A single cylinder engine study of lean supercharged operation for spark ignition engines

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A SINGLE CYLINDER ENGINE STUDY
OF LEAN SUPERCHARGED OPERATION
FOR SPARK IGNITION ENGINES

BY
KENNETH ROBERT SCHMID, 1957-

A THESIS

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(Advisor)
ABSTRACT

A comprehensive single cylinder engine test program to evaluate Lean Supercharged Operation (LSO) for spark ignition engines was conducted. The evaluation involved an experimental program studying the power, emissions, and efficiency of a single cylinder engine. The relationships between engine power, efficiency, and emissions and the engine operating variables such as absolute intake manifold pressure, Exhaust Gas Recirculation rates, and spark timing were studied.

Results of the experimental work indicated that LSO has the potential of improved engine efficiency and \( \text{NO}_x \) emissions comparable to, or lower than, the naturally aspirated engine. For equal power output from the engine, efficiency increases of 14\% were accompanied by reductions in Brake Specific \( \text{NO}_x \) (BSNO\( _x \)) emissions of approximately 76\%. For a case of equal BSNO\( _x \) emissions, an efficiency improvement of 6.4 points or over 40\% was observed. The combustion process is improved and the lean misfire limit is extended with Lean Supercharged Operation. The hydrocarbon and carbon monoxide emissions are not significantly different, from the naturally aspirated engine, by operation at realistic lean supercharged conditions.
ACKNOWLEDGEMENTS

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I. INTRODUCTION

Increased concern about air pollution in the 1960's led to federal regulations restricting crankcase and exhaust emissions from all 1968 and later model year light duty vehicles. Two studies conducted by the National Research Council between 1971 and 1974 contributed to current crankcase and exhaust emissions regulations for light duty vehicles. The exhaust emission requirements for the 1981 and the 1982 model year vehicles are 0.41/3.4/1.0 grams per mile for HC/CO/NOx respectively. Exhaust emission requirements for the 1981 model year are to be met at all possible idle mixtures and choke settings. For the 1982 model year, the exhaust emissions requirements are to be met for all possible settings of idle mixtures, idle speeds, spark timing, and choke settings.

Due to the recent shortage of petroleum fuels, beginning with the 1978 model year, the automobile manufacturers are required to meet "Corporate Average Fuel Economy" (CAFE) requirements, in addition to the crankcase and exhaust emissions requirements. The CAFE requirement for 1981 is 22 miles per gallon, an improvement of 83% compared with the 1974 average fuel economy for the United States (1). To meet these increasingly severe fuel economy and exhaust emissions requirements the need for a clean, efficient engine appears to be mandatory. Currently the automobile manufacturers are using and investigating various techniques to improve vehicle fuel economy and exhaust emissions. Techniques include: the use of lightweight materials to produce a lighter vehicle, aerodynamic refinements to reduce air resistance, lock up torque convertors to improve transmission efficiency, and engine modifications for improved efficiency. Spark ignition engine modifications being investigated include: computer control of the engine,
electronic fuel injection, combustion chamber design, reducing internal friction, variable displacement engines, turbocharging engines, and lean operation.

Some extensions of the lean limit of a naturally aspirated engine were accomplished by increased compression ratio and increased air inlet temperature in work conducted by Quader (2). Turbo-supercharging (turbocharging) the spark ignition engine generally increased the effective compression ratio and inlet air temperature. The study of previous investigators work indicates that lean operation with supercharging would provide extensions of the lean limit.

The intent of this study was to examine the extension of the lean limit by supercharged operation of a spark ignition engine. The intake manifold pressure and temperature, and exhaust pressure were controlled to simulate the addition of a turbocharger to the engine. Estimates were made to determine if sufficient energy existed in the exhaust to operate an exhaust turbine for turbocharging under lean operation. The effects of spark timing and EGR were examined for supercharged operation. Also, pressure-crank angle data were obtained to allow a simplified cycle analysis.
II. REVIEW OF LITERATURE

A. TURBOCHARGING

The invention of turbocharging is credited to Dr. A. J. Buchi. In 1905, Buchi received a patent (U.S. #1,006,902) which describes a combustion engine equipped with an axial compressor on the intake system, an axial turbine on the exhaust system, and the three units mechanically coupled together with a common shaft. Dr. Buchi received another patent in 1915 (U.S. #1,138,007) which removes the mechanical connection between the engine and the compressor-turbine assembly establishing the principle of exhaust turbocharging as it is used today (3). The first use of the turbocharger was in the late 1920's on marine and railroad engines. Increased use of the turbocharger occurred in the 1940's with the application to diesel truck engines and airplane engines. Historically, turbocharging of spark ignition engines has been primarily for racing and high performance applications. Limited applications of turbochargers were made to production automobile engines in the 1960's. However, the turbocharging of the spark ignition engine is receiving renewed interest with the advent of increasingly stricter governmental regulations regarding exhaust emissions and fuel economy for the automobile.

Several authors have investigated the use of a turbocharged engine to obtain lower exhaust emissions and improved fuel economy. Schweikert and Johnson (4) examined a turbocharged thermal reactor system with a multi-cylinder engine coupled to an engine dynamometer. These investigators studied a naturally aspirated engine and a turbocharged engine, each equipped with thermal reactors and secondary air injection. The nominal engine air/fuel ratio investigated was between 12 and 14 to one. With this rich engine operation, there was little difference in fuel economy and exhaust
emissions between the two engines. Schweikert and Johnson predicted better fuel economy and reduced mass emissions with the use of a small displacement turbocharged engine to replace a larger naturally aspirated engine with equivalent power output.

Engine operation near stoichiometric conditions with a 4-cylinder engine equipped with a turbocharger-thermal reactor system was investigated by Goggard, et. al. (5). These investigators were primarily concerned with developing the thermal reactor system for the turbocharged engine. They found the addition of secondary air injection to the thermal reactors provided rapid reactor warm-up, a reduction in exhaust emissions, and a torque increase. The best secondary air injection settings were found to be those which provided 2-3% excess oxygen in the exhaust to achieve rapid warm-up and reduction in exhaust emissions. The torque increase was obtained from the higher mass flow through the turbine providing a higher boost from the compressor.

Initial vehicle test results were reported by Emmenthal, et. al. (6) using small displacement turbocharged engines for improved fuel economy. Two engines were selected and installed in test vehicles, a 4-cylinder 1.6 L engine and 5-cylinder 2.2 L engine. Boost pressure was controlled by a wastegate, with 40 kPa to 50 kPa maximum boost pressure. The engines were equipped with two-stage feedback carburetors. The jets were selected to provide a slightly lean air/fuel mixture. The air/fuel mixture was enriched to stochiometric by throttling the bleed air for idle, first stage, and second stage systems of the carburetor. An oxygen sensor provided the necessary feedback signal to the exhaust treatment. The exhaust emissions did not meet the engineering goals of 0.41/3.4/1.0 gpm HC/CO/NO\textsubscript{x}. The investigators suggest the addition of secondary air and a clean-up catalyst. The fuel economy was approximately 33 mpg for a 100 HP/3000 lbm inertia weight vehicle.
Recently some of the automotive manufacturers have started manufacturing and installing small displacement turbocharged engines \((7,8,9)\) in automobiles. The manufacturers have given special attention to the problems of turbocharger lag and engine detonation. The problem of turbocharger lag has been minimized by careful matching of the turbocharger unit and careful selection of the nominal engine compression ratio to provide good part load engine operation. The nominal compression ratio ranges from 7.1 to 9.1 with maximum boost pressures from 80 kPa (11.4 psig) to 40 kPa (5.5 psig) respectively.

To avoid detonation in the combustion chamber of the engine, Porsche uses a lower nominal engine compression ratio and an after-cooler on the air system \((8)\). The technique used by Ford and Buick is to control the spark timing advance. Ford's spark timing advance control system uses a dual mode ignition module and a conventional breakerless distributor with mechanical and vacuum advance. The dual ignition module retards the spark timing based upon signals received from intake manifold pressure sensors. The ignition module retards the spark timing a preset amount in two steps \((9)\). Buick's spark timing advance control system uses an electronic spark control with detonation feedback and a conventional breakerless distributor. Two special components are used in the electronic control system - a detonation sensor and a controller. The detonation sensor is mounted to the intake manifold and provides an electrical signal corresponding to the intake manifold vibrations. Normal engine vibrations are treated as background noise by the controller. The controller continuously monitors and updates the background noise information. When cylinder detonation occurs, the sensor produces a voltage signal proportional to the intensity of the detonation. The controller compares the detonation voltage signal and the
engine background noise voltage signal to determine the amount of spark retard, which is transmitted to the distributor. The spark timing is restored at a fixed predetermined rate.

To control the maximum intake manifold pressure manufacturers are using a wastegate on the turbocharger turbine (7,8,9). Basically the wastegate is a valve, which permits a controlled amount of the exhaust gas to by-pass the turbine. This allows the turbocharger speed, and thus the intake pressure, to be controlled. The wastegate is operated by a spring-loaded diaphragm actuator connected to the intake manifold pressure.

B. LEAN OPERATION

Theoretically, the lean operation of the spark ignition engine has two advantages: the thermal efficiency of the engine is generally higher and the oxides of nitrogen (NO\textsubscript{x}) emissions are lower at leaner air/fuel ratios. A considerable amount of investigation has been performed on operating the spark ignition engine in the lean region and on extending the lean misfire limit. These studies have examined primarily two areas: spark and flame characteristics, and mixture turbulence and preparation.

Several investigations have been performed studying spark and flame characteristics to improve lean operation of the spark ignition engine. Tanuma, et. al. (10) examined, modifications to both the ignition and intake systems. The study was performed on a 4-cylinder 1982 cc displacement engine. Various spark plug modifications were examined. The spark gap was varied from 0.5 to 2.5 mm, the center electrode diameter from 0.5 to 2.9 mm, and the gap projection from 3.5 to 13 mm. Spark energy effects were examined at values of 30 and 100 millijoules, and the intake system was modified by the addition of 6 vanes to the intake valve seat.
to increase mixture turbulence. In this case, increasing the spark energy, gap projection, and center electrode diameter improved the lean operation of the engine. The lean limit was also extended by the addition of the intake valve seat vanes to increase mixture turbulence. Ryan, et. al. (11) further examined ignition and intake system modifications using a single cylinder CFR engine equipped with a removable dome head. Two types of ignition systems were used, a typical automotive inductive discharge system and a Texaco ignition system. The Tecaco ignition system provided a high energy a-c, controlled duration spark. These investigators ranked, in descending order, the ability of the various modifications toward extending the lean limit as follows: increased gap width, increased spark duration, increased gap projection, and increased mixture turbulence.

Novel ignition systems designs have also been investigated. The testing and development of a plasma jet ignition system is described by Wyczalek, et. al. (12). This ignition system was tested on both a single cylinder and a 4-cylinder engine which was equipped with a transparent piston. The photographs showed that the plasma jet provided an ignition source which traveled ahead of the initial flame front. In some recent work performed by Quader (2), extensions of the lean misfire limit were obtained with a more central spark plug location and multiple spark plugs. A dual spark plug ignition system was examined by Oblander, et. al. (13). Tests were performed on both a single-cylinder and a 6-cylinder engine. The dual spark plug ignition system generally allowed leaner operation by 0.1 to 0.15 air/fuel equivalence ratios. Also, the two plug ignition system provided lower fuel consumption, lower exhaust emissions, and less tendency for engine knock.

Quader (14) reported the results of two single cylinder engine experiments investigating flame initiation and flame
propagation under lean operation. The first experiment investigated flame initiation by advancing and retarding the spark timing from MBT spark timing. The advanced spark timing allowed determination of an ignition limit or failure of flame initiation to occur. The retarded spark timing provided a partial burn limit where failure of the flame to propagate occurred. The flame propagation experiments were conducted by the addition of an instrumented spacer installed between the cylinder block and the head. Quader concluded that both the flame initiation and the flame propagation constrained the spark timing in an engine.

Another area of investigations has been mixture turbulence and mixture preparation. The effects of various engine variables on lean engine operation were examined by Quader (2). Quader obtained extensions of the lean misfire limit by increasing the mixture homogeneity, increased compression ratio, increased air inlet temperature, decreased charge dilution, and decreased engine speed. The generation of a vortex to improve the lean operation of the spark ignition engine was examined by Lucas, et al. (15). These investigators found that the vortex generator improved lean operation and that a variable vortex generator would be desirable to replace the throttle. Recent work conducted by Peters and Quader (16) investigated the mixture preparation for leaner operation. A heterogeneous mixture and a homogeneous mixture were examined. The heterogeneous mixture and a homogeneous mixture were examined. The heterogeneous mixture was obtained by port fuel injection and the mixture was changed by varying the injection timing with respect to the intake valve opening. The homogeneous mixture was obtained by premixing and fully vaporizing the air/fuel mixture. The results showed that the heterogeneous charge allowed leaner engine operation than the homogeneous charge. John discussed the current design and development of various
manufacturers' carburetor and intake manifolds intended for lean operation (17). Adam, et. al. (18) discuss the development and operation of an intake manifold, termed a Turbulent Intake Manifold. The manifold was designed to improve mixing and distribution of the air/fuel mixture. The study included the equipping of various automobiles with the Turbulent Intake Manifold and carburetors adjusted for lean operation. The results indicated lower exhaust emissions, improved fuel economy, cylinder to cylinder mixture variations reduced by two-thirds, and good driveability.
III. EXPERIMENTAL APPARATUS AND PROCEDURE

A single cylinder engine was selected in preference to a multicylinder automotive production engine for several reasons. The single cylinder engine allows better control of engine variables so the variable of interest can be held constant or changed. The amount of fuel needed is substantially less, and air/fuel distribution problems are eliminated.

A. SINGLE CYLINDER ENGINE APPARATUS

The test engine used was a split-head Cooperative Fuel Research (CFR) engine with a high speed crankcase. The cylinder bore of 82.6 mm (3.25 in) and a stroke of 114.3 mm (4.50 in) provided a displacement volume of 0.611 L (37.33 cu.in). The engine was equipped with a shrouded intake valve installed to provide a counter-clockwise swirl inside the combustion chamber. A standard breaker-point ignition system was used with a Champion type D-16 spark plug. The engine was coupled to a 11 Kw dynamometer which provided engine load and speed regulation. Dynamometer control was accomplished by using a Digalog Corp., Model 1022, Dynamometer Controller regulating the dynamometer field voltage. A 60-tooth gear mounted on the dynamometer shaft and a magnetic pick-up provided the necessary shaft speed input. Intake mixture and exhaust temperatures were measured with chromel-alumel thermocouples. The intake mixture thermocouple was located approximately 40 cm (15.7 in) upstream of the intake valve, and the exhaust thermocouple was located approximately 9 cm (3.55 in) downstream of the exhaust valve. The intake manifold pressure was measured with an absolute pressure gauge connected approximately 9 cm (3.55 in) upstream of the intake valve. The exhaust pressure was measured downstream of the exhaust valve approximately 60 cm in a 13.55 L
(827 cu.in) stilling chamber. A control valve installed downstream of the stilling chamber provided exhaust pressure control. A schematic of the test set-up is shown in figure 1.

B. AIR AND FUEL METERING

An air system, shown in figure 1, supplied dry, oil free air to the intake manifold through a calibrated critical flow nozzle. This arrangement allowed engine operation with vacuum or boost pressure in the intake manifold. The air system was equipped with a normally closed solenoid valve and a normally open vent valve. With the valves energized, the engine air flow passed through the critical flow nozzle. With the valves de-energized, the intake manifold was vented to the atmosphere, and the engine air flow entered through the vent valve.

The fuel was metered using an American Bosch injection pump, Type APE, driven by the camshaft. The injection pump was equipped with a modified 5 mm plunger and barrel assembly. The fuel was delivered to an American Bosch injector, Model Akb50563p, which was mounted for port injection. The injection timing was set at 102.5 ATDC on the intake stroke to provide the best lean limit operation following the ideas of Peters and Quader (16). The fuel flow rate was determined on a gravimetric basis using a digital stopwatch, a precision balance, and calibrated weights.

C. EXHAUST GAS RECIRCULATION

Exhaust Gas Recirculation (EGR) was provided by stainless steel tubing, 12.7 mm o.d. (0.5 in), installed between the exhaust stilling chamber and the intake manifold, as shown in figure 1. The stainless steel tubing was connected into the intake system approximately 88 cm upstream of the intake valve. A needle valve allowed control of the amount
Figure 1. Schematic Diagram, Single Cylinder CFR Engine Apparatus
of exhaust gas recirculated. The percent EGR was determined from the intake manifold carbon dioxide (CO$_2$) concentration and the exhaust CO$_2$ concentration. The carbon dioxide concentration in the intake manifold was measured approximately 48 cm (19 in) upstream of the intake valve. Appendix B details the EGR calculation.

**D. EXHAUST EMISSIONS SAMPLING AND INSTRUMENTATION**

The exhaust emissions were sampled from the stilling chamber located approximately 60 cm (24 in) downstream of the exhaust valve. A schematic of the exhaust emissions bench is shown in figure 2. The exhaust sample was passed through a condenser to trap any water present before passing through the following equipment: Beckman Model 864 Non-dispersive infrared (NDIR) analyzers for carbon monoxide and carbon dioxide, a Thermo Electron Model 10A chemiluminescent analyzer for oxides of nitrogen, a Beckman Model 742 polarographic analyzer for excess oxygen, and a Scott Model 116 Flame Ionization Detector (FID) for unburned hydrocarbons. The instruments were calibrated with certified standard span gas mixtures. Dry nitrogen was used for zero gas. The instrument calibrations were checked before each data run.

Special attention was given to the sampling of oxides of nitrogen (NO$_x$). Usually the nitrogen dioxide level from the spark ignition engine is less than 10 ppm and nitric oxide is assumed the major component of the oxides of nitrogen. However, with very lean engine operation the potential for higher nitrogen dioxide emissions exists. Since nitrogen dioxide (NO$_2$) is very soluble in water, the water in the exhaust sample must not be allowed to condense and possibly remove some of the NO$_2$. To minimize this problem, a heated sample line, operated at 100°C, and a separate sampling pump were installed between the exhaust stilling chamber and the
Figure 2. Schematic Diagram, Exhaust Emissions Sampling and Instrument System
NO$_x$ analyzer. To prevent the problem of condensate build-up inside the NO$_x$ instrument, the instrument lines were wrapped with heat tape and the heated sample was obtained in a grab sampling technique.

To determine the percent EGR, the carbon dioxide concentration in the intake manifold was required. A sample was obtained from the intake manifold at approximately 48 cm (19 in) upstream of the intake valve. The sample was passed through a separate condensate trap and pump. A 3-way valve on the carbon dioxide instrument allowed selection of intake or exhaust sample for CO$_2$ measurement.

E. CYLINDER PRESSURE CYCLE MEASUREMENTS

The engine was instrumented to provide acquisition of pressure-crank angle data. A schematic of the pressure-crank angle instrumentation is shown in figure 3. A quartz pressure transducer, Kistler Model 601A, was installed in a water cooled adaptor. The transducer and adaptor assembly was mounted in the detonation access hole in the cylinder head. The pressure transducer was connected to a charge amplifier, Kistler Model 566. A Trump-Ross shaft encoder, Model UM-0360-5se-1, was coupled to the engine crankshaft. The shaft encoder provided two channels of output. One channel, referred to as the clock channel, produced one electrical pulse per degree of rotation and the other channel produced an electrical marker pulse once per revolution. The marker pulse was statically aligned with TDC of the engine. The charge amplifier and the shaft encoder outputs were connected to the data acquisition system of a Data General Nova 3 Minicomputer. A Fortran callable assembler subroutine was used to acquire the pressure-crank angle data. The assembler subroutine waits for the marker pulse when the cylinder pressure is low. This point corresponds with
Figure 3. Schematic Diagram, Cylinder Pressure, Cycle Measurement Apparatus
the beginning of the intake stroke. From this point the computer takes a pressure reading each degree of crankshaft rotation, based upon the input from the shaft encoder clock channel. Each pressure reading is stored in the memory of the computer. When the data acquisition is complete, the data is written into a disk data file. Due to the memory size of the minicomputer, only 30 consecutive engine cycles were obtained for each operating point. The analysis of the pressure-crank angle data will be discussed in a later section.

F. TEST PROCEDURE

After an initial warm up, the engine was operated at the conditions listed in table I using a test condition selected from those listed in table II. The supercharged operating points listed in table II were based upon preliminary vehicle tests conducted on a chassis dynamometer at the University of Missouri-Rolla with a 1979 Buick Century with a 3.8 L turbocharged V-6 engine and from engine data provided by the Buick Division of General Motors Corporation.

The intake manifold pressure was controlled by adjusting the upstream air pressure of the critical flow nozzle. The air/fuel ratio was controlled by adjusting the fuel delivered to the injector from the injection pump and was varied from slightly rich to the lean limit. In addition to using air flow and fuel flow measurements, the air/fuel ratio was determined from the exhaust emissions using a carbon and oxygen balance procedure (19). The lean misfire limit for this study, lacking the instrumentation to determine the misfire frequency, was the operating point at which both hydrocarbon emissions and obvious misfires of the engine indicated engine operation was unstable.
### TABLE I - ENGINE OPERATING CONDITIONS

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<th>Compression Ratio</th>
<th>8.0 to 1</th>
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<tbody>
<tr>
<td>Engine Speed</td>
<td>1200 RPM</td>
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<tr>
<td>Oil Temperature</td>
<td>65 ± 1°C</td>
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<tr>
<td>Coolant Temperature</td>
<td>98 ± 1°C</td>
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<tr>
<td>Spark Plug</td>
<td>Champion D-16</td>
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<tr>
<td>Plug Gap</td>
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<tr>
<td>Fuel Type</td>
<td>Indolene H.O.</td>
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<td>Fuel Temperature</td>
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### TABLE II - ENGINE TEST CONDITIONS

<table>
<thead>
<tr>
<th>INTAKE MANIFOLD PRESSURE (kPa)</th>
<th>MIXTURE TEMP. (°C)</th>
<th>EXHAUST PRESSURE (kPa)</th>
<th>ASSUMED* COMPRESSOR EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.9</td>
<td>52</td>
<td>119.3</td>
<td>----</td>
</tr>
<tr>
<td>89.6</td>
<td>52</td>
<td>119.3</td>
<td>----</td>
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<tr>
<td>112.4</td>
<td>76.7</td>
<td>133.0</td>
<td>50</td>
</tr>
<tr>
<td>126.4</td>
<td>91.1</td>
<td>146.8</td>
<td>60</td>
</tr>
<tr>
<td>140.0</td>
<td>115.6</td>
<td>153.7</td>
<td>55</td>
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</table>

*Compressor efficiency used in estimating mixture temperatures for given intake manifold pressures.
Three possible spark timing settings were used during the test procedure. The spark timing settings were: Minimum spark advance for best torque, 5% power loss spark, and knock limited spark. Minimum spark advance for Best Torque (MBT spark) is the spark timing which provides the maximum torque output. A detailed procedure for determination of MBT spark is given in Appendix - A. Knock Limited spark (K.L. spark) is the spark timing achieved by retarding the spark timing two degrees from the timing which produced steady audible knocking. This timing was used in cases where knocking was produced before the spark timing could be advanced to achieve MBT spark timing. 5% power loss spark timing (5% P.L.) is the spark timing, retarded from MBT or Knock Limited spark, that produces 5% less indicated power output from the engine. Engine torque, airflow, exhaust emission concentrations, and pressure-crank angle data were obtained at spark settings of MBT (or K.L. spark) and 5% power loss. Also, with the spark timing set at MBT, the fuel flow was shut off and the engine motored to determine the frictional losses and obtain motored pressure-crank angle data. After obtaining a complete set of data, the air/fuel ratio, EGR rate, or manifold pressure were changed and the procedure repeated.
IV. EXPERIMENTAL RESULTS

Because of the high frictional losses inherent in the CFR crankcase, indicated power is often used to report results of single cylinder studies using the CFR engine. However, for this study it was decided to report the results on a brake power basis since supercharging can substantially alter pumping and frictional losses in the engine. The exhaust emissions data were reduced to a mass specific basis using a carbon balance technique developed by Stivender (19), and were expressed as micrograms of constituent per joule of energy output produced by the engine. The air/fuel equivalence ratio, \( \phi_{AF} \), used in this study is defined as:

\[
\phi_{AF} = \frac{\text{Actual Air/Ratio}}{\text{Stoichiometric Air/Fuel Ratio}}
\]

This gives \( \phi_{AF} \) a value greater than one for lean operation. Most of the results examined were at MBT or Knock Limited spark timing.

Two intake manifold pressures were selected to simulate naturally aspirated engine operation: moderate load operation, 68.94 kPa (10.0 psia), and full load operation, 89.6 kPa (13.0 psia). This is referred to as the base engine operation and is used for comparison purposes. Three intake manifold pressures were selected for supercharged operation at lean air/fuel mixtures: 112.2 kPa (+2 psig), 126.2 kPa (+4 psig), 140 kPa (+6 psig). The operation of the engine with a lean mixture and positive manifold pressure is referred to as Lean Supercharged Operation (LSO).

A. ENGINE POWER, EFFICIENCY, AND EXHAUST EMISSIONS

The power, efficiency, and emissions data are graphically presented in figures 4 to 12 with the intake manifold parameter. Each figure, divided into three parts, shows the
data for 0%, 5%, and 10% EGR rate to illustrate the effects of EGR on the engine operation.

Brake Power produced by the engine as a function of the air/fuel equivalence ratio is shown in figure 4. The decrease in brake power output with increasing $\varphi_{\text{AF}}$ is predictable. Since the frictional losses and the charge volume are essentially fixed, decreasing fuel energy input leads to reduced brake power. The base engine brake power output, at 0% EGR, ranged between 0.55 Kw and 2.08 Kw. The LSO engine brake power output, at 0% EGR, ranged from 1.53 Kw to 3.07 Kw, an increase of approximately 48% over the base engine.

