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INSTALLATION OF A DIESEL ENGINE COMBUSTION/IGNITION EVALUATION FACILITY

INTERIM REPORT
AFLRL No. 156

By

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A facility for examining shale fuel property-related combustion/ignition effects on diesel engine performance has been installed at the U. S. Army Fuels and Lubricants Research Laboratory (AFLRL). The facility consists of a single-cylinder conversion of a three-cylinder, two-stroke cycle engine, an engine instrumentation package for determining combustion efficiencies, and a dedicated system for rapid data acquisition.

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20. ABSTRACT (Cont'd)

The computer system and software has been developed with the flexibility to expand into other areas of fuels and combustion research. The facility will be an effective tool in the continuing development of Army mobility fuels.

FOREWORD

This work was conducted at the U. S. Army Fuels and Lubricants Research Laboratory (USAFLRL) located at Southwest Research Institute, San Antonio, Texas under Contract Nos. DAAK70-80-C-0001 and DAAK70-82-C-0001 during the period October 1980 through December 1981. This work was funded by the U. S. Army Mobility Equipment Research and Development Command (USAMERADCOM), Ft. Belvoir, Virginia, with Mr. F.W. Schaekel (DRDME-GL) serving as contract monitor, and Mr. M.E. LePera (DRDME-GL) serving as technical monitor.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

At the present rate of energy consumption, the United States will need to supplement depleting domestic crude oil reserves with alternative sources in order to reduce a dependence upon foreign energy reserves from politically unstable countries. The alternative energy sources would include liquids produced from oil shale and coal for the manufacture of mobility fuels. There will be both physical and chemical fuel composition changes, compared to petroleum-derived fuels, whose impact upon engine performance are not known. Since as a tactical measure the U. S. Army will be one of the first users of fuels derived from alternative sources, it must be prepared for the effects of these new fuels on the performance of their equipment.

Figure 1 illustrates the process for evaluating new fuels to assure that there will be no impairment to the overall Army mission(1)*. This process provides for a rapid, but orderly, evaluation which will identify problem areas as early as possible. The facility described in this report falls under the heading of Component and Single-Cylinder Engine Testing and is intended to provide extensive data on the combustion behavior of candidate fuels and fuel components of interest. The engines which will be used in the facility are intended to function as intermittent combustion bombs

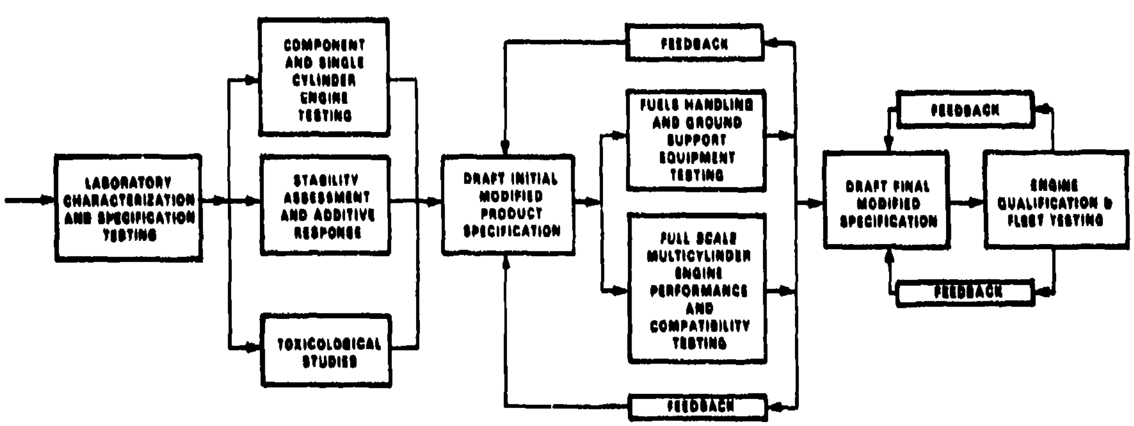


FIGURE 1. PROCESS FOR EVALUATING NEW/SYNTHETIC FUELS

* Underscored numbers in parentheses refer to the list of references at the end of this report.

rather than an emulation of any specific production engine. The reactors (combustion chambers) are one of the variables which will be varied during future projects, and the information generated is intended to be sufficiently basic to allow interpretation of the data without being constrained to a particular production engine design.

Continuing research has been performed on the effects of fuel components on diesel engine operation, but these efforts have concentrated on understanding the results of variations in the refining of petroleum. Review of the literature has indicated that there are major gaps when potential shale fuel properties are considered. A need, therefore, exists for the development of a program designed to fill the gaps in the technology. A program has been outlined which includes the formulation of fuels whose chemical and physical composition will be varied to approximate various potential shale-derived liquids. Every attempt would be made to vary as few properties at a time as possible. Each of these synthesized shale diesel fuels will then be evaluated in a fully instrumented diesel research engine to determine the effects these variations in fuel properties have on engine operation. In this way, an understanding of the impact of each potential change in fuel composition could be developed, leading to sufficient knowledge to point out those physical and chemical properties of shale diesel fuels which must be controlled by specifications.

The installation and calibration of a facility for evaluating the possible finite property variations of the synthesized shale diesel fuels was considered a prime phase of the overall program outline. The monitoring of combustion efficiency, heat release, ignition delay, and pressure rise is a fundamental method of determining effects the fuel property have on engine performance. It was proposed that a high-speed computerized data acquisition system be used to monitor the various inputs needed to compute the aforementioned parameters. A fully instrumented, fuel-sensitive engine, linked to the high-speed system, would provide an effective tool for evaluating the effects of various shale fuel properties.

