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

by

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B.M.E., General Motors Institute
(1977)

SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF
MASTER OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

(MAY, 1979)

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Submitted to the Department of Mechanical Engineering
on May 23, 1979 in partial fulfillment of the requirements
for the Degree of Master of Science

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.

Thesis Supervisor: John B. Heywood
Title: Professor of Mechanical Engineering
ACKNOWLEDGEMENTS

The author wishes to express her sincere appreciation to Professor John B. Heywood for his excellent guidance and support throughout this work.

Many thanks are due Mr. Tom Wallace of Buick Motor Division, GMC for the engine test data he supplied and for his help in understanding the operation of the Buick 3.8L Turbocharged engine.

The author also wishes to thank Mr. Ned McClurgh of Chevrolet Engineering and Mr. Chris Walmsley of AiResearch for the invaluable data they provided for this project.

The author was supported in part by a Cummins Fellowship and an Ashland Oil Fellowship.

This work was supported by NASA under Grant No. NSG-3245 and by the Department of Energy under Contract No. E(11-1)-2881.
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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 engine 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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burned gas zone. The correlations of Woschni (6) have been used to model the heat transfer and the calculation of NO formation in the adiabatic burned gas core is based on the Zeldovich kinetic scheme.

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, O₂ 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 of 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)

$$x = 1 - \exp\left\{-a\left[\left(\theta - \theta_o\right)/\Delta\theta_b\right]\right\}^{m+1} \quad (1)$$

where:

- $x$ = fraction of total mass in cylinder burned
- $a$ = efficiency parameter
- $m$ = form factor
- $\theta$ = crank angle
- $\theta_o$ = 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. $\theta_o$, 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. $\Theta_o$ 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:

\[
\begin{align*}
\dot{E}_u &= -\dot{Q}_u - \dot{W}_u - m_b h_{ub} \\
\dot{E}_a &= -\dot{W}_a + m_b h_{ua} - m_{bl} h_{a} \\
\dot{E}_{bl} &= -\dot{W}_{bl} - \dot{Q}_{bl} + m_{bl} h_{a}
\end{align*}
\]

(2)  
(3)  
(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

$$T_{bl} = (T_a - T_w) / \ln \left( \frac{T_a}{T_w} \right) \quad (5)$$

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:

$$h = 0.0136 \ (W) \cdot 8 / (d \cdot 2^2 \cdot T \cdot 547) \quad (6)$$

$h$ = 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
\[ C = \text{mean piston speed, m/s} \]
\[ V_s = \text{cylinder volume, m}^3 \]
\[ V_i = \text{instantaneous cylinder volume, m}^3 \]
\[ T_i = \text{instantaneous temperature, K} \]
\[ P_i = \text{instantaneous pressure, Pa} \]
\[ P_m = \text{pressure in the cylinder of corresponding motored engine, Pa} \]

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:
\[ Q_j = h \sum_{c} A_c (T_j - T_c) \]  \hspace{1cm} (9)

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

The total rate of heat transfer is:

\[ Q_{\text{total}} = \dot{Q}_b + \dot{Q}_u \]  \hspace{1cm} (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 $\bar{T}_{\text{exh}}$ decreases, less afterburning will occur; if $\bar{T}_{\text{exh}}$ increases, more afterburning will occur. The calculated values of $\bar{T}_{\text{exh}}$ 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, $\Delta \theta_{i,g}$, 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 $\Delta \theta_{i,g}$ and $\Delta \theta_b$ for the model validation studies is given in Appendix A. In the cases where equivalence ratio, $\phi$, was varied the values of $\phi$ were estimated from carburetor flow data as given in Fig. 4. The actual values of bmep 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 ratio 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 (i.e. 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 interdependency 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, bmeq 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 \( \phi \), 2) retarded timing with constant \( \phi \), 3) retarded timing, constant \( \phi \) and \( \Delta \Theta_b \) adjusted to correlate with the retarded timing, 4) retarded timing, \( \phi \) 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 fmeq 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 engine 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 \( \phi \) 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 $\phi$ 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 fmeep 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 $\phi$ 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 5.7% engine, with geometry similar to the Chevrolet 350 CID and Ford 351 CID engines, and the 3.8% 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-stoich-iometric 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° 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 and was found to be essentially independent of equivalence ratio and percent EGR for a given engine geometry, 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 ($\sim 120$ K). The implications for hydro-carbon 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 $\phi = .92$ 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 $\phi = 1.0$, and without EGR at $\phi = .77$) 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 turbo-
charged 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 3.8\% 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 bmepr levels of the 3.8\% turbocharged engine exceed those of the 5.7\% naturally aspirated engine as shown in Fig. 14. However, the bsfc values of the 3.8\% 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 3.8\% turbocharged engine is more efficient than the 5.7\% engine during normal vehicle operating speeds and loads.

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

Figure 16 shows the comparison of the bsNO emissions for the 3.8\% engine and the 5.7\% engine. The 3.8\% engine exhibits higher bsNO emissions than the 5.7\% engine at a given power output. This is due to the higher loads, and consequently, higher cylinder
pressures and temperatures at which the 3.8\% engine must operate to produce the power equal to that of the 5.7\% 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 5.7\% 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 5.7\% and 3.8\% 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\(^\circ\) 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 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 \( k = .001 \text{ BTU/ft-min-}^{0}\text{F} \) to simulate adiabatic behavior. In run #5 the thermal conductivity of all the components was reduced to \( k = .001 \text{ BTU/ft-min-}^{0}\text{F} \) 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 tempera-
tures during compression and therefore a severe knock condition
would exist.

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


Table 1
Engine Specifications

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Table 3 (con't.)
Table 4 - Buick 3.8\text{\textnormal{L}} FmeP*

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<tr>
<td>2000</td>
<td>72.1</td>
<td>103.5</td>
</tr>
<tr>
<td>2400</td>
<td>90.1</td>
<td>117.0</td>
</tr>
<tr>
<td>2800</td>
<td>117.0</td>
<td>130.5</td>
</tr>
<tr>
<td>3200</td>
<td>144.0</td>
<td>144.0</td>
</tr>
<tr>
<td>3600</td>
<td>180.0</td>
<td>166.5</td>
</tr>
<tr>
<td>4000</td>
<td>198.0</td>
<td>180.0</td>
</tr>
<tr>
<td>4400</td>
<td>225.1</td>
<td>202.6</td>
</tr>
</tbody>
</table>

*G.M. Test Code #11
Table 5

Part Load 3.8l Simulation Test Matrix

<table>
<thead>
<tr>
<th>Run #</th>
<th>RPM</th>
<th>S.O.C.</th>
<th>$\Delta \theta_b$</th>
<th>$\phi$</th>
<th>$P_{in}$ (psig)</th>
<th>$P_{ex}$ (psig)</th>
<th>$T_{in}$ (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B01</td>
<td>2000</td>
<td>-32.0</td>
<td>94</td>
<td>1.00</td>
<td>-6.76</td>
<td>0.50</td>
<td>96.0</td>
</tr>
<tr>
<td>B02</td>
<td>2000</td>
<td>-26.0</td>
<td>63</td>
<td>1.10</td>
<td>-3.67</td>
<td>0.50</td>
<td>98.0</td>
</tr>
<tr>
<td>B03</td>
<td>2000</td>
<td>-20.0</td>
<td>50</td>
<td>1.10</td>
<td>-0.49</td>
<td>2.96</td>
<td>98.0</td>
</tr>
<tr>
<td>B04</td>
<td>2000</td>
<td>-18.0</td>
<td>47</td>
<td>1.10</td>
<td>1.76</td>
<td>5.25</td>
<td>105.0</td>
</tr>
<tr>
<td>B05</td>
<td>2000</td>
<td>-15.0</td>
<td>47</td>
<td>1.15</td>
<td>3.72</td>
<td>5.94</td>
<td>118.0</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>--------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalence ratio, $\phi$</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust gas recycle, percent</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start of combustion timing, $\alpha$</td>
<td>$22^\circ_{BTC}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combustion duration, $\Delta\Theta_b$</td>
<td>$60^\circ$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed, rev/min</td>
<td>1400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel heating value, MJ/kg</td>
<td>44.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stoichiometric air-fuel ratio</td>
<td>15.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel molecular composition</td>
<td>$\text{C}<em>8\text{H}</em>{18}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet manifold pressure (gauge), kPa</td>
<td>-23.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet mixture temperature, K</td>
<td>319.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7 - Structure of Parametric Study for Comparison of the 3.8\ell & 5.7\ell Engines

<table>
<thead>
<tr>
<th>Engine</th>
<th>RPM</th>
<th>S.O.C.</th>
<th>$\phi$</th>
<th>$\Delta\theta_b$</th>
<th>$P_{in}$ psig</th>
<th>$P_{ex}$ psig</th>
<th>$T_{in}$ oF</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8\ell</td>
<td>1200</td>
<td>-21.0</td>
<td>1.0</td>
<td>60$^\circ$</td>
<td>-7.74 - 0.59</td>
<td>0.5 - 2.0</td>
<td>98.0 - 112.0</td>
</tr>
<tr>
<td>3.8\ell</td>
<td>2000</td>
<td>-23.0</td>
<td>1.0</td>
<td>60$^\circ$</td>
<td>-6.76 - 5.53</td>
<td>0.5 - 6.9</td>
<td>98.0 - 122.0</td>
</tr>
<tr>
<td>3.8\ell</td>
<td>3200</td>
<td>-25.0</td>
<td>1.0</td>
<td>60$^\circ$</td>
<td>-7.03 - 9.99</td>
<td>0.5 - 16.2</td>
<td>98.0 - 174.0</td>
</tr>
<tr>
<td>5.7\ell</td>
<td>1200</td>
<td>-21.0</td>
<td>1.0</td>
<td>60$^\circ$</td>
<td>-7.74 - W.O.T.</td>
<td>0.5</td>
<td>98.0</td>
</tr>
<tr>
<td>5.7\ell</td>
<td>2000</td>
<td>-23.0</td>
<td>1.0</td>
<td>60$^\circ$</td>
<td>-7.74 - W.O.T.</td>
<td>0.5</td>
<td>98.0</td>
</tr>
<tr>
<td>5.7\ell</td>
<td>3200</td>
<td>-25.0</td>
<td>1.0</td>
<td>60$^\circ$</td>
<td>-7.74 - W.O.T.</td>
<td>0.5</td>
<td>98.0</td>
</tr>
</tbody>
</table>
Table 8

Simulation Input for Heat Transfer Studies

Method 1 - 3.8\% & 5.7\% Engines

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalence ratio</td>
<td>1.0</td>
</tr>
<tr>
<td>Speed, rev/min</td>
<td>1200</td>
</tr>
<tr>
<td>Combustion duration</td>
<td>60°</td>
</tr>
<tr>
<td>Inlet pressure</td>
<td>W.O.T.</td>
</tr>
<tr>
<td>S.O.C. timing</td>
<td>MBT</td>
</tr>
<tr>
<td>Heat transfer multiplier</td>
<td>1.25 - 0</td>
</tr>
</tbody>
</table>

Method 2 - 5.7\% Engine

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalence ratio</td>
<td>1.0</td>
</tr>
<tr>
<td>Speed, rev/min</td>
<td>1200</td>
</tr>
<tr>
<td>Combustion duration</td>
<td>60°</td>
</tr>
<tr>
<td>Inlet pressure</td>
<td>W.O.T.</td>
</tr>
<tr>
<td>S.O.C. timing</td>
<td>MBT</td>
</tr>
</tbody>
</table>

Thermal conductivity:

1) Base condition: $k=0.560 \text{ BTU/ft-min-}^{\circ}\text{F}$ (head, walls, valves)
   $k=2.200 \text{ BTU/ft-min-}^{\circ}\text{F}$ (piston)

2) Head: $k=0.001 \text{ BTU/ft-min-}^{\circ}\text{F}$

3) Piston: $k=0.001 \text{ BTU/ft-min-}^{\circ}\text{F}$

4) Cylinder wall: $k=0.001 \text{ BTU/ft-min-}^{\circ}\text{F}$

5) All components: $k=0.001 \text{ BTU/ft-min-}^{\circ}\text{F}$
<table>
<thead>
<tr>
<th></th>
<th>Base Condition</th>
<th>Adiabatic Piston</th>
<th>Adiabatic Head</th>
<th>Adiabatic Cylinder</th>
<th>All Adiabatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Transfer (-)</td>
<td>.242</td>
<td>.208</td>
<td>.212</td>
<td>.184</td>
<td>.056</td>
</tr>
<tr>
<td>Power, kW</td>
<td>89.77</td>
<td>85.16</td>
<td>85.69</td>
<td>73.03</td>
<td>64.77</td>
</tr>
<tr>
<td>$T_{\text{exh}}$, K</td>
<td>1235</td>
<td>1299</td>
<td>1292</td>
<td>1376</td>
<td>1604</td>
</tr>
<tr>
<td>$\eta_{\text{vol}}$, %</td>
<td>82.6</td>
<td>77.4</td>
<td>77.9</td>
<td>68.8</td>
<td>57.7</td>
</tr>
<tr>
<td>bsNO g/kW-hr</td>
<td>14.03</td>
<td>15.85</td>
<td>15.73</td>
<td>16.19</td>
<td>18.12</td>
</tr>
<tr>
<td>$T_{\text{wall (max)}}$, K</td>
<td>409</td>
<td></td>
<td></td>
<td>1245</td>
<td>1373</td>
</tr>
<tr>
<td>$T_{\text{u (max)}}$, K</td>
<td>836</td>
<td>922</td>
<td>914</td>
<td>1003</td>
<td>1242</td>
</tr>
<tr>
<td>$T_{\text{adiab (max)}}$, K</td>
<td>2637</td>
<td>2681</td>
<td>2678</td>
<td>2716</td>
<td>2821</td>
</tr>
<tr>
<td>$P_{\text{max}}$, kPa</td>
<td>3783</td>
<td>3723</td>
<td>3738</td>
<td>3385</td>
<td>3176</td>
</tr>
<tr>
<td>imep, kPa</td>
<td>957</td>
<td>913</td>
<td>918</td>
<td>794</td>
<td>714</td>
</tr>
<tr>
<td>$\eta_{\text{th}}$</td>
<td>.352</td>
<td>.357</td>
<td>.357</td>
<td>.349</td>
<td>.366</td>
</tr>
<tr>
<td>bmep, kPa</td>
<td>871</td>
<td>826</td>
<td>831</td>
<td>708</td>
<td>628</td>
</tr>
<tr>
<td>$\eta_{\text{th brake}}$</td>
<td>.320</td>
<td>.323</td>
<td>.323</td>
<td>.310</td>
<td>.323</td>
</tr>
</tbody>
</table>
Fig. 1 Profiles of variables predicted by the simulation throughout the four-stroke engine cycle for a 5.7\text{\texttau} 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 $\bar{T}_b$, 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 $\delta_t$ (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. $\theta_s$ is spark timing, $\theta_o$ 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.
Fig. 5  Comparison of bmep values of the simulation output with engine test data at varying speeds for a 5.7l engine at W.O.T.

Fig. 6  Comparison of bsfc values of the simulation output with engine test data at varying speeds for a 5.7l engine at W.O.T.

Fig. 7  Comparison of bmep values of the simulation output with engine test data at varying speeds for a 3.8l turbocharged engine at maximum output power.

Fig. 8  Comparison of bsfc values of the simulation output with engine test data at varying speeds for a 3.8l turbocharged engine at maximum output power.