Engine efficiency is shown in figure 5 as a function of $\varphi_{\text{AF}}$. When compared with the base engine at full load and 0% EGR, an increase of approximately 28% in the brake efficiency was observed with LSO. The decreasing brake efficiency with increasing $\varphi_{\text{AF}}$ is due to the lower energy input and the fixed frictional and pumping losses in the engine. The base engine at part load showed a decrease in brake efficiency with the addition of EGR. However, the naturally aspirated engine at full load and the LSO engine showed less than 5% decrease in the brake efficiency with the introduction of EGR.

MBT spark and Knock Limited spark timing data are shown in figure 6 as a function of $\varphi_{\text{AF}}$. The data are provided to show where Knock Limited spark timing was used (which will effect the exhaust emissions) and to show the effects of intake manifold pressure and EGR on the spark timing. The increased spark advance with increased $\varphi_{\text{AF}}$, at fixed intake manifold pressure, was anticipated due to the slower combustion and longer flame kernel formation times for lean mixtures. At fixed $\varphi_{\text{AF}}$, the degrees of spark advance were reduced with increasing intake manifold pressure, primarily due to the increased charge density and resulting faster flame speed. The addition of EGR produces a diluting effect and reduced flame speeds requiring more spark advance for MBT timing.
Figure 4. Brake Power for Single Cylinder Engine
Figure 5. Brake Efficiency for Single Cylinder Engine
Figure 6. Engine Spark Timing for Single Cylinder Engine
Carbon Monoxide as a function of $\varphi_{AF}$ is displayed in figure 7. Generally, the results are those anticipated in that the Brake Specific Carbon Monoxide (BSCO) is primarily a function of $\varphi_{AF}$ and little else. BSCO emissions are very high for rich operation ($\varphi_{AF}=1.0$) and reduce sharply to a low value for lean operation. For the lean operation data shown in figure 7, a significant increase in BSCO emissions can be observed for the naturally aspirated engine operating at part load. A similar, but less pronounced, trend can be observed for the full load and LSO data as well. This effect is assumed to be due to a combination of decreasing brake power output and a deterioration of combustion at the leaner air/fuel conditions. Other than reducing the lean limits of operation, EGR flow seemed to have little effect on the BSCO emissions.

Unburned Hydrocarbon emissions data are presented in figure 8. The Brake Specific Hydrocarbon (BSHC) emissions were significantly changed by increased intake manifold pressure. The reduced BSHC emissions shown in figure 8 are due to two major effects: improved combustion due to increased charge density, and increased engine power causing a reduction in BSHC in addition to the reductions in the concentration of hydrocarbons in the engine exhaust. This change in the BSHC emissions due to changes in the engine power can also be seen in the gradual increase of these emissions with increasing $\varphi_{AF}$, in that the reduced power associated with increasing $\varphi_{AF}$ contributes to the apparent increase of these emissions. Near the lean misfire limit, deterioration of the combustion process also contributes to the rate of increase of the BSHC emissions.

Oxides of Nitrogen emissions as a function of $\varphi_{AF}$ are presented in figure 9. The oxides of nitrogen emissions follow typical data with the peak BSNO$_X$ at about 10% lean ($\varphi_{AF} = 1.10$). For a constant EGR rate, both the naturally
Figure 7. Brake Specific CO Emissions for Single Cylinder Engine
Figure 8. Brake Specific HC Emissions for Single Cylinder Engine
Figure 9. Brake Specific NO\textsubscript{x} Emissions for Single Cylinder Engine
aspirated and LSO data tend to follow the same curve. The addition of EGR has a substantial effect in reducing the BSNO\textsubscript{X} emissions for $\varphi_{AF}$ between 1.00 and 1.3; however, for equivalence ratios greater than about 1.3, EGR has little effect upon the BSNO\textsubscript{X} emissions. Some of the deviations in the BSNO\textsubscript{X} emissions data can be traced to variations in engine test conditions. In particular, deviation of the actual EGR rate from the desired value, and Knock Limited spark timing rather than MBT operation. The BSNO\textsubscript{X} emissions appear to have substantial sensitivity to EGR rates when operating at an equivalence ratio near peak NO\textsubscript{X}. Spark timing appears to have an influence on NO\textsubscript{X} emissions at virtually all lean operating conditions.

Further analysis of the exhaust emissions data involves some crossplots of the data (figures 10 to 12). The BSHC emissions as a function of the brake efficiency are shown in figure 10. The trend of the data follows a negative slope as the intake manifold pressure increases. The trend indicates that the best operating conditions for lower BSHC emissions and higher engine efficiency are in the LSD regime.

Figure 11 is a crossplot of BSNO\textsubscript{X} emissions and brake efficiency. Two points can be illustrated by this figure. First, for a given level of BSNO\textsubscript{X} emissions, LSO provides definite gains in the efficiency. For example, at an BSNO\textsubscript{X} emission level equal to 10.0 µg/J, the base engine at full load has an efficiency of 16.2%. For LSO with 0% EGR, efficiency ranges between 18.1% and 21.1%, an increase of 11 to 29 percent. Second, several possible LSD operation points have higher brake efficiency and lower BSNO\textsubscript{X} emissions than the base engine, even with EGR.

Figure 12 is a crossplot of BSHC and BSNO\textsubscript{X} emissions for lean operating conditions. This plot is included to examine the typical inverse relationship between BSNO\textsubscript{X} and BSHC emissions. The relationship between these variables
<table>
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<th>MANIFOLD PRESSURE</th>
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<td>○ 68.94 KPA</td>
<td>▽ 126.20 KPA</td>
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<tr>
<td>□ 89.62 KPA</td>
<td>● 139.95 KPA</td>
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</tbody>
</table>

![Graph showing brake specific HC as a function of brake efficiency for different EGR levels.](image)

**Figure 10.** Brake Specific HC as a Function of Efficiency
Figure 11. Brake Specific NO\textsubscript{x} as a Function of Efficiency
Figure 12. Brake Specific HC vs. Brake Specific NO\textsubscript{x}
is dependent on both the manifold pressure (i.e. charge density) and the air/fuel equivalence ratio. Figure 12 clearly shows that the manifold pressure has a significant influence in reducing BSHC for a given level of BSNO\textsubscript{x}. In fact, at the LSO conditions, BSHC emissions change very little from the range of 1.0 microgram per joule for a wide range of BSNO\textsubscript{x} emissions. It is also obvious that the BSNO\textsubscript{x} emissions are virtually independent of manifold pressure and highly dependent on the air/fuel equivalence ratio, particularly at the LSO test conditions. EGR flow has a detrimental effect on the BSHC emissions for the two lower manifold pressure conditions representing the naturally aspirated engine. However, the influence of EGR flow on the BSHC emissions for the LSO conditions seems to be negligible. From these data it is apparent that Lean Supercharged Operation reduces the inverse relationship between BSHC and BSNO\textsubscript{x} emissions. BSHC emissions are stabilized in a range near 1.0 microgram per joule and BSNO\textsubscript{x} emissions are strongly dependent on the air/fuel equivalence ratio.

B. ENERGY AVAILABILITY IN EXHAUST GASES

An objective of this study was to determine available exhaust gas energy for possible turbocharger operation. Estimates of the compressor power needed to provide LSO and the power available from an exhaust driven gas turbine were calculated. These calculations provided data regarding the conditions for which LSO would be possible with a turbocharger. A description of the calculation is given in Appendix - C. Figures 13 and 15 show the necessary compressor power and available power from a turbine at MBT spark and 0% EGR.

The compressor power was calculated for two inlet air pressures: 89.6 kPa and 98.6 kPa. These two compressor inlet air pressures were used to simulate having the
Figure 13. Estimates, Turbine and Compressor Power for 60% Compressor Efficiency
TEST CONDITIONS:
COMP OUTLET PRESS - 149.9 KPA
COMP EFF. = 55.0 %
MBT SPARK TIMING
EGR = 0.0%

EXHAUST TURBINE EFF
○ 50 %
□ 75 %
△ 85 %

COMP INLET PRESS
● 89.6 KPA
■ 98.6 KPA

Figure 14. Estimates, Turbine and Compressor Power for 55% Compressor Efficiency
Figure 15. Estimates, Turbine and Compressor Power for 50% Compressor Efficiency
compressor located upstream or downstream of the throttle plates in calculating the compressor power. Current practice is to locate the compressor downstream of the carburetor. The major reason for this location is to avoid having the carburetor operate under positive pressure, requiring shaft seals, and more complicated fuel metering due to a wide range of operating pressures.

The exhaust turbine power was calculated for three (3) efficiencies, 50%, 75%, and 85%. The 50% efficiency value was used as the worst possible efficiency, and the 75% and 85% efficiencies were used as more realistic values.

The addition of EGR decreased the needed compressor power slightly (approximately 5% for 10% EGR) due to reduced mass airflow needed by the engine at constant equivalence ratio. This condition is correct only in the case where the EGR does not flow through the compressor. Should the EGR flow through the compressor, the compressor power needed will be the same, with or without EGR. Also, the addition of EGR decreased the available power from the exhaust turbine due to lower exhaust temperatures. The 5% P.I. spark timing slightly increased (approximately 4%) the available power from the exhaust turbine due to higher exhaust temperatures.

Assuming a downstream compressor location, the compressor power required for LSO (0% EGR, MBT spark) is between 0.24 Kw and 0.57 Kw for intake manifold pressures of 112.2 kPa and 140 kPa respectively. To obtain this power from an exhaust turbine requires a turbine efficiency between 64% and 80% respectively. Thus, a turbine efficiency of 80% would be needed to provide a maximum manifold pressure of 140 kPa.

C. CYCLE ANALYSIS DEVELOPMENT

The fact that lean operation of the spark ignition
means that any approach to lean operation must in some way attempt to examine the behavior of the combustion process. In this work, pressure-volume data from the single cylinder engine operating at lean supercharged conditions are used to obtain information about the combustion process. The instrumentation used in gathering pressure-crank angle data for analysis was described in an earlier section of this thesis. The purpose of this section is to describe the methods used in analyzing these data.

Since several different steps are involved in the reduction and processing of the pressure-crank angle data, a flow diagram for the process is shown in figure 16. Each of the blocks in the diagram represents a data reduction or presentation step and the names in the blocks are for the computer programs used. The first block at the top of the diagram represents the pressure-crank angle data files produced by the minicomputer data acquisition system. The first use of this information is in the laboratory using program PRELIST. This program prints out the pressure data for the first cycle (720 points) of the 30 consecutive cycles stored in the data file to determine if any obvious problems exist in the data. Since this step is done while the engine is running, additional data sets may be taken to insure that a good set is obtained for further analysis.

Once a satisfactory set of pressure-crank angle data has been taken, data reduction and analysis proceed with the calculation of the average and standard deviation across the 30 cycles at each of the 720 crank angle degrees in a cycle. The average and standard deviation cycles calculated in this step are then stored in individual data files. Two primary reasons for averaging the pressure data are given by Lancaster, et. al. (20). The first is that the engine is an averaging device which responds to mean values of fuel and air flows in delivering power output. The second reason
Figure 16. Cycle Analysis, Data Reduction Flow Chart
is statistical: For a given crank angle, the pressure averaged across many cycles is a better estimator of the nominal cylinder pressure than any individual cycle measurement.

In order to make pressure-crank angle information more useful, several computer programs were written to plot the data in different formats. The three most valuable forms of the graphical presentation used in this work were produced by the computer programs named CAPLOT, PV PLOT, and LPV PLOT. These three programs are shown as output blocks in figure 16. The program CAPLOT was used to plot any number of the 30 original data cycles. This information was useful in tracing down any discrepancies in the results that might be attributable to a problem in the original data, such as complete misfires. Figure 17 is an example of this type of information. As shown in figure 18, the PV PLOT program was used to obtain a classical P-V plot from the average pressure-crank angle cycle. LPV PLOT was a modified version of PV PLOT that produced Log-pressure vs. Log-volume plots for use in final calibration and correction of the pressure-crank angle data. Figure 19 is an example of the graphical output from this program.

Before the averaged data can be used quantitatively, they must be properly scaled and phased. A detailed description of pressure data scaling, phasing, and analysis was made by Lancaster, et. al. (20) and those techniques have been used in this work. The pressure scaling involves converting the binary number stored in the average data file to a relative pressure using the calibration factors for the pressure transducer and data acquisition system. The relative pressures are then shifted by a constant to obtain absolute cylinder pressures. This constant is a reference pressure assigned to one point in the cycle where an accurate estimate of the absolute cylinder pressure can be made. For
Figure 17. Typical Output from CAPLOT Program Showing Partial Burns and Misfire
Figure 18. Typical Pressure-Volume Plot Produced by Program PVPLLOT
Figure 19. Typical Log-pressure vs. Log-volume Plot
Produced by Program LPVPLDT
this case, the intake manifold absolute pressure was assigned to the point corresponding to Bottom Dead Center of the piston on the intake stroke. Once this reduction of the average data was complete, a plot of Log-pressure vs. Log-volume was made. From this graphical output of the data, corrections to the assigned reference pressure were made to obtain a straight line for the compression stroke of the Log-pressure vs. Log-volume plot. The lower reference pressure obtained using this procedure was assumed to have been due to a pressure drop across the shrouded intake valve.

A second correction to the pressure-crank angle data was a "phasing" adjustment to insure that the pressure and crank angle information were concurrent. This correlation is extremely important since minor errors in the pressure-crank angle relationship can produce significant errors in later calculations based upon areas under this curve. The phasing correction is necessary even though great care was exercised in calibrating the engine crankshaft position encoder to identify TDC for the piston. The elastic behavior of the engine parts under load, changes in bearing clearances, and dynamic effects can cause the location of piston TDC to vary a few degrees from that indicated by the crankshaft encoder. The correction for these effects is determined by using a Log-pressure vs. Log-volume plot for motored (non-firing) cycle data. The compression-expansion portion of the motored cycle should contain almost zero area. The pressure-crank angle data were shifted to produce a minimum area between the compression and expansion lines of the Log-pressure vs. Log-volume plot for the motored data. For the test conditions examined in this project, this shift was determined to be 2 crank angle degrees.

Once the average pressure-crank angle data file had been fully calibrated and corrected, useful information from
this data could be obtained. The final four blocks in figure 16 are to identify the data analysis programs which use the final pressure-crank angle data. These programs are MEPS, DEVMEP, HEATREL, and MFBPLOT. Numerical integration of the area under the P-V data using program MEPS provides indicated pumping, and frictional mean effective pressures for the average cycle data examined. The definitions of Lancaster, et. al. (20) were used for these computations. The program DEVMEP provides average and standard deviation values for indicated and pumping mean effective pressures. HEATREL is a program for the approximate calculation of heat release rates and mass fractions burned from the P-V data and other operating conditions. MFBPLOT is a plotting program to graphically display the useful results from the heat release calculations.

In examining the data from these analysis programs, several interesting results were observed. The results from the MEPS program using the pressure data were consistently lower (3 to 6%) than the estimate of Indicated Mean Effective Pressure from the engine dynamometer data. Lancaster, et. al. (20) state that this slight discrepancy is primarily due to the non-zero value of the motoring IMEP (the area between compression and expansion lines for the motored engine), which is assumed to be zero in the computations. The consistent correlation between IMEP calculated from the pressure-crank angle data and that estimated from the dynamometer results was considered to have an important bearing on the validity of the heat release and mass fraction burned computations. A poor correlation would certainly cast some doubt on the usefulness of computations based upon the data.

Cycle-to-cycle variations in the P-V data for the engine are indicative of the quality of the combustion process. The smaller the variation between cycles, the more consistent
the quality of the combustion. Program DEVMEP finds the standard deviation of the indicated and pumping mean effective pressures for the 30 data cycles. Variations in the IMEP are indicative of combustion quality, partial burns, and misfires. The standard deviation for the IMEP as a function of $\phi_{AF}$, for the range of conditions examined in this program, is shown in figure 20. The data follow roughly the same trend for full load naturally aspirated operation or Lean Supercharged Operation. As $\phi_{AF}$ increases, the standard deviation increases, indicating increased cyclic variations and deterioration of the combustion process. Although not shown in figure 20, the use of EGR and the 5% P.L. condition with retarded spark also contribute to the increase of the standard deviation of the IMEP and therefore they also contribute to degrading the combustion process.

An approximate heat release curve was calculated from the pressure data following an empirical technique described by Young and Lieneson (21). The authors indicate that the resulting curve compared favorably with detailed heat release analysis, particularly for mass burned fractions of less than 50%. Figure 21 is an example of the Mass Fraction Burned (MFB) results from this approximate heat release computation. The slope of the MFB curve is also presented since it is a measure of the heat release rate, and thus indicative of the flame speed for the charge. A more detailed discussion of the meaning of this information is contained in the following section.

D. CORRELATION OF CYCLE ANALYSIS AND ENGINE PERFORMANCE

The Mass Fraction Burned (MFB) rate provides an indicator for changes in the combustion process. For this reason, it was anticipated that examination of the MFB rates would provide some explanation of the observed engine performance for Lean Supercharged Operation. Because MFB rate varies
Figure 20. Influence of Equivalence Ratio on IMEP Deviations
Figure 21. Typical Mass Fraction Burned and Mass Burned Rate Plots
continuously as a function of crankshaft rotation, arbitrary single point for comparisons was selected. The point chosen was the MFB rate that corresponded to a Mass Fraction Burned of 25%. This choice was based upon the fact that the approximate heat release calculation used was known to be reasonably accurate for MFB's less than 50%. Also, this choice was at a point where the flame is fully established and partial burns and wall quenching effects should be minimal. Figure 22 shows the influence of air/fuel equivalence ratio and supercharge conditions on the MFB rate at the 25% MFB point. The conditions presented in this figure are for MBT spark timing and no EGR flow.

The trends demonstrated in figure 22 are those anticipated from the inception of this program and from the engine performance data. Basically, the MFB rate decreases with increasing $\varphi_{AF}$, a condition expected due to the slower flame speeds associated with lean combustion. However for a fixed value of $\varphi_{AF}$, the MFB rate increases with increased intake manifold pressure. This is a clear sign that the increased charge density at the supercharged condition is contributing to increased flame speed. This conclusion is reinforced by both spark timing and efficiency data. Figure 6, in section IV-A illustrates that increased intake manifold pressure at a fixed value for $\varphi_{AF}$ reduces the spark advance needed for MBT conditions. This effect implies a more rapid combustion process near piston TDC, or increased flame speed. Since the increased flame speed allows more of the combustion process to take place near piston TDC, more energy should be extracted during the expansion process and improved thermal efficiency should result. Figure 5 in section IV-A shows that the thermal efficiency is indeed improved as intake manifold pressures are increased at constant $\varphi_{AF}$.

In figure 22, the data for the 140 kPa intake manifold pressure do not follow the general trend in increasing the
Figure 22. Burn Rates at 25% Mass Fraction Burned
MFB rate. This discrepancy can be attributed to the fact that virtually all the data at the 140 kPa test condition were taken at knock limited, rather than MBT spark conditions. The effects due to this retarded spark timing are also noted in section IV-A for figure 5 and 6. It should also be noted that the data for operation with EGR flow and/or 5% P.L. spark timing show decreases in the MFB Rate and comparable changes in engine efficiency.

One additional trend that should be noted from figure 22 is that the increased charge density due to supercharging allows extension of the lean operation limits. The data in this figure clearly show that the engine is operating at significantly lower MFB rates for Lean Supercharged Operation than are possible for the naturally aspirated engine.
V. CONCLUSIONS

The results of this experimental study of Lean Supercharged Operation of a spark ignition engine have been positive. Many of the assumptions made concerning how supercharged operation with lean mixtures would influence efficiency and emissions have been verified. Specific conclusions are as follows:

1. Brake Power - Increases in the brake power output were obtained for supercharged operation, even at very lean operating conditions. The power available from the lean supercharged engine was at least equal to that available from the naturally aspirated engine. For the more realistic operating conditions, the power output from the lean supercharged engine was greater than that from the naturally aspirated engine.

2. Engine Efficiency - One of the major incentives for examining Lean Supercharged Operation of the spark ignition engine was the potential for increased engine efficiency. The results from this single cylinder engine test program indicate that, if the engine is operated at high intake manifold pressure conditions, significant increases in engine efficiency are possible. These gains are particularly impressive for conditions that have equal NO\textsubscript{x} emissions rates, as illustrated in figure 23.

3. HC and CO Emissions - The HC and CO emissions produced by the singly cylinder engine operating at lean supercharged conditions were comparable to those for the naturally aspirated engine operating at normal lean air/fuel ratios. As expected, CO emissions were primarily a function of the air/fuel
equivalence ratio. HC emissions were a function of both the equivalence ratio and the intake manifold pressure for supercharged operation. Greater supercharge (increased manifold pressure) reduced BSHC emissions. Generally, operation at lean supercharged conditions produced CO and HC emissions that were comparable to or less than the naturally aspirated engine operating at nominal lean conditions. Figure 23 demonstrates this effect for operation at equal NO\textsubscript{X} levels.

4. NO\textsubscript{X} Emissions - The second major incentive for examining Lean Supercharged Operation of the spark ignition engine was the potential for a reduction in NO\textsubscript{X} emissions at lean operating conditions. The results of this program have clearly shown that, for MBT spark timing and fixed EGR flow, operation at lean supercharged conditions (\\theta_{AF}>1.4) provides greatly reduced NO\textsubscript{X} emissions at high engine efficiency. This fact is illustrated in figure 24 for equal engine power levels.

5. Exhaust Energy - One of the major concerns of simulating lean turbocharged operation with a single cylinder engine was that conditions not representative of turbocharger operation might be used, leading to erroneous conclusions. The exhaust energy studies performed at the lean supercharged conditions selected for testing indicate that sufficient exhaust energy is available to power a typical automotive type turbocharger.

6. Combustion Analysis - The analysis of the pressure-crank angle data to gain information as to how Lean Supercharged Operation influences combustion was very useful. The Mass Fraction Burned rates confirmed that supercharging at lean conditions
Figure 23. Comparison of Naturally Aspirated and Lean Supercharged Engines at Constant BSNO_x = 13 µg/J
Figure 24. Comparison of Naturally Aspirated and Lean Supercharged Engines at Constant Power = 2.0 Kw
improves the flame speed, probably due to increased charge density. This conclusion was reinforced by the behavior of spark advance and efficiency data for the lean supercharged conditions.

Lean Supercharged Operation of the spark ignition engine has the potential of improved efficiency and reduced NO\textsubscript{x} emissions when the operational range of the engine utilizes the higher intake manifold pressures. The combustion process it improved and the lean misfire limits are extended with Lean Supercharged Operation. HC and CO emissions are not greatly changed by operation at realistic lean supercharged conditions.
REFERENCES


VITA

Kenneth Robert Schmid was born on April 13, 1957 in Kansas City, Missouri. He obtained his primary and secondary education in the Center School District in Kansas City, Missouri. He performed his undergraduate studies at the University of Missouri-Rolla. He received a Bachelor of Science degree in Mechanical Engineering from the University of Missouri-Rolla in May 1979. He enrolled in Graduate School at the University of Missouri-Rolla in May 1979. Class work and experimental work were completed in August 1980. He has been employed, since September 1980, by the Mechanical Engineering Department at the University of Missouri-Rolla as a Research Specialist working on the undergraduate laboratories and performing research for Dr. R.T. Johnson.
APPENDICES
APPENDIX A

DETERMINATION OF MBT SPARK TIMING FOR SINGLE CYLINDER ENGINE
The following empirical technique was used to determine MBT spark timing: The spark timing was incremented in 2 degree intervals over a 10 to 12 degree range in the region where MBT spark timing was thought to exist. Dynamometer scale force and spark advance were recorded for each increment. A motoring run was performed to determine the motoring dynamometer scale force for the engine. A graph of the spark timing scale force was constructed from these data. (A more rigorous technique would use indicated power instead of scale force. However, with the test conducted at constant speed, the indicated power and scale force were directly proportional). Figure 25 is a typical graph for these data. Using the peak firing force to determine a 99% indicated force term. This 99% indicated force point was located on the graph and the associated spark advance noted. The MBT spark timing was arbitrarily set equal to this crank angle plus 5 degrees.
Figure 25. Scale Force as a Function of Spark Advance

MBT = 23° + 5° = 28° BTDC

1% INDICATED PEAK FORCE
APPENDIX B

EXHAUST GAS RECIRCULATION CALCULATION
The exhaust gas recirculation (EGR) rate was determined by a Carbon Dioxide Tracer Technique described by Wiers and Scheffler (22). The equation development to determine the percent EGR follows:

Nomenclature:

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<th>Description</th>
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<td>a</td>
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</tr>
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<td>b</td>
<td>Moles of exhaust H₂O in intake manifold</td>
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<td>c</td>
<td>Moles of exhaust O₂ in intake manifold</td>
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<td>d</td>
<td>Moles of exhaust N₂ in intake manifold</td>
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</tr>
<tr>
<td>M</td>
<td>Moles of constituent</td>
</tr>
</tbody>
</table>

Subscripts:

<table>
<thead>
<tr>
<th>Subscript</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Air</td>
</tr>
<tr>
<td>E</td>
<td>Exhaust</td>
</tr>
<tr>
<td>F</td>
<td>Fuel</td>
</tr>
<tr>
<td>I</td>
<td>Intake manifold</td>
</tr>
</tbody>
</table>

The percent EGR was defined as:

\[
\% \text{ EGR} = \frac{(\text{moles exhaust in intake charge})}{(\text{Total moles in intake charge})} \times 100 \tag{B-1}
\]

Which can be written as:

\[
\% \text{ EGR} = \frac{M_E}{M_E + M_A + M_F} \times 100 \tag{B-2}
\]

The molar chemical description of the engine intake charge, including EGR, can be written in the following terms:
(M_F)CH_yO_x+(a)CO_2+(b)H_2O+(c)O_2+(d)N_2+z(0_2+3.76N_2) \quad (B-3)

where: \( z = \) moles \( O_2 \) in air/fuel mixture.