II. DESCRIPTION OF FACILITY

The facility developed for the monitoring of diesel fuel property effects on combustion/ignition characteristics consists of three individual segments. The first segment is the modified Detroit Diesel (DD) 3-53 research engine and its associated hardware. The second segment is the engine instrumentation package, and the third segment is the CALO data acquisition system. The proper interfacing of these three segments is paramount in determining the significance of any property-related fuel effects on engine performance. Figure 2 is a block diagram of the integrated combustion/ignition facility.

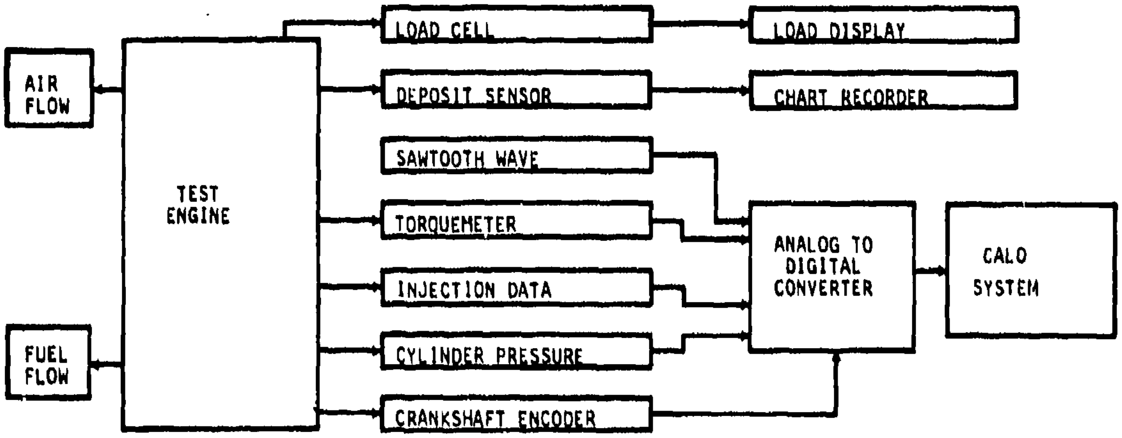


FIGURE 2. COMBUSTION/IGNITION FACILITY BLOCK DIAGRAM

A. Research Engine

The DD3-53 series two-cycle engine is considered one of the more fuel-sensitive engines in the military fleet. A decision was made to use the DD3-53, but to convert it into a single-cylinder research engine. The impetus behind the conversion was to reduce the fuel consumption of the test engine, an important factor when studying fuels which are available in only limited quantities.

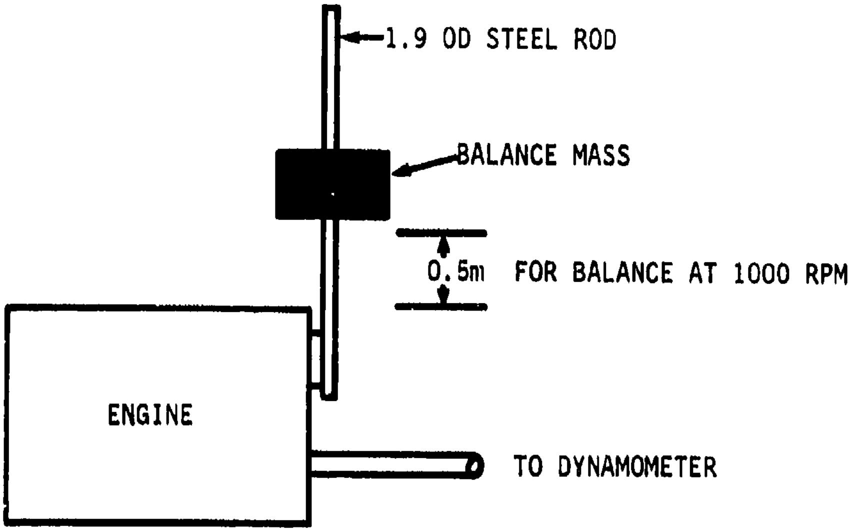
During the initial conversion procedures, the numbers one and three pistons were removed from the engine, and the appropriate counterweights were added to their respective crankshaft throws. Provisions were made to cover the cylinder liner intake ports, and the pushrods and rocker arm assemblies for cylinders 1 and 3 were removed. The fuel system passages were modified in the head so that fuel flows to and from the No. 2 injector only. The governor was removed, and a micrometer adjustment was installed for fuel flow control to the unit injector. The need to control temperature and pressure of the intake air necessitated the removal of the roots blower from the modified DD 3-53 engine. An intake air system, incorporating an in-line air heater, an air dryer to provide constant humidity, and an air compressor, was devised to simulate blower and airbox conditions. The exhaust was fitted with a remote-actuated butterfly valve for control of backpressure to simulate the turbocharger turbine restriction. Upon completion of the modifications, tests were performed to determine the operability of the engine in a one-cylinder configuration.

Preliminary testing with the Detroit Diesel 3-53 single-cylinder conversion revealed no vibrational problems at low speeds and light loads. However, the testing did seem to indicate that severe vibrational problems could occur at the higher speeds. In order to determine the source of the vibrations and to develop corrective action, a computer model was developed and used to compute the forces and force couples generated by the rotating and reciprocating parts within the engine. The model indicated that the imbalances created by the removal of two pistons and connecting rods could be balanced by altering the orientation of the counter rotating balance gears and by removal of some mass from these gears. After the modifications were made, the engine was assembled and tested. The testing revealed two distinct modes of vibration; yawing, caused by an out of balance horizontal force; and rolling, caused by side thrusts during the combustion process. Numerical analysis provided the solution to the yawing problem, by indicating a need to reposition the two pulley counterweights on the front of the engine. These pulleys had been shifted out of phase with one another when the prior modifications had been made. The rolling vibration posed a problem whose solution was not immediately apparent, but was approachable in a unique manner.