Fig. 9  Comparison of bmep values of the simulation output with the engine test data at varying loads for the 3.8l turbocharged engine at 2000 rpm.

Fig. 10 Comparison of bsfc values of the simulation output with the engine test data at varying loads for the 3.8l turbocharged engine at 2000 rpm.

Fig. 11 Comparison of effect of EGR and excess air on plot of brake specific fuel consumption versus brake specific NO emissions. Dashed line $\phi = 1.0$, various percentages EGR. Solid line, EGR = 0; numbers are air-fuel ratio and (equivalence ratio).

Fig. 12 Comparison of effect of EGR and excess air on plot of mean exhaust temperature versus brake specific NO emissions. Details as in Fig. 11.

Fig. 13 Comparison of the bsfc versus power output of the 3.8l
turbocharged and 5.7l naturally aspirated engines at
three speeds. $\phi=1.0$, MBT timing, $\Delta\Theta_b=60^\circ$.

Fig. 14 Comparison of the actual engine bmepr values of the 3.8l
turbocharged and 5.7l naturally aspirated engines at
maximum power output.

Fig. 15 Comparison of the actual engine bsfc values of the 3.8l
turbocharged and 5.7l naturally aspirated engines at
maximum power output.

Fig. 16 Comparison of the bsNO emissions versus power output
of the 3.8l turbocharged and 5.7l naturally aspirated
engines at three speeds. $\phi=1.0$, MBT timing, $\Delta\Theta_b=60^\circ$.

Fig. 17 Plot of the brake power and thermal efficiency versus
percent of normal heat transfer for the 3.8l and 5.7l
N.A. engines. MBT timing, 1200 rev/min, $\phi=1.0$, $\Delta\Theta_b=60^\circ$.

Fig. 18 Plot of the mean exhaust temperature $\bar{T}$ and thermal boundary layer thickness $\delta_{th}$ (normalized by the bore, b)
versus percent normal heat transfer. Details as in Fig. 17.

Fig. 19 Plot of the brake specific NO emissions versus percent
normal heat transfer for the 3.8l and 5.7l N.A. engines.
Details as in Fig. 17.
Figure 1b
Figure 3.
Figure 7: Engine Speed, rev/min vs. bmeP, kPa for 3.8l W.O.T. test data with various conditions:
- ▲ MBT, $\phi=1.2$
- ○ retarded timing, $\phi=1.2$
- ■ retarded timing, adj. $\Delta\theta_b$, $\phi=1.2$
- ● retarded timing, adj. $\Delta\theta_b$, adj.$\phi$
- ▼ retarded timing, adj. $\Delta\theta_b$, adj.$\phi$, actual fmeP
3.8 W.O.T.

- test data
- MBT, $\phi=1.2$
- retarded timing, $\phi=1.2$
- retarded timing, adj. $\Delta\Theta_b$, $\phi=1.2$
- retarded timing, adj. $\Delta\Theta_b$, adj. $\phi$
- retired timing, adj. $\Delta\Theta_b$, adj. $\phi$, actual fmeq

Figure 8

Engine Speed, rev/min
Figure 11

bsfc, g/kWh

bsNO, gNO/kWh

$\phi = 1.0$

EGR

0%

5%

10%

15%

20%

NO EGR

18.9 (.8)

15.9 (.95)

16.8 (.9)

21.6 (.7)

25.2 (.6)

bmean = 325 kPa
1400 rev/min
MBT
$\Delta \theta_b = 60^\circ$
Figure 12
Figure 13

- 1200 rev/min
- 2000 rev/min
- 3200 rev/min

$\phi = 1.0$
$\Delta \theta = 60^\circ$
1200 rev/min
MBT
$\Delta \theta_b = 60^\circ$
$\phi = 1.0$

% Normal Heat Transfer

Figure 17
1200 rev/min
MBT
$\Delta \theta_b = 60^\circ$
$\phi = 1.0$

% Normal Heat Transfer

Figure 18
1200 rev/min
MBT
Δθ_b = 60°
ϕ = 1.0

bsNO, g/kW-hr

% 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, $\Delta \theta_\beta$, and start of combustion timing, $\theta_o$, vary with varying 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 an ignition delay period, $\Delta \theta_{ig}$:

$$\theta_s = \theta_o - \Delta \theta_{ig} \quad (11)$$

Hires et al. (14) performed parametric studies based on the geometry of a 6.6% 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 5.7\,l and 3.8\,l engines.

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

$$
\Delta \Theta_{ig} \propto \left( \frac{S_p}{v} \right)^{1/3} \left( \frac{h}{S_{l}} \right)^{2/3}
$$

(12)

where

- $S_p$ = piston speed
- $v$ = kinematic viscosity
- $h$ = instantaneous chamber height
- $S_{l}$ = laminar flame speed

From basic engine principles it can be shown that

$$
S_p \propto L \text{ RPM}
$$

(13)

and

$$
h \propto L
$$

(14)

where $L$ is the stroke.

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

$$
\Delta \Theta_{ig} \propto \left( \text{LRPM}_v \right)^{1/3} \left( \frac{L}{S_{l}} \right)^{2/3}
$$

(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

\[ \Delta \Theta_{lg} \approx L(RPM) \]  \hspace{1cm} (16)

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

\[ \Delta \Theta_b = \left( \frac{b}{h^*} \right) \left( \frac{S_p v^*}{S_{v^*}} \right) \left( \frac{h_i}{S_{v^*}} \right)^{2/3} \]  \hspace{1cm} (17)

where

- \( b \) = bore
- \( h_i \) = instantaneous chamber height
- \( * \) = values at 50% mass fraction burned

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

\[ \Delta \Theta_b \approx b(RPMv^*) \left( \frac{1}{S_{v^*}} \right)^{1/3} \]  \hspace{1cm} (18)

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

\[
\Delta \Theta_b \propto b(\text{RPM}) \quad (19)
\]

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 5.7\% and 3.8\% 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, NCY0, K1, K2, K3, K4, DPHIO, 0
CD = 5
PRI = 6
DSI = 11
V = 0

C
C WRITE DUMMY RECORD ON TEMPORARY OUTPUT FILES FOR EOF
C
REWRITE 12
REWRITE 13
WRITE ( 12, 71 )
WRITE ( 13, 71 )
71 FORMAT ( ' DUMMY RECORD FOR EOF' )

C
C READ DATA CARDS & BUILD DISK DATA SET
C
C REWRITE INPUT DATA SET FOR MULTI-STEP JOBS
C
C REWRITE 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 REWRITE DSI
SUBROUTINE CONP(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) GOTO 40

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
SUBROUTINE COMPM(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
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/D2,H,LA,EP,PHIO(8),DAE,PHIPR,PHIEND,VZ(8),PHI,PHIX(8),DPHI1,DPHI2
2XC,PK,VH,TAKT
3/MASS/NO,M1,MO,ME,MA,MEA,MEE
COMMON /CNOC/TZU(8),TZUS(8),TZB(8),TZBS(8),NNOU(8),
1NNOB(8),DNNOUG(8),DNNOU(8),DNNOB(8),NNOT(8),
2DNNOB(8),FBURN,IST(8),NRP,BS,FNNOTS,Fburns
COMMON /OUTP/CHOPFM(8)
COMMON /ORG/NEUM(8),PP,CO,DBV,VERD
COMMON /STEPS/DPHII
COMMON/CGCO/XCO,TMOLCO
COMMON/COMB/AV,MA,PHIVA(8),VD
COMMON/APROP/DEL,PSI
COMMON/PHICH/CHI
COMMON/FUEL1/AF(6),FREQ,ORDER,ACTV,TSUBC,ENW,DX,HY,OZ,QLOWER
COMMON/ADIAB/TABSN(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),ISTE(8),
2YBM3(8),YBG(8),YPBM2(8),YM2(8),YPBM1(8),YPBN(8),YBM1(8),
4YPBN1(8),FBURN(8),YPBNP1(8),FNNOTS(8),TX(8)
REAL LAV,ML,MBR,MRG,MO,HO(8),M1(8),MO,HE(8),MA(8),
1MEA(8),MEE(8),M1B,NNOU,NNOB,NNT,INNOT(8),HSTAR
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 (ISTEST(N).EQ.1) GO TO 112
ISTEST(N)=1
ISTBS(1)=0
DNOP1=0.0
DNQAN=0.0
DNORM1=0.0
DNORM2=0.0
IF(PP(N).GT.1) GO TO 360
FBURNS(N)=0.1E-10
INQ(N)=0.3E-20
PNNOTS(N)=0.1E-20
NNOU(N)=INQ(N)
NNOB(N)=0.0
NNOT(N)=0.0
GOTO 361
360 CONTINUE
INQ(N)=(1.-GGZ(N))*PNNOTS(N)
FBURNS(N)=0.1E-10
NNOU(N)=INQ(N)
NNOB(N)=0.0
NNOT(N)=0.0
GOTO 260
361 CONTINUE
CMAPPN(N)=0.0
DMOBLS=0.
BLNO=0.
XMBS=0.
GOTO 260
112 CONTINUE
DNORP1=(FBURN-FBURNS(N))*INQ(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=0314.7/RADB
TBULK=TADB(N)
V81MQ=(XMA*1.0E+06*RADB*TADB(N))/G
VBOUND=(M1B-MSTAR)*EQ*MEAN/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, XMOPR, 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 XMOPR (KEQ) = 1.0E-10
GO TO 6668

6668 XCO = XMOPR (2)

PZ (N) = G

TOTMOL = (XMA)*RADB/8314.7*1000.
NNOE = XMOPR (9)*TOTMOL
NNE = XMOPR (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 = RK1FB*XMOFR (9)/(RK2FB*XMOFR (14) + RKOH*XMOFR (5))
CAPL = XSS
IF (ITEST(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*NNCB(N)/DPHI
MN0B (N) = MN0B (N) + DNOOB (N) * DPHI
MN0B (N) = MN0B (N) + D诺P1 - DNOBL * DPHI
MN0U (N) = MN0U (N) - D诺P1
BLNO = BLNO + DNOBL * DPHI
IF (ITES1 (N) .GT. 0) GO TO 250
ITES1 (N) = ITES1 (N) + 1
YBM3 (N) = MN0B (N)
DN0RN = D诺P1
XBLM3 = BLNO
GO TO 255

250 CONTINUE
IF (ITES1 (N) .GT. 1) GO TO 251
ITES1 (N) = ITES1 (N) + 1
YBM2 (N) = MN0B (N)
YPBM2 (N) = DNOOB (N)
XBLM2 = BLNO
XPBLM2 = DNOBL
DN0RN1 = DN0RN
DN0RN = D诺P1
GO TO 255

251 CONTINUE
IF (ITES1 (N) .GT. 2) GO TO 252
ITES1 (N) = ITES1 (N) + 1
YPBM1 (N) = DNOOB (N)
YBM1 (N) = MN0B (N)
XBLM1 = BLNO
XPBLM1 = DNOBL
DN0RN2 = DN0RN1
DN0RN = D诺P1
GO TO 255

252 CONTINUE
IF (ITES1 (N) .GT. 3) GO TO 253
ITES1 (N) = ITES1 (N) + 1
YPBN (N) = DNOOB (N)
YBN (N) = MN0B (N)
XPBLN=DNOB1
XBLN=BLNO
DNORM2=DNORM1
DNORM1=DNORN
DNORN=DNORP1
253 CONTINUE
254 CONTINUE
YBNP1(N)=(4.*DPHI/3.)*(2.*XPBM2(N)-YPBM1(N)+2.*YPBN(N))+YBM3(N)
YBNP1(N)=YBNP1(N)+DNORP1+DNORM+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)-DNOB1
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
DNOB1=XPNP1
BLNC=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
DNORB(N)=TER1/(0.10472*DR*TER2)-DNOB1
255 CONTINUE
NNOU(N)=NNOB(N)+NNOU(N)+BLNO
CNOPPM(N)=(NNOT(N)*0.30E+08)/(M1(N)*MO)
CNOPPM(N)=CNOPPM(N)*(WNOZ/30.)
CNOPPM(N)=CNOPPM(N)*1.0E-03
IF (ITES1(N).LE.3) GOTO 260
DNORM2=DNORM1
DNORM1=DNORN
DNORN=DNORP1
DNOOB1(N) = YPBNP1(N)  
YBM3(N) = YBM2(N)  
YBM2(N) = YBM1(N)  
YPBM2(N) = YPBM1(N)  
YPBM1(N) = YBN(N)  
YPBN(N) = NNOB(N)  
YPBN1(N) = DNOOB(N)  
XBLM3 = XBLM2  
XBLM2 = XBLM1  
XPBLM2 = XPBLM1  
XBLM1 = XBLN  
XPBLM1 = XPBLN  
XBLN = BLNO  
XPBLN = DNOBL  
TMOLCO = XCO + TMOL  
FNNOTS(N) = NNOT(N)  
FBUURNS(N) = FBUURN  
260 CONTINUE  
5432 CONTINUE  
XMBS = XMB  
RETURN  
END
COMMON/APROP/DEL, PSI
COMMON/PHICHI/CHI
COMMON/ADIAB/TAS, TA, XMA, XMB, VA, VBL, EA, RM
C
LOGICAL VERD, ANALY
C
DIMENSION HG (8), TB (8), TBS (8), TU (8), TUS (8)
1, VB (8), RU (8), UU (8)
2, PZ (8), TZ (8), TZS (8), T2 (8), TZM (8), T2M (8), U2M (8), ALFAM (8),
1ALFAMS (8), B0 (8), DB (8), RZ (8), HZ (8), U2 (8), DU1 (8), DU2 (8), GGZ (8),
2DUDTZ (8), AI (8), AIS (8), QW (8), QWS (8), BGZ (8), BGS (8), RGGZ (8), PHIZ (8)
3, RU2 (8), TEE2 (8), BGE2 (8), GGE2 (8), AH (8), AMS (8), TA (8), TAS (8), TXW (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, RESRK, 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, UPF, H2, H3, H4, H5, H6, H7, H8, H9)
19)
UMIX=UZ (N) * M1 (N) * MO + B0 (N) * (UPF - 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 HITEMP (UNIX, 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)/CSUP 1
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.
TA(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,DK1A,RA,GAMA)
CALL GPROP(TMEAN,PZ(N),LAV,DEL,PSI,RESFRK,HM,UM,CSUPM,1CSUTH,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,KU(N),KU(N))
BB=BO(N)*(1.-EXP(-AV*((PHI-PHIVA(N)-TAKT*PP(N))/VD)**(MV+1.)))
IF (BB.LE.0.) GOTO 211
HB(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=MAB(N)*MO(N)*MO/(1.*ETAU)
DMU=-MMAB
XMA=MAB*(RG(N)*TB(N)-RM*TMEAN)/(RA*TA(N)-RM*TMEAN)
IF(XMA.LE.MAB) XMA=0.99*MMAB
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*DRHTB/DRHOPB-CSUTB)/DRHOPB*DRHTB)
AU=MAU*(CSUPU+1./RHOU*DRHTU/DRHopU-CSUTU)/DRHopU*DRHTU)
AA=XMA*(CSUPA+1./RHOA*DRHTA/DRHopA-CSUTA)/DRHopA*DRHTA)
ANM=XMB*(CSUPM+1./RHOM*DRHOMM/DRHOPM-CSUTM)/DRHOPM*DRHOM)
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)
VB1=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
ZETA 1=XCON*AA*CM/AMM+CA
ZETA 2=XCON*AA*(HM-BM-HA)/AMM-BA
ZETA 3=(HA-BA-HU(N))/AMM-BA
DA=1./RHOA*DRHOPA
DM=1./RHOH*DRHOPM
EA=1./RHOA*DRHOTA
EH=1./RHOH*DRHOTM
BETA 1=DA/DM/(VA(N)-VA)+1./VA+EM*DA*CA/DM/AA/XCON-CA*EA/AA
BETA 2=DA/DM*(1./XNB+BA*EM/XCON/AA)-1./XMA+BA*EA/AA
BETA 3=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*DEHOTB/RHOB)

