU(N)
     IF(TU(N).LT.0.)TU(N)=TB(N)
 134 CONTINUE
     DO 186 N=1,Z
     IF(I.EQ.1)GO TO 138
     CALL INTEG(AIS,AI,MAI,I,N,DPHI)
     CALL INTEG(QWS,QW,MQW,I,N,DPHI)
     CALL INTEG(HWS,HW,HQW,I,N,DPHI)
```

```
      HTOW=HW(N)
      IF(PHI.GE.PHIO(N)-TAKT*PP(N).AND.PHI.LE.3.1416-TAKT*PP(N))
     1 QUAI1=AI(1)
      IF(PHI.GT.3.1416-TAKT*PP(N).AND.PHI.LT.3.*3.1416-TAKT*PP(N))
     1 QUAI2=AI(1)-QUAI1
      TZ3(N)=TZ(N)
      TADB3=TADB(N)
      PCYL3=PZ(N)
      TE3(N)=TE(N)
      GOTO 186
  138 TZ2(N)=TZ(N)
      TADB2=TADB(N)
      PCYL2=PZ(N)
      AA(N)=2.*FK+4.*VZ(N)/D
      IF(PHI.GT.PHIVA(N)+TAKT*PP(N).AND.PHI.LE.PHIVA(N)+VD+TAKT*PP(N))
     1GOTO 622
      GOTO 623
  622 ALC=(TZV(N)/TZ(N))**(-.525)
      ALFAM(N)=ALFAMS(N)+ALFA(N)*ALC*AA(N)*DPHI
      TZM(N)=TZMS(N)+TZV(N)*ALFA(N)*ALC*AA(N)*DPHI
      GOTO 624
  623 ALFAM(N)=ALFAMS(N)+ALFA(N)*AA(N)*DPHI
      TZM(N)=TZMS(N)+TZ(N)*ALFA(N)*AA(N)*DPHI
  624 AM(N)=AMS(N)+AA(N)*DPHI
      TE2(N)=TE(N)
  186 CONTINUE
      IF(I.EQ.2) GOTO 140
      PHI=PHI+DPHI
      I=2
      GOTO 103
  140 IF(KONV.NE.0) GOTO 147
      DO 143 N=1,Z
  143 CALL CONP(TZH,TZ2,TZ3,GZ,N,&148)
      CALL CONPM(PCYL2,PCYL3,ICYL,N)
      CALL CONPM(TADB2,TADB3,ICYLA,N)
      SUMG=0
```

```
      DO 145 N=1,Z
  145 SUMG=SUMG+GZ(N)+ICYL+ICYLA
      IF(SUMG.GE.0) GOTO 147
      KONV=0
      SUMG=-1
      IF(AVS.GE.10) GOTO 148
      AVS=AVS+1
      GOTO 150
  148 KONV=-1
      PHINK=PHI
      PHI=PHIS
      DPHI=DPHIO/2.
      DO 151 N=1,Z
             TZV(N)=TZVS(N)
      TB(N)=TBS(N)
      TADB(N)=TADBS(N)
      TU(N)=TUS(N)
      EO(1)=EOS(1)
      PZ(N)=PZS(N)
      TZ(N)=TZS(N)
      AI(N)=AIS(N)
      QW(N)=QWS(N)
      HW(N)=HWS(N)
      ALFAM(N)=ALFAMS(N)
      TZM(N)=TZMS(N)
      AM(N)=AMS(N)
      GGZ(N)=GGZS(N)
      LGZ(N)=LGZS(N)
      BGZ(N)=BGZS(N)
      RGGZ(N)=RGGZS(N)
      PE(N)=PES(N)
      TE(N)=TES(N)
      MEZ(N)=MEZS(N)
      PA(N)=PAS(N)
      TA(N)=TAS(N)
      MAZ(N)=MAZS(N)
```

```
      MEO(N)=MEOS(N)
      MA2(N)=MA2S(N)
      B(N)=BS(N)
      IF(CO(N).NE.0)  GOTO 151
      TAR(N)=TARS(N)
      TEE(N)=TEES(N)
      ME(N)=MES(N)
      MA(N)=MAS(N)
      MEA(N)=MEAS(N)
      MEE(N)=MEES(N)
      BGE(N)=BGES(N)
      BGAR(N)=BGARS(N)
      RGGE(N)=RGGES(N)
      RGGAR(N)=RGGARS(N)
      LGAR(N)=LGARS(N)
      LGE(N)=LGES(N)
      GGE(N)=GGES(N)
      GGAR(N)=GGARS(N)
      EEIN(N)=EEINS(N)
      EAUS(N)=EAUSS(N)
151   CONTINUE
      I=1
      GOTO 102
147   I=1
      AVS=0
      IF(PHI.LT.PHIV+O-.000100)  GOTO 153
                NRP=1
154   PHIA=PHI/U-TAKT*PP(1)/U
      DO 155  N=1,Z
      EK1=UZ(1)*PZ(1)*VZ(1)/(RZ(1)*TZ(1)*CE*BO(1))
      EK2=BB/BO(1)
      EK3=EEIN(N)/(BO(1)*CE)
      EK4=EAUS(N)/(BO(1)*CE)
      EK5=B(1)/BO(1)
      V1    =PE(N)/UDP
      V2    =PZ(N)/UDP
```