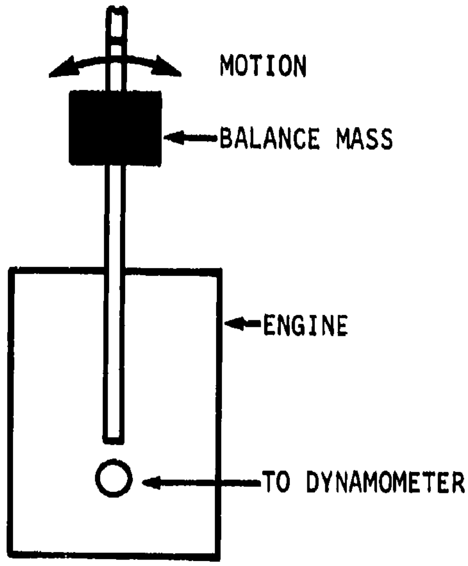
As a refinement to eliminate the side-to-side rolling, a vibration damper was added to the engine. The vibration damper consisted of a still rod attached firmly to the rear of the engine. The rod extended from the engine centerline vertically upward for a total length of 1.5 m. A balance weight was attached to the rod in such a way that it could be repositioned along the length of the rod. Modeling the engine, the engine supports, the rod, and the balance weight as a two mass-two spring system proved to be a complex problem because of the number of unknown constants involved in the dynamics of the engine support structure. Utilizing a number of gross assumptions resulted in the design of a system involving a 2.15-kg mass extending 1.2 m above the centerline of the engine on a 1.9-cm OD steel rod. With this system, it was predicted that the inertial forces generated by the side-to-side motion of the balance mass would just balance the forces exerted on the engine by the combustion process.

The weight manufactured for the system actually had a mass of 3.62 kg. As a result, the actual position of the weight had to be adjusted to approximately 0.5 m above the centerline for balancing at 1000 rpm (see Figure 3). The lengths required for balancing at other engine speeds were also determined experimentally by observing the point at which engine side motion ceased. The engine motion was measured by using a strobe light to observe a mark placed on the head of the engine.

After collecting the data, a first-order polynomial regression was performed in order to provide a calibration curve for predicting the length required for balancing the engine at any given speed within its operating range. A plot of the raw data and the calibration curve for predicting "zero" deflection are shown in Figure 4. Initial testing of the balance rod length has shown the predi ted values to be close enough to the actual values that only minor adjustments need be made during engine operation to ensure "zero" deflection. After the mechanical modifications were made to ensure stable engine operation, the engine instrumentation was installed.



A. SIDE VIEW



B. REAR VIEW

FIGURE 3. ENGINE BALANCING SYSTEM

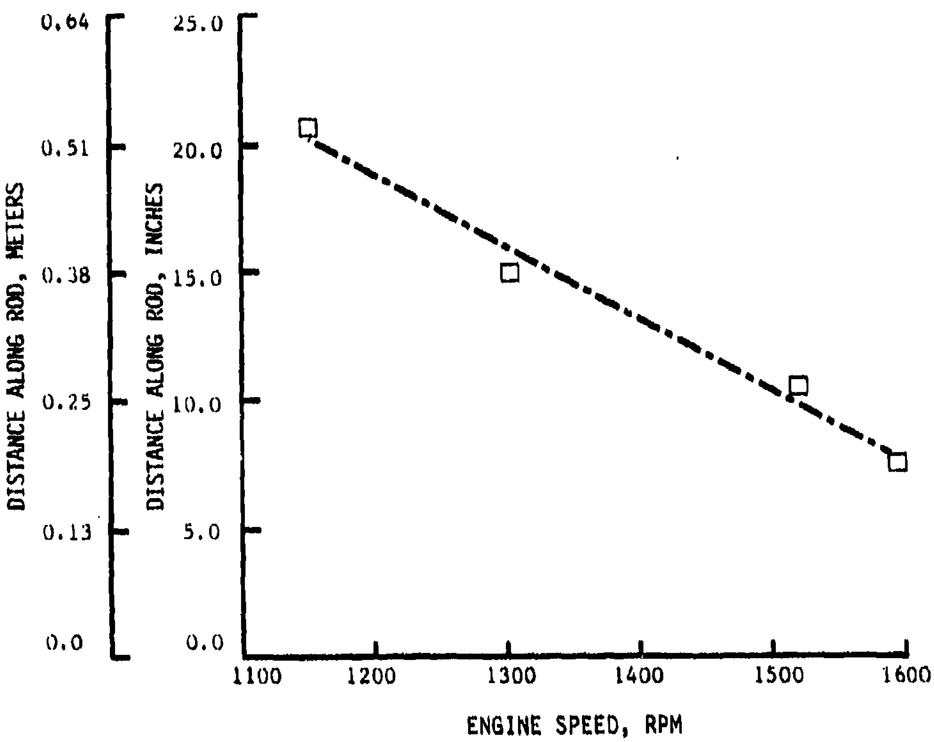


FIGURE 4. DISTANCE OF MASS ALONG ROD VERSUS ENGINE SPEED FOR "ZERO" DEFLECTION

B. Engine Instrumentation

For the installation of the engine instrumentation, several modifications of the cylinder head had to be made. The modifications included installation of a pressure transducer and a deposit probe, within the physical restrictions of the combustion chamber area. Consultation with researchers at General Motors Corporation, who had previously instrumented a DD3-53 head, helped place the pressure transducer and deposit probe where they would not interfere with engine functions.