1-1./RHOU*DRHOTU*CU/AU
IP(BB/B0(N),LE.0.005) MQWB(I,N)=0.
DUM2=1./AB*(HUB(N)+MMAB-(HB(N)-BZB)*MMAB-MQWB(I,N))
DUM3=1./AU*(-HUB(N)+MMAB*(HB(N)-BZU)*MMAB-MQWB(I,N))
DUM4=1./HHH*DRHOTU*CU/AU
TERM1=MMAB*(QUAN1/HAB+1./MAU)
TERM2=PHIZ(N)*(1./VU(N)-DUM4)
TERM3=1./RHOU*DRHOTU*DUM3-QUAN1*DUM2*DRHOTB/RHOB
MV (I,N) = (TERM1+TERM2+TERM3)/DUM1
BETA4=DA/DM*MV (I,N)/VBL
ZETA4=XCON*AA/AMM*(CM*MV (I,N)+MQWB(I,N))
DMLB=(DUM1*(BETA1*ZETA3-BETA3*ZETA1)+BETA1*ZETA4-BETA4*ZETA1)

/ (ZETA1*BETA2-BETA1*ZETA2)
DVA=(DMLB*BETA2+BETA3*DUM1+BETA4)/BETA1
MTA(I,N)=1./AA*((HA-BA-HU(N))*DUM-BA*DMLB-CA*DVA)
MTB(I,N)=(DUM2-CA/AB*MV (I,N)
MTU(I,N)=DUM3-CU/AU*(PHIZ(N)-MV (I,N))
MPZ(I,N)=RHOU*DRHOPU*(-PHIZ(N)-MV (I,N))/VU(N)-MMAB/MAU-1./RHOU

1*DRHOTU*MTU(I,N)
IF(BB/B0(N),LE.0.005) GO TO 901
CALL INTEG(TBS,B,MTB,I,N,DH)
IF(TB(N),GT.2900.) TB(N)=2900.
CALL INTEGR(TUS ,TU ,MTU,I,N,DPHI)
CALL INTEGR(TAS,TA,HTA,I,N,DPHI)
901 CALL INTEGR(PZS ,PZ ,MPZ,I,N,DPHI)
IF (BB/B0 (N) .GT. 0 .005) GO TO 902
IKK=0
RESPHK=1.-GGZ(N)
CALL GPROP(TU(N),PZ(N),LAV,DEL,PSI,RESPHK,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,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 = K * TA (N) * XMA / PZ (N)
VBL = RM * TMEAN * XMB / PZ (N)
END OF UPDATE
LGZ (N) = LGB (N)
BGZ (N) = BGB (N)
BGZZ (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, 1, SUTA, RHOA, DRHOTA, DRHOPA, DH1A, RA, GAMA)
CALL GPROP (TMEAN, PZ (N), LAV, DEL, PSI, RESFRK, HM, UM, CSUPM, 1, SUTM, RHOM, DRHOTH, DRHOPM, DH1M, RM, GAMM)
CALL GPROP (TZ (N), PZ (N), LAV, DEL, PSI, RESFRK, HZ (N), UZ (N), CSUPZ, 1, SUTZ, RHOZ, DRHOTZ, DRHOPZ, DH1Z, 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 * EM * TMEAN / PZ (N)
AA = XMA * (CSUPA + 1.) / RHOA * DRHOTA / DRHOPA * CSUTA / DRHOPA * DRHOTA
AMH = XMB * (CSUPM + 1.) / RHOM * DRHOTH / DRHOPM * CSUTM / DRHOPM * DRHOTH
BM = (1. - RHOM * CSUTM) / DRHOPM
BA = (1. - RHCA * CSUTA) / DRHOPA
CA = BA * RHOA

00002530
00002540
00002550
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00002570
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00002600
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00002770
00002780
00002790
00002800
00002810
00002820
00002830
00002840
00002850
00002860
00002870
00002880
CM = BM * RHOM
DA = DRHOPA / RHOA
DM = DRHOPM / RHOM
EA = DRHOTA / RHOA
ED = DRHOTM / RHOM

ALPHA = (ALOG (TA (N) / TWX (N)) - (1. - TWX (N) / TA (N))) / (ALOG (TA (N) / TWX (N)) ** 2)

BMM = HA - HM * BN

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) + 1)

MQW (I, N) / ALPHA / AMM)

YN1 = (1. / VA - EA * CA / AA + DA / DM * (1. / (VZ (N) - VA) - EM / AMM * CM))
YN1 = (-1. / XMA + EA * BA / AA - DA / DM * (1. / XMB - EM * BMN / AMM))

Y1 = YN1 / YD1

Y2 = YN2 / YD1

DNBL = (X1 * X2 + Y2) / (-1. * Y1 * X1)
DVA = X1 * DNBL * X2

MTA (I, N) = 1. / AA * (-BA * MNBL - CA * DVA)

CALL INTEG (TAS, TA, MTA, I, N, DPHI)

AUX = NO (N) * MO * (CSUPZ + 1. / RHOZ * DRHC + DRHZ - 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 +

TAKT * PP (N)) MT (1, N) = MT (2, N)

MPZ (I, N) = RHOZ * DRHOPZ * (-PHIZ (N) / VZ (N) - DRHOTZ / RHOZ * MT (I, N))

CALL NEWT (T2S, T2, T2Z, MT, I, N, CO, DPHI)

CALL CPRRESS (PZ, T2, RZ, I, N)

CALL INTEG (PZ, PZ, MP2, 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, ROAO, DRHOTA, DRHOPA, DH1A, RA, GAMA)

CALL GPRCP (TMEAN, PZ (N), LAV, DEL, PSI, 1., HM, UM, CSUPM,
1CSUTM, RHOM, DRHOTM, DRHOPM, DH1M, RM, GAMA)
CALL GPROP (TZ (N) , PZ (N) , LAV , DEL , PSI , 1 , HZ (N) , UZ (N) , CSUPZ ,
1 CSUTZ , 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 INTLEG (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 READ ENGINE DATA SET INTO COMMON AFTER CHECKING FOR VALID PASSWORD

C

INTEGER CD, PRI, DSI, DSQ, V, C, P1, P2, PR
INTEGER T, TP, Z, TEX, TIN, VERS

C REAL LAND, LANW, LANK, LANEV, LANAV, LA, H0 (8), M1 (8), MO, ME (8), MA (8),
1 MEA (8), MEE (8), LAV, ML, MBR, MRG, MV, MUOE, MU1E, MU2E, MU3E, MUOA, MU1A,
2 MU2A, MU3A

REAL LDEL, LDIL

C

COMMON /TITLE/ NA(60)
COMMON /CTRL/ CD, PRI, DSI, DSQ, V, C, P1, P2, NDAT1, NDAT2,
1 T, TP, Z, NCY, NCYO, K1, K2, K3, K4, DPHIO, O

COMMON /INPUTP/ INPUTT
COMMON /HTL/ TD, TKD, DD, ALD, LAND, TW, TKW, DW, ALW, LANW, TK, TTK, DK, ALK,
1 LANK, TEV, TKEV, DEV, ALEV, LANEV, TAV, TKAV, DAV, ALAV, LANAV, FDFK, WF, ZETA
2 GEOM/D, H, LA, EPS, PHI0 (8), DAE, PHPIR, PHIENT, VZ (8), PHI, PHIX (8), DPHI,
3 XC, PK, VH, TAKT
6 FUEL/SLB, CE, LAV, RB, ML, MBR, MRG, VERDQ (3, 7)
7 COMB/AV, MV, PHIVA (8), VD
8 OPD/PO, TO, PE, TE, PA, PB, DR, PB0, TEO, FE0, VER
9 SC/MUOE, MU1E, MU2E, MU3E, FER, MUOA, MU1A, MU2A, MU3A, PAR
COMMON /VALVE/ PHI0EX, PHI0IN, PHICEX, PHICIN, SAEX, RI1EX, R2EX, R3EX, R4EX,
1 RAREX, SAIN, R1IN, R2IN, R3IN, R4IN, RARIN
3 VARIA/ PAV, PVE, LE, LI, TEX, TIN, TWU, VERG, LDEL, CDEL, LDIL, CDIL, FEL,
4 FAL, PHI, PHIL, PHIP, PEL, PAL, REZ, CN

COMMON /VALASH/ VLASH
COMMON /FUEL1/ AF (6), FREQ, ORDER, ACTV, TSUBC, ENW, CX, HY, OZ, QLOWER

C THIS INPUT ROUTINE IS MODIFIED FOR USE WITH M. MARTINS
C SUBROUTINES FOR GAS PROPERTIES

C

DIMENSION PE (8), TE (8), PA (8), PHIL (320), FEL (320), PAL (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 PR IS USED LOCALLY FOR PRINTER
C
    PR = PRI
C    MKU = 29
C
C REWIND FOR MULTI-STEP JOBS
C READ CLOCK FUNCTION TO GET CURRENT DATE & SAVE IN DKEY FILE
C
C    REWIND MKU
C    KDATE(2) = NBLK
C    XZERO = 0.
C
C FIRST 16 DATA CARDS ARE REQUIRED
C
C READ TITLE, 2 COMMENT, AND 1 CONTROL CARDS
C
C    READ (DSI, 7011, END=7990) ( WA(II), II = 1, 60 )
7011 FORMAT ( 20A4 )
    READ ( DSI, 7017, END=7990 ) V, C, P1, P2, NDAT1, NDAT2,
      1 T, TP, Z, NCY, NCYD, K1, K2, K3, K4, DPHIQ, O, IKEY1, IKEY2
7017 FORMAT ( 4I1, 4X, 2A4, 4X, 5I2, 2X, 4I2, 10X, 2F6.2, 2A4 )
      INPUT = 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
     00000370
     00000380
     00000390
     00000400
     00000410
     00000420
     00000430
     00000440
     00000450
     00000460
     00000470
     00000480
     00000490
     00000500
     00000510
     00000520
     00000530
     00000540
     00000550
     00000560
     00000570
     00000580
     00000590
     00000600
     00000610
     00000620
     00000630
     00000640
     00000650
     00000660
     00000670
     00000680
     00000690
     00000700
     00000710
     00000720
C KEYA(1, 4) = 1 PASSWORD NOT REQUIRED
C
C READ (NKU, 7019, END=7990, ERR=7980 ) (KEYA(1,II), II = 1, 10 ) 00000750
C7019 FORMAT ( 3A4, I4, 6A4 )
C IF (KEYA(1,2) .NE. NKEY ) 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 ) 00000840
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. NKEY ) 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 DO 7036 KK = 1, LL
C
C7036 WRITE (NKU, 7019 )  
C    REWIND NKU
C    WRITE (PRI, 7037 )
C7037 FORMAT ( //' 10X, 'PASSWORD VALID' )  
C    CHECK IF CALC = YES = 1
C7040 IF ( C .LT. 1 ) STOP
C    READ DETAILED ENGINE DATA
C
FREQ=2.34127E17
ORDER=1.5922
ACTV=80.0535
TSUBC=6430.43
ENVW=0.0
READ (DSI, 7121) D, H, LA, EPS, PAR, PER, DD, DW, DK, DAV, DEV,
1 PHIOEX, PHIOIN, PHICEX, PHICIN, PAV, PEV, PPDFK, LE, LI, TIX, TIN,
2 SAEX, R1EX, R2EX, R3EX, R4EX, RAEY, SAIN, R1IN, R2IN, R3IN, R4IN, RARIN,
3 MUOA, MU1A, MU2A, MU3A, MUOE, MU1E, MU2E, MU3E, VLASH, VLASH2,
4 WP, 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) ( AP(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) - VFLASH2
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) - VFLASH
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

LAST SETS OF DATA ARE PROGRAM VERSION DEPENDENT

C

STARTS WITH DATA 'OPC2' (SEE CALC)

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), NPAG,
2  V, C, P1, P2, (NA(J), J = 21, 60)
7711 FORMAT (1H1, 10X, 2A4, 7X, 20A4, 5X, A4, A1, T120, 'PAGE', I4,
1  'I / 10X, 'VERSION', I2 / 10X, 'CALC', I2, 4X, 'PLOT1', I2,
2  '4X, 'PLOT2', I2, 2(10X, 20A4)
WRITE (PR, 7717) INPUTT, TP, Z, NCY, NCVO, K1, K2, K3, K4, DPHEL, O
7717 FORMAT (// 6X, 'CONTROL', 7X, 'NT', 6X, 'TP', 5X, 'NCY', 5X,
2  '6X, 'DPHEL', 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, PAR, PER, DD, DW, DK, DAV, DEV,
1  PHIOEX, PHIOIN, PHICEX, PHICIN, FAV, FEV, PDFK, LE, LI, TEX, TIN,
2  SAEX, R1EX, R2EX, R3EX, R4EX, RAREX, SAIN, R1IN, R2IN, R3IN, R4IN, RARIN
1  'AEX', APIN, DELC, DELL, DELE, DELIN, 00002090
2  '/' 18X, 'IN', 6X, 'IN', 22X, 'SQ.IN', 'SQ.IN', 5X, 5('IN', 6X),
4  6X, 'VALUE1', 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, 'VALUE2', 6X, 'SAEX R1EX R2EX R3EX R4EX', 00002160

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9 4X,'RAREX  SAIN  R1IN  R2IN  R3IN  R4IN  RARIN',00002170
A / 3X, 2( 15X, 'DEG. IN.', 3( 6X, 'IN.' )), 00002180
B / 13X, 2( P9.1, 5P9.3)) 00002190

C
WRITE (PR, 7727) MU0A, MU1A, MU2A, MU3A, MUOE, MU1E, MU2E, MU3E, 00002210
2 VLASH,VLASH2, 00002220
4 WF, TWU, ALD, ALW, ALK, ALAV, ALEV,
5 LAND, LANW, LANK, LANA, LANOE, TKD, TKW, TKE, TKEV,
6 CE, SLB, NBR, NRE,CX, HY, OZ, ENW
7727 FORMAT ( / 6X, 'VFLOWC FC0EX FC1EX FC2EX FC3EX', 00002260
1 4X, 'FC0IN FC1IN FC2IN FC3IN VLA'00002270
1ISHI VLASH', 00002280
2 // 13X, 10P9.3, 00002290
3 // 6X, 'HTRANS1 MULTHTR TDISTR ALPH ALFCL', 00002300
4 5X, 'ALPP ALPEX ALFIN', 00002310
5 / 35X, '--------------BTU/SQ.FT.-DEG.F-MIN--------------', 00002320
6 / 13X, 7P9.2, 00002330
7 // 6X, 'HTRANS2 LANNH LANCHL LANOCL LANEX LANIN', 00002340
8 5X, 'TCH TCCL TCP TCEX TCIN', 00002350
9 / 17X, '--------------BTU/FT.-DEG.F-MIN--------------', 00002360
A 5( 4X, 'DEG.F' ), 00002370
B / 13X, 5P9.3, 5P9.1, 00002380
C // 6X, 'FUEL', 8X, 'CV  SA/F  MFUEL', 00002390
E / 1/6X, 'BTU/LB.', 9X, 2( 2X, 'LB/MOLE' ), 00002410
F / 13X, P9.0, P8.1, 1X, 2P9.1, 4P9.2) 00002420