The moles of intake charge can be expressed as:

\[
M_I = a + b + c + d + 4.76z + M_F \quad (B-4)
\]

The measured intake \( CO_2 \), on a dry molar basis, is:

\[
ICO_2 = \frac{a}{a + c + d + 4.76z} \quad (B-5)
\]

Substituting equation B-5 into equation B-4 yields an expression for the moles of intake charge.

\[
M_I = \frac{a}{ICO_2} + b + M_F \quad (B-6)
\]

Assuming that the measured (dry) exhaust \( CO_2 \) can be expressed as:

\[
ECO_2 = \frac{a}{a + c + d}, \quad (B-7)
\]

an expression for the moles of exhaust in the intake charge can be determined:

\[
M_E = \frac{a}{ECO_2} + b \quad (B-8)
\]

From equations B-1, B-6, and B-8:

\[
EGR = \left( \frac{ICO_2}{ECO_2} \right) \cdot \frac{1 + (b/a) ECO_2}{1 + (b/a) ICO_2 + (M_F/a) ICO_2} \quad (B-9)
\]
In this equation, \( \text{ICO}_2 \) and \( \text{ECO}_2 \) are the measured quantities and \( \frac{b}{a} \) and \( \frac{M_F}{a} \) must be evaluated before EGR can be determined. If ideal combustion is assumed, the reaction of a typical hydrocarbon fuel can be written in the form:

\[
\text{CH}_y\text{O}_x + z(\text{O}_2 + 3.76\text{N}_2) \rightarrow \text{CO}_2 + \frac{y}{2}\text{H}_2\text{O} + (3.76z)\text{N}_2 + (z - 1 - \frac{y}{4} + \frac{x}{2})\text{O}_2. 
\]  

(B-10)

The reaction products are the engine exhaust. The molar ratio of \( \text{H}_2\text{O} \) to \( \text{CO}_2 \) in the exhaust should be the same as the molar ratio of \( \text{H}_2\text{O} \) to \( \text{CO}_2 \) in the exhaust gases in the intake manifold due to EGR. Therefore:

\[
\frac{b}{a} = \frac{y}{2}. 
\]  

(B-11)

In the ideal combustion equation, B-10, one mole of fuel is assumed. Thus,

\[
M_F = 1. 
\]  

(B-12)

In order to use equation B-9 to calculate EGR, the moles of exhaust \( \text{CO}_2 \) in the intake manifold, \( a \), must be found. The quantity, \( a \), can be expressed as:

\[
a = \left(\frac{\text{moles of } \text{CO}_2 \text{ in Exhaust}}{\text{Total moles of Exhaust}}\right) \cdot M_E, 
\]  

(B-13)

For the one mole of fuel assumed in equation B-10, one mole of \( \text{CO}_2 \) will be produced in the exhaust. Also, the total moles of exhaust can be taken from the products in equation B-10, yielding:

\[
a = \left(\frac{1}{1 + \frac{y}{4} + \frac{x}{2} + 4.76z}\right) \cdot M_E. 
\]  

(B-14)
Noting that

\[ M_A = 4.76 z, \]

equation B-14 can be expressed:

\[ a = \left( \frac{1}{1 + y/4 + x/2 + M_A} \right)^{M_E}. \]  \hspace{1cm} (B-15)

In order to evaluate \( a \) using this relationship, \( M_A \) and \( M_E \) must be determined. Taking the expression for air/fuel ratio (A/F),

\[ \frac{M_A}{M_F} \cdot \frac{\text{molecular wt. of air}}{\text{molecular wt. of fuel}} = \frac{A/F}{M_A}. \]  \hspace{1cm} (B-16)

and rearranging it with the substitution of appropriate molecular weights yields:

\[ M_A = (A/F) \left( \frac{12.01 + 1.008 y + 16.0 x}{28.96} \right). \]  \hspace{1cm} (B-17)

Since A/F can be found from the measured exhaust constituents and \( y \) and \( x \) for the given fuel are known, equation B-17 can be used to evaluate \( M_A \). In order to find \( M_E \), equation B-2 can be expressed for EGR in decimal form as follows:

\[ \text{EGR} = \frac{M_E}{M_E = M_A + M_F}. \]  \hspace{1cm} (B-18)

Since \( M_F \) is taken as one and \( M_A \) can be found using equation B-17, \( M_E \) can be expressed as:

\[ M_E = \frac{\text{EGR} (1 + M_A)}{(1 - \text{EGR})}. \]  \hspace{1cm} (B-19)
Substitution of B-19 into B-15 gives the following expression for \( a \):

\[
a = \frac{EGR (1 + M_A)}{(1 - EGR) (1 + y/4 + x/2 + M_A)} \tag{B-20}
\]

Using \( M_A \) from equation B-17, equation B-20, and \( b/a = y/2 \) in equation B-9, EGR can be evaluated. Since EGR must be known in order to evaluate \( a \), an interactive process is used to compute EGR starting with a value \( EGR = IC_{O_2}/EC_{O_2} \). The iteration is continued until the value of EGR changes less than 0.001.
APPENDIX C

COMPRESSOR AND TURBINE POWER CONSIDERATIONS FOR TURBOCHARGING
From the initiation of this program, one of the objectives was to examine the limits of Lean Supercharged Operation due to insufficient recoverable exhaust energy for operating a turbocharger. The basic problem was to insure that the energy in the exhaust gases was sufficient to drive a single shaft turbine and compressor, with appropriate efficiencies, such that the compressor output would supply the needed intake engine mass flow. The engine test conditions, discussed in section IV-F and listed in table II, were selected to simulate the addition of a turbocharger by adjusting both the intake manifold conditions and the exhaust pressure.

A computer program entitled ENERGY was written to perform two sets of calculations in evaluating the potential for exhaust turbocharging. One set of calculations was used to determine the power necessary to operate a compressor to obtain the desired LSO. This calculation was performed for two compressor inlet pressures to determine the power needed for locating the compressor either upstream or downstream of the throttle plate(s). The second set of calculations was used to estimate the possible exhaust turbine output. This calculation was performed at three turbine efficiencies; 50%, 75%, and 85%, to bracket reasonable operating regions. The general equations and constants used to compute the exhaust turbine power available and the compressor power required are given by Taylor (23). The following equations and information were drawn from this source.

Nomenclature:

\[ C_p = \text{Specific heat at constant pressure} \]
\[ k = \text{Ratio of specific heats} \]
\[ M = \text{Mass flow rate through device} \]
\[ P = \text{Absolute pressure} \]
\[ T = \text{Absolute temperature} \]
\[ \eta = \text{Efficiency} \]
Subscripts:
1 = Inlet
2 = Outlet
c = Compressor
e = Exhaust
I = Intake
t = Turbine

Constants:
\( C_{PE} = 1.128 \ \text{kJ/kg °K} \)
\( C_{PI} = 1.003 \ \text{kJ/kg °K} \)
\( J = 2390 \ \text{CAL/kJ} \)
\( k_E = 1.343 \)
\( k_I = 1.40 \)

The power required to drive the compressor can be written:
\[
P_c = J M_c C_{PI} T_1 Y_c / \eta_c \tag{C-1}
\]

Where:
\[
Y_c = \left( \frac{P_2}{P_1} \right)^{\frac{k_I - 1}{k_I}} - 1 \tag{C-2}
\]

The available power from the exhaust turbine can be written:
\[
P_t = J M_t C_{PE} T_1 Y_t \eta_t \tag{C-3}
\]

Where:
\[
Y_t = 1 - \left( \frac{P_2}{P_1} \right)^{\frac{k_E - 1}{k_E}} \tag{C-4}
\]
APPENDIX D

COMPUTER PROGRAM LISTINGS
Comment statements were used in each individual program to provide necessary and useful program documentation. The first part of each program listing includes: a brief description of the program function, author(s), loading information, and variable name nomenclature. The following is a number system used for program statement numbers.

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<th>Number Range</th>
<th>Description</th>
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<tr>
<td>100 - 299</td>
<td>Do Loops</td>
</tr>
<tr>
<td>300 - 399</td>
<td>Format Statements for console input</td>
</tr>
<tr>
<td>400 - 499</td>
<td>Format Statements for program printed output</td>
</tr>
<tr>
<td>500 - 599</td>
<td>Format Statements for file input/output</td>
</tr>
<tr>
<td>600 - 699</td>
<td>Format Statements for plotter</td>
</tr>
<tr>
<td>700 - 799</td>
<td>Format Statements for line printer control</td>
</tr>
</tbody>
</table>
# Listing of Computer Programs

## 1. Main Programs

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<td>CFRCALC.FR</td>
<td>80</td>
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<tr>
<td>CROSSPLOT3.FR</td>
<td>85</td>
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<td>DEVMEP.FR</td>
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<td>ENGPLOT.FR</td>
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<td>MEPS.FR</td>
<td>109</td>
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</table>

## 2. Subroutines

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<td>GETCYCLE.SR</td>
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<tr>
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</tr>
<tr>
<td>PHASE</td>
<td>135</td>
</tr>
<tr>
<td>SHIFT</td>
<td>136</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>137</td>
</tr>
<tr>
<td>TITLE</td>
<td>139</td>
</tr>
</tbody>
</table>
C ******** CAPLOT.FR ********************************************
C
C THIS PROGRAM IS DESIGNED TO PLOT PRESSURE VS. CRANK ANGLE
C INFORMATION FROM A FILE CONTAINING VOLTS (PRESSURE) -
C CRANK ANGLE DATA.
C
C AUTHOR: R. T. JOHNSON
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MO - ROLLA
C ROLLA, MO 65401
C (314) 341 4661
C
C K. R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MISSOURI - ROLLA
C ROLLA, MO 65401
C
C REVISION HISTORY:
C 12/2/80 - CREATED ORIGINAL FROM PVPLOT.FR
C 12/4/80 - DEVIATION PLOTTING ADDED
C
C LOADING INFORMATION
C RLDR CAPLOT SHIFT GRID VECTR.LB FORT.LB
C
C DEFINITIONS:
C BORE = ENGINE BORE (IN.)
C CALB = CALIBRATION FACTOR (PSI/VOLT)
C CR = COMPRESSION RATIO
C DFILE = FILENAME OF DEVIATION DATA FILE
C IFILE = FILENAME OF PRESSURE DATA
C PREF = REFERENCE PRESSURE
C PRES = CALIBRATED PRESSURE DATA
C R = ENGINE CRANK THROW (IN.)
C RL = CONNECTING ROD LENGTH (IN.)
C
C *****************************************************************
DIMENSION IFILE(10), IHEADR(40), IDATA(720), VOLT(720)
DIMENSION DFILE(10), IHEADR(40), IDEV(720)
COMMON /PDATA/ PRES(720,2), PRES(720,2)

C MCREASE = 0
C CALB = 91.274
C BORE = 3.250
C R = 2.250
C RL = 10.0
C CR = 8.0
C
C i0 CONTINUE
C WRITE(10,400)
C 400 FORMAT(/IX," INPUT FILE ",Z)
C READ(11,300) IFILE(1)
C CALL FOPEN(0,IFILE)
C READ BINARY (0) IHEADR, ICYCLE
C 300 FORMAT (S18)
C WRITE(10,401)
C 401 FORMAT(/IX," ABSOLUTE REFERENCE PRESSURE (KPA) ",Z)
C READ(11,301) PREF
C 301 FORMAT(F6.2)
C WRITE(10,402)
C 402 FORMAT(/IX," PRESSURE SHIFT (DEGREES) ",Z)
C ACCEPT JDEG
C WRITE(10,403)
C 403 FORMAT(/IX," PLOT CRANK ANGLE 180-540 DEGREES 
& (1-YES,0-NO) ",Z)
C ACCEPT ICA
ICA = ICA+1
WRITE(10,404)

404 FORMAT(/,1X,"FLOT DEVIATION DATA ?(1-YES,0-NO) ",Z)  
ACCEPT IPILOT
IF(IPLOT.EQ.0)GO TO 1S
WRITE(10,405)

405 FORMAT(/,1X," DEVIATION FILENAME ",Z)  
READ(11,300)DFILE(I)  
CALL FOPEN(I,DFILE)  
READ BINARY (I) JHEADR,JCYCLE  
WRITE(10,410)JHEADR(1),JCYCLE  
JCYCLE=1
NUM=1
GO TO 16

C ***** WRITE FILE HEADER AND DESCRIPTIVE INFORMATION *****
C
C CONTINUE
WRITE(10,410)JHEADR(1),JCYCLE

410 FORMAT(/,10X,S78," CYCLES RECORDED")
WRITE(10,411)

411 FORMAT(/,1X," NUMBER OF CYCLE TO BE PLOTTED = ",Z)  
ACCEPT JCYCLE
WRITE(10,412)

412 FORMAT(/,1X," NUMBER OF CYCLES TO BE PLOTTED = ",Z)  
ACCEPT NUM

16 TYPE " "
TYPE" READING DATA FILE"
C

C ***** READ AND SCALE PRESSURE DATA *****
C
FACTOR = (CALB/3276.6)*6.895  
NCYCLE = JCYCLE-1  
DO 100 J=1,NCYCLE  
DO 110 I=1,720
READ BINARY(0) IDATA(I)

110 CONTINUE

100 CONTINUE
DO 112 KK=1,NUM
DO 115 I=1,720
READ BINARY(0) IDATA(I)
PRES(I) = FLOAT(IDATA(I))

115 CONTINUE
PRES(1) = PRES(180)-PREF  
DO 120 I=1,720
PRES(I) = PRES(I)-PRES(1)

120 CONTINUE
C
IF(KK.GT.1)GO TO 11
C
WRITE(10,420)

420 FORMAT(/,1X," ***** TURN ON PLOTTER ***** ",/)
PAUSE
C
IF(MCURVE.EQ.1)GO TO 11
C
C ***** DRAW GRID *****
C
WRITE(10,600)

600 FORMAT(1X,",(33)C1 40 75 ")  
GO TO(30,40)ICA

30 CALL GRID(0.0,720.0,180.0,1.0,0,5000.0,1000.0,1,150,  
&900,130,730,1,1)
GO TO 50

40 CALL GRID(180.0,540.0,90.0,1.0,0,5000.0,1000.0,1,150,  
&900,130,730,1,1)

50 CONTINUE
C
CALL ANMDE(580,670)
WRITE(10,610)IFILE(1)
610     FORMAT(1X, "INPUTFILE: ",S18)
     CALL AMNDE(580, 640)
     WRITE(10,611)PREF
     FORMAT(1X, "MANIFOLD PRESS. (KPA) ",F8.2)
     CALL AMNDE(430, 75)
     WRITE(10,612)
     FORMAT(1X, "CRANK ANGLE DEGREES")
     WRITE(10,613)
     FORMAT(1X, *(33)C 90 * )
     CALL AMNDE(50, 275)
     WRITE(10,614)
     FORMAT(1X, "PRESSURE (KPA)")
     WRITE(10,615)
     FORMAT(1X, *(33)C 0")
     CONTINUE

C
C ****** READ AND SCALE DEVIATION DATA ******
C
IF (IPLOT.EQ.0) GO TO 22
DO 130 I=1,720
READ BINARY(1) IDEV(I)
PREIS(I,2) =FLOAT(IDEV(I))/32767.0
PREIS(I,2) = PRES(I,2)*PRES(I,1)
130    CONTINUE
22    CONTINUE

CALL SHIFT(JDEG)
GO TO (35,45)I1A

C
C ****** PLOT PRESSURE VS. CRANK ANGLE DATA ******
C
35    CALL DPORT(150,900,130,730,0.0,720.0,0.0,5000.0)
     ISTART = 2
     ISTOP = 720
     PRES2 = PRES(I,1)
     CALL MOVEA(0.0,PRES2)
     GO TO 55
45    CALL DPORT(150,900,130,730,180.0,540.,0.0,5000.0)
     ISTART = 181
     ISTOP = 540
     PRES2 = PRES(I,1)
     CALL MOVEA(180.0,PRES2)
     CONTINUE

DO 140 I=ISTART,ISTOP
     K = I-I
     CA = FLOAT(K)
     PRESY=PRES(I,1)
     CALL DRAWA(CA, PRESY)
140    CONTINUE

IF(IPLOT.EQ.0) GO TO 25

C
C ****** PLOT (+) DEVIATION FROM THE AVERAGE PRESSURE DATA ******
C
YDATA = PRES(180,1)+PRES(180,2)
CALL MOVEA(180.0,YDATA)
DO 150 I=180,540
     K = I-I
     CA = FLOAT(K)
     YDATA = PRES(I,1)+PRES(I,2)
     CALL DRAWA(CA,YDATA)
150    CONTINUE

C
C ****** PLOT (-) DEVIATION FROM THE AVERAGE PRESSURE DATA ******
C
YDATA = PRES(180,1)-PRES(180,2)
CALL MOVEA(180.0,YDATA)
DO 160 I=180,540
K = I-1
CA = FLOAT(K)
YDATA = PRES(1,1) - PRES(1,2)
CALL DRAWA(CA,YDATA)
CONTINUE

C

CONTINUE

CALL MVABS(150,130)
REWIND 0
CALL FCLOSI
IF(IPLLOT.EQ.0)GO TO 60
REWIND 1
CALL FCLOSI
CONTINUE

CALL MVABS(0,0)
WRITE(10,601)
601 FORMAT(1X,"(33) CN")
CALL ANHDE(0,0)
ACCEPT FAKE
C

*** STOP TO TURN OFF PLOTTER ***
C

*** HIT RETURN TO COMPLETE PROGRAM ****
C

WRITE(10,430)
430 FORMAT(1X," PLOT A SECOND CURVE ? (NO-0,YES-1)" ,Z)
READ(11,330)M CURVE
330 FORMAT(I1)
IF(MCURVE.EQ.1)GO TO 10
WRITE(10,431)
431 FORMAT(/1X," REPEAT PROGRAM ? (NO-0,YES-1)" ,Z)
READ(11,331)NCON
331 FORMAT(I1)
IF(NCON.EQ.0)GO TO 13
WRITE(10,440)
440 FORMAT(1X,"(33)<(14)"
GO TO 10

13 CONTINUE
STOP
END
C DATA REDUCTION PROGRAM FOR SINGLE CYLINDER ENGINE DATA.

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C REVISION HISTORY:
4/15/79 - CREATED ORIGINAL
12/10/79 - REVISED FOR LEAN SUPERCHARGE STUDY
07/12/81 - SUBROUTINE EGR ADDED

C LOADING INFORMATION:
RLDR CFRCALC EGR FORT.LB

C NOMENCLATURE:
AFlow = MASS OF AIR FLOW, LB/MIN
Afs = STOICHIOMETRIC A/F
BFuel = BASE FUEL NAME, 8 CHARACTERS
BPres = BAROMETRIC PRESSURE, IN.HG.
BFr = BEAM FORCE WHEN FIRING, LB
Btemp = BAROMETRIC TEMPERATURE, F
CO = CARBON MONOXIDE, %
C02 = CARBON DIOXIDE, %
CR = COMPRESSION RATIO
Eff = INDICATED OR BRAKE EFFICIENCY
FUEL = MASS FUEL FLOW, LB/MIN
HC = HYDROCARBONS, PPM (PROPANE)
IKW = INDICATED OR BRAKE POWER, KW
ISC0 = INDICATED OR BRAKE SPECIFIC CO, UGM/J
ISFC = INDICATED OR BRAKE SPECIFIC FUEL CONSUMPTION, GM/KJ
ISHC = INDICATED OR BRAKE SPECIFIC HC, UGM/J
ISNO = INDICATED OR BRAKE SPECIFIC NOX, UGM/J
LHV = LOWER HEATING VALUE OF FUEL, BTU/LBM
MC02 = INTAKE MANIFOLD CO2, %
MPres = INTAKE MANIFOLD PRESSURE, KPA
Ntemp = INTAKE MANIFOLD TEMPERATURE, DEG F
Motor = MOTORING BEAM FORCE, LB
NOX = OXIDES OF NITROGEN, PPM
Nozzle = NOZZLE NUMBER
NPres = CRITICAL FLOW NOZZLE PRESSURE, PSIG
NTemp = CRITICAL NOZZLE TEMPERATURE, DEG F
O2 = OXYGEN, %
OTemp = OIL TEMPERATURE, DEG F
PHIC = CARBON BASED A/F EQUIVALENCE RATIO
PHIO = OXYGEN BASED A/F EQUIVALENCE RATIO
PHIX = EXPERIMENTAL A/F EQUIVALENCE RATIO
Rpm = ENGINE SPEED, RPM
Runno = RUN NUMBER, 8 DIGIT NUMBER, 1ST 6 DIGITS = MO/DAY/YEAR
Last 2 DIGITS = RUN FOR DAY
SG = SPECIFIC GRAVITY OF FUEL, FM/HL
SPKt = SPARK TIMING, DEG BTDC, ENTER DATA IN WHOLE DEGREE IDENTIFY
MBT BY ADDING DECIMAL 0.10. EXAMPLE: 31.5 INDICATES MBT
SPARK TIMING OF 31 DEGREES. 20.0 = NON MBT SPARK TIMING
OF 20 DEGREES.

WTEMP = COOLANT TEMPERATURE, DEG. F
XTEMP = EXHAUST TEMPERATURE, DEG F
XPRES = EXHAUST PRESSURE, KPA
X = MOLAR O/C RATIO OF FUEL
Y = MOLAR H/C RATIO OF FUEL

FORMAT FOR DATA ENTRY INTO FILE SCD-:

BFUEL
LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTEMP,OTEMP,WTEMP,XPRES,NOZZLE
RUNNO,BPRES,BTEMP,MPRES,NTEMP,FUFL,SKPT,BKFR,MTRFR
HC,NOX,CO2,CO,02,MC02,XTEMP
0,0,0,0,0,0,0,0,0,0,0.

(ZEROS ARE PLACED AT END OF FILE AS END OF FILE INDICATORS)

C **********************************************************************
DIMENSION BFUEL(3),FNAME(6),RNAME(6),IDATE(10),KDATE(3)
DOUBLE PRECISION RUNNO
COMMON /A! C02,HC02,CO2B,AFC,AFO,XML,Y
REAL IKW,ISCO,ISHC,ISFC,ISNO,LHV,MTEMP,MTRFR,NOX,MPRES,MC02
REAL NPRES,NTEMP,NOZZLE
TYPE * TYPE IN THE INPUT FILENAME: 
READ(11,300)FNAME(1)
FORMAT(510)
5 TYPE " TYPE IN THE OUTPUT FILENAME: 
READ(11,300)RNAME(1)
CALL CFILW(RNAME,IER)
IF(IER.EQ.1)GO TO 15
WRITE(10,400)
FORMAT(1X," FILE ALREADY EXISTS ",S20)
GO TO 5

15 CONTINUE
CALL OPEN(16,FNAME,1,IER)
CALL FOPEN(16,RNAME)
READ(16,500)BFUEL(1)
FORMAT(58)
READ(16,LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTEMP,OTEMP,WTEMP,XPRES,NOZZLE
WRITE(10,410)
FORMAT(1X,16,10X," POWER ? (1-BRAKE,O-INDICATED : )",Z)
READ(11,310)IPOWER
FORMAT(11)
WRITE(10,420)
FORMAT(1X,16,10X," OUTPUT DEVICE (10-CONSOLE,12-PRINTER): ",Z)
READ(11,320)IOUT
FORMAT(12)
IF (IOUT.EQ.10.OR.IOUT.EQ.12)GO TO 35
GO TO 71
35 CONTINUE
IF (IOUT.EQ.10)GO TO 36
WRITE(12,700)
700 FORMAT(1X,"(33)(46)(153)(62)(123)
C

C ****** OUTPUT HEADER *****
C
36 CONTINUE
CALL FCTIM(IHR,IMIN,ISEC)
CALL DATE(KDATE,IER)
WRITE(IOUT,430)KDATE(1),KDATE(2),KDATE(3),IHR,IMIN,ISEC
FORMAT(1X,"FUEL CHARACTERISTICS ")
WRITE(IOUT,432)BFUEL(1),LHV,AFS,Y,X,SG

C
FORMAT(5X, "BASE FUEL ", 11X, S8. /, S5, "LOWER HEATING VALUE", 2X, AF6.6 /, S5, "STOICHIOMETRIC A/F ", 2X, F6.3 /, S5, "FUEL MOLECULE ", &7X, CH("F5.3, ")/10("F5.3 ")/", S5, "SPECIFIC GRAVITY", S5, AF3.3 /)

WRITE(IOUT)" ENGINE TEST CONDITIONS".
WRITE(17, 505) CR, RPM, N2PRES, MTEMP, OTEMP, WTEMP

507 FORMAT(1X, 7F10.4)
WRITE(IOUT, 433) CR, RPM, N2PRES, MTEMP, OTEMP, WTEMP

WRITE(IOUT, 434)
WRITE(IOUT, 435)
WRITE(IOUT, 436)
WRITE(IOUT, 437)

434 FORMAT("4", " INPUT DATA "/)


C 40 CONTINUE
READ(16) RUNNO, BPRES, BTEMP, N2PRES, MTEMP, FUFL, SPKT, BKFR, MTRFR
IF(RUNNO.LT.10.0) GO TO 50
READ(16) HC, NOX, CO2, CO, O2, MCO2, XTEMP
WRITE(IOUT, 440) RUNNO, BPRES, BTEMP, N2PRES, MTEMP, FUFL, SPKT, BKFR, & MTRFR, HC, NOX, CO2, CO, O2, MCO2, XTEMP

440 FORMAT(1X, F10.0, 1X, F10.0, 1X, F5.3, 3X, F3.0, 4X, F4.1, 5X, F5.0, 5X, F5.4, 4X, &F5.2, 4X, F5.2, 4X, F4.1, 5X, F4.0, 1X, F6.0, 2X, F4.1, 2X, F4.2, 2X, F5.2, &A3X, F4.2, 5X, F5.0)