```
      V3    =PA(N)/UDP
      V4    =FMFRI*2.2046*DR/9.55*MO
      V5    =FMFRO*2.2046*DR/9.55*MO
      V6    =ME(N)-MEA(N)+MEE(N)
      V7    =TZ(N)*9./5.
      V8    =HTRANS/(BO(N)*CE)
      V9    = WER(N)  / .3048
      V10   = WAR(N)  / .3048
      V11 = TU(N)*9./5.
      FK=D*D*3.1416/4.
      AREAC = (2.*FK+VZ(1)/FK*3.1416*D)
      IF(VB(N).LE.0.001*VZ(N))  V13=0.
      IF(VB(N).LE.0.001*VZ(N))  V12=0.
      IF(VB(N).LE.0.001*VZ(N))  GO TO 1234
      AREABC =  (VB(N)/VZ(N))**.66*AREAC
      V12=TADB(1)*9./5.
      V13 = VBL/AREABC/D
 1234 CONTINUE
      IPV=IPV+1
      PPLOT(IPV)=V2
      VPLOT(IPV)=VZ(N)*1.E+06/16.39
      V4PLOT(IPV)=V4
      V5PLOT(IPV)=V5
      CAPLOT(IPV)=PHIA
      IF(CO(N).NE.1)  GOTO 156
C
C    COMBUSTION DATA OUTPUT
C        CO(N)  =  1
C
      NOPP = CNOPPM(N)
      WRITE ( DSO, 8501 ) N, CO(N) , NOPP, PHIA,
     1  V1, V2, V3, V7, V11, V12, V8, V13
 8501 FORMAT ( 4X, 2I2, I5, 7X, 5F10.3, 50X, 3F10.3, F10.7 )
      GOTO 155
  156 IF(CO(N).NE.0) GO TO 155
C
```

```
C     GAS EXCHANGE DATA OUTPUT
C         CO(N) = 0
C
      WRITE (DSO, 8601 )  N, CO(N), PHIA,
     1  V1, V2, V3, V7, V6, MA(N),
     2  MGZ(N), GGZ(N),  V4, V5
 8601 FORMAT ( 4X, 2I2, 12X, 11F10.3 )
  155 CONTINUE
      PHIV=PHI
      GOTO 102
  153 IF(PHI.GE.PHIEND) GOTO 154
      GOTO 102
  101 RETURN
 8980 WRITE ( PRI, 8981 ) V, NVER
 8981 FORMAT ( // 10X, 'ERROR,  PROGRAM VERSION IS', I2,
     1  5X, 'ENGINE DATA VERSION IS', I2 )
      STOP
 8990 WRITE (PRI, 8991)
 8991 FORMAT ( /// 10X, 'UNEXPECTED EOF' )
      STOP
      END
```

```
MEMBER NAME  REPORT
      SUBROUTINE REPORT
C
C
      INTEGER CYL, T, TP, Z
      INTEGER CD, PRI, DSI,DSO,V,C,P1,P2, PR
      COMMON /TITLE/ NA(60)
      COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
     1  T,TP,Z,NCY,NCYO,K1,K2,K3,K4, DPHIO, O
      DIMENSION FA(14), NN(11)
C
C
C    PR IS USED LOACALLY FOR PRINTER
C
      PR = PRI
      NPAGE = 1
      LNCT  = 14
      REWIND DSO
      READ (DSO, 111, END=990)     ( NN(I), I = 1, 11 )
  111 FORMAT ( /// 4I1, 4X, 2A4, 4X, 5I2 )
C
C    WRITE HEADING
C
      WRITE (PR, 201 )  NN(5), NN(6), (NA(I), I = 1, 20), NPAGE,
     1 NN(1), NN(10), ( NN(II), II = 2, 4 ), ( NA(J), J = 21, 60 )
  201 FORMAT ( 1H1 /// 10X, 2A4, 7X, 20A4, T120, 'PAGE', I4,
     1  // 10X, 'VERSION', I2, 6X, 'CYCLE', I2,
     2  / 10X, 'CALC', I2, 4X, 'PLOT1', I2,
     3  4X, 'PLCT2' , I2 , 2( / 10X, 20A4 ) )
C
C    WRITE COLUMN HEADINGS FOR COMBINED COMBUSTION & GAS EXCHANGE
C
  206 WRITE ( PR, 207 )
  207 FORMAT (       /// 6X, 'N    PHI     PIN      PC      PEX      TC' ,
     1  5X, 'MIN    MEX    CTR     CC   DMDTI  DMDTO    TU  '  ,
     2  3X, '  TA   HTRAN    NO     XBL/D ' // 6X,
```