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)', 00002460
2 8X,'A(2)',8X, 'A(3)', 8X, 'A(4)', 8X, 'A(5)', 8X, 'A(6)',
3 / 16X, 'FUEL', 18X, 6E12.3) 00002470

C
WRITE (PR, 7737) PHIVAR(1), VD, MV, AV, XLAV, PO, TO, PB, DB
7737 FORMAT ( // 6X, 'OPC1', 7X, 'PHISC  CD  MWIEBE AWIEBE', 00002510
3X, 'EXHAIRN', PREF, TREF, PBARO, RPM',
2 / 13X, 2( 3X, 'DEG.CA' ), 31X, 'PSIG', DEG.F, IN.HG',

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',

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 WRITE (PR, 7761) (PHIL(L), FAL(L), FEL(L), L = 1, T )
7761 FORMAT ( // 6X, 'VAREA', 7X, 3( 'PHI', VAEX, VAIN', 9X),
00002570
00002580
00002590
00002600
00002610
00002620
00002630
00002640
00002650
00002660
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00002860
00002870
00002880
PAGE 28
1 / 10X, 3( 'DEG.CA SQ.IN. SQ.IN.' ),
2 / ( '9X, 3(P13.1, P8.3, P9.3))

C

7780 IF ( TP .EQ. 0 ) GO TO 7800
7783 WHITE (PR, 7783) (PHILP(L), PAL(L), PEL(L), L = 1, TP )
7783 FORMAT ( // 6X, 'PRESSFL', 5X, 3( 'PHI PEX PIN', 9X ),
1 / 10X, 3('DEG.CA PSIG PSIG' ),
2 ( / 10X, 3('P12.1, 2P9.2'))

C

7800 RETURN

C

7980 WHITE (PRI, 7981 )
7981 FORMAT ( // 10X, 'ERROR IN READING PASSWORD FILE' )
STOP
7986 WHITE ( PRI, 7987 )
7987 FORMAT ( // 10X, 'NO PASSWORD' )
STOP
7990 WAITE (PR, 7991)
7991 FORMAT ( // 10X, 'UNEXPECTED EOF' )
STOP
END
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
SUBROUTINE LINPO(X,XL,PL,NXL,F)
C LINEAR INTERPOLATION
DIMENSION XL(NXL),PL(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=PL(N)+(PL(N+1)-PL(N))/DST*(X-XL(N))
RETURN
END
MEMBER NAME MFR

SUBROUTINE MFR(MM, P0, T0, P1, WR, FR, PV, MU0, MU1, MU2, MU3, K, GK, DR, MO, I1, N)

C EVALUATION OF MASS FLOW RATE

C GETESTED 6.8.69

DIMENSION P0(8), T0(8), P1(8), WR(8), PV(8), GK(8), P(8)
REAL MU0, MU1, MU2, MU3, K(8), NO, MM(2, 8), NU
P(N) = P0(N)
P1 = P1(N)/PO(N)
PIK = (2./(K(N)+1.))**(K(N)/(K(N)-1.))
IF(PG(N) .LT. P1(N)) GOTO 10
MU = NU0 + NU1/PI
IF(MU.GT.MU2) MU = MU2
PEFF = PV(N)*MU
IF(P1.LE.PIK) PI = PIK
GOTO 20
10 PEFF = -MU3*PV(N)
P(N) = P1(N)
IF(P1.LE.1./PIK) GOTO 30
PI = PIK
GOTO 20
30 PI = 1./PI
20 WF = SQRT(2.*K(N)/(K(N)-1.))*GK(N)*T0(N)*((1.-PI**((K(N)-1.)/K(N))))
WR(N) = PEFF/FR * WF
PSI = PI**((1./K(N))-SQRT(2.*K(N)/(K(N)-1.))*(1.-PI**((K(N)-1.)/K(N))))
MM(I, N) = PEFF*PSI*P(N)*9.55/(MO*DR*SQR(T(GK(N)*T0(N))))
RETURN
END
SUBROUTINE MFRP(MM,P1,P2,PREF,TREF,T1T,WR,FR,FV,NUO,NU1,NU2,NU3,  
1K,GK,DR,M0,1,N)
C EVALUATION OF MASS FLOW RATE, MEASURED PIPE PRESSURE
DIMENSION WR(N),FV(N),GK(N)
REAL MM(2,N),NUO,NU1,NU2,NU3,K(N),M0,MU
PI=P2/P1
MU=NU0+NU1/PI
FI=FV(N)*MU/FR
IF(FI.GT.1.) PI=1.
WZ=2./((K(N)-1.)*(PI**((-K(N)-1.)/K(N))-1.))
WN=1./((PI*FI)*PI**((-2./K(N))-1.))
ARG=WZ/WN
IF(ARG.LT.0.) ARG=0.
W=SQR(T(ARG)
A2=SQR(T(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))))
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
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/PROP/DL, PSI
COMMON/PHICI/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) < .001)) GOTO 20

TAM=TAM+ (SENT/(MA*MO)-HAM)*(KAM-1.)/(RAM*KAM)

GO TO 10

20 RETURN

END
SUBROUTINE MTEMP1(SENT, MA, NO, TAM, LGA, BGA, LAV, PAM)

C AVERAGE CYLINDER TEMPERATURE AFTER EVAPORIZATION OF FUEL

REAL MA, NO, LGA, KAM, LAV
COMMON/FUEL1/AF(6), FREQ, ORDER, AACTV, TSUBC, ENW, CX, HY, OZ,
1 QLOWER
COMMON/APROP/DL, PSI
COMMON/PHICHI/CHI

TAM=500.
RGGA=1.-LGA-BGA
RESFRK=0.

10 CALL (PROP(TAM, PAN, LAV, DEL, PSI, RESFRK, HAH, UAH, CAMP, CAMT,
1 RHOA, DRHOTA, DRHPA, DHA, RAM, KAM)
IF (ABS((UAH-SENT)/(MA*NO))/UAH).LT..001) GOTO 20
TAM=TAM+ (SENT/((MA*NO)-UAH)*(KAM-1.))/(RAM)
GO TO 10

20 RETURN
END
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
SUBROUTINE VA(VHUB,SA,R,R1,R2,VPMAX,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)*SQR((VHUB**2.-2.*VHUB*(R2-R1)*TAN(SA)+(R2-R1)**2.)*
1*(1.+((TAN(SA)**2.)
10 IF(VF.GT.VPMAX) VF= VPMAX
RETURN
END
SUBROUTINE WTEMP1(TWO, TKO, DO, ALO, LAO, TZN, ALFAM, N, TAKT)

C EVALUATION OF WALLTEMPERATURES
C GETESTET 30.7.69

DIMENSION TZN(N), ALFAM(N)
REAL LAO

TWO = (TZN(N) * ALFAM(N) * (DO/LAO + 1. / ALO) + TKO) / (ALFAM(N) * (DO/LAO + 1. / ALO) + 1.)

RETURN

END
SUBROUTINE WTEMP2(TWO, TK0, DO, ALO, LAO, TZM, ALFAM, N, AM)

C GETESTED 12.8.69

DIMENSION TZM(N), ALFAM(N), AM(N)

REAL LAO

TWO = (TZM(N)/AM(N)*(DO/LAO+1./ALO)+TK0)/(ALFAM(N)/AM(N)*(DO/LAO+1.)/ALO)+1.)

RETURN

END
MEMBER NAME CPRESS

SUBROUTINE CPRESS(PZ, TZ, RZ, I, N)

C EVALUATION OF CYLINDER PRESSURE

C GETESTET 1.8.69

COMMON/HYP/CRR, BO, SO, CRL, CR, EX, ARG, X1W, X2W, PHI1
COMMON /MASS/M0, M1, MO, ME, MA, MEA, MEE/GEON/D, R, LA, EPS, PHIO(8), D AE,
1PHIPR, PHIEND, VZ(8), PHI, PHIX(8), DPHI, XC, FK, VH, TAKT

DIMENSION PZ(N), TZ(N), RZ(N)

REAL M0(8), M1(8), MO, ME(8), MA(8), MEA(8), MEE(8), LA

IF (I.EQ.2) GOTO 20

PZ(N) = (M0(N) + ME(N) + MEE(N) - MA(N) - MEA(N)) * MO * RZ(N) * TZ(N) / ((XC + R/2.
1* (1 - COS (PHIX(N) + DPHI)) + LA/2. * SIN (PHIX(N) + DPHI) * SIN (PHIX(N) + DPHI))

2*FK)

GOTO 30

20 PZ(N) = (M0(N) + ME(N) + MEE(N) - MEA(N) - MA(N)) * MO * RZ(N) * TZ(N) / VZ(N)

30 RETURN

END
SUBROUTINE GASEX (PE, TE, PA, DR, REZ)

C GAS EXCHANGE

COMMON/RUCK2/LGEE(8), RGGE(8)
COMMON/PCTRL/CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2,
1 T, TP, Z, NCY,NCYO,K1,K2,K3,K4, DPHIO, O
COMMON/SC0/SC0/PZ, TZ, T2Z, RZ, HZ, UZ, KZ, MT, LGZ, LGZS, BGZ, BGZS, RGZ
1,GGZ, PHIZ, MQW, IN, LGRG, RUZ, TEE2, LGE2, BGE2, GGE2, PZS
COMMON/SC1/ MGZ, GZS, GZ, PES, TEE, LGZ, BGE, GGE, RE, HG, UE, KE
1, FE, WER, TAR, LGAR, BGC, RGC, SGC, RAR, WAR, WAR, MES
2, MAS, UA, MEES, MEAS, EEIN, EEINS, EAUS, EAUS, MEZ, MALS, MAZ, MAZE, ER, AR
3, PMPHO, PMPRI, PEP, TREF

DIMENSION PZ(8), PZS(8), TZ(8), T2Z(8), RZ(8), HZ(8), UZ(8), KZ(8), MT(8), LGZ(8), LGZS(8), BGZ(8), BGZS(8), RGZ(8),
1 GZ(8), GZS(8), MGZ(8), RE(8), HG(8), UE(8), KE(8), LGC(8), PA(8),
2 TEE(8), BGE(8), GGE(8), RE(8), HG(8), UE(8), KE(8), LGC(8), PA(8),
3 TAR(8), BGC(8), RGC(8), SGC(8), RAR(8), WAR(8), WAR(8), PA(8),
4, PHIZ(8), EEIN(8), EAUS(8), EAUS(8), EEINS(8), ER(8), AR(8), UA(8),
5 REAL LGZ(8), LGZS(8), MGZ(8), KE(8), LGG(8), KZ(8), MT(8), LGG(8), LGZ(8),
1 LGG(8), MES(8), MAS(8), MEES(8), MEAS(8), MQW(2,8), MT(2,8),
2, MEZ(8), MGZ(8), MAZ(8), MALS(8),
3 COMMON/EXKON/BB, TREF1(8), TREF2(8), PPREF1(8), PPREF2(8)
4 COMMON/FUEL/SLB, C, LA, KB, ML, MB, MRG, VERDD, Q(3,7),
1 GEOEG, D, H, LA, EPS, PHIO(8), DAE, PHIPR, PHIEND, VZ(8), PHI, PHI(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, MU0A, MU1A, MU2A, MU3A, PAR
COMMON/FUEL1/AP(6), PREQ, ORDER, ACTV, T/SUC, ENW, CX, HY, OZ,
1 QLOWER
COMMON/APEP/DEL, PSI
COMMON/PHICHI/CHI
REAL LAV, ML, MB, MRG, LA, MO(8), M1(8), MO, ME(8), MA(8), MEA(8), MEE(8),
1 MUOE, MU1E, MU2E, MU3E, MU0A, MU1A, MU2A, MU3A
2, LG2E(8)
INTEGER PP(8), CO(8), DBV(8)
LOGICAL VERD

0000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
0000120
0000130
0000140
0000150
0000160
0000170
0000180
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0000350
0000360

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DIMENSION DU1(8), DU2(8), DU3(8), DU4(8), DUDTZ(8), DUDTE(8), HEE(8), 
REE(8), HMMA(2,8), DUDTAR(8), DUDTEE(8), UEE(8) 
2, RUE(8), TEE(8), BGE(8), GGE(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. STATEMENT 1 
C REFERS TO INFLOW AND STATEMENT 2 REFERS TO OUTFLOW. 
IF(PZ(N)-PA(N)) 1, 2, 2 
RESFRK=1.-GGAR(N) 
1 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, PA, PZ, TAR, PA, WAR, FAR, FA, MU0A, 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, PA, PZ, TAR, PA, WAR, FAR, FA, MUC0A, 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)
    FMFRI = 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
    PE(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
    CONTINUE
    CALL MFR(MMEA, PE, TZ, PZ, WEB, PE, MUOE, MU1E, MU2E, MU3E, KZ, RZ, DR, MO, I, N)
    FMFRI = MMEA(I, 1)
    ET = (HZ(N) - QUANZ) * MMEA(I, N) * MO
    MEIN(I, N) = HZ(N) * MMEA(I, N) * MO
    HMMEA(I, N) = -MMEA(I, N)
    CALL INTEG(HEAS, MEA, HMMEA, I, N, DPHI)
    IF (PZ(N) .GE. PA(N)) GOTO 5
    MGGZ(I, N) = - (GUAR(N) - GGZ(N)) * MMEA(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 BEGINNS
    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
    RESFRK = 1. - GGE(N)
    CALL GPROP(TEE(N), PE(N), LAV, DEL, PSI, RESFRK, HEE(N), UEE(N), CSUPEE

00000730
00000740
00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
00000870
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00000890
00000900
00000910
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00000980
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00001000
00001010
00001020
00001030
00001040
00001050
00001060
00001070
00001080

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1. CSUTE, RHODE, DRHOTE, DROHE, DH1EE, REE(N), KEE(N)

IF (MEAS(N) .GE. MEES(N)) GOTO 42
IF (K2 > 1.0 OR K4 .LT. 0) GOTO 41

42 CALL MFR (MEES, PE, TEE, PZ, WER, PER, PE, MUOE, MU1E, MU2E, MU3E, KEE, REE, DR, MO, I, N)
GOTO 45

41 CALL MFRP (MEES, PE(N), PZ(N), PREF2(N), TREF2(N), TEE(N), WER, PER
1, PE, MUOE, 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,
1, CSUTE, RHODE, DRHOTE, DROHE, DHI, REE(N), KEE(N))

45 PMPRI = 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)) / MZ00001270
1(N)
9 CALL INTEG (GGZS, GGZ, MGGE, 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)
LGGE(N) = LGE2(N)
BGGE(N) = BGE2(N)
RGGGE(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,TE(N),WER,FER,FE,MUOE,MU1E,
1,MU2E,MU3E,KE,RE,DR,MO,I,N)

34 PMFRP=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,M,E,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
   MGBKZ(I,N) = -BGZ0(N) * MGGZ(I,N)
   GOTO 22
21 MGBKZ(I,N) = MGGZ(I,N) / (1. + LAV*SLB) - BGZ0(N) * MGGZ(I,N)
22 CONTINUE

C CALCULATE THE CHANGE IN TEMPERATURE IN THE CYLINDER
   QUANDT = MZ(N) * MO * (CSUBFZ + 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)
   MZ(N) = MZ(N) * MZ(N)
   CALL INTEG(LGZS, LGZ, MLGZ, I, N, DPHI)
   CALL INTEG(BGZS, BGZ, MGBKZ, I, N, DPHI)
   RGGZ(N) = 1. - LGZ(N) - BGZ(N)
23 IF(PZ(N) .LT. PA(N)) GOTO 23
   LGAR(N) = LGZ(N)
   TAR(N) = TZ(N)
   GGAR(N) = GZGZ(N)
   RGGAR(N) = RGGZ(N)
   BGAR(N) = BGZ(N)
23 CALL INTEG(EEINS, EEIN, MEEIN, I, N, DPHI)
   CALL INTEG(EEAUS, EAU, MEAUS, I, N, DPHI)
   RETURN
END
SUBROUTINE CLDPRD

PURPOSE:
TO CALCULATE THE SPECIFIC ENTHALPY OF THE PRODUCTS OF HC-AIR COMBUSTION AT TEMPERATURES AND PRESSURES WHERE DISSOCIATION OF THE PRODUCT GASES MAY BE IGNORED. THE DENSITY OF THE PRODUCT GAS IS ALSO CALCULATED, AS ARE THE PARTIAL DERIVATIVES OF BOTH OF THESE QUANTITIES WITH RESPECT TO PRESSURE AND TEMPERATURE.