C ***** BAROMETRIC PRESSURE CORRECTION AND AIR FLOW CALCULATION *****

C C1=(9.08E-5)*(BTEMP-28.63)
C C2=+(1.01E-4)*(BTEMP-32)
C CORR=C1/C2)*BPRES
C ATM=(BPRES-CORR)*0.49076
C D=(NTEMP+460.0)**0.5
C IF(NOZZLE.EQ.2) GO TO 41
C AFLOW=0.2175*((ATM+N2PRES)**1.0315)/D
C GO TO 42
C AFLOW=0.468*((ATM+N2PRES)**1.066)/D
C CONTINUE
C AFMASS=AFLOW/FUFL
C PHIX=AFMASS/AFS

C ***** EXHAUST EMISSIONS AIR/FUEL CALCULATIONS

C XHC=HC/10000. 0
C XNO=NOX/10000. 0
C XN=100. /(3.0*HC+CO+CO2)
C H2O=(50.0*Y/XN-4.0*HCX)/(CO/(3.0*CO2)+1.0)
C XM=12.01+0.008*Y+16.*X
C A=(3.0*HC-CO/2.-1.5*H2O)*XN/100.
C AFC=(28.97/XMF)*((XN+A-(Y*X))/2.)
C PHIC=AFC/AFS
C B=CO2+CO+H2O+XNO+CO+O2
C C=(B*XN/100.)-X/2.
C AF0=4.76*B*PHIC
C PHIO=AF0/AFS

C ***** CALCULATION OF SPECIFIC EMISSIONS

C IF(POWER.EQ.0) GO TO 44
IKW = (BKFR) * RPM * 0.746 / 5250
GO TO 45
IKW = (BKFR + MTRF) * RPM * 0.746 / 5250
45 ISFC = (FUEL * 1.535E05) / (60.0 * IKW)
EFF = (IKW * 3421.14) / (LHV * FUEL * 60.0) * 100.0
AD = ISFC / (XAF * (3.0 * XHC + C0 + C02))
ISHC = 3.0 * XM * XHC * AD
ISNO = 46.0 * XNO * AD
ISCO = 28.0 * C0 * AD
ISPK = SPK
SPKT1 = ISPK
DIFF = SPKT - SPKT1
IF (DIFF LT 0.01) GO TO 46
XMBT = SPKT1
46 RELMBT = SPKT1 - XMBT
MPRES1 = MPRES / 6.894
DENSITY = (MPRES1) / (640.0 * (MTEMP + 460.0))
THEAIR = 33.330 * RPM * DENSITY * 0.5
VOL = (AFLOW / THEAIR) * 100.0
C
CO2B = 400.0
CALL EGR (XXGR)
C
WRITE (17, 510) RUNNO
510 FORMAT (F10.0)
WRITE (17, 515) PHIX, PHIO, PHIC, RELMBT, XEGR, ISHC, ISCO, ISNO, IKW,
& ISFC, EFF, VOL
515 FORMAT (1X, 12F10.4)
GO TO 40
50 CONTINUE
RUNNO = 1.0 DO
WRITE (17, 510) RUNNO
CALL CLOSE (16, IER)
C
REWIND 17
C
***** OUTPUT DATA *****
C
WRITE (1OUT, 448) FNAME (1), RNAME (1)
IF (IPPOWER . EQ. 1) GO TO 60
WRITE (1OUT, 450)
WRITE (1OUT, 451)
WRITE (1OUT, 453)
GO TO 61
60 CONTINUE
WRITE (1OUT, 449)
WRITE (1OUT, 452)
WRITE (1OUT, 453)
61 CONTINUE
448 FORMAT (1X, ' RESULTS CALCULATED FROM DATA IN FILE: ', $, 510, ' ARE
& STORED IN FILE: ', $, 510, '/)
449 FORMAT (1X, ' POWER BASE USED - BRAKE ', /)
450 FORMAT (1X, ' POWER BASE USED - INDICATED ', /)
& 6X, 'VOL '
& 6X, 'VOL '
C
READ (17, 505) CR, EFM, MPRES, XPRES, MTEMP, OTEMP, WTEMP
64 READ (17, 510) RUNNO
IF (RUNNO . LT. 15.0 DO) GO TO 65
READ (17, 515) PHIX, PHIO, PHIC, RELMBT, XEGR, ISHC, ISCO, ISNO, IKW,
& ISFC, EFF, VOL
WRITE (1OUT, 460) RUNNO, PHIX, PHIO, PHIC, RELMBT, XEGR, ISHC, ISCO, ISNO,
& IKW, ISFC, EFF, VOL
460       FORMAT(/, F10.0, 5X, F5.3, 4X, F5.3, 4X, F5.3, 4X, F5.3, 4X, F5.3, 4X, F5.3, 4X, F5.3, 4X, F5.2, 6X, 
          4F4.2, 5X, F5.2, 5X, F5.2, 5X, F5.2, 5X, F5.2, 5X, F5.2, 6X, F6.2, 3X, F5.1, 4X, F5.1)
       GO TO 64
65       CONTINUE
C
       REWIND 17
       CALL FCLOS(17)
       IF(IOUT.EQ.10)GO TO 66
       WRITE(12,701)
701       FORMAT(1X, "(33)(14)"")
       WRITE(12,702)
702       FORMAT(1X, "(33)(46)(153)(60)(123)"")
66       CONTINUE
STOP
70       TYPE " ERROR FOR OUTPUT DEVICE CODE"
       REWIND 17
       CALL CLOSE(16, IER)
       CALL FCLOS(17)
       STOP
END
C **********************************************************
C THIS PROGRAM IS DESIGNED TO READ THE RESULT FILE CREATED
C BY THE PROGRAM CFR CALC.FR AND PLOT THE DATA.
C
C AUTHOR K. R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MO - ROLLA
C ROLLA, MO 65401
C
C REVISION HISTORY:
C 6/30/80 - CREATED ORIGINAL
C 8/15/80 - SUBROUTINE GRID ADDED
C 10/7/81 - MODIFIED TO DO 3 PLOTS
C
C **********************************************************

C LOADING INFORMATION
C RLD R CROSSPLOT SYMBOL GRID TITLE VECTR.LB FORT.LB
C
C **********************************************************

DIMENSION BFUEL(3)
DOUBLE PRECISION RUNNO
COMMON IPOWER
REAL TTEMP,OTEMP,NUX,MPRES,MC02,MPRES,ICPP
REAL IMW,ISCO,ISHC,ISNO,ISFC,LPV,NOZZL
INTEGER XDATA, YDATA, RATE, TIMING, YDIV
MPINT=0
RATE = 0
10 CONTINUE
WRITE(10,400)
400 FORMAT(1X,'("POWER BASE (0-BRAKE POWER; 1-INDICATED POWER"
& "",Z)
READ(11,300) IPOWER
300 FORMAT(I1)
WRITE(10,402)
402 FORMAT(1X,'"MANIFOLD PRESSURE" "",/10X," CHANNEL 1 =
& 10.0 PSIA",/10X," CHANNEL 2 = 13.0 PSIA",/10X," CHANNEL 3 = 16.3 PSIA",/)
&10X," CHANNEL 4 = 18.3 PSIA",/10X," CHANNEL 5 = 20.3 PSIA",/)
WRITE(10,403)
403 FORMAT(1X,'"MANIFOLD PRESSURE CHANNEL ":",Z)
READ(11,303)J
303 FORMAT(I1)
WRITE(10,404)
404 FORMAT(1X,'"SPARK TIMING (1-5% POWER LOSS; 0-MBT SPARK"
& "TIMING ",Z)
READ(11,304) TIMING
304 FORMAT(I1)
IF(MPOINT.EQ.0)GO TO 15
WRITE(10,430)
PAUSE
15 CONTINUE
C
C **********************************************************
C OPEN RESULT FILES FOR READING
C
C IF(J.EQ.1) CALL OPEN(1, "RSLTIND10", 1, IER)
C IF(J.EQ.2) CALL OPEN(2, "RSLTIND13", 1, IER)
C IF(J.EQ.3) CALL OPEN(3, "RSLTIND16", 1, IER)
C IF(J.EQ.4) CALL OPEN(4, "RSLTIND18", 1, IER)
C IF(J.EQ.5) CALL OPEN(5, "RSLTIND20", 1, IER)
GO TO 30
20 CONTINUE
C IF(J.EQ.1) CALL OPEN(1, "RSLTBRK10", 1, IER)
C IF(J.EQ.2) CALL OPEN(2, "RSLTBRK13", 1, IER)
C IF(J.EQ.3) CALL OPEN(3, "RSLTBRK16", 1, IER)
IF(J.EQ.4) CALL OPEN(4, "RSLTRK18", i, IER)
IF(J.EQ.5) CALL OPEN(5, "RSLTRK20", i, IER)
30 CONTINUE
K = J+20
GO TO (41,42,43,44,45, J)
CALL OPEN(21, "DATA10.TC", i, IER)
GO TO 40
CALL OPEN(22, "DATA13.TC", i, IER)
GO TO 40
CALL OPEN(23, "DATA16.TC", i, IER)
GO TO 40
CALL OPEN(24, "DATA18.TC", i, IER)
GO TO 40
CALL OPEN(25, "DATA20.TC", i, IER)
40 CONTINUE
READ(K,505) BFUEL(1)
505 FORMAT (86)
READ(K,LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTEMP,WTEMP,
XPRES,NOZZLE)
READ(J,500) CR,RPM,MPRES,XPRES,MTEMP,WTEMP
500 FORMAT (1X,7F10.4)
C
JSYM = J
IF(J.EQ.5) JSYM = 1
C
IF(MPOINT.GT.0) GO TO 50
IF(RATE.EQ.5) GO TO 60
IF(RATE.EQ.10) GO TO 70
C
C ***** INPUT DATA CHANNEL *****
C
C ***** X - AXIS INPUT DATA *****
C
WRITE(10,406) " *** X-AXIS DATA INPUT ***** ",/"
WRITE(10,407) FORMAT(1X," CHANNEL 1 ISHC "/,10X," CHANNEL 2 ISCO "/,10X,
&" CHANNEL 3 ISNO "/,10X," CHANNEL 4 POWER "/,10X,
&" CHANNEL 5 A/F EQ. RATIO "/,10X," CHANNEL 6 EFFICIENCY. "/,10X,
&" CHANNEL 7 SPARK TIMING"/",10X," CHANNEL 8 EXHAUST TEMP."/")
WRITE(10,408) " *** INPUT DATA CHANNEL ":/"
WRITE(10,409) ACCEPT XDATA
408 FORMAT(1X," INPUT DATA CHANNEL ":/"
WRITE(10,410) ACCEPT XMN
409 FORMAT(1X," X-AXIS STARTING COORDINATE =?",/"
ACCEPT XMN
410 FORMAT(1X," X-AXIS FULL SCALE =?",/"
ACCEPT XMAX
411 FORMAT(1X," AXIS DIVISION INCREMENT =?",/"
ACCEPT XINC
C
C ***** Y-AXIS DATA INPUT (0% EGR) *****
C
WRITE(10,420) " *** Y-AXIS DATA INPUT ***** ",/"
WRITE(10,421) ACCEPT YDATA
WRITE(10,422) ACCEPT YMN
419 FORMAT(1X," Y-AXIS STARTING COORDINATE =?",/"
ACCEPT YMN
WRITE(10,423) ACCEPT YMAX
420 FORMAT(1X," Y-AXIS FULL SCALE =?",/"
ACCEPT YINC
WRITE(10,424) " *** TURN ON PLOTTER ***** ",/"
PAUSE

C **** DRAW GRID LINES *****

C WRITE(10,600)
600 FORMAT(1X:"(33)CI40 75 ")
   CALL GRID(XMIN,XMAX,XINC,1,YMIN,YMAX,YINC,0,200,
   660,500,0,0)
   CALL MVABS(200,700)
   CALL DWABS(200,700)
   CALL DWABS(600,700)
C

C **** LABEL AXIS ****

C CALL TITLE(XDATA,0,275,50)
C CALL TITLE(YDATA,1,120,300)

C **** WRITE OUT ENGINE TEST CONDITIONS ****

C CALL ANHDE(250,660)
   IF(TIMING.EQ.0)WRITE(10,620)
   IF(TIMING.EQ.1)WRITE(10,621)
620 FORMAT(1X:"MT")
621 FORMAT(1X:"% P.L.")
   CALL ANMDE(220,760)
   WRITE(10,623)
623 FORMAT(1X,"MANIFOLD PRESSURE")
   CALL MVABS(230,740)
   CALL SYMBOL(JSYM)
   CALL ANMDE(250,735)
   WRITE(10,624)MPRES
624 FORMAT(1X,F7.2," KPA")
   CALL ANMDE(500,660)
   WRITE(10,622)RATE
622 FORMAT(1X,",EGR","11,",","%")
   GO TO 75

C **** Y-AXIS DATA INPUT (5 % EGR) ****

C CONTINUE

C CALL GRID(XMIN,XMAX,XINC,1,YMIN,YMAX,YINC,0,200,
   660,300,500,0,0)
   CALL ANMDE(250,460)
   IF(TIMING.EQ.0)WRITE(10,620)
   IF(TIMING.EQ.1)WRITE(10,621)
   CALL ANMDE(500,460)
   WRITE(10,622)RATE
   GO TO 75
C

C **** INPUT Y-AXIS DATA (10% EGR) ****

C CONTINUE

C CALL GRID(XMIN,XMAX,XINC,1,YMIN,YMAX,YINC,0,200,
   460,100,300,1,0)
   CALL ANMDE(250,260)
   IF(TIMING.EQ.0)WRITE(10,620)
   IF(TIMING.EQ.1)WRITE(10,621)
   CALL ANMDE(500,260)
   WRITE(10,632)RATE
632 FORMAT(1X,",EGR","11,",","%")
   GO TO 75
C

C CONTINUE

C IF(RATE.EQ.5.OR.RATE.EQ.10)GO TO 75
   WRITE(10,600)
   IF(MPOINT.EQ.1)GO TO 21
   IF(MPOINT.EQ.2)GO TO 22
IF(MPOINT.EQ.3)GO TO 23
IF(MPOINT.EQ.4)GO TO 24
GO TO 25
CONTINUE
CALL MVABS(230,715)
CALL SYMBOL(JSYM)
CALL ANMDE(250,710)
WRITE(10,624)MPRES
GO TO 25
CONTINUE
CALL MVABS(425,765)
CALL SYMBOL(JSYM)
CALL ANMDE(445,760)
WRITE(10,624)MPRES
GO TO 25
CONTINUE
CALL MVABS(425,740)
CALL SYMBOL(JSYM)
CALL ANMDE(445,745)
WRITE(10,624)MPRES
GO TO 25
CONTINUE
CALL MVABS(425,715)
CALL SYMBOL(JSYM)
CALL ANMDE(445,710)
WRITE(10,624)MPRES
25 CONTINUE
C ***** PLOT DATA *****
C 75 CONTINUE
READ(J,510)RUNNO
510 FORMAT(F10.0)
IF(RUNNO.LT.10.0)GO TO 95
READ(J,511)PHIX,PHIO,PHIC,RELMBT,EGR,ISHC,ISCO,ISNO,IKW,
&ISFC,EFF,VL
511 FORMAT(1X,12F10.4)
READ(K)RUN,BPRES,BTEMP,MPRES,NTEMP,FUFL,SPKT,BRKFR,MTRFR
READ(K)HC,NOX,CO2,CQ,O2,MCO2,XTEMP
ISPARK = IFIX(SPKT)
C ***** CHECKING SPARK TIMING POINT *****
C IF(TIMING.EQ.0)GO TO 81
IF(RELMBT.NE.0.0)GO TO 82
GO TO 75
81 IF(RELMBT.EQ.0.0)GO TO 82
GO TO 75
82 CONTINUE
C ***** CHECKING EGR RATE *****
C IF(RATE.EQ.0)GO TO 85
IF(RATE.EQ.5)GO TO 86
IF(EGR.GE.7.0.AND.EGR.LE.11.0)GO TO 90
GO TO 75
85 IF(EGR.EQ.0.0)GO TO 90
GO TO 75
86 IF(EGR.GE.3.0.AND.EGR.LE.6.5)GO TO 90
GO TO 75
90 CONTINUE
C ***** DETERMINE X DATA POINT FOR PLOTTING *****
C IF(XDATA.EQ.1)XPOINT = ISHC
IF(XDATA.EQ.2)XPOINT = ISCO
IF(XDATA.EQ.3)XPOINT = ISNO
IF(XDATA.EQ.4)XPOINT = IKW
IF(XDATA.EQ.5)XPOINT = PHIO
IF(XDATA.EQ.6)XPOINT = EFF
IF(XDATA.EQ.7) XPOINT = ISPARK
IF(XDATA.EQ.8) XPOINT = XTEMP

C

***** DETERMINE Y DATA POINT FOR PLOTTING *****
C

IF(YDATA.EQ.1) YPOINT = ISHC
IF(YDATA.EQ.2) YPOINT = ISC0
IF(YDATA.EQ.3) YPOINT = ISNO
IF(YDATA.EQ.4) YPOINT = IKW
IF(YDATA.EQ.5) YPOINT = PHI0
IF(YDATA.EQ.6) YPOINT = EFF
IF(YDATA.EQ.7) YPOINT = ISPARK
IF(YDATA.EQ.8) YPOINT = XTEMP

C

IF(RATE.EQ.0) CALL DPORT(200,600,500,700,XMIN,XMAX,YMIN,YMAX)
IF(RATE.EQ.5) CALL DPORT(200,600,300,500,XMIN,XMAX,YMIN,YMAX)
IF(RATE.EQ.10) CALL DPORT(200,600,100,300,XMIN,XMAX,YMIN,YMAX)
CALL MOVEA(XPOINT, YPOINT)
CALL SYMBOL(JSYM)

C

GO TO 75
CONTINUE
RE@IND K
RE@IND J
CALL ANMDE(0,0)
RATE = RATE+5
IF(MPOINT.GT.0 AND RATE.LE.10) GO TO 15
IF(RATE.LE.10) GO TO 15
ACCEPT FAKE

C

***** STOP TO TURN OFF PLOTTER *****
C

***** HIT RETURN KEY TO COMPLETE PROGRAM *****

WRITE(10,450)
FORMAT(1X, "PLOT MORE POINTS ? (0-NO; 1-YES)", Z)
ACCEPT MORE
IF(MORE.EQ.0) GO TO 96
MPOINT = MPOINT+1
RATE = 0
GO TO 10

C

CONTINUE
WRITE(10,440)
FORMAT(1X,"(33)CN")
WRITE(10,460)
FORMAT("/1X, "REPEAT PROGRAM ? (NO-0, YES-1)", Z)
ACCEPT NCON
IF(NCON.EQ.0) GO TO 97
MPOINT = 0
RATE = 0
GO TO 10
C

CONTINUE
STOP
END
C ******* DEVMEP.FR ******************************************************
C
C THIS PROGRAM IS DESIGNED TO CALCULATE DEVIATION OF
C THE MEAN EFFECTIVE PRESSURES FROM THE PRESSURE CRANK
C ANGLE DATA GENERATED BY PRESFILE.FR OR PRESAVE.FR AND
C SHIFT THE DATA IN THE PROCESS.
C
C AUTHOR:  K.R. SCHMID
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C ROLLA, MISSOURI 65401
C
C REVISION HISTORY:
C 07/14/80 - CREATED ORIGINAL
C 07/25/80 - REVISED FOR MULTIPLE RUNS
C 12/29/80 - STANDARD DEVIATION ADDED
C 03/08/81 - STANDARD DEVIATION CHANGED TO %
C 07/12/81 - SUBROUTINE EGR ADDED
C
C LOADING INFORMATION:
C RLDR DEVMEP EGR PHASE FORT.LB
C
C DEFINITIONS:
C AIMEP  = AVERAGE INDICATED MEAN EFFECTIVE PRESSURE
C APMEP  = AVERAGE PUMPING LOOP MEPC
C ATMEP  = AVERAGE THERMODYNAMIC MEP
C BORE   = ENGINE BORE (IN.)
C CALB   = CALIBRATION FACTOR (PSI/VOLT)
C CR     = COMPRESSION RATIO
C FIHEP  = FIRING INDICATED MEP
C FIWK   = FIRING INDICATED WORK
C IDATA  = BINARY VOLTAGE DATA
C IFILE  = FILENAME OF PRESSURE DATA
C PMEP   = PUMPING MEP
C R      = CRANK THROW (IN.)
C RL     = CONNECTING ROD LENGTH (IN.)
C SDIHEP = STANDARD DEVIATION OF FIRING INDICATED MEC
C SDPMEP = STANDARD DEVIATION OF PUMPING MEP
C SDTMEP = STANDARD DEVIATION OF THERMODYNAMIC MEP
C TMEP   = THERMODYNAMIC MEP
C
C SET IFIRST = 1 SO RESULT FILE WILL BE CREATED
C SET IFIRST = 2 TO APPEND EXISTING FILE
C
C**************************************************************************
DIMENSION IFILE(10),AFILE(10),DFILE(10),MFILE(10)
DIMENSION FILE(10),DATE(10),KDATE(10)
DIMENSION BFUEL(3),IHEADR(40),IDATA(720),RFILE(10)
DIMENSION VOLT(720),TESTFILE(20),FIMEP(30),PMEP(30),TMEP(30)
DOUBLE PRECISION RUN,RUNNO
COMMON/A/CO2,CO2C2O2,AFRC,AF0,XYF,Y
COMMON/PDATA/PRES(720),PRES(720)
REAL MCO2,NPRES,NTEMP,NOXLE
REAL LHV,NTEMP,MTRFR,NPRES,ISMEP,NOXLE
C
N = 0
CALB = 91.274
BORE = 3.250
R = 2.250
RL = 10.0
CR = 8.0
C
WRITE(10,400)
400 FORMAT(1X,"FILENAME OF DATA:",Z)
READ(11,300)FILE(1)
300 FORMAT(318)
CALL OPEN(0, FILE(1), IER)
IF (IER .NE. 1) TYPE "FILE OPEN ERROR CHAN 0", IER
READ(0) NUM, PREF, JCYCLE, IOUT, IFIRST
READ(0, 510) TESTFILE(1)
READ (0, S10) RFFILE(1)

510 FORMAT(S18)
CALL OPEN(3, TESTFILE, 1, IER)
READ(3, 500) BFUEL(1)

500 FORMAT(S8)
READ(3) LHV, AFS, Y, X, SG, CR, RPM, MPRES, MTEMP, OTEMP,
&WTEMP, XPRES, NOZZLE
CALL FGIM(1HR, IMIN, ISEC)
CALL DATE(KDATE, IER)

C**** READ AND WRITE HEADER INFORMATION *****

WRITE(IOUT, 410) KDATE(1), KDATE(2), KDATE(3), IHR, IMIN, ISEC
WRITE(410) KDATE(1), KDATE(2), KDATE(3), IHR, IMIN, ISEC

410 FORMAT(///,100X, "DATE : I2,"/**, I2,"/**, I2,"/**, 100X,
&"TIME : I2,"/**, I2,"/**, I2,"/**, 100X)
WRITE(410)
WRITE(IOUT, 411)
411 FORMAT(///, "FUEL CHARACTERISTICS :")
WRITE(IOUT, 412) BFUEL(1), LHV, AFS, Y, X, SG
WRITE(412)
WRITE(IOUT, 413)
413 FORMAT(///, "ENGINE CONDITIONS")
WRITE(IOUT, 414) CR, RPM, MPRES, XPRES, MTEMP, OTEMP, WTEMP
WRITE(414)

414 FORMAT(///, "COMPRESSION RATIO ",14X,F4.1,/5X,"ENGINE
& SPEED, RPM ",16X,F5.0,/,5X, "INTAKE MANIFOLD PRESSURE, KPA
&", 4X,F6.2,/,5X, "EXHAUST PRESSURE, KPA ",11X,F5.2,/,5X,
&"MIXTURE TEMP, DEG. F ",12X,F4.0,/,5X, "OIL TEMP, DEG. F
&",15X,F4.0,/,5X, "COOLANT TEMP., DEG. F",12X,F4.0,/)
\[
\sin^2 \alpha = \sin^2 \beta \\
\rho L = (\rho \rho_L)^{**2} \]

\[
q_{\text{nt}} = (1 - \rho L) \sin^2 \alpha \approx 0.5 \\
v = \alpha \cdot (1 - \cos \alpha + \rho L (1 - q_{\text{nt}})) \\
v = (v + v_L) \cdot 0.00001638 \\
120 \quad \text{CONTINUE}
\]

**C**

**CONTINUE**

**READ ENGINE DATA FILE & CALCULATE AIR/FUEL RATIO**

**READ**(0,520) \( \text{RUN}, \text{IFILE}(1), \text{AFILE}(1), \text{DFILE}(1), \text{HFILE}(1) \)

**FORMAT**(10,1,32,12,12)

**READ**(3) \( \text{RUN}, \text{BPRES}, \text{BTEMP}, \text{NPRE}, \text{NTEMP}, \text{FUEL}, \text{BKT}, \text{BKFR}, \text{MTRFR} \)

**IF**(RUN \( \leq 10.0000) \text{GO TO 35}**

**READ**(3) \( \text{HC}, \text{NOX}, \text{CO}, \text{CO}_2, \text{MCO2}, \text{XTEMP} \)

**IF**(RUN \( \neq \text{RUN}) \text{GO TO 16}**

\[
X_{\text{HC}} = \text{HC} / 10000.0 \\
X_{\text{NO}} = \text{NOX} / 10000.0 \\
X_H = 100.0 / (3.0 \times X_{\text{HC}} + \text{NO} + \text{CO}_2) \\
X_2 = (0.0 \times X_H / \text{XNO}/3.0 - \text{CO}/2.0 + \text{H2O}/2.0 + \text{XNO}/2.0 + \text{O}_2 \\
C_2 = (100.0 / X_H - X_2) \\
AFO = 4.76 \times 28.97 / XMF \\
PHIO = AFO / AFS
\]