The pressure transducer is a water-cooled piezoelectric-type transducer, with its output going to a charge amplifier. The charge amplifier output signal is then an input to the data acquisition system. The transducer itself has been coated and calibrated as described in the literature on the subject of cylinder pressure measurement(2). The most important aspect of pressure measurement is the accurate phasing of the cylinder pressure with top dead center (TDC). This was accomplished by locating TDC of the crank-throw (2), then phasing the optical shaft encoder marker pulse to coincide with the TDC marker. The optical shaft encoder was used to trigger the analog-to-digital (A/D) converter, so that synchronous channels of data could be taken. By minutely adjusting the shaft encoder, and examining log pressure-log volume plots, correct cylinder pressure phasing was accomplished.

The deposit probe consists of a central electrode, electrically insulated from an outer cylinder. The probe is mounted in such a way that the electrodes are flush with the combustion chamber surface. Two different modes of operation will be tested. In one method, the change in electrical resistance with time between the center electrode and the outer cylinder will be measured. In the other method, a potential will be induced between the electrodes and the change in current through the gap will be measured as a function of time. In either case, the changes which will be observed will be due to deposit formation in the gap between the electrodes. Selection of the appropriate method will be based on the sensitivity and noise associated with each one. At this point, a selection of the method of deposit measurement has not yet been made.

The measurement of instantaneous torque is to be used to calculate instantaneous brake horsepower. The torque is to be measured with an in-line torque meter coupled in the driveline between the engine and dynamometer. The torque meter consists of a shaft instrumented with strain gauges. The output from the torque meter is fed to a strain gauge amplifier which has a ±10 volts direct current (VDC) output which serves as an input to the data acquisition system. Along with the torque, an instantaneous measure of engine speed is needed to calculate the brake horsepower. A sawtooth waveform of known amplitude and frequency can be used as an input to calculate an instantaneous engine speed. By measuring the voltage differential between consecutive data points which lie on the sawtooth wave, real time can be calculated from which an engine speed can be computed.

The instantaneous mass fuel flow rate was attempted as the final input channel to the A/D converter. A literature survey revealed that in previous work, the mass fuel flow rate could be measured by modifying a unit injector to accept a strain gage (3). The strain gage, bonded to the injector tip, is used to measure the hoop stress, which is proportional to the fuel pressure in the injector tip. By using the strain gage as the active leg of a wheatstone bridge, a method was proposed for in situ calibration in the operating engine. In situ calibration is necessary because the instantaneous fuel flow rate is a function of the instantaneous pressure drop across the injector tip spray holes. As part of the calibration, an electronic weigh scale with digital readout was acquired to give an integrated mass fuel flow rate upon which the instantaneous flow rate is based. Reoccurring problems with the durability of the strain gage under the high heat and pressures at the unit injector tip made the calibration of the instantaneous mass fuel flow rate impossible. Additional problems with this method included the seal between the injector and its tube because of the wires to the strain gage, the durability of the wires coming from the strain gage, and noise due to the grounding of the strain gage and wires to the engine. The absence of the mass fuel flow rate data also meant that injection timing could not be acquired due to the lack of needle lift and line pressure data. The unit injector construction does not allow for the inclusion of a needle lift or line pressure transducer; therefore, a different approach will have to be developed in order to acquire injection timing and rate data.

Various other instruments are being used for the support of engine operation. A vortex shedding flowmeter is being used to monitor the intake air flow rate. The flowmeter has a TTL (Transistor Transistor Logic) pulse train output with a frequency that is linearly proportional to the flow rate. The flow rate is monitored with a digital frequency counter to give an account of the approximate amount of air used by the engine. Because the engine operates on a port scavenged two-stroke cycle, the air flow cannot be used to calculate the air-fuel ratio of the operating engine since the engine transfers substantially more air through the engine than is actually used for combustion.

The engine is loaded using a 93.3 kW (125 hp) universal eddy current dynamometer. An electronic load cell is attached via a torque arm to the dynamometer to measure the brake torque. The output of the load cell is monitored with a digital load readout calibrated to ft-lb of torque. The engine speed is monitored with a 60-tooth gear, magnetic pickup, and digital frequency counter. A dynamometer controller is used to provide either speed or load control.

Various temperatures and pressures are monitored to establish stabilized engine operating conditions. Table 1 lists the various engine parameters that are measured. A list of the instrumentation used in the facility is presented in Appendix A. Photographs of the research engine and the instrumentation control panel are also presented in Appendix A.

TABLE 1. ENGINE PARAMETERS

Pressures	Temperatures
Oil, psi	Water In, °F
Fuel, psi	Water Out, °F
Airbox, in. Hg	Fuel, °F
Exhaust, in. Hg	Oil In, °F
	Oil Sump, °F
	Airbox, °F
	Exhaust, °F
	Intake Air, °F

The proper interfacing of the instrumentation to the data acquisition system was critical in developing the fuels combustion/ignition facility. The proper grounding and shielding techniques were required to ensure that ground loops were avoided when the instrumentation was interfaced to the computer. Due to the sensitivity of the transducers and amplifiers, and the high rate of data acquisition, electrical noise could alter the true readings significantly. This avoidance of extraneous noise on the inputs to the A/D converter is important in determining the accuracy of the data. Appendix B contains the wiring diagrams for the instrumentation and computer interfacing.