USAGE:
CALL CLDPRD(P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,DRHODT, DRHODP,IER)

DESCRIPTION OF PARAMETERS:

GIVEN:
P - ABSOLUTE PRESSURE OF PRODUCTS (ATM)
T - TEMPERATURE OF PRODUCTS (DEG K)
PHI - EQUIVALENCE RATIO (FUEL/AIR RATIO DIVIDED BY THE CHEMICALLY CORRECT FUEL/AIR RATIO)
DEL - MOLAR C:H RATIO OF THE PRODUCTS
PSI - MOLAR N:O RATIO OF THE PRODUCTS

RETURNS:
ENTHLP - SPECIFIC ENTHALPY OF THE GAS (KCAL/G)
CSUBP - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO T AT CONSTANT P (CAL/G-DEG K)
CSUBT - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO P AT CONSTANT T (CC/G)
RHO - DENSITY OF THE MIXTURE (G/CC)
DRHODT - PARTIAL DERIVATIVE OF RHO WITH RESPECT TO T AT CONSTANT P (G/CC-DEG K)
DRHODP - PARTIAL DERIVATIVE OF RHO WITH RESPECT TO P AT CONSTANT T (G/CC-ATM)
IER - FLAG, SET TO 1 FOR T<100 DEG K
2 FOR T> 6000 DEG K
0 OTHERWISE

REMARKS:
1) ENTHALPY DATUM STATE IS AT T = 0 ABSOLUTE WITH
   O2,N2,H2 GASSEOUS AND C SOLID GRAPHITE
2) IN CASE OF PROBLEMS CONTACT MIKE MARTIN AT 253-2411
   (ROOM 3-339 D)

SUBROUTINES AND FUNCTION SUBPROGRAMS NEEDED: NONE

METHOD:
DEPIECED IN APPENDIX IV OF WRITEUP

SUBROUTINE CLDPRD (P,T,PHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,
1 DRHODT,DRHODP,IER)

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

INITIALIZE PARAMETERS, AND CHECK TO SEE IN WHAT TEMPERATURE
RANGE WE ARE SO THAT THE CORRECT FITTED COEFFICIENTS WILL BE
USED. FLAG TEMPERATURES TOO BIG OR TOO SMALL

DATA A1/11.94033,2.083581,-0.47029,.037363,-.589447,-97.1418,
1 6.139094,4.00783,-.9356009,.0666948,.0335801,-56.62588,
2 7.099556,1.275957,-.2877457,.022356,1599696,-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/

PAGE 48
DATA A2/4.737305,16.65283,-11.23249,2.828001,.00676702,-93.75793, 00000730
7 7.809672,.-2023519,3.418708,-1.179013,.00143629,-57.08004, 00000740
8 6.97393,.-8238319,2.942042,-1.176239,.000413409,-27.19597, 00000750
9 6.991878,16.17044,-21.82071,2968197,-1.01625234,-118189, 00000760
E 6.295715,2.388387,-3.014788,-3.3267433,.00435925,1.03637, 00000770
- 7.092199,-1.295825,3.20688,-1.202212,-.0003457938,-.013967/ 00000780
DATA TABLE /-1.1,1.,-1.,0.,0.,0./ 00000790
00000800
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
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)
\[ X(1) = \text{EPS} \cdot \text{PHI} - C \]
\[ X(2) = 2. \cdot (1.0 - \text{EPS} \cdot \text{PHI}) + C \]
\[ X(3) = C \]
\[ X(4) = 2. \cdot (\text{PHI} - 1.) - C \]
\[ X(5) = 0. \]
\[ 20 \quad X(6) = \text{PSI} \]

C
CONVERT COMPOSITION TO MOLE FRACTIONS AND CALCULATE AVERAGE MOLECULAR WEIGHT

C
IF (LEAN) TMOLES = 1. + PSI + PHI*(1. - EPS)
IF (RICH) TMOLES = PSI + PHI*(2. - EPS)
DO 30 J = 1, 6
30 \quad X(J) = X(J)/TMOLES
\[ \text{MBAR} = \left( \left( (8. \cdot \text{EPS} + 4.) \cdot \text{PHI} + 32. + 28. \cdot \text{PSI} \right) / TMOLES \right) \]
C
CALCULATE H, CP, AND CT AS IN WRITEUP, USING FITTED COEFFICIENTS FROM JANAF TABLES

C
\[ \text{ENTHLP} = 0. \]
\[ \text{CSUBP} = 0. \]
\[ \text{CSUBT} = 0. \]
\[ \text{ST} = T / 1000. \]
DO 40 J = 1, 6
\[ \text{TH} = \left( \left( \left( A \left( 4, J, \text{IR} \right) / 4 \right) \cdot \text{ST} + A \left( 3, J, \text{IR} \right) / 3 \right) \right) \cdot \text{ST} \]
\[ + A \left( 2, J, \text{IR} \right) / 2 \cdot \text{ST} + A \left( 1, J, \text{IR} \right) \right) \cdot \text{ST} \]
\[ \text{TCP} = \left( \left( A \left( 4, J, \text{IR} \right) \cdot \text{ST} + A \left( 3, J, \text{IR} \right) \right) \cdot \text{ST} \]
\[ + A \left( 2, J, \text{IR} \right) \cdot \text{ST} + A \left( 1, J, \text{IR} \right) \right) \cdot \text{ST} \]
\[ \text{TH} = \text{TH} - A \left( 5, J, \text{IR} \right) / \text{ST} + A \left( 6, J, \text{IR} \right) \]
\[ \text{TCP} = \text{TCP} + A \left( 5, J, \text{IR} \right) / \text{ST} \cdot 2 \]
\[ \text{ENTHL} = \text{ENTHL} + \text{TH} \cdot X(J) \]
40 \quad \text{CSUBP} = \text{CSUBP} + \text{TCP} \cdot X(J) + 1000 \cdot \text{TH} \cdot \text{DCDT} \cdot \text{TABLE} (J)
\[ \text{ENTHL} = \text{ENTHL} / \text{MBAR} \]
\[ \text{CSUBP} = \text{CSUBP} / \text{MBAR} \]
C
NOW CALCULATE RHO AND ITS PARTIAL DERIVATIVES
C USING PERFECT GAS LAW
C
RHO = .012187*MBAR*P/T
D RHODT = -RHO/T
D RHODP = 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
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)
REMARKS:

1) ENTHALPY DATUM STATE IS AT T = 0 ABSOLUTE WITH O2, N2, H2 GASEOUS AND C SOLID GRAPHITE

2) MULTIPLY ATM-CC BY .0242173 TO CONVERT TO CAL

3) MODIFIED VERSION OF MIKE MARTIN'S PROGRAM BPROP1

4) COLIN FERGUSON 253-5348

SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED:

CLDPAD

METHOD:

SEE MARTIN & HEYWOOD 'APPROXIMATE RELATIONSHIPS FOR THE THERMO-
DYNAMIC PROPERTIES OF HYDROCARBON-AIR COMBUSTION PRODUCTS'

******************************************************************************

SUBROUTINE HPRED (P, T, PHI, DEL, PSI, H, CP, CT, RHO, DRHODT,
*       DRHODP)

LOGICAL RICH, LEAN, NOTHOT, NOTWRT, NOTCLD

REAL MCP, MWT, K1, K2

INITIALIZE PARAMETERS USED IN THE CALCULATION

DATA R, ROVER2 / 1.9869, .99345 /, PSCLAE /2.42173E-2 /
DATA TCOLD, THOT /1000., 1100. /

KICH = PHI .GE. 1.0
LEAN = .NOT. RICH
NOTHOT = T .LT. THOT
NOTCLD = T .GT. TCOLD
NOTWRT = .NOT. (NOTCLD .AND. NOTHOT)
EPS = (4.*DEL)/(1. + 4.*DEL)
USE SIMPLE ROUTINE FOR LOW TEMPERATURE MIXES

IF (NOTCLD) GO TO 5
CALL CLDPRD (P,T,PHI,DEL,PSI,H,CP,CT,RHO,DRHODT,DRHODP,IER)
RETURN

CALCULATE EQUILIBRIUM CONSTANTS FOR DISSOCIATION (EQS. 3.9 & 3.10)
(NOTE THAT THESE HAVE UNITS ATM**(.5) )

5

K1 = 5.819E-6 * EXP(.9674*EPS + 35810./T)
K2 = 2.961E-5 * EXP(2.593*EPS + 28980./T)

CALCULATE A, X, Y, & U AS IN EQS. 5.24, 5.5, 5.25, 3.7, 2.18,
2.19, 3.8

C5 = 2.- EPS + PSI
A = ( C5/(4.*P*K1*K1*EPS) )**(3.3333333)

C6 = EPS + 2.*C5
X = A*EPS*(3.*C5 + C6*A)/(3.*(1. + 2.*A)*C5 + 2.*C6*A*A)

Z = ABS((1.- PHI)/X)
IF (LEAN) Y = X/SQRT(1. + 666667*Z + 1.333333*(1.-PHI))
IF (RICH) Y = X/(1.+666667*Z+.3333333*Z*Z -.666667*(PHI-1.))
U = C5*(EPS - 2.*X)/(4.*K1*K2*P*X)

CALCULATE THE ENTHALPY OF FORMATION FOR THIS APPROXIMATE
COMPOSITION AS IN EQS. 3.21, 3.22, & 5.7
ALSO GET THE COEFFICIENTS FOR T & TV TERMS IN 3.15 USING 5.3 & 5.4

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)

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
ADD IN TRANSLATIONAL, VIBRATIONAL, AND ROTATIONAL TERMS TO GET
TOTAL ENTHALPY, USING Eqs. 3.16, 5.6, 3.11, & 3.15

C
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
B = .001*ROVER2*(C1*T + C2*TVTIL + HF)/MCP

C
CALCULATE AVERAGE MOLECULAR WEIGHT, AND GET DENSITY BY
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)
BHO = MWT*P*PSCALE/(R*T)

C
GET PARTIAL DERIVATIVES IF DESIRED

C
THE FOLLOWING USES IN ORDER Eqs. 5.8, 5.9, 5.32, 5.31, 5.30,
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
\[ \text{DUDXPT} = -U*EPS/(X*(EPS - 2.*X)) \]
\[ \text{DADTP} = 23873.*A/(T*T) \]
\[ \text{DADPT} = -A/(3.*P) \]
\[ T5 = 3.*C5 \]
\[ DXDA = T5*EPS*(T5 + 2.*C6*A)/(T5*(1. + 2.*A) + 2.*C6*A*A)**2 \]
\[ \text{FOLLOWING USES EQUATIONS 5.23, 5.19-5.22, 5.18-5.14, 5.12, \& 5.13} \]
\[ \text{IF (LEAN) DYDX} = (Y*Y*Y)/(X*X*X) * (1. + Z + 1.333333*(1.-PHI)) \]
\[ \text{IF (RICH) DYDX} = (Y*Y)/(X*X)*(1. + 4.*Z/3. + Z*Z - 2.*(PHI-1)/3.) \]
\[ \text{DYDTP} = \text{DYDX}+\text{DXDA}+\text{DADTP} \]
\[ \text{DYDPT} = \text{DYDX}+\text{DXDA}+\text{DADPT} \]
\[ \text{DUDTP} = \text{DUDXPT}+\text{DXDA}+\text{DADTP}+\text{DUDTPX} \]
\[ \text{DUDPT} = \text{DUDXPT}+\text{DXDA}+\text{DADPT}+\text{DUDPTX} \]
\[ \text{DHFDPT} = C3*DYDPT + C4*DUDPT \]
\[ \text{DC2DPT} = -2.*(3.*DYDPT + DUDPT) \]
\[ \text{DC1DPT} = 5.*DYDPT + 3.*DUDPT \]
\[ \text{DHFDTP} = C3 * DYDTP + C4*DUDTP \]
\[ \text{DC2DTP} = -2.*(3.*DYDTP + DUDTP) \]
\[ \text{DC1DTP} = 5.*DYDTP + 3.*DUDTP \]
\[ \text{DTVDP} = (TVTIL*TVTIL)/(T*T)*EXPTVT \]
\[ \text{FOLLOWING USES EQUATIONS 5.10, \& 5.11} \]
\[ \text{CP} = \text{ROVER2/MCP}*(C1 + T*DC1DTP + C2*DTVDP + TVTIL*DC2DTP} \]
\[ \hspace{3cm} \text{+ DHFDPT} \]
\[ \text{CT} = \text{ROVER2/MCP}*(T*DC1DTP + TVTIL*DC2DPT + DHFDPT)*PScale \]
\[ \text{FOLLOWING USES EQUATIONS 5.46, 5.35-5.37, 5.33, \& 5.34} \]
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

DBHODT = PSSCALE*P*(DMDTP - MWT/T)/(R*T)
DRHODP = PSSCALE*(MWT + P*DMDPT)/(R*T)

C

IF CALCULATING FOR AN INTERMEDIATE TEMPERATURE, USE A WEIGHTED
AVERAGE OF THE RESULTS FROM THIS ROUTINE AND THOSE FROM THE
SIMPLE ROUTINE

C

IF (NOTWRN) RETURN

C

CALL CLDPBD (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
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,DRHDT,DRHDP,DH?,GASCON,GAMMA)
REAL LAV
COMMON/FUEL1/AP(6),FREQ,ORDER,ACTV,TSUBC,ENW,CX,HY,0Z.
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,DRHDT,DRHDP,CHI)
GO TO 1000
200 CALL HPRED(PATM,T,CHI,DEL,PSI,ENTHLP,CSUBP,CSUBT,RHO,
1DRHDT,DRHDP)
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.
DRHDT=DRHDT*10.**3.
DRHDP=DRHDP*10.**3.*9.68692*10.**(-6.)
GASCON=P/RHO/T
CSUBT=CSUBT*10.**(-3)
GAMMA=CSUBP/(CSUBP-GASCON)
ENERGY=ENTHLP-P/RHO
SUBROUTINE UPROP

PURPOSE:
TO CALCULATE THE ENTHALPY AND DENSITY OF A HOMOGENOUS MIXTURE
OF AIR, RESIDUAL GAS, AND FUEL AS A FUNCTION OF
EQUVALENCE RATIO, TEMPERATURE, AND PRESSURE

USAGE:
CALL UPROP(P, T, PHI, DEL, PSI, RESFRK, ENTHLP, CSUBP, CSUBT, RHO,
DRHOCT, DRHODP, CHI)

DESCRIPTION OF PARAMETERS:

GIVEN:

P - ABSOLUTE PRESSURE OF PRODUCTS (ATM)
T - TEMPERATURE OF PRODUCTS (DEG K)
RESFRK - RESIDUAL GAS FRACTION
PHI - EQUVALENCE RATIO (FUEL/AIR RATIO DIVIDED BY THE
CHEMICALLY CORRECT FUEL/AIR RATIO)

GIVEN IN COMMON AREA /FUEL/:

AP(I) - 6 DIMENSIONAL VECTOR OF ENTHALPY COEFFICIENTS SUCH
THAT THE ENTHALPY OF FUEL VAPOR AS A FUNCTION
OF TEMPERATURE ( T DEG K ) IS GIVEN BY:

H(T) = AP(1) ST + (AP(2) ST**2)/2 + (AP(3) ST**3)/3
     + (AP(4) ST**4)/4 - AP(5)/ST + AP(6)

WHERE ST = T/1000 AND H(T) = <KCAL/MOLE>

FOR MOST APPLICATIONS THE ENTHALPY FUNCTION H(T) SHOULD BE VALID
OVER AT LEAST THE FOLLOWING TEMPERATURE RANGE:

300 < T < 1000

ENTHALPY DATUM STATE IS AT T = 0 ABSOLUTE WITH O2, N2,
AND H2 GASEOUS AND C SOLID GRAPHITE.