**CALL** EGR(XEGR)

**CALL** FOPEN(1,IFILE)

**READ** BINARY(1) \( \text{HEA}, \text{ICYCLE} \)

**WRITE**(10,425) \( \text{HEA}, \text{ICYCLE} \)

**FORMAT**(5X,560,5X,12,*) \( \text{CYCLES RECORDED}*,//
\]

**SCALE PRESSURE DATA**

**DO** 200 \( J = 1, \text{ICYCLE} \)

**DO** 100 \( I = 1,720 \)

**READ** BINARY(1) \( \text{DATA}(I) \)

**FACTOR** = \( (\text{CALB} / 3276.7) \times 6.895 \)

**PRES**(I) = \( \text{FLOAT}(\text{DATA}(I)) \)

**PRES**(I) = \( (\text{PRES}(I) - 310.) \times \text{FACTOR} \)

**CONTINUE**

**PRES**(I) = \( \text{PRES}(180) - \text{PREF} \)

**DO** 110 \( I = 1,720 \)

**PRES**(I) = \( \text{PRES}(I) - \text{PRES} \)

**CONTINUE**

**SHIFT PRESSURE DATA BY THE AMOUNT IDEG**

**CALL** PHASE(2)

**CALCULATE WORK**

**WK12T** = 0.0

**DO** 130 \( I = 1,179 \)

**WK12** = \( (\text{PRES}(I) + \text{PRES}(I+1)) \times (\text{VOLT}(I+1) - \text{VOLT}(I)) / 2.0 \)

**WK12T** = **WK12** + **WK12T**

**CONTINUE**

**WK23T** = 0.0

**DO** 140 \( I = 180,359 \)

**WK23** = \( (\text{PRES}(I) + \text{PRES}(I+1)) \times (\text{VOLT}(I+1) - \text{VOLT}(I)) / 2.0 \)

**WK23T** = **WK23** + **WK23T**

**CONTINUE**

**WK34T** = 0.0

**DO** 150 \( I = 360,539 \)

**WK34** = \( (\text{PRES}(I) + \text{PRES}(I+1)) \times (\text{VOLT}(I+1) - \text{VOLT}(I)) / 2.0 \)

**WK34T** = **WK34** + **WK34T**
150 CONTINUE
  WK41T=0.0
  DO 160 I=540,719
    WK41=(PRES(I)+PRES(I+1))*(VOLT(I+1)-VOLT(I))/2.
    WK41T=WK41+WK41T
  CONTINUE
  DEM = VOLD*0.00001638
C
C ***** CALCULATIONS FOR FIRING DATA
C
  FIWK = WK34T+WK23T
  PWK = WK41T+WK12T
  FIMEP(J) = FIWK/DEM
  PMEP(J) = PWK/DEM
  TMEP(J) = (FIWK+PWK)/DEM
C
200 CONTINUE
  REWIND 1
  CALL FCLOSE (1)
C
C ***** FIND THE AVERAGE AND STANDARD DEVIATION
C
  SUM = 0.0
  SUM1 = 0.0
  SUM2 = 0.0
  SIMEP = 0.0
  SPMEP = 0.0
  STMPEP = 0.0
  DO 210 I=1,JCYLE
    SIMEP = SIMEP+I
    SPMEP = SPMEP+I
    STMPEP = STMPEP+I
  CONTINUE
  AIMEP = SIMEP/JCYLE
  APMEP = SPMEP/JCYLE
  ATMPEP = STMPEP/JCYLE
  DO 220 I=1,JCYLE
    SUM = ((FIMEP(I)-AIMEP)**2)*SUM
    SUM1 = ((PMEP(I)-APMEP)**2)*SUM1
    SUM2 = ((TMEP(I)-ATMEP)**2)*SUM2
  CONTINUE
  NCYCLE = JCYLE-1
  SDIMEP = (SUM/NCYCLE)**0.5
  SDPMEP = (SUM1/NCYCLE)**0.5
  SDTMEP = (SUM2/NCYCLE)**0.5
C
C ***** CALCULATE % STANDARD DEVIATION *****
C
  SDIMEP = (SDIMEP/AIMEP)*100.0
  SDPMEP = (SDPMEP/(-1.0*APMEP))*100.0
  SDTMEP = (SDTMEP/ATMEP)*100.0
C
C ***** WRITE OUT RESULTS *****
C
  WRITE(IOUT,430)RUNNO,IFILE(1),PHIO,XEGR,AIMEP,SDIMEP,APMEP,
  &SDPMEP,ATMEP,SDTMEP
  430 FORMAT(1X,F10.0,1X,S11,3X,F5.3,2X,F6.2,5X,F6.1,2X,F6.2,5X,F6.1,
  &2X,F6.2,5X,F6.1,2X,F6.2,5X)
C
  WRITE(4,430)RUNNO,IFILE(1),PHIO,XEGR,AIMEP,SDIMEP,
  &APMEP,SDPMEP,ATMEP,SDTMEP
C
  N=N+1
  IF(N.EQ.NUM)GO TO 25
  GO TO 15
C
25 CONTINUE
  REWIND 0
  REWIND 3
  REWIND 4
  CALL CLOSE(0,IER)
IF(IER.NE.1) TYPE "FILE CLOSE ERROR CHAN 1", IER
 CALL CLOSE(3, IER)
 IF(IER.NE.1) TYPE "FILE CLOSE ERROR CHAN 3", IER
 CALL CLOSE(4, IER)
 IF(IER.NE.1) TYPE "FILE CLOSE ERROR CHAN 4", IER
 STOP
 CONTINUE
 CALL RESET
 CALL CLOSE(0, IER)
 CALL CLOSE(3, IER)
 TYPE "RUN NUMBER NOT FOUND"
 STOP
 END
C ***** ENGPLOT.FR ***********************************************
C
C THIS PROGRAM IS DESIGNED TO READ THE DATAFILE OF ENGINE DATA
C AND CALCULATE THE AMOUNT OF AVAILABLE EXHAUST ENERGY TO POSSIBLE
C DRIVE AN EXHAUST TURBINE. THE DATAFILE HAS THE SAME FORMAT AS THE
C DATAFILE USED IN THE PROGRAM CFRCALC.

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C REVISION HISTORY:
C
04/15/79 - ORGINAL CREATED
12/10/79 - REVISED FOR LEAN SUPERCHARGE STUDY
11/14/80 - ENGERY.FR CREATED FROM CFRCALC.FR
07/12/81 - SUBROUTINE EGR ADDED
09/19/81 - MODIFIED TO PLOT DATA

C LOADING INFORMATION:
C
RLDR ENGPLOT EGR GRID SYMBOL VECTR.LB FORT.LB

C NOMENCLATURE:
C
AFLOW = MASS OF AIR FLOW, LB/MIN
AFS = STOICHIOMETRIC A/F
BFUEL = BASE FUEL NAME, 8 CHARACTERS
BPRES = BAROMETRIC PRESSURE, IN.HG.
BRFR = BEAM FORCE WHEN FIRING, LB
BTEMP = BAROMETRIC TEMPERATURE, F
CEFF = COMPRESSOR EFFICIENCY (%)  
CIP = COMPRESSOR INLET PRESSURE (PSIA)
C0 = CARBON MONOXIDE, %
C02 = CARBON DIOXIDE, %
COP = COMPRESSOR OUTLET PressURE (PSIA)
CPE = EXHAUST SPECIFIC HEAT
CPI = INTAKE SPECIFIC HEAT
CR = COMPRESSION RATIO
FUFL = MASS FUEL FLOW, LB/MIN
HC = HYDROCARBONS, PPM (PROPANE)
ITEMP = COMPRESSOR INLET TEMPERATURE DEG. R
KE = EXHAUST SPECIFIC HEAT RATIO
KI = INTAKE SPECIFIC HEAT RATIO
LHV = LOWER HEATING VALUE OF FUEL, BTU/LB
MASS = MASS FLOW THROUGH THE COMPRESSOR AND TURBINE
MC02 = INTAKE MANIFOLD CO2, %
MPRES = INTAKE MANIFOLD PRESSURE, KPA
MTEMP = INTAKE MANIFOLD TEMPERATURE, DEG F
MTRFR = MOTORING BEAM FORCE, LB
NOX = OXIDES OF NITROGEN, PPM
NOZZLE = NOZZLE NUMBER USED FOR TEST
NPRES = CRITICAL FLOW NOZZLE PRESSURE, PSIG
NTEMP = CRITICAL NOZZLE TEMPERATURE, DEG F
O2 = OXYGEN, %
OTEMP = OIL TEMPERATURE, DEG F
PC = KILOWATTS NEEDED TO DRIVE COMPRESSOR
PHIC = CARBON BASED A/F EQUIVALENCE RATIO
PHIO = OXYGEN BASED A/F EQUIVALENCE RATIO
PHIX = EXPERIMENTAL A/F EQUIVALENCE RATIO
PT50 = KILOWATTS DEVELOPED BY EXHAUST TURBINE @ 50% EFF.
PT75 = KILOWATTS DEVELOPED BY EXHAUST TURBINE @ 75% EFF.
PT85 = KILOWATTS DEVELOPED BY EXHAUST TURBINE @ 85% EFF.
RPM = ENGINE SPEED, RPM
RUNNO = RUN NUMBER, 8 DIGIT NUMBER. 1ST 6 DIGITS = MO/DAY/YEAR
LAST 2 DIGITS = RUN FOR DAY
SG = SPECIFIC GRAVITY OF FUEL, FM/ML
SPKT = SPARK TIMING, DEC BTDC, ENTER DATA IN WHOLE DEG. IDENTIFY
MBT BY ADDING DECIMAL \( 0.1 \); EXAMPLE: 31.5 INDICATES MBT SPARK TIMING OF 31 DEG. 20. = NON MBT SPARK TIMING OF 20 DEGREES.
TIP = TURBINE INLET PRESSURE (PSIG)
WTMP = COOLANT TEMPERATURE, DEG F
XTMP = EXHAUST TEMPERATURE, DEG F
XPRES = EXHAUST PRESSURE, KPA
X = MOLAR O/C RATIO OF FUEL
Y = MOLAR H/C RATIO OF FUEL

C FORMAT FOR DATA ENTRY INTO FILE SCD-:

BFUEL
LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTEMP,OTEMP,WTEMP,XPRES,NOZZLE,SPKT,FM/ML
RUNNO,BPRES,STMP,NPRES,XPRES,FUFL,SPKT,BKFR,MTRFR
HC,NOX,CO2,CO,02,MC02,XTMP
RUNNO,BPRES,STMP,NPRES,XPRES,FUFL,SPKT,BKFR,MTRFR
HC,NOX,CO2,CO,02,MC02,XTMP
0.0.0.0.0.0.0.0.0.0.

ZEROS ARE PLACED AT END OF FILE AS END OF FILE INDICATORS)

C **********************************************************************
C DIMENSION BFUEL(3),FNAME(6),RNAME(6),IDATE(10),KDATE(3)
C DOUBLE PRECISION RUNNO
C COMMON /A/ CO2,MC02,CO2R,AF0,AF0,XMF,Y
C REAL IKW,ISCO,ISHC,IFSC,ISNO,LHV,MTEMP,MTRFR,NOX,MPRES,MC02
C REAL NPRES,NTEMP,NOZZLE,KE,KI,MASS,ITEMP
C CPE = 0.27
C CPI = 0.24
C KE = 1.343
C KI = 1.40
C ITEMP = 585.0
C MORE = 0
C 5 CONTINUE
WRITE(10,400)
FORMAT(1X,"(33)(14)"")
WRITE(10,401)
FORMAT/,5X,"INPUT ENGINE DATA FILENAME:";Z)
WRITE(10,410)
FORMAT(510)
READ(11,300)FNAME(1)
FORMAT(1011)
WRITE(10,411)
FORMAT/,5X,"COMPRESSOR OUTLET PRESSURE (PSIA) ";Z)
ACCEPT COP
FORMAT(5X,"COMPRESSOR EFFICIENCY (%) ";Z)
ACCEPT CEFF
WRITE(10,413)
FORMAT(5X,"TURBINE INLET PRESSURE (PSIG) ";Z)
ACCEPT TIP
WRITE(10,420)
FORMAT(5X,"SPARK TIMING (1-5% POWER LOSS;0-MBT SPARK & TIMING) ";Z)
ACCEPT TIMING
WRITE(10,421)
FORMAT(5X,"EGR RATE (0,5,10 %) = ?",Z)
ACCEPT RATE
CALL OPEN(16,FNAME,1,IER)
IF(IER.NE.1)TYPE"FILE OPEN ERROR CHAN 16",IER
CALL OPEN(15,"TEMP01",3,IER)
IF(IER.NE.1)TYPE "FILE OPEN ERROR CHAN 15",IER
```plaintext
READ(16,500)BFUEL(1)
500 FORMAT(5B)
READ(16)LHV,AFS,Y,X,SG,CR,RPM,MPRES,NTMP,OTEMP,WTMP,
&XPRES,NOZZLE

NUM = 0
CIP13 = 13.0
CIP14 = 14.3
CEFF = CEFF/100.0

CONTINUE
NUM = NUM + 1
READ(16)RINNO,BPRES,BTEMP,MPRES,NTMP,FUFL,SPKT,BKFR,MTFR
IF (RINNO.LT.10.0)GO TO 60
READ(16)HC,NOX,CO2,CO,NO2,CO2,XTEMP

C
C
C
**** BAROMETRIC PRESSURE CORRECTION AND AIR FLOW CALCULATION *****
C
C1=(9.08E-5)*(BTEMP-28.63)
C2=1+(1.01E-4)*(BTEMP-32)
CORR=(C1/C2)*MPRES
ATM=(MPRES-CORR)*0.49075
D = (NTMP+460.0)*0.5
IF(NUZZLE.EQ.2)GO TO 32
AFLOW=0.2175*((ATM+MPRES)**1.0315)/D
GO TO 33
AFLOW=0.468*((ATM+MPRES)**1.066)/D
CONTINUE
AFHASS=AFLOW/FUFL
PHIX=AFHASS/AFS

C
C
C
**** EXHAUST EMISSIONS AIR/FUEL CALCULATIONS *****
C
XHC=HC/10000.0
XNO=NOX/10000.XN=(3*H2O+CO+CO2)/((3*H2O+CO+CO2)+1.)
XMF = 12.01+1.008*Y+1.3*X
A = (3.0*H2O+CO+CO2+H2O)*XN/100.
AFC = (28.97/XMF)*XN*(X+Y)/2.
PHIC = AFC/AFS
B = CO2+CO/2. +H2O/2.+XNO/2.+02
C = (8*XN/100.)-X/2.
AFO = 4.76*28.97/XMF+C
PHIO = AFO/AFS

C
C
C
**** CALCULATION OF COMPRESSOR AND TURBINE POWER *****
C
XTEMP = XTEMP+460.0
MASS = (PHIO*AFS+1.0)*FUFL
YCI3=(((COP/CIP13)**((KI-1.0)/KI))-1.0
YCI4=(((COP/CIP14)**((KI-1.0)/KI))-1.0
YT=1.0-((14.3/(1(IPI+14.3)))**((KE-1.0)/KE))
PC13 = MASS*CI3*XTEMP*YCI3*(1.0/CEFF)*(778.0/33000.0)*0.746
PC14 = MASS*CI4*XTEMP*YCI4*(1.0/CEFF)*(778.0/33000.0)*0.746
PT = MASS*CI1*XTEMP*YT*(778.0/33000.0)*0.746
PT85 = PT*0.85
PT75 = PT*0.75

C
C
C
**** MBT SPARK TIMING CHECK *****
C
ISPK = SPKT
SPKTI = ISPK
DIFF = SPKT-SPKTI
IF(DIFF.LT.0.0)GO TO 35
XMBT = SPKTI
RELMBT = SPKTI-XMBT
```
C ***** EGR CALCULATION
C
  CO2B = 400.0
  CALL EGR(XEGR)
C
C ***** STORE DATA IN FILE (CHAN 15)
C
  WRITE(15,501)RUNNO,PHIX,PHIO,PHIC,RELMBT,XEGR,MASS,PC13,PC14,
  &PT50,PT75,PT85

501  FORMAT(1X,12F10.6)
C
  GO TO 30
  CONTINUE
  CALL CLOSE(16,IER)
C
  WRITE(10,480)
  FORMAT(/,1X," ***** TURN ON PLOTTER ******",/)
  PAUSE
  REWIND 15
  CEFF = CEFF*100.
  WRITE(10,600)

600  FORMAT(1X,"(33)CI 40 75 ")
  CALL GRID(1.0,2.0,0.20,1,0.0,1.0,0.20,1,150,900,130,730,1,1)
C
C ***** LABEL AXIS
C
  CALL ANMDE(400,75)
  WRITE(10,610)
  FORMAT(1X," AIR/FUEL EquIVALENCE RATIO")
  WRITE(10,611)
  FORMAT(1X,"(33)CJ 90 ")
  CALL ANMDE (70,350)
  WRITE(10,612)
  FORMAT(1X," POWER - KW")
  WRITE(10,613)
  FORMAT(1X,"(33)CJ 0 ")
C
  CALL ANMDE(280,68)
  WRITE(10,620)
  FORMAT(1X," TEST CONDITIONS:")
  SICOP = COP*6.875
  CALL ANMDE(280,660)
  WRITE(10,621)SICOP
  FORMAT(1X," COMP OUTLET PRESS =",F6.1," KPA")
  CALL ANMDE(280,635)
  WRITE(10,622)CEFF
  FORMAT(1X," COMP EFF. = ",F4.1," %")
  CALL ANMDE (280,610)
  IF(TI MING.EQ.0)WRITE(10,623)
  IF(TI MING.EQ.1)WRITE(10,624)
  FORMAT(1X," MBT SPARK TIMING")
  FORMAT(1X," S % POWER LOSS")
  CALL ANMDE(280,585)
  WRITE(10,625)RATE
  FORMAT(1X," EGR = ",F4.1," %")
  CALL ANMDE (625,685)
  WRITE(10,626)
  FORMAT(1X," EXHAUST TURBINE EFF")
C
  DO 100 I=1,3
  GOTO (65,66,67) I

65  ISYM = 660
  IPERCENT=50
  GO TO 70
66  ISYM = 635
  IPERCENT=75
  GO TO 70
67  ISYM = 610
  IPERCENT=85
C
70  CONTINUE

CALL MVABS(675, ISYM)
CALL SYMBOL(1)
ISYM = ISYM - 5
CALL ANMDE(705, ISYM)
WRITE(10, 630) IPERCENT
630 FORMAT(1X, 12, " % ")
100 CONTINUE
CALL ANMDE(625, 580)
WRITE(10, 635)
635 FORMAT(1X, "COMP INLET PRESS")
CALL MVABS(675, 560)
CALL SYMBOL(1)
CALL ANMDE(705, 555)
WRITE(10, 636)
636 FORMAT(1X, "89.6 KPA")
CALL MVABS(675, 535)
CALL SYMBOL(2)
CALL ANMDE(705, 530)
WRITE(10, 637)
637 FORMAT(1X, "98.6 KPA")

C **** PLOT DATA

NUM = NUM - 1
DO 110 I = 1, NUM
READ(IS, 50) RUNNO, PHI0, PHI0, PHIC, RELMBT, XEGR, MASS, PC13, PC14,
P7S0, P7S, P85
C
C ***** CHECK SPARK TIMING
C
IF(TIHING.EQ.0) GO TO 40
IF(RELMBT.NE.0) GO TO 41
GO TO 110
40 IF(RELMBT.EQ.0.0) GO TO 41
GO TO 110
41 CONTINUE
C
C ***** CHECK EGR RATE
C
IF(RATE.EQ.0) GO TO 80
IF(RATE.EQ.5) GO TO 81
IF(XEGR.GE.7.0 AND XEGR.LE.11.0) GO TO 85
GO TO 110
80 IF(XEGR.EQ.0) GO TO 85
GO TO 110
81 IF(XEGR.GE.3.0 AND XEGR.LE.6.50) GO TO 85
GO TO 110
85 CONTINUE
C
C ***** DETERMINE Y-DATA POINT FOR PLOTTING
C
IF(IDATA.EQ.1) YPOINT=PT50
IF(IDATA.EQ.2) YPOINT=PT75
IF(IDATA.EQ.3) YPOINT=PT85
C
CALL DPORT(150, 900, 130, 730, 1.0, 2.0, 0.0, 0.0, 1.0)
CALL MOVEA(PHI0, PT50)
CALL SYMBOL(1)
CALL MOVEA(PHI0, PT75)
CALL SYMBOL(2)
CALL MOVEA(PHI0, PT85)
CALL SYMBOL(3)
CALL MOVEA(PHI0, PC13)
CALL SYMBOL(1)
CALL MOVEA(PHI0, PC14)
CALL SYMBOL(2)
110 CONTINUE
C
CALL ANMDE(0, 0)
REWIND 15
CALL CLOSE(15, IER)
IF (IER .NE. 1) TYPE "FILE CLOSE ERROR CHANNEL 15", IER
CALL DFILW("TEMP01", IER)
IF (IER .NE. 1) TYPE "FILE DELETE ERROR CHANNEL 15", IER
WRITE(10, 440)
FORMAT(1X, '(33) CN")
ACCEPT FAKE
WRITE(10, 450)
FORMAT(1X, "REPEAT PROGRAM ? (0-NO, 1-YES)", Z)
ACCEPT NCW
IF (NCW .EQ. 0) GO TO 90
GO TO 5
90 CONTINUE
STOP
END
C ***** HEATREL.FR  **********************************************************************
C
C THIS PROGRAM IS DESIGNED TO DETERMINE AND WRITE OUT
C NUMERICAL RESULTS FOR AN APPROXIMATION OF THE HEAT RELEASE FOR A SPARK
C IGNITION ENGINE FROM PRESSURE (VOLTAGE DATA) VS. CRANK ANGLE DATA
C OBTAINED FROM THE ENGINE LAB AND STORED ON DISK OR FLOPPY. THE
C PROGRAM WAS DEVELOPED FROM A CONCEPT GIVEN IN SAE PAPER NO. 780967.
C
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C ROLLA, MISSOURI 65401
C
C REVISION HISTORY
C 8/1/80 ORGINAL CREATED
C 9/13/80 REVISED FOR MULTIPLY RUNS
C 7/12/81 SUBROUTINE EGR ADDED
C
C LOADING INFORMATION
C RLDR HEATREL EGR PHASE FORT.LB 12/C
C
C DEFINITIONS:
C FILE = FILENAME
C IDATA = BINARY VOLTAGE DATA
C PRES = CALIBRATED PRESSURE DATA
C CALB = CALIBRATION FACTOR (PSI/VOLT)
C BORE = ENGINE BORE (IN.)
C R = ENGINE CRANK THROW (IN.)
C RL = CONNECTING ROD LENGTH (IN.)
C CR = COMPRESSION RATIO
C CSLOPE = SLOPE OF COMPRESSION LINE (LOG-LOG PLOT)
C DSLOPE = SLOPE AT DATA POINT
C ESLOPE = SLOPE OF EXPANSION LINE
C IGN = SPARK TIMING
C IGN1 = 20 DEGREES BEFORE SPARK TIMING
C EVO = EXHAUST VALVE OPENING
C EVO1 = 20 DEGREES BEFORE EXHAUST VALVE OPEN
C CPOINT = EXTRAPOLATION OF COMPRESSION LINE TO ORDEINATE AXIS
C DPOINT = DATA POINT
C EPOINT = EXTRAPOLATION OF EXPANSION LINE TO ORDEINATE AXIS
C COMB = COMBUSTION DURATION
C MFB = MASS FRACTION BURNED
C START = START OF COMBUSTION
C FINISH = END OF COMBUSTION
C
C ****************************************************************************
DIMENSION RFILE(10),IHEADR(40),IDATA(720),TESTFILE(20)
DIMENSION IFILE(10),AFILE(10),DFILE(10),MFILE(10)
DIMENSION VOLT(720),RATE(720),XMFB(720)
DIMENSION IDATE(10),KDATE(3),BFUEL(3),FILE(20)
DOUBLE PRECISION RUN, RUNNO
COMMON /A/ CO2,CO2Z,CO2B,AF0,AF0,XMF,Y
COMMON /PDATA/ PRES(720),PRESS(720)
REAL MCO2,NPRE,NTMP,NOZE,LHV,MTMP,MTFR,MPRES,NOX
INTEGER EVO,EVO1,SPARK,START,FINISH,COMB
C
CALB = 91.274
BORE = 3.250
R = 2.250
RL = 10.0
CR = 8.0
EVO = 500
EVO1 = 480
MCURVE = 0
C

N = 0

WRITE(10,400)
400 FORMAT(1X, "FILENAME OF DATA: ",Z)
READ(11,300)FILE(1)
300 FORMAT(S18)
ACCEPT "OUTPUT DEVICE CODE (10-CONSOLE; 12-PRINTER);IOUT"
CALL OPEN(0,FILE(1),IER)
IF(IER.NE.1) TYPE "FILE OPEN ERROR - CHAN 0",IER
READ(0,S10)TESTFILE(1)
READ(0,S10)RFILE(1)

510 FORMAT(S18)
CALL OPEN(3,TESTFILE,1,IER)
IF(IER.NE.1)TYPE "FILE OPEN ERROR - CHAN 3",IER
CALL OPEN(4,RFILE,2,IER)
IF(IER.NE.1)TYPE "FILE OPEN ERROR - CHAN 4",IER
READ(3,500)BFUEL(1)

500 FORMAT(S8)
READ(3)LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTEMP,OTEMP,
& TEMP, XPRES, NOZLE
CALL FGTM(INHR,IMIN,ISEC)
CALL DATE(KDATE,IER)
IF(IER.NE.1) TYPE "ERROR IN CALLING THE DATE"