C. CALO-Data Acquisition System

A high-speed data acquisition system was acquired for the analysis of combustion/ignition fuel property related effects. The CALO system was based on an existing system in operation at Southwest Research Institute, so that existing software could be used to eliminate development time. A controlled environment room was built in the engine lab, in order to house the system. The room contains an air conditioner, which recirculates the air, to maintain the room in the proper temperature range for computer operation. An electrostatic precipitator is used to remove the dust and dirt particles present in incoming fresh air.

The CALO data acquisition system consists of a digital computer, a disc drive and controller, a system console, a printer-plotter, a four-channel A/D converter, and associated software. The computer is a disc-based unit, and has 256 Kbytes of resident main memory. The computer communicates to the disc through a dual channel port controller (DCPC) interface. The DCPC interface allows the computer to read and write directly into main memory for data acquisition and disc access. The disc, which is the mass storage device for the system, has 19.6 Mbytes of available memory, and is interfaced to the computer through the disc controller.

The access to the computer is provided by the system console. Through the system console, the system status is monitored, and programs can be developed and executed. The console is a CRT terminal with graphics capability and minitape drives. An IEEE 488 interface bus connects a dot matrix printer-plotter to the terminal for screen copy capability in both the graphics and alphanumeric modes. The printer-plotter is also set up to be used as the system printer.

The unique component of the CALO System is the high-speed A/D converter. The A/D converter has the capability of sampling data at a maximum conversion rate of 200 kHz, with a resolution of 12 binary bits and sign. The converter has filtering frequencies ranging from 20 kHz to wide band across the four channels. A special feature is simultaneous sample and hold, which allows for the simultaneous acquisition of up to four channels of data synchronous with the clocking signal. The clock signal can be internal, or an external clock pacer can be enabled. For the combustion/ignition facility, the A/D converter is clocked by the shaft encoder in one-degree crankshaft increments. A special interface is used for compatibility with the computers I/O buffer.

The software that is associated with the CALO system is the operating system software, the special function utility programs, and the data acquisition/ application programs. The operating system is of the file manager type, which is accessed in a session monitor mode. The session monitor has an account system which keeps track of system connect time and CPU (central processing unit) usage. The file manager is a program which allows procedure files to be built and executed. It also performs the scheduling of programs and performance of other system functions. Included in the system is an interactive editor, a program which is used to create and/or modify programs and files. The CALO system has a FORTRAN IV compiler to convert FORTRAN source code into relocatable binary files. A loader then is used to convert the relocatables into a memory image module. Once the program is loaded, it can be saved and executed by the file manager.

Included in the utility programs is the software which controls the functioning of the Distributed Systems (DS) link. The DS link allows interactive access to a remote computer, thus forming a computer-to-computer communication path. The other computer is an SwRI-owned machine that has a magnetic tape drive unit available for mass data storage. The main purpose of the DS software and link will be for transferring raw data to the remote computer for processing, saving data for future reference, and for system backups on magnetic tape.

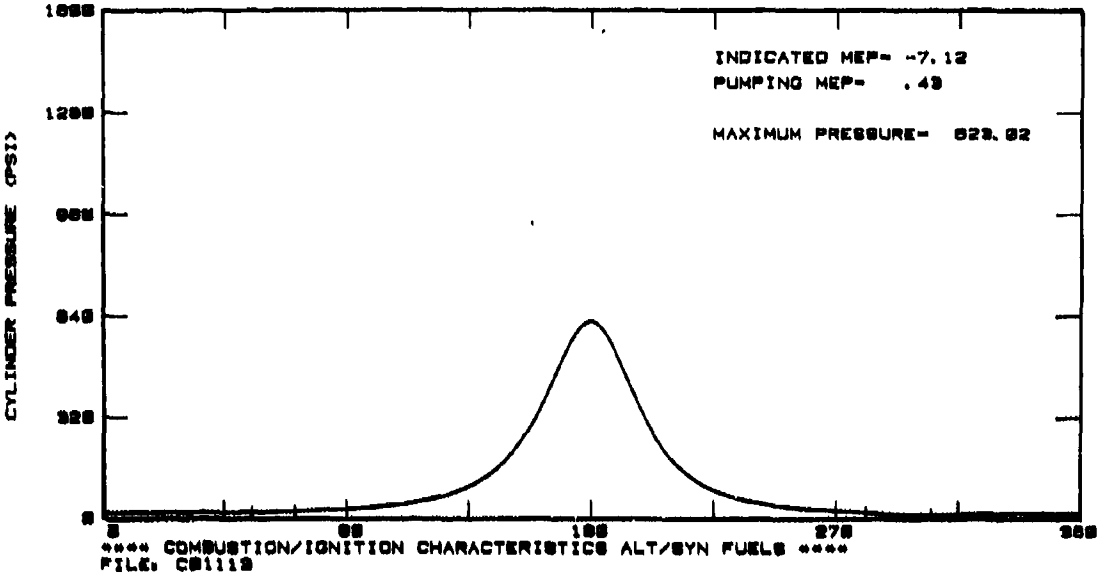
The data acquisition/application programs include special software drivers for operating the A/D converter, and the programs written at Southwest Research Institute for data manipulation. The drivers control the interfacing between the computer and A/D converter so that analog data can be acquired, digitized, and written to the computer disk for storage. A control file program is used to create a control file, which is used by the high-speed system programs for the collection, separation, manipulation, and display of high-speed data. The program which is used for data collection is executed by a transfer file. This program uses the parameters in the control file for the data acquisition, such as; number of cycles, data points/cycle, expected clocking rate, etc. This program then schedules the data separation and program execution phases of the data acquisition process. When the data collection program is executing, all other computer activity must be suspended, and all other programs displaced from main memory.