FREQ - FREQUENCY FACTOR <(CC/G)**(ORDER - 1) PER SEC>
ORDER - REACTION ORDER
ACTV - ACTIVATION ENERGY (KCAL/MOLE)
TSUBC - CHARACTERISTIC TEMPERATURE OF NONADIABATIC FLAME (DEG K)  00000370
ENW - AVERAGE NUMBER OF NITROGEN ATOMS PER FUEL MOLECULE  00000380
CX - AVERAGE NUMBER OF CARBON ATOMS PER FUEL MOLECULE  00000390
HY - AVERAGE NUMBER OF HYDROGEN ATOMS PER FUEL MOLECULE  00000400
OZ - AVERAGE NUMBER OF OXYGEN ATOMS PER FUEL MOLECULE  00000410
QLOWER - LOWER HEATING VALUE (KCAL/G)  00000420
RETURNS:
DEL - MOLAR C:H RATIO OF THE PRODUCTS  00000430
PSI - MOLAR N:O RATIO OF THE PRODUCTS  00000440
CHI - EQUIVALENCE RATIO OF THE PRODUCTS (C:O2 RATIO DIVIDED  00000450
BY THE CHEMICALLY CORRECT C:O2 RATIO)
ENTHLP - SPECIFIC ENTHALPY OF THE PRODUCTS (KCAL/G)  00000460
CSUBP - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO T  00000470
AT CONSTANT P (CAL/G-DEG K)  00000480
CSUBT - PARTIAL DERIVATIVE OF ENTHLP WITH RESPECT TO P  00000490
AT CONSTANT T (CC/G)  00000500
RHO - DENSITY OF THE PRODUCTS (G/CC)  00000510
DRHODT - PARTIAL DERIVATIVE OF RHO WITH RESPECT TO T AT  00000520
CONSTANT P (G/CC-DEG K)  00000530
DRHODP - PARTIAL DERIVATIVE OF RHO WITH RESPECT TO P AT  00000540
CONSTANT T (G/CC-ATM)  00000550
00000560
00000570
00000580
00000590
00000600
00000610
00000620
00000630
00000640
00000650
00000660
00000670
00000680
00000690
00000700
00000710
00000720

**SUBROUTINE UPROP (P,T,PHI,DEL,PSI,RESFRK,ENTHLP,CSUBP,CSUBT,RHO,-subroutine**
C DRHODT, DRHODP, CHI

COMMON /FUEL1/ AP(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, X

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

DATA A1/11.94033, 2.088581, -0.47029, .037363, -.589447, -97.1418,
1 6.139094, .4.60783, -.9356009, .06669498, .0335801, -56.62588,
2 7.059556, 1.275957, -.2877457, .022356, -.1598696, -27.73464,
3 7.865847, .6803719, -.031944, -.00268708, -.2013873, -893455,
4 6.807771, 1.453404, -.328985, .02561035, -.1189462, -331835,
5 6*0.0,
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, .004132409, -27.19597,
9 6.951878, 16.17044, -.2182071, 2.968197, -.01625234, 118189,
& 6.295715, 2.388387, -.0314788, -.3267433, .00435925, 103637,
- 7.092199, -1.295825, 3.20688, -1.202212, -.0003457938, -0.13967,
$ 6*0.0/

DATA TABLE /-1., 1., 1., -1., 0., 0., 0. /

C ENTER INTO ARRAYS A1 AND A2 THE FUEL PARAMETERS

DO 5 I=1,6
A1(I + 36) = AP(I)
A2(I + 36) = AP(I)
RICH = PHI . GT. 1.0
LEAN = . NOT. RICH
W = ENW/CX
Z = O2/CX

C

PAGE 62
DEL = CX/HY
EPS = 4.*DEL/(1. + 4.*DEL - 2.*DEL*Z)
C
IAR = 0
C
IF (T .LT. 100.) IER = 1
C
IF (T .GT. 6000.) IER = 2
IR = 1
IF (T .LT. 500.) IR = 2
C
GET THE COMPOSITION IN MOLES/MOLE OXYGEN OF OXIDANT
C
PCTRES = RESPRK
PCTNEW = 1.0 - RESPRK
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 = 1000.0/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.
\[
X(7) = \text{PCTNEW} \times \text{EPS} \times \text{PHI}/\text{CX}
\]

\[\text{CONVERT COMPOSITION TO MOLE FRACTIONS AND CALCULATE AVERAGE MOLECULAR WEIGHT}\]

\[
\text{IF (LEAN) TMOLES} = 3.76 \times (1. + \text{EPS} \times \text{PHI}/\text{CX}) \times \text{PCTNEW} + \text{EPS} \times \text{PHI} + \text{EPS} \times \text{PHI} \times (Z + W/2.) \times \text{PCTRES}
\]

\[
\text{IF (RICH) TMOLES} = 3.76 \times (1. + \text{EPS} \times \text{PHI}/\text{CX}) \times \text{PCTNEW} + \text{EPS} \times \text{PHI} + \text{EPS} \times \text{PHI} \times (Z + W/2.) \times \text{PCTRES}
\]

\[
\text{DO 30 J = 1,7}
\]

\[
X(J) = X(J)/\text{TMOLES}
\]

\[
\text{MBAR} = \text{EPS} \times \text{PHI} \times (12. + 1./\text{DEL} + 16. \times Z + 14. \times W) + 32. + 28. \times 3.76
\]

\[
\text{MBAR} = \text{MBAR}/\text{TMOLES}
\]

\[\text{CALCULATE H, CP, AND CT AS IN WRITEUP, USING FITTED COEFFICIENTS FROM JANAF TABLES}\]

\[
\text{ENTHLP} = 0.
\]

\[
\text{CSUBP} = 0.
\]

\[
\text{CSUBT} = 0.
\]

\[
\text{ST} = T/1000.
\]

\[
\text{DO 40 J = 1,7}
\]

\[
\text{TH} = ((A(4,J,IR)/4. \times \text{ST} + A(3,J,IR)/3.) \times \text{ST} + A(2,J,IR)/2.) \times \text{ST} + A(1,J,IR)
\]

\[
\text{TCP} = ((A(4,J,IR) \times \text{ST} + A(3,J,IR) \times \text{ST} + A(2,J,IR)) \times \text{ST} + A(1,J,IR)
\]

\[
\text{TH} = \text{TH} - A(5,J,IR)/\text{ST} + A(6,J,IR)
\]

\[
\text{TCP} = \text{TCP} + A(5,J,IR)/\text{ST} \times 2
\]

\[
\text{ENTHLP} = \text{ENTHLP} + \text{TH} \times X(J)
\]

\[
\text{CSUBP} = \text{CSUBP} + \text{TCP} \times X(J) + 1000. \times \text{TH} \times \text{DCDT} \times \text{PCTRES} \times \text{TABLE}(J)
\]

\[
\text{ENTHLP} = \text{ENTHLP}/\text{MBAR}
\]

\[
\text{CSUBP} = \text{CSUBP}/\text{MBAR}
\]

\[\text{NOW CALCULATE RHO AND ITS PARTIAL DERIVATIVES}\]

\[\text{USING PERFECT GAS LAW}\]
\( \rho_0 = 0.12187 \times \text{MBAE}^{2/P} \)

\( \text{DEHODD}^{T} = -\rho_0 / \rho \)

\( \text{DHRDOP} = \rho_0 / \rho \)

**CALCULATE PSI AND CHI FOR BURNED GASES**

\[
\psi = (3.76 + \varepsilon * \phi^{*} \phi^{*} / 2.) / (1. + \varepsilon * \phi^{*} \phi^{*} / 2.)
\]

\[
\chi = \phi^{*} (1. + \varepsilon * \phi^{*} \phi^{*} / 2.) / (1. + \varepsilon * \phi^{*} \phi^{*} / 2.)
\]

RETURN

END
SUBROUTINE PTCHEM (TMP, PRS, D, XMOPR, ISENT)

THE ORIGINAL MIT EQUILIBRIUM PTCHEM SUBROUTINE HAS BEEN REDUCED
AND IS DESIGNED TO PROCESS 4 ELEMENTS & 14 SPECIES

ARRAY D CONTAINS RATIOS OF ELEMENTS H, C, N, O RESPECTIVELY;

E.G., DATA D / 1.43, 1.0, 13.0, 3.46 /

ARRAY XMOPR CONTAINS MOLE FRACTIONS OF EACH SPECIES;
SYMBOLS OF EACH SPECIES 1 TO 14 (HEX'ED') ARE AS FOLLOWS:

0  'HCO ', 'CO ', 'CO2 ', 'H ', 'OH ', 'H2 '
1  'H2O2 ', 'N ', 'NO ', 'NO2 ', 'N2 ', 'N2O '
2  'O ', 'O2 '

INPUT:  ( DOUBLE PREC. )
TMP  = TEMPERATURE ( DEGREES K )
PRS  = PRESSURE   ( ATMOSPHERES )
D    = ARRAY(4)  ( RATIO, 4 ELEMENTS )

OUTPUT:  ( DOUBLE PREC. )
XMOPR = ARRAY(14) ( MOLE FRACTIONS, 14 SPECIES )
ISENT = ERROR CODE:
0  = NO ERROR
1  = TEMP TOO HIGH
2  = TEMP TOO LOW
3  = ( UNUSED )
4  = TOO MANY ITERATIONS, RESULTS DOUBTFUL, LOOK UP NW
5  = TOO MANY ITERATIONS

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6 = THERE ARE NO GASES PRESENT
7 = CHECK IF THERE ARE ENOUGH SPECIES
8 = TOO MANY TRIES FOR T

AUTHOR: DAM DANTZER    LATEST REVISION 12/14/72

IMPLICIT REAL*8(A-H,O-Z)

EQUIVALENCE ( ITOTSP, M )
EQUIVALENCE ( ITOTSP, M1 )
EQUIVALENCE ( NELEM, N )
EQUIVALENCE ( G(1,1), CMN(1) )

DIMENSION D(1), XMOPR(1)
DIMENSION A(4,14), ZL(14,8)
DIMENSION ZL1(56), ZL2(56)

FOLLOWING ARRAYS ARE 'NELEM' IN SIZE

DIMENSION DD(4), XNU(4), XNU(4), E(4), F(4,4)

FOLLOWING ARRAYS ARE 'NELEM' +2 = 'INXNSL'

DIMENSION R(6), G(6,6)

FOLLOWING ARRAYS ARE 'ITOTSP'

DIMENSION CMN(14), CP(14), CPT(14), X(14), XMAX(14)
DIMENSION HORT(14), SR(14), C(14)

NSAME = INITIALIZATION FLAG
NELEM = NR OF ELEMENTS INVOLVED
ITOTSP = TOTAL NR OF SPECIES INVOLVED
DATA NSAME / 0 /
DATA NELEM / 4 /
DATA INXNSL / 6 /
DATA ITOTSP / 14 /

DATA DD, XMU, XNU, E, F / 32 * 0. /
DATA R, G / 42 * 0. /
DATA A, CMN, CP, CPT, X, XMAX / 126 * 0. /

ARRAY ZL(K,J) CONTAINS THE HI-TEMP DATA FOR EACH OF 14 SPECIES

K = SPECIES NR ( 1 - 14 )
J = DATA ( 1 - 8 EACH SPECIES )

DATA WAS TAKEN FROM ORIGINAL DATA SET ( CARDS ), ARRANGED IN
ROW,COL (14,8), BUT DATA STATEMENT INTERNALLY STORES
BY COL,ROW; THEREFORE, DATA MUST BE REVERSED FOR PROG EXEC.
ORIGINAL DATA ARRANGEMENT MAINTAINED FOR CONVENIENCE IN MAKING
CHANGES TO SPECIES DATA.

NR OF CONTINUATION CARDS LIMITED TO 19
CONTINUATION COL #6 CONTAINS THE HEXADECIMAL SPECIES NR

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 1.3418689D-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,  000001090
  7  3.3580098D-02, -5.9687866D 01,  5.1456772D 01,  3.0619965D 00 /  000001100
     DATA ZL2 /  000001110
     8  5.1632023D 00,-1.8977487D-01,  3.6921006D-02,  3.6241105D-03,  000001120
     8 -3.2718156D-02,  1.1134157D 02,  4.2783066D 01,  1.0359793D 00,  000001130
     9  7.5180626D 00,  1.0245209D 00,-2.3053735D-01,  1.7926671D-02,  000001140
     9 -1.9369543D-01,  1.8756821D 01,  5.8378296D 01,  2.0729971D 00,  000001150
    A  1.2123282D 01,  1.2564993D 00,-3.0112296D-01,  2.3658749D-02,  000001160
    A -6.2256289D-01,  2.3839598D 00,  6.8810959D 01,  3.1109982D 00,  000001170
    B  6.8077698D 00,  1.4534035D 00,-3.2898575D-01,  2.5610346D-02,  000001180
    B -1.1894619D-01,-2.4038353D 00,  5.3165161D 01,  2.0719986D 00,  000001190
    C  1.2365961D 01,  1.7261782D 00,-4.0528846D-01,  3.1418435D-02,  000001200
    C -5.8120877D-01,  1.4105570D 01,  6.4331467D 01,  3.1099979D 00,  000001210
    D  5.1006308D 00,-1.5177220D-01,  4.8953138D-02,-2.8814352D-03,  000001220
    D  8.9299418D-03,  5.8080948D 01,  4.4752548D 01,  1.0379944D 00,  000001230
    E  7.8658457D 00,  6.8837190D-01,-3.1944100D-02,-2.6870817D-03,  000001240
    E -2.0138729D-01,-2.9684544D 00,  5.7424637D 01,  2.0749989D 00 /  000001250
     C  000001260
     C  000001270
     C  000001280
     C
     IF(NSAME) 2000, 2000, 2004
     2000
     NSAME=1
     AR=1.98726D0
     ITMAX = 500
     ITW = 400
     DIF = 15.00D0
     DIF1 = DIF
     T = 1.000
     TLUB = 6000.
     XN=N
     TOL1 = .01D0
     TOL3 = .00001D0
     TOL5 = 1.0D-5
     TOL6 = .1D0
     TOL7 = 10.0D0
     C
ARRAY A(I,K) CONTAINS NR OF ATOMS PER ELEMENT (IN SPECIES)

I = ELEMENTS H, C, N, O RESPECTIVELY
K = SPECIES NR

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.