C

***** READ AND WRITE HEADER INFORMATION *******

C

IF(IOUT.NE.10)GO TO 6
WRITE(IOUT,700)
700 FORMAT(1X, "(33)(46)(153)(62)(123)"
6 WRITE(IOUT,401)KDATE(1),KDATE(2),KDATE(3),INHR,IMIN,ISEC
401 FORMAT(///,100X, "DATE": "I2","/","I2","/","I2","/","I2","/","100X,
& TIME": "I2","/",":","I2","/","I2","/","I2","/"))
WRITE(IOUT,402)
402 FORMAT(///, "FUEL CHARACTERISTICS :)"
WRITE(IOUT,403)BFUEL(1),LHV,AFS,Y,X,SG
403 FORMAT(5X,"BASE FUEL ": "I1X",S8,"/",S5,"LOWER HEATING VALUE": "I2X,
&F6.0,"/",S5,"STOICHIOMETRIC A/F": "2X",F6.3,"/",S5,"FUEL MOLECULE ",
&A7X,"CH": "F5.3","O"("F5.3"," ","S5,"SPECIFIC GRAVITY": "6X,
&F5.3",""))
WRITE(IOUT) "ENGINE TEST CONDITIONS"
WRITE(IOUT,404)CR,RPM,MPRES,XPRES,MTEMP,OTEMP,WTEMP
404 FORMAT(///,5X,"COMPRESSION RATIO": "4X",F4.1,"/",5X,"ENGINE
& SPEC. RPM": "4X",F5.0,"/",5X,"INTAKE MANIFOLD PRESSURE, KPA
&": "4X",F6.2,"/",5X,"EXHAUST PRESSURE, KPA": "1X",F5.2,"/",5X,
& MUSURE TEMP., DEG. F": "12X",F4.0,"/",5X,"OIL TEMP., DEG. F"
&": "15X,F4.0,"/",5X,"COOLANT TEMP., DEG. F": "12X",F4.0,"/")
WRITE(IOUT,408)
WRITE(IOUT,405)
WRITE(IOUT,406)
WRITE(IOUT,407)
WRITE(IOUT,409)
WRITE(IOUT,407)
WRITE(IOUT,405)
WRITE(IOUT,406)
WRITE(IOUT,407)
WRITE(IOUT,408)
WRITE(IOUT,404)
WRITE(IOUT,400)
WRITE(IOUT,409)
WRITE(IOUT,407)
WRITE(IOUT,406)
WRITE(IOUT,405)
WRITE(IOUT,404)
WRITE(IOUT,400)
WRITE(IOUT,403)BFUEL(1),LHV,AFS,Y,X,SG
WRITE(IOUT) "ENGINE TEST CONDITIONS"
WRITE(IOUT,404)CR,RPM,MPRES,XPRES,MTEMP,OTEMP,WTEMP
WRITE(IOUT,408)
WRITE(IOUT,405)
WRITE(IOUT,406)
WRITE(IOUT,407)
WRITE(IOUT,408)
WRITE(IOUT,409)
WRITE(IOUT,407)
WRITE(IOUT,406)
WRITE(IOUT,405)
WRITE(IOUT,404)
WRITE(IOUT,400)
WRITE(IOUT,403)BFUEL(1),LHV,AFS,Y,X,SG
WRITE(IOUT) "ENGINE TEST CONDITIONS"
WRITE(IOUT,404)CR,RPM,MPRES,XPRES,MTEMP,OTEMP,WTEMP
WRITE(IOUT,408)
WRITE(IOUT,405)
WRITE(4,407)

CALL OPEN(16,"TEMP01",3,IER)
IF(IER.NE.1)WRITE(*,13)IER

OPEN TEMPORARY STORAGE FILES

CALL OPEN(1B "TEMP01",13,IER)
IF(IER.NE.1)WRITE(*,16)IER

CALCULATE VOLUME *****

VOLD = BORE**2.0*0.7854*R*2.0
VOLC = VOLD/(CR-1.0)
VOLMAX = VOLD+VOLC
DO 100 I=1,1720
J=I-1
CA = FLOAT(J)
CA = CA**0.01745
SINA = SIN(CA)
COSA = COS(CA)
AP = (BORE**2)*0.7854
SIN2A = SINA**2
RL2 = (R/RL)**2
QNT = (1.0-RL2*SIN2A)**0.5
VOL = AP*(1.0-COSA)+RL2*(1.0-QNT)
VOLT(I) = ((VOL+VOLC)/VOLMAX)*100.
TEMP = VOLT(I)
VOLT(I) = ALOG10(TEMP)
CONTINUE
LHV = LHV*1.054

READ ENGINE DATA FILE & CALCULATE AIR/FUEL RATIO *****

MFB25 = EVO
MFB50 = EVO
MFB75 = EVO
START = EVO
FINISH = EVO
COMB = EVO
SUM = 0.0

READ(0,520)RUN,IFILE(1),AFILE(1),DFILE(1),MFILE(1)
FORMAT(F10.0,S12,S12,S12,S12)
READ(3)RUNNO,BPRES,BTMP,MPRES,NTEMP,FLUL,SPRK,BKR,MTRFR
IF(RUNNO.LE.10.0)GO TO JS
READ(3)HC,NOX,CO2,C02,AG02,XTEMP
IGN = IFIX(SPRK)
IF(RUN.NE.RUNNO)GO TO 16
XHC = HC/10000.0
XNO = NOX/10000.0
XN = (100.0*(3.0**XHC+CO+C02))/((CO/(3.0+C02)+1.0)
XMF = 12.01+1.008*Y+16.01*X
A = (3.0**XHC-C02/2.0+1.5**H2O)**XN/100.0
B = CO2+CO/2.0+H2O/2.0+XNO/2.+D2
C = (B*XN/100.0-X/2.0
AFO = 4.76**28.97/XMF*IC
PHIO = AFO/AFS
C02B = 400.0
CALL EGR(XEGR)

READ AND WRITE FILE HEADER ****

CALL FOPEN(1,AFILE)
READ BINARY (1) IHEADR,ICYCLE
WRITE(10,410)IHEADR(1),ICYCLE
FORMAT(5X,560,5X,12," CYCLES RECORDED",/)

FACTOR = (CALB/3276.7)*6.895
DO 110 I=1,720
READ BINARY (1) IDATA(I)
PRES(I) = FLOAT(IDATA(I))
PRES(I) = (PRES(I)-310.)*FACTOR
CONTINUE
PRES = PRES(180)-PREF
DO 120 I=1,720
TEMP = PRES(I)-PRES
PRES(I) = ALOG10(TEMP)
CONTINUE
C
C **** SHIFT PRESSURE DATA BY THE AMOUNT IDEG
C
IDEG = 2
CALL PHASE(IDEG)
C
CALL FCLOSE(I)
C
C **** CALCULATE APPROXIMATE HEAT RELEASE CURVE ****
C
SPARK = IGN
IGN1 = IGN-20
XMFB(IGN1) = 0.0
XMFB(IGN1+1) = 0.0
CSLOPE = (PRES(IGN1)-PRES(IGN))/VOLT(IGN1)-VOLT(IGN))
ESLOPE = (PRES(EV0+1)-PRES(EV0))/VOLT(EV0+1)-VOLT(EV0))
CPPOINT = (-CSLOPE)*VOLT(IGN)+1.0)+PRES(IGN)
EPPOINT = (-ESLOPE)*VOLT(EV0)+1.0)+PRES(EV0)
DIFF = EPPOINT-CPPOINT
C
DO 130 K=580,720
SUM = SUM + PRES(K)
130 CONTINUE
AVEEXH = SUM/141.0
VOLS = ((AVEEXH-EPPOINT)/ESLOPE)+1.0
VOLS = ((10.0**VOLS)*VOLMAX)/100.0
RES = VOLC/VOLS
AVEEXH = 10.0**AVEEXH
TRAPF = (FUFL*2.0)*453.6/RPM
THEAT = TRAPF*LHV
TRAPF = (TRAPF*(1.0+AFD))/(1.0*RES)
C
DO 135 I=IGN1,EV0
DSLOPE = CSLOPE*(1.0-XMFB(I-1))+ESLOPE*(XMFB(I-1))
DPPOINT = -(DSLOPE)*VOLT(I)-1.0)+PRES(I)
XMFB(I) = (DPPOINT-CPPOINT)/(EPPOINT-CPPOINT)
C
C **** DETERMINE HEAT RELEASE RATE ****
C
RATE(I) = XMFB(I)-XMFB(I-1)
C
C **** DETERMINE SELECTED POINTS AND FLAG ****
C
IF(XMFB(I).LE.0.0005)XMFB(I)=0.0000
IF(XMFB(I).GE.9999)XMFB(I) = 1.0000
IF(XMFB(I).LE.0.020 AND XMFB(I).GE.0.005)START=I-360
IF(XMFB(I).LE.0.920 AND XMFB(I).GE.0.890)FINISH=I-360
IF(XMFB(I).LE.275 AND XMFB(I).GE.225)MFB25 = I
IF(XMFB(I).LE.525 AND XMFB(I).GE.475)MFB50 = I
IF(XMFB(I).LE.775 AND XMFB(I).GE.725)MFB75 = I
135 CONTINUE
COMB = FINISH-START
IGN = IGN-360
CA25 = FLOAT(MFB25)
CA50 = FLOAT(MFB50)
CA75 = FLOAT(MFB75)
C
C **** OUTPUT NUMERICAL RESULTS ****
C
C

423  FORMAT(2X,F10.0,1X,F6.3,1X,F6.2,3X,F6.5,2,3X,F5.2,3X,F5.2,3X,
     &F6.3,5X,F7.4,3X,F7.4,3X,F7.5X,I3,6X,I3,6X,I3,6X,I3,6X,I3,)

C

WRITE(BINARY(16),RUNNO,PHIO,XEGR,CA25,CA50,CA75,RATE(MFB50),
     &RATE(MFB75)
N = N+1
IF(N.EQ.NUM)GO TO 25
GO TO 15
TYPE"RUNNO NOT FOUND"
CONTINUE
REWIND 16
WRITE(IOUT,429)
WRITE(IOUT,430)
WRITE(IOUT,431)
WRITE(IOUT,432)
WRITE(4,429)
WRITE(4,430)
WRITE(4,431)
WRITE(4,432)

C

DO 140 I=1,NUM
READ BINARY(16),RUNNO,PHIO,XEGR,CA25,CA50,CA75,RATE25,RATE50,
     &RATE75
WRITE(IOUT,433)RUNNO,PHIO,XEGR,CA25,RATE25,CA50,RATE50,
     &CA75,RATE75
WRITE(4,433)RUNNO,PHIO,XEGR,CA25,RATE25,CA50,RATE50,
     &CA75,RATE75
CONTINUE

C

429  FORMAT(1X,"///.40X","*** MASS FRACTION BURN RATE ***","///)
430  FORMAT(3X,"Run No.",5X,"PHI",5X,"EGR",4X,"--- 25% MFB ----",
     &5X,"---- 50% MFB ----",5X,"---- 75% MFB ----")
431  FORMAT(15X,"OXY",6X,"\%",5X,"CRANK",4X,"MFB RATE",5X,
     &"CRANK",5X,"MFB RATE",5X,"CRANK",4X,"MFB RATE")
     &5X,"ANGLE",4X,"1/DEG")
433  FORMAT(1X,F10.0,2X,F6.3,1X,F6.2,5X,F4.0,3X,F8.5,7X,F4.0,
     &4X,F8.5,F4.0,3X,F8.5)
IF(IOUT.EQ.10)GO TO 7
WRITE(IOUT,701)

701  FORMAT(1X,*"(33)(46)(153)(60)(123)"")

C

7  CALL RESET
CALL DFILW("TEMP01",IER)
IF(IER.NE.1)TYPE"FILE ERROR (DELETE)"
STOP
END
C ***** LPVPLTO.FR **********************************************************************
C THIS PROGRAM IS DESIGNED TO PLOT LOG-PRESSURE VS LOG-VOLUME
C DATA FROM A FILE CONTAINING VOLTS (PRESSURE) VS CRANK ANGLE DATA.
C
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C
C REVISION HISTORY:
C
C 10/13/79 - CREATED ORIGINAL
C 10/15/79 - UPDATE ORIGINAL
C 7/12/80 - UPDATE WITH SUBROUTINE PHASE
C 8/13/80 - UPDATED WITH SUBROUTINE GRID
C
C LOADING INFORMATION
C RLDR LPVPLTO PHASE GRID VECTR.LB FORT.LB
C
C DEFINITIONS:
C BORE = ENGINE BORE(IN.)
C CALB = CALIBRATION FACTOR(PSI/VOLT)
C CR = COMPRESSION RATIO
C DATA = BINARY VOLTAGE DATA
C IFILE = FILENAME OF PRESSURE DATA
C PRES = CALIBRATED PRESSURE DATA
C R = ENGINE CRANK THROW (IN.)
C RL = CONNECTING ROD LENGTH
C
C ************************************************************************************
C DIMENSION IFILE(10),IHEADR(40),IDATA(720),VOLT(720)
C COMMON /PDATA/PRES(720)
C
C CALB = .91274
C BORE = 3.250
C R = 2.250
C RL = 10.0
C CR = 8.0
C MCURVE = 0
C
C CONTINUE
C WRITE(10,400)
C 400 FORMAT(1X,"(33)(14)"
C WRITE(10,401)
C 401 FORMAT(1X," INPUT FILE:"",Z)
C READ(11,301)IFILE
C 301 FORMAT(S10)
C WRITE(10,402)
C 402 FORMAT(1X," ABSOLUTE REFERENCE PRESSURE (KPA) : ",Z)
C READ(11,302)PREF
C 302 FORMAT(F6.2)
C WRITE(10,403)
C 403 FORMAT(1X," PRESSURE SHIFT (DEGREES) : ",Z)
C READ(11,303)JDEC
C 303 FORMAT(I1)
C CALL FOPEN(0,IFILE)
C READ BINARY (0)IHEADR,ICYCLE
C
C C ***** WRITE FILE HEADER AND DESCRIPTIVE HEADER *****
WRITE(10,404) IHEADR(1), ICYCLE
WRITE(10,405)
405   FORMAT(/,4X,S78,//,4X,12," CYCLES RECORDED")
WRITE(10,410)
410   FORMAT(/,1X," NUMBER OF CYCLES TO PLOT = ? ",Z)
ACCEPT JCYCLE
WRITE(10,410)
410   FORMAT(/,1X," ****** TURN ON PLOTTER ****** ",/)
PAUSE
IF(MCURVE.EQ.1)GO TO 11
C ****** CALCULATE VOLUME ******
C  VOLD = BORE**2.0*0.7854*R**2
  VOLC = VOLD/(CR-1.0)
  VOLMAX = VOLD+VOLC
  DO 100 I=1,720
      J=I-1
      CA = FLOAT(I)
      CA = CA*0.01745
      SINA = SIN(CA)
      COSA = COS(CA)
      AP = (BORE**2)*0.7845
      SIN2A = SINA**2
      RL2 = (R/RL)**2
      QNT = (1.-RL2*SIN2A)**0.5
      VOL = AP*(1.-COSA)+RL*(1.-QNT)
      VOLT(I) = VOL+VOLC/VOLMAX*100.0
      TEMP = VOLT(I)
      VOLT(I) = ALOG10(TEMP)
100  CONTINUE
C ****** DRAW GRID ******
C  WRITE(10,600)
600   FORMAT(/X,"(33)CI 40 75 ")
     CALL GRID(1.0,2.0,0.2,1,1.0,4.0,1.0,1,150,900,130,730,1,1)
C  CALL ANMDE(580,670)
610   WRITE(10,610)I FILE(1)
       FORMAT(/1X,16,INPUTFILE: ",,518)
       CALL ANMDE(580,640)
       WRITE(10,611)PREF
611   FORMAT(/1X,"MANIFOLD PRESS. (KPA) ",F8.2)
       CALL ANMDE(430,75)
       WRITE(10,612)
612   FORMAT(/1X,"LOG10 - % OF MAX. VOL. ")
       WRITE(10,613)
613   FORMAT(/1X,"(33)CI 90 ")
       CALL ANMDE(50,300)
       WRITE(10,614)
614   FORMAT(/1X,"LOG10 - PRESSURE (KPA)")
       WRITE(10,615)
615   FORMAT(/1X,"(33)CI 0")
C  ****** PLOT PRESSURE VS. VOLUME DATA ******
C 11 CONTINUE
11   CALL DPORT(150,900,130,730,1.,2.,1.,4.8)
     FACTOR = (CALB/3276.7)*6.895
     DO 200 J=1,ICYCLE
         DO 210 I=1,720
             READ BINARY(I) IDATA(I)
             PRES(I) = FLOAT(IDATA(I))
             PRES(I) = (PRES(I)-310.)*FACTOR
200     CONTINUE
     PRESC = PRES(180)-PREF
     DO 220 I=1,720
         TEMP = PRES(I)-PRESC
         PRES(I) = ALOG10(TEMP)
220 CONTINUE
   CALL PHASE(JDEG)
C
   VOLT2=VOLT(1)
   PRES2=PRES(1)
   CALL MOVEA(VOLT2,PRES2)
   DO 225 I=2,720
      VOLTX=VOLT(I)
      PRESY=PRES(I)
      CALL DRAWA(VOLTX,PRESY)
   CONTINUE
   CALL MVABS(150,130)
   CONTINUE
   CALL FCLOSE(0)
   CALL MVABS(0,0)
   WRITE(10,601)
601 FORMAT(1X,"(33) CN")
   CALL ANMDE(0,0)
   ACCEPT FAKE
C ***** STOP TO TURN OFF PLOTTER *****
C ***** HIT RETURN KEY TO COMPLETE PROGRAM *****
   WRITE(10,430)
430 FORMAT(/1X," PLOT A SECOND CURVE ? (NO-0,YES-1)*",Z)
   READ(11,330)MCURVE
330 FORMAT(1I1)
   IF(MCURVE.EQ.1)GO TO 10
   WRITE(10,435)
435 FORMAT(/1X," REPEAT PROGRAM ? (NO-0,YES-1)*",Z)
   READ(11,335)NCON
335 FORMAT(1I1)
   IF(NCON.EQ.1)GO TO 10
STOP
END
**MEPS.FR**

**THIS PROGRAM IS DESIGNED TO CALCULATE VARIOUS INDICATED MEAN EFFECTIVE PRESSURES FROM THE PRESSURE - CRANK ANGLE DATA GENERATED FROM PRESFILE OR PRESAVE. THE DEFINITIONS FOR THE TERMS WERE BASED UPON S.A.E PAPER NO. 7500026.**

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**REVISION HISTORY:**
7/14/80 - CREATED ORIGINAL
7/25/80 - REVISED FOR MULTIPLE RUNS
7/13/81 - REVISED TO STORE RESULTS IN DATAFILE

**LOADING INFORMATION:**
RLDR MEPS SHIFT FORT.LB 11/C

**DEFINITIONS:**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFILE</td>
<td>FILENAME</td>
</tr>
<tr>
<td>IDATA</td>
<td>BINARY VOLTAGE DATA</td>
</tr>
<tr>
<td>PRESS</td>
<td>CALIBRATED PRESSURE DATA</td>
</tr>
<tr>
<td>CALB</td>
<td>CALIBRATION FACTOR (PSI/VOLT)</td>
</tr>
<tr>
<td>BORE</td>
<td>ENGINE BORE (IN.)</td>
</tr>
<tr>
<td>R</td>
<td>ENGINE CRANK THROW (IN.)</td>
</tr>
<tr>
<td>RL</td>
<td>CONNECTING ROD LENGTH (IN.)</td>
</tr>
<tr>
<td>CR</td>
<td>COMPRESSION RATIO</td>
</tr>
<tr>
<td>BSMEP</td>
<td>BRAKE MEP (SCALE)</td>
</tr>
<tr>
<td>ISMEP</td>
<td>INDICATED MEP (SCALE)</td>
</tr>
<tr>
<td>FIWK</td>
<td>FIRING INDICATED WORK</td>
</tr>
<tr>
<td>PWK</td>
<td>FIRING PUMPING WORK</td>
</tr>
<tr>
<td>FIMEP</td>
<td>FIRING INDICATED MEP</td>
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<tr>
<td>PMEP</td>
<td>FIRING PUMPING MEP</td>
</tr>
<tr>
<td>FMEP</td>
<td>FIRING FRICTIONAL MEP</td>
</tr>
<tr>
<td>SMMEP</td>
<td>MOTOR MEP (SCALE)</td>
</tr>
<tr>
<td>XIWK</td>
<td>MOTORING INDICATED WORK</td>
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<tr>
<td>XPW</td>
<td>MOTORING PUMPING WORK</td>
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<tr>
<td>XIMEP</td>
<td>MOTORING INDICATED MEP</td>
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<td>XPMEP</td>
<td>MOTORING PUMPING MEP</td>
</tr>
<tr>
<td>XFMEP</td>
<td>MOTORING FRICTIONAL MEP</td>
</tr>
</tbody>
</table>

SET IFIRST = 1 TO CREAT A RESULT FILE
SET IFIRST = 2 TO APPEND A EXISTING RESULT FILE

**DIMENSION**

```
DIMENSION RFILE(10),FILE(10),IDATE(10),KDATE(10)
DIMENSION IFILE(10),AFILE(10),DFILE(10),MFILE(10)
DIMENSION BFUEL(3),HHEADR(40),MHEADR(40),IDATA(720,2)
DIMENSION VOLT(720),TESTFILE(20)
DOUBLE PRECISION RUNNO,RUN
COMMON /PDATA/ PRES(720,2),TRES(720,2)
REAL MCO2,MPRES,NTEMP,NOXLE
REAL LHV,MTEMP,MTFRF,MPRES,ISMEP,NOX
```

N = 0
CALB = 91.274
BORE = 3.250
R = 2.250
110

RL = 10.0
CR = 8.0

C

WRITE(10,400)
FORMAT(1X, "FILENAME OF DATA:", Z)
READ(11,300)FILE(1)

300 FORMAT(S18)
CALL OPEN(0,FILE(1),IER)
IF (IER.NE.1) TYPE " FILE OPEN ERROR - CHANNEL 0", IER
READ(0,NUM,PREF,IFIRST
READ(0,S10)TESTFILE(1)
READ(10,510)RFILE(1)

510 FORMAT(S18)
CALL OPEN(3,TESTFILE,1,IER)
READ(3,500)BFUEL(1)

500 FORMAT(S8)
READ(3)LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTEMP,TEMP,XPRES,WTEMP,
& COMPRESS Ratio, "ENGINE TEST CONDITIONS"
WRITE(3,420)
GO TO 6
CONTINUE
CALL APPEND(4,RFILE,2,IER)
IF (IER.NE.1) TYPE " FILE APPEND ERROR - CHANNEL 4", IER
WRITE(4,410)KDATE(1),KDATE(2),KDATE(3),IHR,MIN,S,
& "TIME: " ,I2, ",", I2, ",", I2,
& DATE Bands: "ENGINE TEST CONDITIONS"
WRITE(4,413)CR,RPM,MPRES,XPRES,MTEMP,TEMP,WTEMP

413 FORMAT(1X, "COMPRESSION RATIO", 14X,F4.1,/SX,"ENGINE"
& SPEED,RPM", 16X,F5.0, /SX,"INTAKE MANIFOLD PRESSURE, KPA"
& "MIXTURE TEMP., DEG F",12X,F4.0, /SX,"OIL TEMP., DEG F"
& "12X,F4.0, /SX,"COOLANT TEMP., DEG F",12X,F4.0,/)
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DO 125 J = 1, 2
WK12T=0.0
DO 130 I=1,179
WK12=(PRES(I,J)+PRES((I+1),J))*(VOLT(I+1)-VOLT(I))/2.0
WK12T=WK12+Wk12T
130 CONTINUE
WK23T=0.0
DO 140 I=180,359
WK23=(PRES(I,J)+PRES((I+1),J))*(VOLT(I+1)-VOLT(I))/2.0
WK23T=WK23+Wk23T
140 CONTINUE
WK34T=0.0
DO 150 I=360,539
WK34=(PRES(I,J)+PRES((I+1),J))*(VOLT(I+1)-VOLT(I))/2.0
WK34T=WK34+Wk34T
150 CONTINUE
WK41T=0.0
DO 160 I=540,719
WK41=(PRES(I,J)+PRES((I+1),J))*(VOLT(I+1)-VOLT(I))/2.0
WK41T=WK41+Wk41T
160 CONTINUE
DEm = VOLD*0.00001638
IF(J.EQ.2)GO TO to
C
C ***** CALCULATIONS FOR FIRING DATA
C
BSMPEP = BKFR*27.89
ISMEP = (BKFR+MTRFR)*27.89
FIWK = WK34T+WK23T
PWK = WK41T+WK12T
FIMEP = FIWK/DEm
PMEP = PWK/DEm
FMEP = -BSMPEP+FIMEP+PMEP
C
C ***** CALCULATIONS FOR MOTORIZING DATA *****
C
10 CONTINUE
SMMEP = MTRFR*27.89
XFIWK = WK34T+WK23T
XPWK = WK41T+WK12T
XFIMEP = XFIWK/DEm
XPMEP = XPWK/DEm
XFMEP = SMMEP+XFIMEP+XPMEP
C
C ***** WRITE OUT RESULTS *****
C
WRITE(12,430)RUNNO,PHIO,BKFR,MTRFR,SMMEP,ISMEP,FIMEP,PMEP
&FMEP,XFIMEP,XPMEP,XFMEP
WRITE(4,430)RUNNO,PHIO,BKFR,MTRFR,SMMEP,ISMEP,FIMEP,PMEP
&FMEP,XFIMEP,XPMEP,XFMEP
430 FORMAT(1X,F10.2,F5.2,3X,F5.2,3X,F5.2,3X,F6.2,3X,F6.2,3X)
N=N+1
IF(N.EQ.NUM)GO TO 25
GO TO 15
25 CONTINUE
REWIND 0
REWIND 3
REWIND 4
CALL RESET
STOP
35 CONTINUE
REWIND 0
REWIND 3
REWIND 4
CALL RESET
TYPE* RUN NUMBER NOT FOUND"
STOP
END
C **** MFBPLOT.FR ******************************************************************************
C
C THIS PROGRAM IS DESIGNED TO DETERMINE AND PLOT THE
C APPROXIMATION OF THE MASS FRACTION CURVE FOR A
C SPARK IGNITION ENGINE FROM A FILE CONTAINING
C VOLTS(PRESSURE) VS. CRANK ANGLE DATA. DEVELOPED
C FROM CONCEPT GIVEN IN S.A.E. PAPER NO. 780967.
C
C AUTHOR: K.R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MISSOURI-ROLLA
C ROLLA, MISSOURI 65401
C
C REVISION HISTORY
C
C 08/1/80 ORGINAL CREATED
C 11/22/80 PLOTTING ADDED
C 07/12/81 SUBROUTINE EGR ADDED
C
C LOADING INFORMATION:
C
C DEFINITIONS:
C
C BORE = ENGINE BORE (IN.)
C CALB = CALIBRATION FACTOR (PSI/VOLT)
C COMB = COMBUSTION DURATION
C CPOINT = EXTRAPOLATION OF COMPRESSION LINE TO ORDIINATE AXIS
C CSLOPE = SLOPE OF COMPRESSION LINE (LOG-LOG PLOT)
C CR = COMPRESSION RATIO
C DPOINT = DATA POINT
C D5LOPE = SLOPE AT DATA POINT (LOG-LOG PLOT)
C EPOINT = EXTRAPOLATION OF EXPANSION LINE TO ORDIINATE AXIS
C E5LOPE = SLOPE OF EXPANSION LINE (LOG-LOG PLOT)
C EVO = EXHAUST VALVE OPEN
C FINISH = END OF COMBUSTION PROCESS
C IDATA = BINARY VOLTAGE DATA
C IGN = SPARK TIMING
C IFILE = FILENAME OF PRESSURE DATA
C MFB = MASS FRACTION BURNED
C PRES = CALIBRATED PRESSURE
C RL = CONNECTING ROD LENGTH (IN.)
C START = START OF COMBUSTION
C
C *********************************************************************
DIMENSION IFILE(10),IHEADR(40),IDATA(720),TESTFILE(20)
DIMENSION VOLT(720),RATE(720),XMFB(720)
DIMENSION IDATE(10),KDATE(3),DFUEL(3),FILE(20)
DOUBLE PRECISION RUN RUNNO
COMMON /A7/C02,MC02,t02B; AFC,AF0,XMF,Y
COMMON /PDATA/ PRES(720),PRES(720)
REAL MC02,NPRESS,NTMP,NOZLLe,LHV,MTMP,MIHR,MPRES,NOX
INTEGER EVO,EVO1,SPARK,START,FINISH,COMB