The data separation program separates the raw data into separate files for each channel, then schedules the data manipulation programs which modify the data according to the parameters contained in the control file. Two application programs can be scheduled, the first will input a number of cycles of data and output an averaged engine cycle and, if required, the standard deviation at each crankangle. This application program creates the average cycle by computing the mean of the values that occurred at each crank angle increment. The second program accesses a file containing a number of engine cycles of data, and produces a file containing the minimum, mean and maximum value of each cycle and each channel. When the application programs are completed, the transfer file is terminated, and the data reduction programs can be used to access the binary data files and convert them into decimal real numbers for performance comparisons.

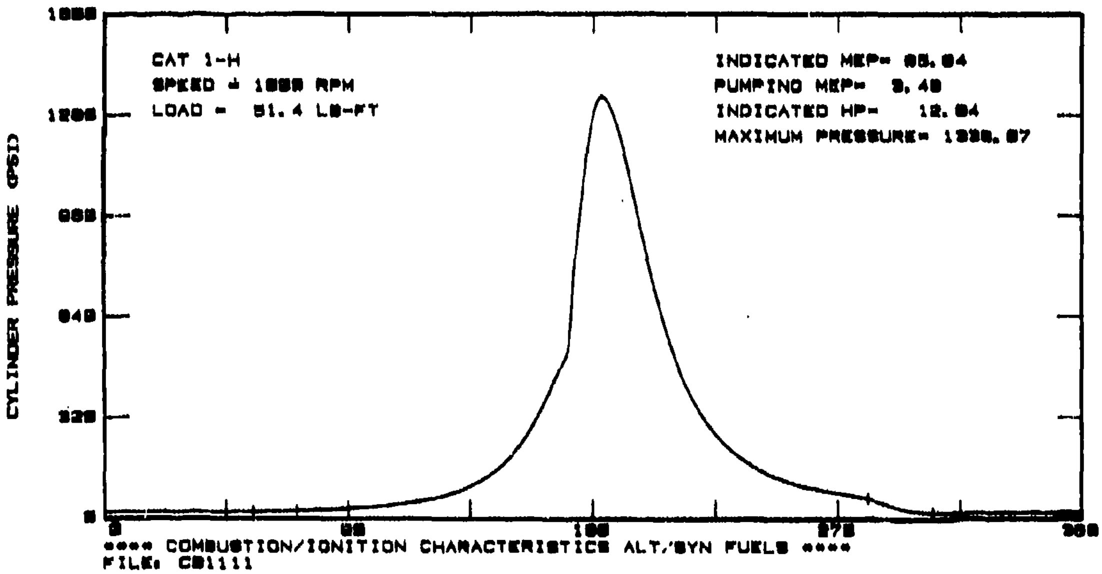
D. Data Analysis

After the data have been manipulated and separated into voltage data files, which takes approximately 2 minutes of processing time for 100 cycles of 360 point data cycles, data reduction programs can be used to determine if the data is good. The typical procedure is to warm the engine up to the predetermined operating temperatures, then take 100 cycles of data in a hot motoring mode, i.e., with rack fully closed, the engine hot and being driven by the dynamometer. After the data is separated, the operator schedules a program to examine the data and calculate a pressure adjustment based on absolute airbox pressure at bottom dead center (BDC). When the pressure adjustment is calculated, the program is exited, and a program which will produce log pressure-log volume plots is scheduled. By knowing the calculated pressure adjustment, the correct pressure-crankangle phasing can be found by examining the peculiarities of the log P-log V plots. Typically once the pressure-crankangle offset is found, it will not vary unless the shaft encoder has changed in its phasing with top dead center (TDC); however as a precaution, this procedure is repeated before each set of data is taken. Once the operator is satisfied with the phasing data, firing cycles (rack open and combustion taking place) can be acquired with the test and base fuels. The turn-around time in taking the data, and examining it, is approximately 5 minutes for 100 cycles of 360 point data cycles. A more detailed explanation of the programs for data analysis follows.

The analysis of pressure data can reveal valuable information about the combustion characteristics of a fuel. Several of the data reduction programs available are for the analysis of pressure data. The pressure-time diagrams are plotted by a program, which locates peak pressures, calculates mean effective pressures, calculates indicated horsepower, calculates a pressure adjustment (based on airbox reference pressure at BDC), and allows the pressure offset to be varied for proper crankangle phasing. An example of pressure time diagrams for motoring and firing cycles is shown in Figure 5. The slashes locate valve and port openings and closings. The program, which produces pressure-volume, log pressure-log volume diagrams, is a very useful tool for analyzing motoring and firing pressure data. With a motoring trace, proper phasing between the pressure signal and engine TDC can be monitored by examining the slope of the polytropic compression process on a log P-log V plot. Since the compression process is polytropic, PV^n = Constant, on a logarithmic scale the slope of the line should be equal to -n. The polytropic exponent, n, generally varies between 1.24 and 1.35 for motored engine data. Incorrect phasing, incorrect pressure referencing, or a nonlinear pressure transducer can all be determined from the abnormalities present in the hot motoring log P-log V diagrams. Figures 6, 7, and 8 are examples of the effects pressure phasing has on the shape of the diagrams. Figure 6 is a properly phased pressure signal of a hot motoring trace,