LOAD DATA INTO SPECIES ARRAY ZL

II = 0
DO 1050 K = 1, 7
I = K + 7
DO 1050 J = 1, 8
II = II + 1
ZL(K,J) = ZL1(I)
1050 ZL(I,J) = ZL2(I)

C
C END OF ONE-TIME INITIALIZATION
C
2004 IF ( TMP - 700.0 ) 2112, 2112, 2355
2355 CONTINUE
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 / 4.0D0 + ZL(K10,3) / 3.0D0 ) * 
1 TK + ZL(K10,2) / 2.0D0 ) * 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 / 3.0D0 ) -
2 ZL(K10,5) * 0.5D0 / TK ** 2 + ZL(K10,7) ) / AR
   GO TO 5004
5004 C(K10) = HORT(K10) - SR(K10) + XLP

C
C END OF ORIGINAL 'HS' SUBROUTINE
C
ISENT=0
ITER=0
ITRDG=0
TOL4 = 0.1DO
YMAX = 0.
  DO 412 J=1,N
   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
   XO=0.0D0
   DO 90 I=1,N
50   XO=X0+D(I)
   AVD = XO / XN
   YO=0.0D0
   DO 93 J=1,N
90   Y0=YO+ XMAX(J)
93   XO=DMIN1(X0,Y0)
   XO=XO*1.05D0
   DO 825 J=1,N
825  XMAX(J) =XMAX(J)*1.05D0

CAUTION*** ASSUMPTION: THAT EACH ELEMENT Mole RATIO DIVIDED BY
THE SUM OF THE RATIOS WILL BE GREATER THAN 0.01;
IF OR < 0.01, THEN MUST USE FOLLOWING ROUTINE;
I.E., REMOVE THE 'C' COMMENT FROM COL 1 FROM HERE TO LABEL 530 &
FROM LABEL 503 TO 475
NOTE: ARRAY K2 IS DIMENSIONED (2)

L1=0
NG05=1
RATIO = .01D0
  DO 526 I=1,N
      IF (D(I)/SUM - RATIO ) 527,527,526
526    L1=L1+1
527    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
ITER4=0
NGO6=1
RH2=1.0D0
C
END OF ENTRY INITIALIZATION & CHECKING OF TEMPERATURE
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
        SUM=SUM+A(I,J)*X(J)
105 F(I,1)=SUM
    YMAX=X0
106 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
        SUM=SUM+X(J)
    DO 416 J=1, M
        SUM=X0/SUM
108 X(J)=X(J)*SUM
    DO 109 I=1, N
        SUM=DD(I)
    DO 110 J=1, M
        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  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,N1
      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(D)
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,N
      IF (CPT(J) - EXMIN) 511,510,510
511  CONTINUE
      EXMIN= CPT(J)
510  CONTINUE
      SUMEX =0.0D0
      DO 513 J=1,N
      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(SUM*DEXP(-EXMIN)-1.0D0) 443,521,521
   PROD = X0 /SUMEX
   DO 522 J=1,H
522   H= H+ PROD* X(J)*C(N(J)
   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   XNU(I) = XNU(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)
   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 = 0.0DO
    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) + P(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, 550, 552
552 ITER4=0
    NGO1=2
    GO TO 330
550 H0=0.0DO
    DO 26 I = 1, N
26 H0=H0+XNU(I)**2
    H2= H0
    T0=0.0DO
    T=1.0DO
GO TO 330

C  SEE COMMENTS ABOVE ( LABEL 527 )
C  503 CONTINUE
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))-.15) 475,475,8000
C  8000 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  TO=0.0D0
C  T=1.0D0
C  GO TO 430
C  475 DIF1=DIF
C  GO TO 430
330 ITER= ITER+1
C  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
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
        CONTINUE
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
NOTE: ROUTINE TO CHECK FOR A SINGULAR DERIVATIVE MATRIX
C IN RTP & RPP ARRAYS HAS BEEN REMOVED.
C
RETURN
C
ERROR: SET MOLE FRACTIONS TO 0.
C
5000 DO 5100 I = 1, ITOTSP
5100 XMOFR(I) = 0.
RETURN
END
MEMBER NAME MXSOL

FUNCTION MXSOL(IN,IN,A,B)

C IXMSOL

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(2),B(2)
INTEGER XROW
XROW(K000FX,K001FX)=K001FX*M-N+K000FX
M=IN
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)
A(KL)=WS1
26 WS1=B(J)
B(J)=B(K)
B(K)=WS1

31 DO 33 L=J1,N
JL= XROW(J,L)

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IF (A(JJ)) 33, 54, 33
A(JL) = A(JL) / A(JJ)
B(J) = B(J) / A(JJ)
DO 43 L = 1, N
IF (L - J) 37, 43, 37
LJ = XROW(L, J)
DO 41 L2 = J1, N
LL2 = XROW(L, L2)
JL2 = XROW(J, L2)
A(LL2) = A(LL2) - A(LJ) * A(JL2)
B(L) = B(L) - A(LJ) * B(J)
CONTINUE
CONTINUE
C LAST COLUMN HAS NOT BEEN DONE YET
NN = XROW(N, N)
IF (A(NN)) 46, 54, 46
B(N) = B(N) / A(NN)
DO 50 L = 1, N1
LN = XROW(L, N)
B(L) = B(L) - A(LN) * B(N)
NXNSOL = 1
RETURN
RETURN
NXNSOL = 2
RETURN
END
REAL MNOU, MNOB, MNAT
REAL KS3(8)
REAL LAND, LAMU, LANK, LANEV, LANAV, LA, MO(8), M1(8), MO, ME(8), MA(8),
1MEA(8), MEE(8), LAV, ML, MBR, MBG, MV, MUOE, MUOE1, MU2E, MU3E, MU0A, MU1A,
2MU2A, MU3A
REAL MLZ(8), LGZ(8), LGZS(8), MT(2, 8), MLGZ(2, 8), MBGZ(2, 8), KO, LGRG(8), 00000130
1MEAS(8), LAVS, LGE(8), LGA(8), HGGZ(2, 8), MEZS(8), MES(8), MEAS(8), NEES(8), 00000140
2MEAS(8), LGES(8), LGAS(8), MAI(2, 8), MGZ(8), MQW(2, 8)
3, KZ(8), KE(8), KA(8), MHSO(2, 8), MHA2(2, 8), MBA(2, 8), MPZ(2, 8)
4, MAZ(8), NAZS(8), ME0(8), NEOS(8), MHA2(8), MA2(8), M2S(8), M01(8), M02(8)
5, KEO(8), LGAR(8), KAR(8), LGS(8), MTE(2, 8), MTA(2, 8)
6, LGZ(8), M1B, M1U
REAL MQW2(2, 8), MQWU(2, 8)
REAL LDLE, LDIL

C C PUT C'S ON ALL CARDS NOT IN ORIGINAL MEINRAD VERSION
C C REAL MAUX, MOUTCA, MOUTCA, MINAC, MINAP, MRESAC C C C C C C C C
C C REAL MVPF C C C C C C C C C C C C C C C C C C
C C COMMON/AUXPT/TAUX, PAUX, MAUX, EIRA, DMAUX, MOUTCA, MINAC, MRESAC C
1, SMOPA, SMAP, SMOC, SMINC, RMAUX, XAA, XFA, XSBPA, VAUX, TBAUXC C C
C C COMMON/AUXPLE/TPLE, PPLE, PPLE, AEEAV, AREAV, XAP, XFP, XSBPP, JBKFL, C
C C COMMON/MOUTPA, MOUTPA, MOUTPA, MOUTPA, SUMQ, SRMCY, VELV, VELV, SBKPL2, SBKFLC C C C
C C COMMON /CONTRL/ CD, PRI, DSI, DSO, V, C, P1, P2, NDAT1, NDAT2
1 T, TP, N, NCY, N, NOY, K1, K2, K3, K4, DPBIO, C
C C COMMON/SCCOMB/PZ, T2, T2S, T2S, RZ, RZ, T2S, T2S, ME, LGZ, LGZS, BGZ, BGZS, RGGZ
1, GGZ, PHIZ, MQW, I, N, LGRG, RU2, TEEZ, LGEZ, BGE2, GGE2, PZS
C C COMMON/HREL/ZN, TN, ZS, ALFAM, ALFAM, B0, DB, LAWS, DU1, DU2, DUFTZ
1, ALI, AIS, QW, QWS, LGZ, MBGZ, MLZ, HG, KONV, B, BS, MBA, MPZ, TPZ, ETAU
2AM, AMS, TB, TB, UB, UB, HNW2, HNW2, TB, TUS, T2V
C C COMMON /HTR/TD, TKD, DD, ALD, LAND, TW, TKW, DW, ALW, LANW, TK, TKK, DK, ALK,
1 LANK,TREV,TEV,DEV, ALEV,LANEV,TAV,TKAV,DAV,ALAV, LANAV,FPDK,WF,ZETA 00000370
2/GEON, D, H, LA, EPS,PHIO (8), DAE, PHIPR,PHIEND,VZ (8),PHI,PHIX (8),DPHI, 00000380
3XC, FK, V1, TAKT 00000390
6/FUEL/SLB,CE, LAV, RB, NL, MBR, MCG, VERDD, Q (3, 7) 00000400
7/COMB/AV, NV, PHIVA (8),VD 00000410
8/OPD/PO, TO, PE, PA, PB, DR, PEO, TEO, PO, VER 00000420
9/SC/MUE, MU1E, MU2E, MU3E, PEE, MU0A, MU1A, MU2A, MU3A, PAR 00000430
COMMON/VALVE/PHIOEX,PHIOIN,PHIOEC,PHIOIN,SAEX,R1EX,R2EX,R3EX,R4EX, 00000440
1KARLX,SAIX, R1IN, R2IN, R3IN, R4IN, RARIN 00000450
3/VARI/AEV, FEX, LE, LI, TEx, TIN, TWU, VERG, LDEL, CDE, LDEL, CDIL, FEL, 00000460
4 FEL, PHIL, PHEL, PHEL, PAL, PAL, REZ, CN 00000470
COMMON /OUTP/ CNOOPM (8) 00000480
C C COMMON /DIVCHRG/CDINT, CDCOMP, CDCOMBC C C C C C C C C C C C C C 00000490
C C COMMON /HLPRE/VD, MVP, AVPC C C C C C C C C C C C C C C 00000500
C C LOGICAL VERD, EIN, AUS 00000510
C
DIMENSION PZ (8), PZS (8), TZ (8),TZS (8), TZZ (8), TZS (8), TZZ (8), TZS (8), TZZ (8), 00000520
1TZZS (8), ALFAM (8), ALFAMS (8), BO (8), BD (8), BZ (8), H (8), UZ (8), 00000530
2DU1 (8), DU2 (8), DUDTZ (8), AI (8), AIS (8), W (8), QW (8), WGS (8), BWG (8), BGZS (8), 00000540
3RGZG (8), X (8), PE (8), TE (8), PA (8), PHIL (320), PEL (320), PEL (320), 00000550
FPHEL (300), PHEL (300), PHEL (300), PHEL (50), PHEL (50), 00000560
4 WER (8), WAR (8), GGE (8), BGE (8), BGS (8), TEE (8), TA (8), RGE (8), 00000570
5RGGA (8), BGA (8), TES (8), TEH (8), PES (8), GGS (8), BGS (8), TES (8), TES (8), 00000580
6,BGES (8), BGAS (8), BGS (8), BGE (8), GGE (8), TLG (8), TGA (8), GGA (8), 00000590
7TE3 (8), TEZ (8), TIZ (8), TWX (8), PE (8), PA (8), ALPA (8), 00000600
8,RE (8), RE (8), UE (8), RA (8), HA (8), UA (8), 00000610
9, EIN (8), EINS (8), EAUS (8), EAUS (8), FPIL (300), FALL (300), 00000620
A,ER (8), AR (8), PEO (8), TEO (8), PEO (8), TEO (8), PEO (8), TEO (8), 00000630
B, VAE (8), TAR (8), BGA (8), BGGS (8), BGA (8), BGA (8), BGA (8), BGA (8), 00000640
C, TARS (8), BGARS (8), GGEARS (8), GGA (8), VEE (8), 00000650
D, DUDTEQ (8), HEG (8), UEO (8), REO (8), DUO (8), DUO (8), DUDTA (8), 00000660
E, PAS (8), ERO (8), AR2 (8), RGA (8), DUDTE (8), B (8), BS (8) 00000670
F, RU2 (8), BGE (8), TEE (8), GGE (8) 00000680
DIMENSION EO (1), EOS (1), AEO (2, 1) 00000690
DIMENSION LDEL (20), CCDEL (20), CDE (300), LDEL (20), CDIL (20), CDI (300) 00000700
PB=PB*UDI
PO=PO*UDP+PB
TO=(TO-32.)*UT+273.
TZN(1)=1000.
ALFAN(1)=160.
TAKT=4.*3.1415926
IF(TEX.GT.0)GOTO 20
DO 10 L=1,T
PHIL(L)=PHIL(L)*U
IF(LEX.GT.0)GOTO 50
FEL(L)=FEL(L)*UPI
FAL(L)=FAL(L)*UPI
AUXV(L)=AUXV(L)*UPI
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
COMMON/APROP/DEL, PSI
COMMON/PUBLIC/CHI
COMMON/ADIAB/TADBS (8), TADB (8), XMA, XME, VAADB, VBL, RADB, RBL

C
LOGICAL VERD, EIN, AUS

C
DIMENSION PZ (8), PZS (8), TZ (8), TZE (8), TZ2 (8), TZE3 (8), TZM (8),
TZH (8), TZN (8), ALFAM (8), ALFAMS (8), B0 (8), DB (8), R2 (8), HZ (8), U2 (8),
2DU1 (8), DU2 (8), DUT (8), AI (8), AIS (8), QW (8), QWS (8), BGZ (8), BGZS (8),
BGZG (8), X (8), PE (8), TE (8), PA (8), PHIL (320), FEL (320), FAL (320),
PPEL (300), PAL (300), PHILP (300), PZL (300), PHZIP (300),
4 WER (8), WARR (8), GZG (8), BGE (8), BGZ0 (8), TEE (8), TAE (8), RGG (8),
5RGG (8), BGA (8), TES (8), TEH (8), PEE (8), GGS (8), RGGZS (8), TES (8), TES (8),
6, BGES (8), BGAS (8), RGGES (8), RGGAS (8), GGS (8), GGAS (8), GGAE (8),
7TE3 (8), TEE2 (8), PHZ (8), TXX (8), PE (8), PA (8), ALPA (8),
8, RE (8), HE (8), UE (8), RA (8), HA (8), UA (8),
9, EEEI (8), EEINS (8), EAUS (8), EAUSS (8), FELL (300), FAL (300),
0, EAR (8), ARR (8), PE0 (8), TE0 (8), PEO (8), VER (8), PA (8), PA2 (8),
1, VBR (8), TAR (8), BGR (8), RGGAR (8), BAR (8), HAR (8), UAR (8), GGR (8),
C, TAE3 (8), BGR2 (8), RGGARS (8), GGA (8), WRH (1),
D, DUTTE0 (8), HEO (8), UE0 (8), RBO (8), DU3 (8), DU4 (8), DUDTA (8),
E, PAS (8), ERP (8), AR2 (8), RGA (8), DUDTE (8), B (8), BS (8),
P, RUE2 (8), BGE2 (8), TEE2 (8), GGE2 (8),
00000730
00000740
00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
00000870
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00000950
00000960
00000970
00000980
00000990
00001000
00001010
00001020
00001030
00001040
00001050
00001060
00001070
00001080