CALB = 91.274
BORE = 3.250
R = 2.250
RL = 10.0
CR = 8.0
EVO = 500
EVO1 = 480
MCFRUE = 0
N = 0

CONTINUE
WRITE(10,403)
115

400 FORMAT(1X,"('33'(14))")
WRITE(10,401)
401 FORMAT(/,1X,"FILENAME OF DATA:",Z)
READ(11,301)FILE(1)
301 FORMAT(S18)
CALL OPEN(0,FILE(1),IER)
IF(IER.NE.1)WRITE(10,402)
402 FORMAT(/,1X,"RUN NUMBER OF DATA:",Z)
ACCEPT RUN
WRITE(10,403)
403 FORMAT(/,1X,"PRESSURE DATA FILENAME:",Z)
READ(11,303)FILE(1)
303 FORMAT(S18)
WRITE(10,404)
404 FORMAT(/,1X,"REFERENCE PRESSURE (KPA):",Z)
ACCEPT PREP
READ(0,500)BFUEL(1)
500 FORMAT(SB)
READ(0)LHV,AFS,Y,X,SG,CR,RPM,MPRES,MTMP,OTMP,TMP,XPRES,HUZZLE
C
C ***** CALCULATE VOLUME *****
C
VOLD = BORE**2.0*0.7854*R*2.0
VOLC = VOLD/(CR-1.0)
VOLMAX = VOLD+VOLC
DO 100 I=1,720
J=I-1
CA = FLOAT(J)
CA = CA*0.01745
SINA = SIN(CA)
COSA = COS(CA)
AP = (BORE**2)*0.7854
SIN2A = SINA**2
RL2 = (R/RL)**2
QNT = (1.0-RL2*SIN2A)**0.5
VOL = AP*(R*(1.0-COSA)+RL*(1.0-QNT))
VOLT(I) = ((VOL+VOLC)/VOLMAX)*100.
TEMP = VOLT(I)
VOLT(I) = ALOG(TEMP)
100 CONTINUE
LHV = LHV*1.054
C
C ***** READ ENGINE DATA FILE & CALCULATE AIR/FUEL RATIO *****
C
MF825 = EVO
MF850 = EVO
MF875 = EVO
START = EVO
FINISH = EVO
COMB = EVO
SUM = 0.0
C
16 CONTINUE
READ(0)RUNNO,BPRES,RTMP,NPRES,NTMP,FUFL,SPRK,BKR,MTFR
IF(RUNNO.LE.10.000)GO TO 20
READ(0)HC1NOX,CO2,CO,02,MC02,XTEMP
IF(RUN.NE.RUNNO)GO TO 16
IGN = IFIX(SPRK)
C
XHC = HC/10000.0
XNO = NOX/10000.0
XN = 100.0/(3.0*XHC+CO+CO2)
H2O = (5.0*0.04*XHC)/(CO/(3.0*CO2)+1.0)
AMF = 12.01+1.008*Y+16.01*X
A = (3.0*XHC-CO/2.0+1.5*H2O)*XN/100.0
B = CO2+CO/2.0+H2O/2.0+XNO/2.0+D2
C = (B*XHC/100.0-X/2.0)
$AFO = 4.76 \times 28.97 / XMFB$ 

$PHIO = AFO / AFS$

$C02B = 400.0$

$CALL EGR(XEGR)$

$C ***** READ AND WRITE FILE HEADER *****$

$CALL FOPEN(1, IFILE)$

$READ BINARY (1, IHEADR, ICYCLE)$

$WRITE(10, 410) IHEADR, ICYCLE$

$FORMAT(//, 5X, 560, //, 5X, 12, " CYCLES RECORDED", /)$

$FACTOR = (CALB / 3276.7) \times 6.895$

$DO 110 I = 1, 720$

$READ BINARY (1, IDATA(I))$

$PRES(I) = FLOAT(IDATA(I))$

$PRES(I) = (PRES(I) - 310.0) \times FACTOR$

$CONTINUE$

$PRESSC = PRES(180) - PREFERENCES$ 

$DO 120 I = 1, 720$

$TEMP = PRES(I) - PRESSC$

$PRES(I) = ALOG10(TEMP)$

$CONTINUE$

$110$

$120$

$C ***** SHIFT PRESSURE DATA BY THE AMOUNT IDEG$

$IDEG = 2$

$CALL PHASE(IDEG)$

$CALL FCLOSE(1)$

$CALL RESET$

$C ***** CALCULATE APPROXIMATE HEAT RELEASE CURVE *****$

$SPARK = IGN$ 

$IGN = 360 - IGN$ 

$IGN1 = IGN - 20$

$XMFB(IGN1) = 0.0$

$XMFB(IGN1 + 1) = 0.0$

$CSLOPE = (PRES(IGN1) - PRES(IGN)) / (VOLT(IGN1) - VOLT(IGN))$

$ESLOPE = (PRES(EV01) - PRES(EVD)) / (VOLT(EV01) - VOLT(EVD))$

$CPOINT = -(CSLOPE) \times (VOLT(IGN) - 1.0) + PRES(IGN)$

$EP0INT = -(ESLOPE) \times (VOLT(EV01) - 1.0) + PRES(EV01)$

$DIFF = EP0INT - CPOINT$

$DO 130 K = 580, 720$

$SUM = SUM + PRES(K)$

$CONTINUE$

$AVEEXH = SUM / 141.0$

$VOLS = ((AVEEXH - EP0INT) / ESLOPE) + 1.0$

$VOLS = (10.0 * VOLS) * VOLMAX / 100.0$

$RES = VOLS / VOLC$

$AVEEXH = 10.0 * AVEEXH$

$TRAPF = (FUIFL * 2.0) / 453.6 / RPM$

$THEAT = TRAPF * LHV$

$TRAPF = (TRAPF * (1.0 + AFO)) / (1.0 + RES)$

$DO 135 I = IGN1, EVOD$

$DSLOPE = CSLOPE * (1.0 - XMFB(I - 1)) + ESLOPE * (XMFB(I - 1))$

$DPOINT = -(DSLOPE) * (VOLT(I) - 1.0) + PRES(I)$

$XMFB(I) = (DPOINT - CPOINT) / (EP0INT - CPOINT)$

$C ***** DETERMINE HEAT RELEASE RATE *****$

$RATE(I) = XMFB(I) - XMFB(I - 1)$

$C ***** DETERMINE SELECTED POINTS AND FLAG *****$

$IF(XMFB(I).LE.0.0005) XMFB(I) = 0.0000$
IF(XMFB(I).GE.9999999)XMFB(I) = 1.0000
IF(RATE(I).LE.0.0005)RATE(I) = 0.0000

CONTINUE
J = - SPARK

FORMAT(/,1X,"***** TURN ON PLOTTER ***** ")
PAUSE

***** PLOT MASS FRACTION BURNED RESULTS *****
WRITE(10,600)
FORMAT(1X,*(33)CI 40 75")
CALL GRID(-60.0,140.0,20.0,1,0.0,1.0,20.1,140.0,860,130,730,1,1)
YNUM = 0.0
DO 140 IY = 130,730,120
I2Y = IY-5
CALL ANMDE(800,I2Y)
WRITE(10,610)YNUM
140 FORMAT(1X,F5.3)
YNUM = YNUM+0.01
CONTINUE

***** LABEL AXIS *****
CALL ANMDE(380,90)
WRITE(10,620)
FORMAT(1X,"CRANK ANGLE DEGREES")
WRITE(10,621)
FORMAT(1X,"(33)CJ 90 ")
CALL ANMDE(60,300)
WRITE(10,622)
FORMAT(1X,"MASS FRACTION BURNED")
CALL ANMDE(966,300)
WRITE(10,623)
FORMAT(1X,"MASS BURNED RATE -1/DEG")
WRITE(10,624)
FORMAT(1X,"(33)CJ 0 ")
CALL ANMDE(175,700)
WRITE(10,630)FILENAME(1)
FORMAT(1X,"DATAFILE: ",S18)
CALL ANMDE(175,675)
WRITE(10,631)XECR
FORMAT(1X,"ECR RATE =",F4.1,"%")
CALL ANMDE(175,650)
WRITE(10,632)PHIO
FORMAT(1X,"EQ. AIR/FUEL = ",F5.3)
CALL ANMDE(175,625)
WRITE(10,633)SPARK
FORMAT(1X,"SPARK TIMING",I3)

***** PLOT DATA *****
CALL DPORT(140,860,130,730,-60.0,140.0,0.0,1.0)
CA = FLOAT(I)
YDATA = XMFB(IGN)
CALL MOVEA(CA,YDATA)
DO 210 I = IGN,EVO
YDATA = XMFB(I)
CALL DRAWA(CA,YDATA)
CA = CA+1
210 CONTINUE

***** PLOT MASS BURNED RATE *****
CALL DPORT(140,860,130,730,-60.0,140.0,0.0,0.05)
CA = FLOAT(I)
YDATA = RATE(IGN)
CALL MOVEA(CA,YDATA)
DO 220 I=IGN,EVO
DATA = RATE(I)
CALL DRAWA(CA,YDATA)
CA = CA+1.

CONTINUE
CALL MVABS(0,0)
WRITE(10,601)

FORMAT(1X,'(33)CN ')
CALL ANMDE(0,0)
ACCEPT FAKE
WRITE(10,430)

FORMAT(1X,"REPEAT PROGRAM ? (NO-O;YES-1):",Z)
ACCEPT NCON
IF(NCON.EQ.0)STOP
GO TO 10

CONTINUE
REWIN 0
CALL CLOSE(0,IER)
IF(IER.NE.1)TYPE "FILE CLOSE ERROR CHAN 0",IER
TYPE " ",
TYPE " RUN NUMBER NOT FOUND ",
WRITE(10,430)
ACCEPT NCON
IF(NCON.EQ.0)STOP
GO TO 10
END
C ****** PRESAVE.FR ****************************
C
C THIS PROGRAM IS DESIGNED TO CALCULATE THE AVERAGE
C AND STANDARD DEVIATION FOR THE PRESSURE DATA OBTAINED
C FROM THE PROGRAM PRESFILE. THE PROGRAM IS STRUCTURED
C SO THAT SEVERAL PRESSURE - CRANK ANGLE DATA FILES
C CAN BE PROCESSED.
C
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C
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C
C REVISION HISTORY:
C 12/2/79 CREATED ORIGINAL
C 8/20/80 ORIGINAL UPDATED FOR MULTIPLE RUNS
C
C LOADING INFORMATION:
C RLDR PRESAVE F0RT.LB
C
C TESTFILE FORMAT:
C NUM PREF
C DATA FILENAME
C AVE DATA FILENAME
C DEV. DATA FILENAME
C
C ******************************************************************
C DIMENSION TESTFILE(10)
C DIMENSION IFILE(10),DFILE1(10),DFILE2(10),PRESAV(720),
C &PRESVAR(720),IHEADRI(40),IHEADRO(40),IHEADRD(40)
C
C WRITE(10,400)
C 400 FORMAT(1X," FILENAME OF DATA : ",Z)
C READ(11,300)TESTFILE(1)
C 300 FORMAT(18)
C CALL OPEN(3,TESTFILE(1),IER)
C IF (IER.NE.1) TYPE " FILE OPEN ERROR CHAN 3 "
C READ(3)NUM,PREF
C N = 0
C
C 10 CONTINUE
C READ(3,500)IFILE(1)
C READ(3,500)DFILE1(1)
C READ(3,500)DFILE2(1)
C PREF=1EREF*5.207
C 500 FORMAT(18)
C
C C ****** OPEN DATA AND RESULT FILES *****
C
C CALL OPEN (0,IFILE,1,IER)
C IF (IER.NE.1) TYPE "FILE OPEN ERROR CHAN 0 ",IER
C CALL OPEN (1,OF1LE1,3,IER)
C IF (IER.NE.1) TYPE "FILE OPEN ERROR CHAN 1 ",IER
C CALL OPEN (2,OF1LE2,3,IER)
C IF (IER.NE.1) TYPE "FILE OPEN ERROR CHAN 2 ",IER
C READ BINARY (0) IHEADRI,ICYCLE
C WRITE(10,425) IHEADRI(1),ICYCLE
C 425 FORMAT(1X,//1X,S78,//1X,"NO. OF CYCLES = ",I2)
C WRITE BINARY (1) IHEADRI,ICYCLE
WRITE BINARY (2) IHEADRI, ICYCLE

C **** CALCULATE AVERAGE CYCLE ****

ACYCLE=FLOAT(ICYCLE)
ACYCLE1=ACYCLE-1.
DO 100 I=1,720
READ BINARY (0) IDAT
DAT=FLOAT(IDAT)
PRESAV(I)=DAT
CONTINUE
PRESV=PRESAV(180)-PREF
DO 110 J=1,720
PRESAV(I)=PRESAV(I)-PRESV
CONTINUE
TYPE "END OF FIRST CYCLE AVERAGE"
ICYCLE1=ICYCLE-1
DO 120 I=1,ICYCLE1
DO 120 J=1,720
READ BINARY (0) IDAT
DAT=FLOAT(IDAT)
DAT1=DAT-PRESV
PRESAV(J)=PRESAV(J)+DAT1
CONTINUE
DO 130 I=1,720
PRESAV(I)=PRESAV(I)/ACYCLE
ITEMP=IFIX(ITEMP)
WRITE BINARY (1) ITEMP
CONTINUE
TYPE "END OF AVERAGE FILE WRITE, BEGIN DEVIATION"

C **** CALCULATE DEVIATION ****

REWIND 0
REWIND 1
READ BINARY (0) IHEADRI,ICYCLE
READ BINARY (1) IHEADRI,ICYCLE
DO 140 I=1,720
READ BINARY (1) ITEMP
ITEMP=FLOAT(ITEMP)
PRESAV(I)=ITEMP
READ BINARY (0) IDAT
DAT=FLOAT(IDAT)
DAT=DAT-PRESV
DIF2=(DAT-PRESAV(J))**2
PRESVAR(J)=PRESVAR(J)+DIF2
CONTINUE
DO 160 I=1,720
PRESVAR(I)=((PRESVAR(I))/ACYCLE1)**0.5
TEMP1=(PRESVAR(I)/(PRESAV(I)+PREF))**32768.
PRESV=IFIX(TEMP1)
WRITE BINARY (2) IPRESV
CONTINUE
REWIND 0
REWIND 1
REWIND 2
CALL CLOSE(0,IER)
CALL CLOSE(1,IER)
CALL CLOSE(2,IER)
N=N+1
IF(N.EQ.NUM)GO TO 25
GO TO 10
CONTINUE
REWIND 3
CALL CLOSE(3,IER)
IF(IER.NE.1) TYPE" FILE CLOSE ERROR CHAN 3"
STOP
END
**PREFILE.FR**

**THIS PROGRAM IS DESIGNED TO ACQUIRE "ICYCLE" (1-30) CYCLES OF PRESSURE - CRANK ANGLE DATA. DATA IS TAKEN AT ONE CRANK ANGLE DEGREE INCREMENTS.**

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**DEFINITIONS:**

IDATA = DATA ARRAY
3200 = TRIGGER THRESHOLD (BINARY)
ICYCLE = NUMBER OF CYCLES
IHEADR = DESCRIPTIVE INFORMATION FOR FILE

**LOADING INFORMATION:**

RLDR PRESFILE GETCYCLE.RB FORT.LB 2/K

**DIMENSION IDATA(720,30), IFILE(10),IHEADR(40)**

CALL DSTRT(IER)
IF (IER .NE. 1) GO TO 10
WRITE(10,400)
400 FORMAT(1X:"FILENAME ",Z)
READ(11,300) IFILE(1)
300 FORMAT(30)
CALL OFILW(IFILE,2,IER)
IF (IER .EQ. 1) GO TO 20
WRITE(10,410) IFILE(1)
410 FORMAT(1X:"FILE ALREADY EXISTS ",S20)
GO TO 5
20 CALL FOPEN(I,IFILE)
GO TO 415
415 FORMAT(1X:"DESCRIPTIVE DATA ",Z)
READ(11,315) IHEADR(1)
315 FORMAT(78)
WRITE(10,420)
420 FORMAT(1X:"NUMBER OF CYCLES (1-30) ",Z)
READ(11,320) ICYCLE
320 FORMAT(12)
WRITE BINARY (0) IHEADR,ICYCLE
ICNT = ICYCLE*720
CALL GETCY(IDATA(1,1),3200,ICNT)
TYPE "DATA TAKEN - BEGINNING WRITE TO FILE"
DO 100 I=1,ICYCLE
100 WRITE BINARY(0) IDATA(J,I)
CALL FCLOS(0)
GO TO 11
11 TYPE "DSTRT ERROR"
CONTINUE
STOP
END
C **** PREREAD.FR ****************************************************
C
C THIS PROGRAM IS DESIGNED TO OUTPUT THE CONTENTS OF A PRESSURE-
C CRANK ANGLE DATAFILE TO EITHER THE CONSOLE OR LINE PRINTER.
C
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C ROLLA, MISSOURI 65401
C
C REVISION HISTORY:
C
C REV DATE COMMENTS
C
C 01 9/17/79 INITIAL REVISION
C 02 10/28/79 REVISED TO INCLUDE MULTIPLE FILES WITH HEADERS
C 03 11/4/79 REVISED TO SEPARATE CYCLES
C 04 01/3/80 REVISED TO INCLUDE LINE NUMBER
C
C *******************************************************************************

DIMENSION IFILE(10),ICHAN(10),PVOLT(10),IHEADR(40)

WRITE (10, 400)
   FORMAT (1X,10X,"INPUTFILE : ",Z)
READ (11, 300) IFILE(1)

300 FORMAT (3I8)
   CALL FOPEN (0,IFILE)
   WRITE (10, 410)
   FORMAT(1X/,10X,"OUTPUTFILE (10-CONSOLE, 12-PRINTER) : ",Z)
   ACCEPT IOUT
   IF (IOUT.EQ.10 .OR. IOUT.EQ.12) GO TO 6
   GO TO 5

6 CONTINUE
   READ BINARY (0) IHEADR,ICYCLE
   WRITE (10, 420) IHEADR(1),ICYCLE

420 FORMAT (/10X,560," CYCLES RECORDED")
   WRITE (10, 430) IHEADR(10),ICYCLE

430 FORMAT (/10X,"NUMBER OF CYCLES TO BE OUTPUT : ",Z)
   READ(11, 330) ICYCLE

330 FORMAT(1I2)
   IF(IOUT.EQ.10) GO TO 7
   WRITE(12, 440) IFILE(1)

440 FORMAT(10X,518,/) 
   WRITE(12, 450) IHEADR(1)

450 FORMAT(10X,578,/) 
7 CONTINUE
   NUM=1
   DO 100 K=1,ICYCLE
   WRITE (IOUT, 460) NUM
   460 FORMAT (/10X," CYCLE ",I2,/) 
   NUM=NUM+1
   DO 101 I=1,72
      DO 102 J=1,10
      READ BINARY (0) ICHAN(J)
      PVOLT(J)=FLOAT(ICHAN(J))
      PVOLT(J)=PVOLT(J)/3276.7
      CONTINUE
      WRITE(IOUT, 470) (PVOLT(J),J=1,10),I
   102 CONTINUE
   WRITE(IOUT, 470) (PVOLT(J),J=1,10),I
   101 CONTINUE
   100 CONTINUE
   CALL FCLOS(0)
STOP
TYPE " ERROR FOR OUTPUT DEVICE CODE "
CALL FCLOSE(0)
STOP
END
C ***** PVPLOT.FR ***************************************************
C THIS PROGRAM IS DESIGNED TO PLOT PRESSURE VS. VOLUME
C DATA FROM A FILE CONTAINING VOLTS (PRESSURE) - CRANK
C ANGLE DATA.
C C AUTHOR: R. T. JOHNSON
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C ROLLA, MO 65401
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C C K.R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MISSOURI - ROLLA
C ROLLA, MISSOURI 65401
C C REVISION HISTORY:
C 10/13/79 - CREATED ORIGINAL
C 10/15/79 - UPDATE ORIGINAL
C 7/12/80 - UPDATE WITH SUBROUTINE PHASE
C 8/13/80 - UPDATED WITH SUBROUTINE GRID
C C LOADING INFORMATION
C RLDR PVPLOT PHASE GRID VECTR.LB FORT.LB
C C DEFINITIONS:
C BORE = ENGINE BORE (IN.)
C CALB = CALIBRATION FACTOR (PSI.IN)
C CR = COMPRESSION RATIO
C IDATA = BINARY VOLTAGE DATA
C IFILE = FILENAME OF PRESSURE DATA
C PRES = CALIBRATED PRESSURE DATA
C R = ENGINE CRANK THROW (IN.)
C RL = CONNECTING ROD LENGTH (IN.)
C C ***************************************************
DIMENSION IFILE(10),IHEADR(40),IDATA(720),VOLT(720)
COMMON /PDATA/PRES(720),PRES(720)
C MCURVE = 0
CALB = 91.274
BORE = 3.250
R = 2.250
RL = 10.0
CR = 8.0
C 10 CONTINUE
WRITE(10,400)
400 FORMAT(1X,'(33)(14)"
WRITE(10,401)
401 FORMAT(1X,'INPUT FILE ":",Z)
READ(11,301) IFILE(1)
301 FORMAT(918)
WRITE(10,402)
402 FORMAT(1X,"ABSOLUTE REFERENCE PRESSURE (KPA) ":",Z)
READ(11,302) PEF
302 FORMAT(6.2)
WRITE(10,403)
403 FORMAT(1X,"PRESSURE SHIFT (DEGREES) ":",Z)
READ(11,303) DEG
303 FORMAT(II)
CALL FOPEN(0,IFILE)
READ BINARY (0) IHEADR,ICYCLE
C ***** WRITE FILE HEADER AND DESCRIPTIVE HEADER *****
C
404 WRITE(10,404) IHEADR(I),ICYCLE
FORMAT(//,60X,578,/,40X,I2," CYCLES RECORDED")
WRITE(10,405)
405 FORMAT(/,1X,"NUMBER OF CYCLES TO PLOT = ? ",I)
ACCEPT JCYCLE
WRITE(10,410)
410 FORMAT(/,1X," ***** TURN ON PLOTTER ***** ")
PAUSE
IF(MCURVE.EQ.1)GO TO 11
C
C ***** CALCULATE VOLUME *****
C
VOLD = BORE**2.0*0.7854*R**2
VOLC = VOLD/(CR-1.0)
DO 100 I=1,720
J=1-1
CA = FLOAT(I)
CA = CA*0.01745
SINA = SIN(CA)
COSA = COS(CA)
AP = (BORE**2)*0.7845
SINV = SINE**2
RL2 = (R/RL)**2
QNT = (1.-RL2*SINV)**0.5
VOL = AP*(R*(1.-COSA)+RL*(1.-QNT))
VOLT(I) = (VOL+VOLC)*16.387
100 CONTINUE
C
C ***** DRAW GRID *****
C
WRITE(10,600)
600 FORMAT(1X,"(30)CL 40 75 ")
CALL ANMD(0.0,100.0,200.0,1.0,0.0,5000.0,1000.0,0.1,150,
4900.0,130.730,1,1)
C
CALL ANMDE(580,670)
WRITE(10,610)FILE(1)
610 FORMAT(1X,"INPUTFILE: ",S18)
CALL ANMDE(580,640)
WRITE(10,611)PREF
611 FORMAT(1X,"MANIFOLD PRESS. (KPA) ",F8.2)
CALL ANMDE(430,75)
WRITE(10,612)
612 FORMAT(1X,"VOLUME - CU. CM. ")
WRITE(10,613)
613 FORMAT(1X,"(30)CL 90 ")
CALL ANMDE(50,275)
WRITE(10,614)
614 FORMAT(1X,"PRESSURE (KPA)"
WRITE(10,615)
615 FORMAT(1X,"(30)CL 0 ")
C
C ***** PLOT PRESSURE VS. VOLUME DATA *****
C
11 CONTINUE
C
CALL DPOR(.150,900,130,730,0.0,1000.0,0.0,5000.0)
FACTOR = (CALB/3276.7)*6.995
DO 200 I=1,ICYCLE
DO 210 I=1,720
READ BINARY(0) IDATA(I)
PREI = FLOAT(IDATA(I))
PREI = (PREI-310.)*FACTOR
CONTINUE
PRESC = PRES(180)-PREF
DO 220 I=1,720
PREI = PRES(I)-PRESC
CONTINUE
CALL PHASE(JDEG)
C
VOLT2=VOLT(1)
PRES2=PRES(1)
CALL MOVA(VOLT2,PRES2)
DO 225 I=2,720
VOLTX=VOLT(I)
PRESY=PRES(I)
CALL DRAWA(VOLTX,PRESY)
225 CONTINUE
CALL MVABS(150,130)
200 CONTINUE
CALL FCLOSE(0)
CALL MVABS(0,0)
WRITE(10,601)
601 FORMAT(1X,<(33) CM*)
CALL ANMDE(0,0)
ACCEPT FAKE
C ***** STOP TO TURN OFF PLOTTER *****
C ***** HIT RETURN KEY TO COMPLETE PROGRAM *****
WRITE(10,430)
430 FORMAT(/,1X," PLOT A SECOND CURVE ? (NO-0,YES-1)",Z)
READ(11,330)MCURVE
330 FORMAT(I)
IF(MCURVE.EQ.1)GO TO 10
WRITE(10,435)
435 FORMAT(/,1X," REPEAT PROGRAM ? (NO-0,YES-1)",Z)
READ(11,335)NCON
335 FORMAT(I)
IF(NCON.EQ.1)GO TO 10
STOP
END
SUBROUTINE EGR(EGRCAL)

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

COMMON fA/ (02)MC02}C02B)AFC}AFO}XMF,Y
REAL HC02

IF(MC02.LE.0.000)GO TO 35
EC02 = (C02-C02B*0.0001)/100.
IC02 = (MC02-C02B*0.0001)/100.
EGR1 = IC02/EC02
AF0 = (AFC+AFO)/2
XMFA = 1.+AF0*XMF/28.96
15 XNE = (XMFA*EGR1)/(1.-EGR1)
XME = XMFA-1.+Y/4.
XA = XNE/XME

EGR = (IC02/EC02)*(1.+Y/2*EC02)/(1.+Y/2*IC02+IC02/XA)
DIF = EGR1-EGR
ADIF = ABS(DIF)
EGR1 = EGR
EGR = EGR*100.
IF(ADIF.GT.0.0001) GO TO 15
GO TO 25
25 CONTINUE
EGRCAL = EGR
RETURN
CONTINUE
35 EGRCAL = 0.0000
RETURN
END
GETCYCLE
CODE FOR PRESSURE-CRANLANGE DATA ACQUISITION
FROM MECHANICAL ENGINEERING ENGINE LAB.