Hot Motoring Trace



Firing Pressure Trace

FIGURE 5. HOT MOTORING AND FIRING PRESSURE TRACES, AVERAGE OF 100 CYCLES

indicated by maximum pressure occurring near TDC or minimum volume. The maximum pressure point of a motored engine occurs slightly before TDC because of the effect of heat transfer from the working fluid (i.e., the intake air). Figure 7 is an example of a pressure signal advanced one degree with respect to engine TDC, the peak pressure is occurring slightly before TDC. Figure 8 is an example of a signal retarded by one crankangle degree; the maximum pressure is seen to occur slightly after engine TDC. Figure 9 shows an example of log P-log V diagrams for the three cases of crankangle phasing for an engine firing cycle, while Figure 10 shows examples of pressure-volume diagrams for hot motoring and firing cycles. The compression and expansion lines do not coincide on the hot motoring traces due to heat transfer from the working fluid to the cylinder walls and cooling jacket. The straightness of the lines on the lop P-log V plot is also useful for determining the kind of error present. Incorrect pressure referencing and a nonlinear transducer will show up as a curvature in the line during the compression and expansion process. A program was developed to calculate rate of heat release and cumulative heat release from cylinder pressure data for an engine firing cycle. The rate of heat release and cumulative heat release are effective tools for measuring combustion characteristics of various fuels. The heat release calculations and diagrams are sensitive to changes in ignition delay, rate of pressure rise, maximum cylinder pressure, and injection timing. By comparing the magnitudes, shapes, duration, and crankangle phasing of the heat release data, the combustion characteristics of various fuels can be determined. Provisions have been made in the heat release program to calculate the centroid of the heat release diagram to obtain a quantitative comparison of fuel-related combustion effects. The centroid of a heat release diagram is a geometric concept expressing the center of area bounded by the instantaneous heat release curve. The centroid has two components, the phasing:

$$\bar{\theta} = \frac{\int \theta \, \dot{Q} \, d\theta}{\int \dot{Q} \, d\theta}$$

where:

$\bar{\theta}$ = phasing of centroid, degrees

θ = crankangle, degrees

$\dot{Q}$ = instantaneous heat release at angle θ, Btu/degrees

and the magnitude:

$$\bar{\dot{Q}} = \frac{\int .5\ \dot{Q}^2\ d\theta}{\int \dot{Q}\ d\theta}$$

where:

$\bar{\dot{Q}}$ = magnitude of centroid, Btu/degrees

$\dot{Q}$ = instantaneous heat release, Btu/degrees

which are sensitive to the effects the chemical and physical delays have on the instantaneous heat release curve. The sensitivity of the phasing and magnitude of the centroid, to fuel property changes, will be used to correlate combustion characteristics of various alternative/synthetic fuels. By examining the phasing of the centroid to injection and ignition events, a better understanding of what fuel properties effect combustion could be acquired. The magnitude can help determine any increase/decrease in combustion efficiency, and helps characterize the region of main burning on the instantaneous heat release diagram. Figure 11 is an example of the rate of heat release and cumulative heat release plots. Several important areas of the plot are indicated. Figure 12 is a plot of the derivative of pressure versus crankangle. The dependence of the heat release on cylinder pressure and its derivatives is visible when the figures are compared. Therefore, it is expected that any fuel properties which have an effect on the cylinder pressure will also affect the heat release data.

The calculation of the rate of heat release assumes that all of the heat released from the combustion of the fuel is reflected by the increase in cylinder pressure. However, this is not the case, since heat is lost to the cylinder walls through heat transfer. The resulting calculated heat release is thus the net, after such as yet unaccounted for losses. As a result, the