```
    3  '-      CA     PSIA    PSIA     PSIA  DEG.R' ,
    4  5X, 4( '-' , 6X ), 'LBM/SEC.' , 4X, 'DEG.R' ,
    5  4X, 'DEG.R    -/SEC     PPM      -' / 1H )
210 READ (DSO, 211, END=990 ) CYL, NCODE, NPM, (FA(I), I = 1, 14)
211 FORMAT ( 4X, 2I2, I5, 7X, 13F10.3, F10.7 )
    IF (NCODE -9 ) 214, 410, 410
214 IF ( CYL -1 ) 215, 215, 250
215 LNCK = 56 - LNCT - Z
    IF (LNCK) 216, 216, 220
216 NPAGE = NPAGE +1
    LNCT = 7
    WRITE ( PR, 217 )    NPAGE
217 FORMAT ( 1H1 , // T120, 'PAGE' , I4 , /
    1                   6X, 'N    PHI     PIN      PC      PEX      TC' ,
    2  5X, 'MIN     MEX     CTR      CC   DMDTI  DMDTO     TU   '  ,
    3  3X, '  TA    HTRAN     NO      XBL/D ' // 6X,
    4  '-      CA     PSIA    PSIA     PSIA  DEG.R' ,
    5  5X, 4( '-' , 6X ), 'LBM/SEC.' , 4X, 'DEG.R' ,
    6  4X, 'DEG.R    -/SEC     PPM      -' / 1H )
     GO TO 250
220 IF ( Z -1 ) 250, 250, 240
240 WRITE (PR , 241 )
241 FORMAT ( 1H )
    LNCT = LNCT +1
250 IF (NCODE) 210, 260, 280
C
C    GAS EXCHANGE ( CODE = 0 )
C
260 WRITE ( PR, 261 )  CYL, ( FA(I), I = 1, 11 )
261 FORMAT ( 5X, I2, F7.1, F7.2, F8.2, F7.2, F8.1, 4F7.3,
    1    2F7.3 )
     GO TO 290
C
C    COMBUSTION ( CODE = 1 )
C
280 WRITE ( PR, 281 ) CYL, (FA(I), I = 1,5),  (FA(J), J = 11, 13),NPM,
```

```
      1FA(14)
  281 FORMAT ( 5X, I2, F7.1, F7.2, F8.2, F7.2, F8.1,  42X,
     1  2F8.1, F7.1, I6,2X,F10.7)
  290 LNCT = LNCT +1
      GO TO 210
C
C     CYCLE RESULTS (CODE = 9 ),  READ 2ND DATA CARD
C     WRITE COLUMN HEADINGS , NEW PAGE
C
  410 NPAGE = NPAGE +1
      WRITE (PR, 411 ) NPAGE, NN(10)
  411 FORMAT ( 1H1 // T120, 'PAGE' , I4 , /
     1  6X, I2, ' CYCLE RESULTS CYL. 1:' /6X, 'FULL CYCLE RESULTS'//
     2  3X, 'ITHEFF  HTW   IMEP    IHP    ISFC       MREF', 9X,
     3  'BO       PHI    RPM   PHP   PMEP    AF', 5X,
     4  ' CO        NO      TEX  ' , // 5X,
     5  '-', 6X, '-', 5X, 'PSI      HP  LBS/IHP/HR   LBS', 9X,'LBS', 6X,
     6  '-', 6X, '     HP      PSI', '  LBS/HR  '    GM/IHP/HR',5X,'DEG.R'
     1,/ 1H  )
  430 READ (DSO, 431, END = 990 )  REF, BO, A5A,A14A,A4A,A16A
  431 FORMAT ( 20X, 2E10.3 ,4F10.3)
  460 WRITE ( PR, 461 )  (FA(I), I = 1 , 5 ) , REF, BO,
     1  FA(6), NPM, (FA(J), J = 7, 12 )
  461 FORMAT ( 1X, 2F7.3,  F7.1, F7.2, F7.3, 2E12.3, F7.3, I6,
     1  2F7.3, F7.1, 2F9.4, F7.0  )
      WRITE (PR, 811 ) NPAGE, NN(10)
  811 FORMAT ( 1H1 // T120,'PAGE' , I4 ,/
     1 6X, I2, ' CYCLE RESULTS CYL. 1:' /6X, 'HALF CYCLE RESULTS'//
     2 3X, 'ITHEFF  HTW   IMEP    IHP    ISFC       MREF', 9X,
     3 'BO       PHI    RPM   PHP   PMEP    AF', 5X,
     4 ' CO        NO      TEX  ',//5X,
     5 '-', 6X, '-', 5X, 'PSI      HP  LBS/IHP/HR   LBS', 9X,'LBS',6X,
     6 '-', 6X, '     HP      PSI', '  LBS/HR      GM/IHP/HR',5X,'DEG.R',
     7 /1H )
      WRITE ( PR, 461) FA(13),FA(2),FA(14),A4A,A5A,REF,BO,
     1 FA(6),NPM,FA(7),FA(8),FA(9),A16A,A14A,FA(12)
```

```
      RETURN
  990 WRITE (PR, 991 )
  991 FORMAT ( // 5X, 'UNEXPECTED EOF' )
      STOP
      END
```