; TITL GETCY
; EN'T GETCY, DSTR
; EXTN .UIEX, .IXMT, .REC
; EXTD .CPYL, .FRET
; NREL

ADSLS = 0
DISLOT = 4
DAC = 40 ; DEVICE CODE FOR DGDA\nCP = 180 ; CLEAR PENDING FLAG

; AI
; ROUTINE TO ACCESS THE A/D CONVERTOR
; CALL AI(I\CHAN, IDATA, IER)
; WHERE:
; ICHAN IS THE INTERGER CHANNEL YOUR WISH TO ACCESS (0-31)
; IDATA IS AN INTEGER IN THE RANGE OF \-32768 TO +32768.
; IER IS THE RETURNED ERROR CODE, 1 SYSTEM OK.

AI:
STA 3 AIRTN ; SAVE RETURN

READ CONTROLER STATUS
DIA 0 DAC
STA 0 OLDSTAT ; SAVE IT

SELECT AND START A/D CHANNEL
AISTRT: LDA 1 ADRCNX ; GET ADDRESS/CONTEXT WORD FOR A/D
NOS DAC ; SET CONTROLER BUSY
DIA 1 DAC ; SELECT A/D CONVERTER
LDA 0 MAXPIO
DOB 0 DAC ; SELECT PIO AND MUX BUS FOR A/D
SUB 0 0 ; GET CHANNEL # 0
LDA 1 MUXNO ; GET MUX NUMBER
ADD 1 0 ; ADD TO CHANNEL NO
DIA 2 DAC ; GET PRESTART STATUS
DOCS 0 DAC ; SELECT CHANNEL AND START CONVERSION
DIA 0 DAC ; GET MODULE STATUS
LDA 1 CMODE ; GET CM BIT
AND # 1 SIZR ; SKIP IF MODULE MODE
JMP AISTRT ; SLIPPED OUT OF MODULE MODE
MOVZL 0 0 SIZC ; SKIP IF BUSY
JMP AIOK ; A STARTED OK
MOVZL 0 0 SNC ; SKIP IF DONE
JMP AISTRT ; NOT BUSY OR DONE

AIOK: SKPDN DAC ; WAIT FOR DONE
JMP -1

JSR DACIN ; CHECK REASON FOR DONE
JMP AIOK ; JUST A CHASSIS IRPT, IGNORE IT
STA 1 IDATA ; SAVE DATA

RETURN TO CALLER AFTER RESTORING ORIG STATUS
LDA 0 OLDSTAT
LDA 1 C37
AND 1 0 ; MASK OFF ALL BUT CM AND ADDR BITS
DIA 0 DAC ; RESTORE OLD STATUS
LDA 0 IDATA ; GET DATA
JMP @AIRTN ; AND RETURN

IDATA: 0
AIRTN: 0
ADRCTX: ADSLOT
OLDSTAT: 0
MUXIO: 1B11 ; MUX BUS BIT FOR SPEC CONV INSTRUCTION
MUXWO: 0B11
CMODE: 1B11
C37: 37
MSG: .+1
MSG: 0
ADNP: 0 ; ANALOG INPUT DATA
D4000: 4000. ; OFFSET FOR CONTROLLER MODE INTERRUPT ADDRESS

; CONTROLLER MODE INTERRUPT - ERROR

; DSTR
; THIS ROUTINE MUST BE CALLED TO IDENTIFY DEVICE FOR RDOS BEFORE ANY OTHER
; GGDACPAC ROUTINES ARE CALLED.
; CALL DSTR(IER)
; WHERE IER = 1 IF ALL WENT OK
; = 3+SYSTEM ERROR CODE IF NOT OK

DSTR: JSR @.CPYL ; GET ARG LIST
LDA 0 DVCDE ; IDENTIFY DEVICE TO RDOS
.SYSTM
.DEBL
JMP SYSER
LDA 1 .DCT
.SYSTM
.IDEF
JMP SYSER
LDA 0 C77
.SYSTM
.DEBL
.JMP .+1 ; ENABLE CPU INSTR
JMP .+FRET

; THE FOLLOWING SETS THE INTERRUPT MASK BITS
LDA 1 CMODE
DOA 1 DAC ; SELECT CM MODE
SUB 0 0
DOB 0 DAC ; SPECIFY MODULE SUBMASK
LDA 0 CMASK
DOC 0 DAC ; SPECIFY CONTROLLER SUBMASK

; RETURN WITH ERROR CODE = 1 (OK)
SUBZL 0 0
STA 0 @-167 3 ; RETURN CODE = 1
JMP @.FRET

SYSER: LDA 0 C3
.ADD 0 2
STA 2 @-167 3
JMP @.FRET ; RETURN WITH ERROR CODE IN IER

CMASK: 13B7+1B10 ; OTMP,Y-AD,Y-BY,Y-TM
C3: 3
C77: ??
DVCDE: DAC
.DCT: .+1
DAC DCT

; DAC DCT

185
+1

ISR DACIN
JMP +1

; DAC 'DONE' CHECK ROUTINE
; CALL TO CHECK REASON FOR 'DONE' SET
;
; ISR DACIN
; (CHASSIS IRPT)
; (A/D IRPT) (DATA IN AC1)

DACIN: DIAP 0 DAC  ; IDENTIFY SUBSYSTEM INTERRUPT
DIA 1 DAC  ; FIRST DIA IS OLD STATUS
LDA 2 CMDINT
AND# 2 1 SRZ  ; SKIP IF NOT CHASSIS INTERRUPT
JMP CMISV  ; GO SERVICE CHASSIS

LDA 1 ADRC1
DOA 1 DAC  ; SELECT A/D AND CP
DIBC 1 DAC  ; GET DATA AND CLEAR A/D

LDA 2 C37
AND 2 0  ; MASK OFF ALL BUT CM AND ADDR BITS
DOA 0 DAC  ; RESTORE ORIG STATUS

DACSM: JMP 1 3  ; RETURN, CALL+2 WITH DATA IN AC1

; ACTIVE DONE IS ONLY ALLOWABLE CONTROLLER IRPT
; JUST RESTART BUSY AND DISMISS INTERRUPT

CMISV: NIOS DAC
JMP 0 3  ; RETURN CALL+1

C2: 2

CMDINT: IB11
ADRC1: CP+ADSLOT  ; SELECT A/D AND SET CLEAR PENDING FLAG

; DI
;
; CALL DI(IDATA)
;
; FUNCTION: TRANSFER 16-BIT DIGITAL INPUT WORD TO IDATA

; DUE TO PECULIARITY OF 4291 DIGITAL INPUT MODULE, THE WORD
; WHICH IS TRANSFERRED TO IDATA IS THE STATE OF THE DIGITAL INPUT
; LINES AT THE TIME OF THE PREVIOUS CALL TO DI. THE 'S' PULSE
; ACTUALLY CAUSES THE DATA TO BE LATCHED IN THE INPUT BUFFER REGISTER.
; CONSEQUENTLY, YOU WILL NEED TO CALL DI ONCE BEFORE THE DATA
; IS REALLY VALID.

DI: DIA 1 DAC  ; GET OLD STATUS
NIOS DAC  ; BUSY CONTROLLER
LDA 0 ADRC3
DOA 0 DAC  ; SELECT DI AND MODULE MODE
DIBS 0 DAC  ; GET DATA AND LATCH IN NEW DATA FOR NEXT TIME
MOV 0 2  ; RETURN WITH DATA IN AC2
LDA 0 C37
AND 1 0
DOA 0 DAC  ; RESTORE OLD STATUS
MOV 2 0  ; RETURN WITH DATA IN AC0 TOO
JMP 0 3  ; RETURN

ADRC3: DISLOT  ; DI SLOT

; GETCY
;
; ROUTINE TO WAIT FOR TRIGGER PULSE, THEN GET (RAPIDLY)
CALL GETCY(IARAY,ITHRSH,KNT)

WHERE:

IARAY IS DATA ARRAY DIMENSIONED 'KNT'
KNT IS NUMBER OF SAMPLES TO TAKE
ITHRESH IS A/D THRESHOLD AT WHICH SAMPLING BEGINS

GETCY WaITS FOR BIT TRANSITION ON DI LINE 0, THEN
IF A/D CHANNEL ZERO IS BELOW THRESHOLD, SAMPLES
AND STORES KNT SAMPLES IN SYNCRONISM WITH TIMING
MARK ON DI BIT 1. GETCY IS DESIGNED TO BE USED
WITH ENGINE PERFORMANCE SYSTEM.

GETCY: JSR @.CPYL ; GET ADDRESS OF ARRAY
LDA 0 -167 3 ; GET ARRAY ADDRESS
STA 0 ARAY ; SAVE IT
LDA 0 R-166 3 ; GET THRESHOLD
STA 0 THRSH ; SAVE IT
LDA 0 R-165 3 ; GET # OF SAMPLES TO TAKE
STA 0 KNT ; INIT COUNTER
INTDS ; TURN OFF THE LIGHTNING, IGOR

GETCY GETS KNT SAMPLES STARTING WITH AN INDEX MARK ON DI BIT 0
SAMPLES ARE TAKEN WHEN BIT1 MAKES 1-0 TRANSITION

WFTM: JSR @.DI ; GET DIGITAL INPUT
MOVZL 0 0 SNC ; SKIP IF TIMING MARK
JMP .-2 ; WAIT FOR IT

GETSMPL: JSR @.AI ; GET SAMPLE

LDA 1 THRSH ; GET THRESHOLD
SUBZL# 1 0 SNC ; SKIP IF BELOW THRESHOLD
JMP WFTM ; WAIT FOR ANOTHER TIMING MARK

SVSMP: STA 0 ARAY ; SAVE IT
ISZ ARAY
DSZ KNT ; DONE?
JMP GETNX ; NOPE
INTEN ; YUP, LET EM RIP
JMP @.FRET ; RETURN

GETNX: JSR @.DI
MOVZL 0 0
MOVZL 0 0 SNC ; WAIT FOR A 1 TIME MARK
JMP GETNX

JSR @.DI
MOVZL 0 0
MOVZL 0 0 SNC ; WAIT FOR A 1-0 TRANS
JMP .-3

JSR @.AI ; GET SAMPLE
JMP SVSMP ; SAVE SAMPLE

.AI: AI
.DI: DI
.THRSH: 0
.ARAY: 0
.KNT: 0
.END
SUBROUTINE GRID(XSTART, XSCALE, XINC, NXTIC, YSTART, YSCALE, YINC, KTOP, IM1, IM2, J1, J2, KNM, KIU)

C*************************************************************************
C  THIS PROGRAM IS DESIGNED TO DRAW THE GRID
C  FOR PLOTTING OF DATA, THE PROGRAM WILL
C  DRAW THE AXIS AND LABEL WITH NUMBERS THE TICK
C  MARKS.
C
C  AUTHOR:  K.R. SCHMID
C  MECHANICAL ENGINEERING DEPARTMENT
C  UNIVERSITY OF MISSOURI - ROLLA
C  ROLLA, MISSOURI 65401
C
C  REVISION HISTORY:
C  8/14/80 - ORIGINAL CREATED
C
C  DEFINITIONS:
C  IXDIV = X-AXIS SPACING OF NUMBERS IN SCREEN COORDINATES
C  NXTIC = X-AXIS SPACING OF TICK MARKS
C  XSTART = X-AXIS STARTING COORDINATE
C  XSCALE = X-AXIS FULL SCALE COORDINATE
C  XINC = X-AXIS NUMERICAL_INCREMENT
C  KNUM = X-AXIS NUMBER OF TICK MARKS BETWEEN NUMERALS
C  IYDIV = Y-AXIS SPACING OF NUMBERS IN SCREEN COORDINATES
C  IYTIC = Y-AXIS SPACING OF TICK MARKS
C  YSTART = Y-AXIS STARTING COORDINATE
C  YSCALE = Y-AXIS FULL SCALE COORDINATE
C  YINC = Y-AXIS NUMERICAL_INCREMENT
C  NYTIC = Y-AXIS NUMBER OF TICK MARKS BETWEEN NUMERALS
C  IY1 = Y-AXIS LOWER LEFT SCREEN COORDINATE
C  IY2 = Y-AXIS UPPER RIGHT SCREEN COORDINATE
C  J1 = Y-AXIS LOWER LEFT SCREEN COORDINATE
C  J2 = Y-AXIS UPPER RIGHT SCREEN COORDINATE
C  KNUM = DRAW GRID TOP LINE (1-YES)
C  KNUM = WRITE X-AXIS NUMERICALS (1-YES)
C
C*************************************************************************
C ****** CALCULATE CONSTANTS ******
C
IXDIV=(IX2-IX1)/(XSCALE-XSTART)/XINC)
IYDIV=(IY2-IY1)/(YSCALE-YSTART)/YINC)
IXTIC=IXDIV/(NXTIC+1)
IYTIC=IYDIV/(NYTIC+1)
IT1X=IX1+5
IT2X=IX2-5
IT1Y=IY1+5
IT2Y=IY2-5
JY1=IY1*IYTIC
JY2=IY2*IYTIC
JX=IX1+IXTIC
JX2=IX2-IXTIC
KY1=IY1-20
KX1=IX1-70
C
C ****** DRAW GRID LINES ******
C
CALL TKINI(10,11)
CALL MVABS(IX1, IY1)
CALL DWABS(IX2, IY1)
CALL DWABS(IX2, IY2)
IF(KTOP.EQ.0)CALL MVABS(IX1, IY2)
IF(KTOP.EQ.1)CALL DWABS(IX1, IY2)
CALL DWABS(IX1, IY1)
DO 100 IY = JY1, JY2, IYTIC
CALL MVABS(IX1, IY)
CALL DWABS(IT1X, IY)
100 CONTINUE
DO 110 IX = JX1, JX2, IXTIC
CALL MVABS(IX, IY2)
CALL DWABS(IX, IYT2)
110 CONTINUE
DO 120 IX = JX1, JX2, IXTIC
CALL MVABS(IX, IY1)
CALL DWABS(IX, IYT1)
120 CONTINUE
DO 130 IY = JY1, JY2, IYTIC
CALL MVABS(IX2, IY)
CALL DWABS(IT2X, IY)
130 CONTINUE

C ***** LABEL AXIS *****
C
XNUM = XSTART
IF(KNUM.EQ.0)GO TO 151
DO 150 IX=IX1, IX2, IXDIV
  I2X=IX-35
  CALL ANMDE(I2X, KY1)
  WRITE(10,610)XNUM
610 FORMAT(1X,F6.1)
  XNUM= XINC*XNUM
150 CONTINUE
151 CONTINUE
YNUM= YSTART
DO 160 IY=IY1, IY2, IYDIV
  I2Y = IY-5
  CALL ANMDE(KX1, I2Y)
  WRITE(10,610)YNUM
  YNUM= YNUM+YINC
160 CONTINUE
RETURN
END
SUBROUTINE PHASE(IDEG)
C *********************************************************************
C THIS PROGRAM IS DESIGNED TO SHIFT PRESSURE DATA.
C THE AMOUNT OF THE DATA SHIFT IS DEFINED BY THE TERM IDEG.
C
C AUTHOR: K.R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MISSOURI-ROLLA
C ROLLA, MISSOURI 65401
C
C REVISION HISTORY:
C
C 07/10/80 - ORIGINAL CREATED
C
C *********************************************************************
C COMMON /PDATA/ PRES1(720), PRES(720)
C
DO 100 J=1, IDEG
  K = IDEG-J
  PRES1(J) = PRES(720-K)
CONTINUE
DO 100 J=1, IDEG
  K1 = 720-IDEG
  DO 110 J=1, K1
    PRES1(J+IDEG) = PRES(J)
  CONTINUE
DO 120 I=1, 720
  PRES(I) = PRES1(I)
CONTINUE
RETURN
END
SUBROUTINE SHIFT(IDEG)
C
C THIS PROGRAM IS DESIGNED TO SHIFT THE PRESSURE DATA.
C THE AMOUNT OF THE DATA SHIFT IS DEFINED BY THE TERM
C IDEG.
C
C AUTHOR: K.R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MISSOURI - ROLLA
C ROLLA, MISSOURI 65401
C
C REVISION HISTORY:
C 07/10/80 - ORIGINAL CREATED
C
C*******************************************************************************
C*******************************************************************************
COMMON /PDATA/ PRES1(720,2),PRES(720,2)
C DO 100 KK = 1,2
DO 110 J=1,IDEG
K = IDEG-J
PRES1(J) = PRES(720-K)
110 CONTINUE
K1 = 720-IDEG
DO 120 J=1,K1
PRES1(J+IDEG) = PRES(J)
120 CONTINUE
DO 130 I=1,720
PRES(I) = PRES1(I)
130 CONTINUE
RETURN
END
SUBROUTINE SYMBOL(ISYM)
C **********************************************************
C THIS PROGRAM IS DESIGNED TO DRAW SYMBOLS FOR
C PLOTTING DATA POINTS.
C
C AUTHOR:  K.R. SCHMID
C MECHANICAL ENGINEERING DEPARTMENT
C UNIVERSITY OF MISSOURI-ROLLA
C ROLLA, MISSOURI 65401
C
C REVISION HISTORY:
C 07/17/80 - ORIGINAL CREATED
C
C SYMBOLS :
C CIRCLE = 1
C BOX = 2
C TRI1 = 3
C TRI2 = 4
C
C **********************************************************
IF(ISYM.EQ.1)GO TO 10
IF(ISYM.EQ.2)GO TO 20
IF(ISYM.EQ.3)GO TO 30
IF(ISYM.EQ.4)GO TO 40

C ***** CIRCLE *****
10 CONTINUE
CALL DWREL(1,0)
CALL DWREL(0,-1)
CALL DWREL(-1,0)
CALL DWREL(0,1)
CALL MUREL(3,7)
CALL DWREL(4,-4)
CALL DWREL(0,-6)
CALL DWREL(-4,-4)
CALL DWREL(-6,0)
CALL DWREL(-4,4)
CALL DWREL(0,6)
CALL DWREL(4,4)
CALL DWREL(6,0)
RETURN

C ***** BOX *****
20 CONTINUE
CALL DWREL(1,0)
CALL DWREL(0,-1)
CALL DWREL(-1,0)
CALL DWREL(0,1)
CALL MUREL(-3,7)
CALL DWREL(-4,4)
CALL DWREL(0,-6)
CALL DWREL(-6,0)
CALL DWREL(-4,4)
CALL DWREL(0,6)
CALL DWREL(4,4)
CALL DWREL(6,0)
RETURN

C ***** TRIANGLE POINTING UPWARD *****
30 CONTINUE
CALL DWREL(1,0)
CALL DWREL(0,-1)
CALL DWREL(-1,0)
CALL DWREL(0,1)
CALL MUREL(0,9)
CALL DWREL(-7,-14)
CALL DWREL(14,0)
CALL DWREL(-7,14)
RETURN

C ***** TRIANGLE POINTING DOWNWARD *****

C 40 CONTINUE
CALL DWREL(1,0)
CALL DWREL(0,-1)
CALL DWREL(-1,0)
CALL DWREL(0,1)
CALL MUREL(0,-10)
CALL DWREL(0,10)
CALL DWREL(-7,14)
CALL DWREL(14,0)
CALL DWREL(-7,-14)
RETURN
END
SUBROUTINE TITLE(IDATA, IROTATE, X, Y)
C ***********************************************************************
C
C THIS PROGRAM IS DESIGNED TO TITLE THE AXIS OF SEVERAL
C PLOTTING PROGRAMS.
C
C AUTHOR: K.R. SCHMID
C UNIVERSITY OF MISSOURI - ROLLA
C MECHANICAL ENGINEERING DEPARTMENT
C ROLLA, MISSOURI 65401
C
C DEFINITIONS:
C
C IPower = Designates the power base
C IDATA = Data channel to be plotted
C IROTATE = Determines if the lettering is to be rotated
C 90 degrees (1 = YES, 0 = NO).
C
C REVISION HISTORY:
C 07/07/80 - ORIGINAL CREATED
C
C ***********************************************************************
COMMON IPower
IF (IROTATE .EQ. 1) WRITE (10, 690) CALL ANMDE(X,Y)
IF (IPower .EQ. 0) GO TO 19
C
C IF (IDATA .EQ. 1) WRITE (10, 101)
C IF (IDATA .EQ. 2) WRITE (10, 102)
C IF (IDATA .EQ. 3) WRITE (10, 103)
C IF (IDATA .EQ. 4) WRITE (10, 104)
C IF (IDATA .EQ. 5) WRITE (10, 105)
C IF (IDATA .EQ. 6) WRITE (10, 106)
C IF (IDATA .EQ. 7) WRITE (10, 107)
C IF (IDATA .EQ. 8) WRITE (10, 108)
GO TO 20
C
C 19 CONTINUE
C IF (IDATA .EQ. 1) WRITE (10, 201)
C IF (IDATA .EQ. 2) WRITE (10, 202)
C IF (IDATA .EQ. 3) WRITE (10, 203)
C IF (IDATA .EQ. 4) WRITE (10, 204)
C IF (IDATA .EQ. 5) WRITE (10, 205)
C IF (IDATA .EQ. 6) WRITE (10, 206)
C IF (IDATA .EQ. 7) WRITE (10, 207)
C IF (IDATA .EQ. 8) WRITE (10, 208)
GO TO 20
C
C 20 CONTINUE
C IF (IROTATE .EQ. 1) WRITE (10, 510)
RETURN
600 FORMAT (1X, ' (33) CI 90 "')
610 FORMAT (1X, ' (33) CJ 0 "')
101 FORMAT (1X, ' Indicated Specific HC - Ug/J")
102 FORMAT (1X, ' Indicated Specific CO - Ug/J")
103 FORMAT (1X, ' Indicated Specific NO - Ug/J")
104 FORMAT (1X, ' Indicated Power - KW")
105 FORMAT (1X, ' Air/Fuel Equivalence Ratio ")
106 FORMAT (1X, ' Indicated Efficiency - %")
107 FORMAT (1X, ' Spark Timing - Degrees")
108 FORMAT (1X, ' Exhaust Temp. - F")
201 FORMAT (1X, ' Brake Specific HC - Ug/J")
202 FORMAT (1X, ' Brake Specific CO - Ug/J")
203 FORMAT (1X, ' Brake Specific NO - Ug/J")
204 FORMAT (1X, ' Brake Power - KW")
205 FORMAT (1X, ' Air/Fuel Equivalence Ratio ")
206 FORMAT (1X, ' Brake Efficiency - %")
END