C
INITIALIZATION

C
DSO = 13
NVER = 1
HTRANS = 1.
IPV=0

CK FOR CORRECT PROG VERSION (NVER) AGAINST
THE ENGINE INPUT DATA SET VERSION (V)

IF ( V .NE. NVER ) GO TO 8980

READ LAST DATA, FORMAT DEPENDS ON PROGRAM VERSION (CALC)

NO ADDITIONAL DATA REQUIRED FOR VER1, BASIC

COMPLETE THE INPUT DATA REPORT

WRITE (PRI,7897)
7897 FORMAT ( /// 10X, 'END OF INPUT DATA' )

REWIND & RELEASE BUFFERS
REWIND DSI

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

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DPHIO=DPHIO*U
PP(1)=0
O=O*U

DO 1111 N=1,2
  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
FO=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
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
   IF (L.E.GT.0) CALL LINPO(XH,LDEL,CDEL,LE,CDDE(L))
   IF (L.E.GT.0) FAL(L)=CDEE(L)*R2EX*R2EX*3.141593
   CONTINUE
562 CONTINUE
563 CONTINUE
   FAV=3.1416*R2IN*R2IN
   CAV=3.1416*R2EX*R2EX
   IF (TP.EQ.0) GO TO 564
   DO 565 L=1,TP
      PHILP(L)=PHILP(L)*U
   IF (K2.LE.0.OR.K4.LE.0) PEL(L)=PEL(L)*UDP*PB
   IF (K3.LE.0.OR.K4.LE.0) PAL(L)=PAL(L)*UDP*PB
   CONTINUE
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=1,2
      X(N)=.0
      PHI0(N)=PHI0(1)+X(N)
      PHI1A(N)=PHI1A(1)+X(N)
      PHIX(N)=PHI-X(N)
      TZM(N)=.0
      ALFAM(N)=.0
      AM(N)=0.
      GGE(N)=1.
      GGZ(N)=1.
      GGA(N)=.0
      RESPRK=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 GP60P (TZ (N), PZ (N), LAV, DEL, PSI, RESFRK, HZ (N), UZ (N), CSUBPZ
1. CSUBTZ, RHOZ, DRHOTZ, DRHOPZ, DH1, RZ (N), KZ (N))
VZ (N) = (XC+R/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)
B0 (N) = GGZ (N) * M1 (N) * MO / (1. + LAV*SLB)
IF (.NOT. VERD) B0 (N) = B0 (N) * (1. + LAV*SLB) / (LAV*SLB)
LGRG (N) = 0.
W&R (N) = 0.
W&R (N) = 0.
M& (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)
BGGAR(N) = BGZ(N)
BGAR(N) = BGZ(N)
15 CONTINUE
PREF = PE(1)
TREF = TE(1)
N = 1
GGEK = 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
LG E(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 BGG(E(N) = 1. - LG(E(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
FMFR0=0.
FMFRI=0.
IWPCE=-1
EIN=.TRUE.
AUS=.FALSE.
ETAU=1.-EXP(-AV)
KCO=0.
ICYLA=0

C
C
C
C
C
C

C STEUERTEIL
C
102 IF(PHI.GE.PHIEND) GOTO 101
103 IF(PHI.LT.PHIN) GOTO 103
SUMG=0
KONV=0
DPHI=DPHIO
107 DO 109 N=1,Z
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*PK
PHIZ(N)=H/2.*PK*(SIN(PHIX(N))+LA*SIN(PHIX(N)))*COS(PHIX(N)))
TWX(N)=TW*(XC+H)/(VZ(N)/PK*TW)*((1.-EXP(-TW*VZ(N)/PK)/(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  BGGZ(N) = 1. - LGZ(N) - BGZ(N)
BGZO(N) = BGZ(N)
TEN(N) = TZ(N)
TAR(N) = TZ(N)
DBV(N) = 1
WER(N) = 0.
WAR(N) = 0.
LGAR(N) = LGZ(N)
BGGAR(N) = BGGZ(N)
BGAR(N) = 0.
MGGZ(I,N) = 0.
LGA(N) = LGZ(N)
BGA(N) = BGZ(N)
BGGA(N) = 1. - LGZ(N) - BGZ(N)
110  CONTINUE
IF (L.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))  
GOTO 1005  
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 + (IX+I/2.)*((1.-COS(PHIX(N)) + LA/2.*SIN(PHIX(N)))*1.*14/16+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  
IPZ = IPZ + 1  
OPZN = PZ(N) * 0.0001  
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)
ALPAMS (N) = ALPAM (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)
ME0S (N) = ME0 (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)
TSES (N) = TEE (N)
MES (N) = ME (N)
MAS (N) = MA (N)
MEAS (N) = MEA (N)
MEES (N) = MEE (N)
BGES (N) = BGE (N)
BGAER (N) = BGAER (N)
RGBG (N) = RGBG (N)
LGES (N) = LGE (N)
GGES (N) = GGE (N)
GGARS (N) = GGAR (N)
 EEINS (N) = EEin(N)
EAUS (N) = EAUS (N)

132 CONTINUE
PHI = 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) GOTO 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)) * CK * CK
627  ALFA (N) = .035*3.65E-04*(W*PZ (N)/(287.5*71E-07)) ** .8*D**(-.2)
    1*TZ (N)**(-.547)
    1*ALFA (N) ** WP
    MQW (I, N) = ALFA (N) * W
    MQW (I, N) = ALFA (N) * 9.55/DR*(PK*(TZ (N) - TK)+PK*(TZ (N) - TD)*FPK
    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 = (VU (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*(PK*(TU (N) - TK)
    1+PK*(TU (N) - TD) * FDPK+4.*VZ (N)/D*(TU (N) - TWX (N)) + FEV*(TU (N) - TEV)
    2+FAV*(TU (N) - TAV)) * ARU
    HQW (I, N) = MQWB (I, N) + MQWU (I, N)
    HQW (I, N) = MQWB (I, N)

621 CONTINUE
    HTEANS = MQW (I, N) * DR/9.55
    IF (PHI.GT.PHIVA (N) + VD+TAKT*PP (N)) MQW (I, N) = MQW (I, N)
    MAI (I, N) = PZ (N) * PHIZ (N)
    IF (CO (N) .LT. 134, 158, 157
    158 CALL GASEX (PE, TE, PA, DR, REZ)
        IF (TEST (N) = 0
    GOTO 134

157 IF (1.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, LAN, TZA, ALFAM, N, AM)
    CALL WTEMP2 (TW, TKW, DW, ALW, LAN, TZA, ALFAM, N, AM)

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CALL WTEMP2 (TK, TKK, DK, ALK, LANK, TZM, ALFAM, N, AH)
CALL WTEMP2 (TEV, TEKV, DEV, ALEV, LANEV, TZM, ALFAM, N, AH)
CALL WTEMP2 (TAV, TKAV, DAV, ALAV, LANAV, TZM, ALFAM, N, AH)
A1 = AI (N) / (B0 (N) * CE)
A2 = QW (N) / (B0 (N) * CE)
A3 = AI (N) * 0.00001 / VH * 14.5
A4 = AI (N) * DR / 1200000. * 1.341
A5 = B0 (N) * 36000000 / 1.341 * 2.2046 / AI (N)
A6 = NO * 2.2046
A7 = B0 (N) * 2.2046
A8 = TD / UT
A9 = TW / UT
A10 = TK / UT
A11 = TEV / UT
A12 = TAV / UT
A1A = A1 * (AI (N) - QUAI 2) / AI (N)
A4A = A4 * (AI (N) - QUAI 2) / AI (N)
A5A = A5 * AI (N) / (AI (N) - QUAI 2)
A4B = QUAI2 * DR / 1200000. * 1.341
A3A = A3 * (AI (N) - QUAI 2) / AI (N)
A3B = QUAI2 * 0.00001 / VH * 14.5
A16 = TMOLCO * 28. * DR * 30. / A4
A16A = TMOLCO * 28. * DR * 30. / A4A
IF (VERD) A13 = MGZ (N) * HO * DR * 30. * 2.2046 * (1 - 1 / (1 + LAV * SLB))
IF (. NOT. VERD) A13 = MGZ (N) * HO * DR * 30. * 2.2046

CALL WTEMP2 (EAUS (1), MA (1), NO, 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) - 394.1)
TE (1) = GGER * TEF + (1 - GGER) * TREZ
TES (N) = TE (N)
RESFRK = 1 - GGER
CALL GPROP (TE (N), PE (N), LAV, DEL, PSI, RESFRK, 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
   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, 15, 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
   GOTO 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,
INPUT, TP, Z, NCYCLE

FORMAT ( 4I1, 4X, 2A4, 4X, 4I2 )

ALFAMS(N)=0.
TZMS(N)=0.
AMS(N)=0.
M1(N) = PZ(N) * VZ(N) / (BZ(N) * TZ(N) * MO)
RU2(N) = HSE(N) - HEE(N)
BGE2(N) = BGZ(N)
LGE2(N) = LGZ(N)
GGE2(N) = GGZ(N)
IF(KU2(N) .LT. 0.) RU2(N) = 0.
IF(.NOT.VERD) GOTO 6
M0(N) = M1(N)

BO(N) = GGZ(N) * M1(N) * MO / (1. + LAV*SLB)
IF(.NOT.VERD) BO(N) = BO(N) * (1. + LAV*SLB) / (LAWS*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.
HEA(N) = 0.
MLZ(N) = LGZ(N) * M1(N)
HG(N) = 0.

CALL HEATR(DR,PES(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)

CALL INTEG(AIS, AI, MAI, I, N, DP HI)
CALL INTEG(QWS, QW, MQW, I, N, DP HI)
CALL INTEG(HWS, HW, HQW, I, N, DP HI)
DO 145 N=1,Z
145 SNG=SNG+GY(N)+ICYL+ICYLA
IF(SNG.GE.0) GOTO 147
KONV=0
SNG=-1
IF(AVS.GE.10) GOTO 148
AVS=AVS+1
GOTO 150
148 KONV=-1
PHIN=PHI
PHI=PHIS
DHI=DPHIO/2.
DO 151 N=1,Z
    TZV(N)=TZVS(N)
TB(N)=TBS(N)
TADN(N)=TADBS(N)
TN(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)
ALPH(N)=ALPAMS(N)
TZN(N)=TZMS(N)
AN(N)=AMS(N)
GGZ(N)=GGGS(N)
LGZ(N)=LGSZ(N)
BGZ(N)=BGZS(N)
RGG(N)=RGGS(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)
NEO(N) =MBOS(N)
NA2(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)
NA(N) =NAS(N)
MEA(N) =MEAS(N)
MEE(N) =MEES(N)
BGB(N) =BGBS(N)
BGAR(N) =BGARS(N)
RGGE(N) =RGGBS(N)
RGGAR(N) =RGGARS(N)
LGAR(N) =LGARS(N)
LGE(N) =LGES(N)
GGE(N) =GGES(N)
GGAR(N) =GGARS(N)
EEIM(N) =EEIMS(N)
EAUS(N) =EAUS(S(N)
151 CONTINUE
   I=1
   GOTO 102
147 I=1
   GOTO 102
   AVS=0
   IF(PHI.LT.PHIV+G-.000100) GOTO 153
       NRP=1
   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=EEIM(N)/(BO(1)*CE)
       EK4=EAUS(N)/(BO(1)*CE)
       EK5=B(1)/BO(1)
       V1 =PZ(N)/UDP
       V2 =PZ(N)/UDP
   155 CONTINUE
V3 = PA(N)/UDP
V4 = FMFRI*2.2046*DB/9.55*MO
V5 = FMPIO*2.2046*DB/9.55*MO
V6 = ME(N) - MEA(N) + MEE(N)
V7 = T(N)*9 ./5 .
V8 = HTRANS/(B0(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
PLOT(IPV)=V2
PLOT(IPV)=V3
V4PLOT(IPV)=V4
V5PLOT(IPV)=V5
CAPLOT(IPV)=PHIA
IF(CO(N).NE.1) GOTO 156
C
C COMBUSTION DATA OUTPUT
C
CG(N) = 1
C
N OPP = 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

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 PA(14), NN(11)

PR IS USED LOCALLY FOR PRINTER

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 )

WRITE HEADING

WRITE (PR, 201) NN(5), NN(6), (NA(I), I = 1, 20), NPAGE,
            1 NN(1), NN(10), (NN(I1), 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 ) )

WRITE COLUMN HEADINGS FOR COMBINED COMBUSTION & GAS EXCHANGE

206 WRITE ( PR, 207 )
207 FORMAT (  /// 6X, 'N PHI PIN PC PEX TC', 00000340
            1 5X, 'MIN HEX CTR CC DMDTI DMDTO TU ', 00000350
            2 3X, ' TA HTTRAN NO XBL/D ' /// 6X, 00000360

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3 '  - CA PSIA PSIA PSIA DEG.R',
4 5X, 4(' -', 6X), 'LBM/SEC.', 4X, 'DEG.R',
5 4X, 'DEG.R -/SEC PPM -'/1H, 00000370
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 - LMCT - 2
   IF (LNCK) 216, 216, 220
216 NPAGE = NPAGE +1
   LMCT = 7
   WRITE (PR, 217) NPAGE
217 FORMAT (1H1, // T120, 'PAGE', I4, /,
   1 ' 6X, 'M PHI PIN PC PEX TC', 6X, 'MIN MEX CTR CC DMDTI DMDTO TU',
   3 '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 )
   LMCT = LMCT +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, 00000720

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1FA(14)

281 FORMAT ( 5X, I2, F7.1, F7.2, P8.2, P7.2, P8.1, 42X,
1 2P8.1, F7.1, I6, 2X, P10.7)

290 LMCNT = LMCNT + 1
GO TO 210

C

CYCLE RESULTS (CODE = 9 ), READ 2ND DATA CARD
C
WRITE COLUMN HEADINGS , NEW PAGE

410 NPAG = NPAG + 1

WRITE (PR, 411) NPAG, NH(10)

411 FORMAT (4H1/ ; 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 AP', 5X,
4 ' CO NO TEP ', 5X,
5 ' X , 6X , ', 5X, 'PSI HP LBS/IHP/HR LBS', 9X,'LBS', 6X,
6 ' X , 6X , ', 5X, ' HP PSI', 5X,' GM/IHP/HR', 5X,' DEG R', 00000900
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 (4X, 2F7.3, F7.1, F7.2, F7.3, 2E12.3, F7.3, I6,
1 2F7.3, F7.1, 2F9.4, F7.0)

WHITE (PR, 811) NPAG, NH(10)

811 FORMAT (4H1/ ; 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 AP', 5X,
4 ' CO NO TEP ', 5X,
5 ' X , 6X , ', 5X, 'PSI HP LBS/IHP/HR LBS', 9X,'LBS', 6X,
6 ' X , 6X , ', 5X, ' HP PSI', 5X,' GM/IHP/HR', 5X,' DEG R', 00001050
7/1H )

WHITE (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)