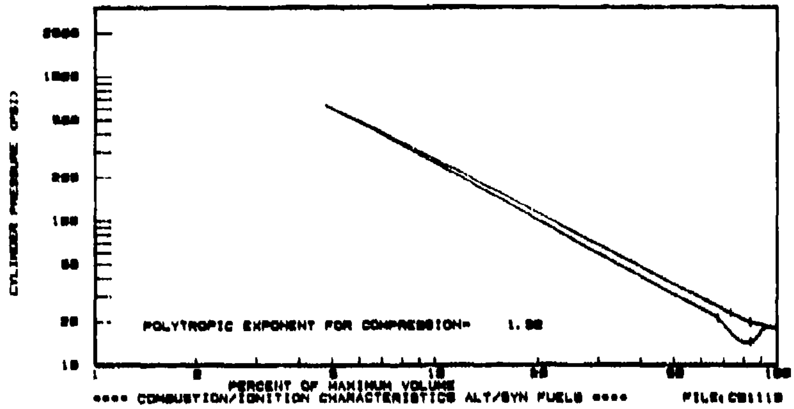


FIGURE 6. HOT MOTORING, PROPER CRANKANGLE PHASING, LOG P-LOG V

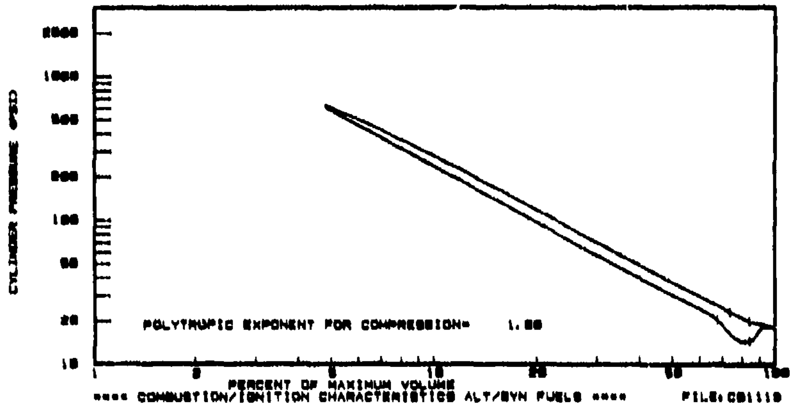


FIGURE 7. HOT MOTORING, ONE DEGREE ADVANCED LOG P-LOG V

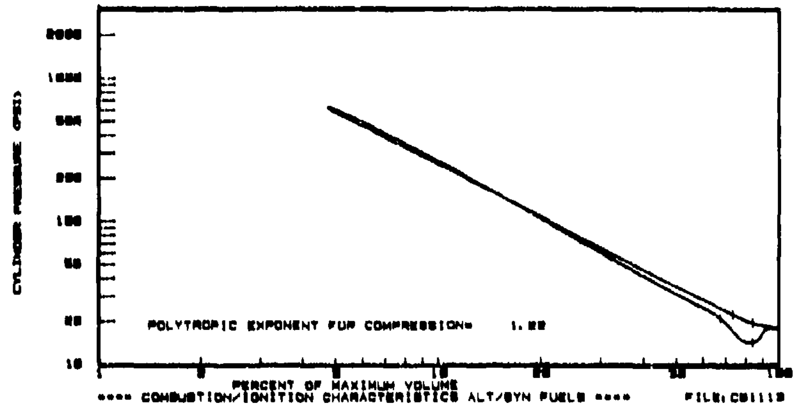


FIGURE 8. HOT MOTORING, ONE DEGREE RETARDED LOG P-LOG V

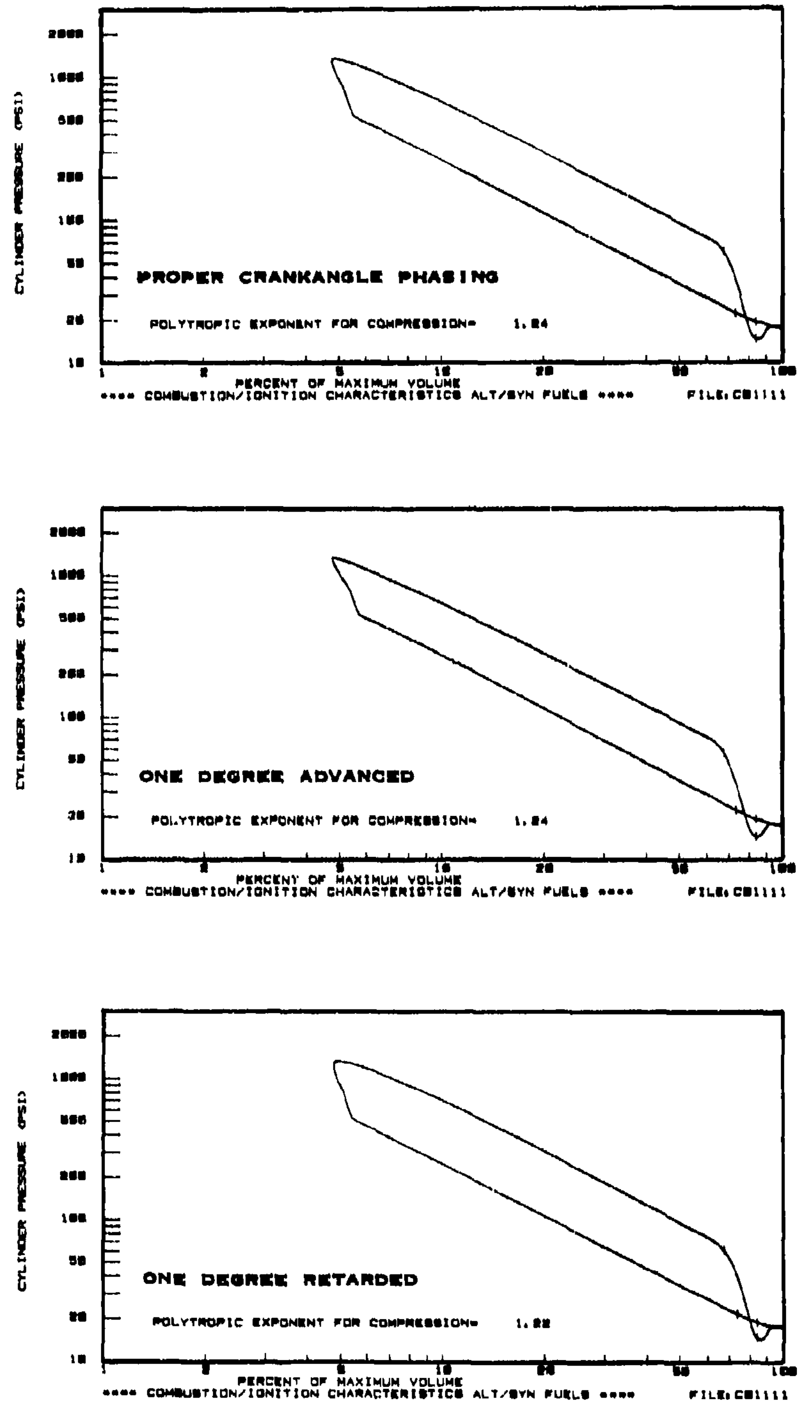
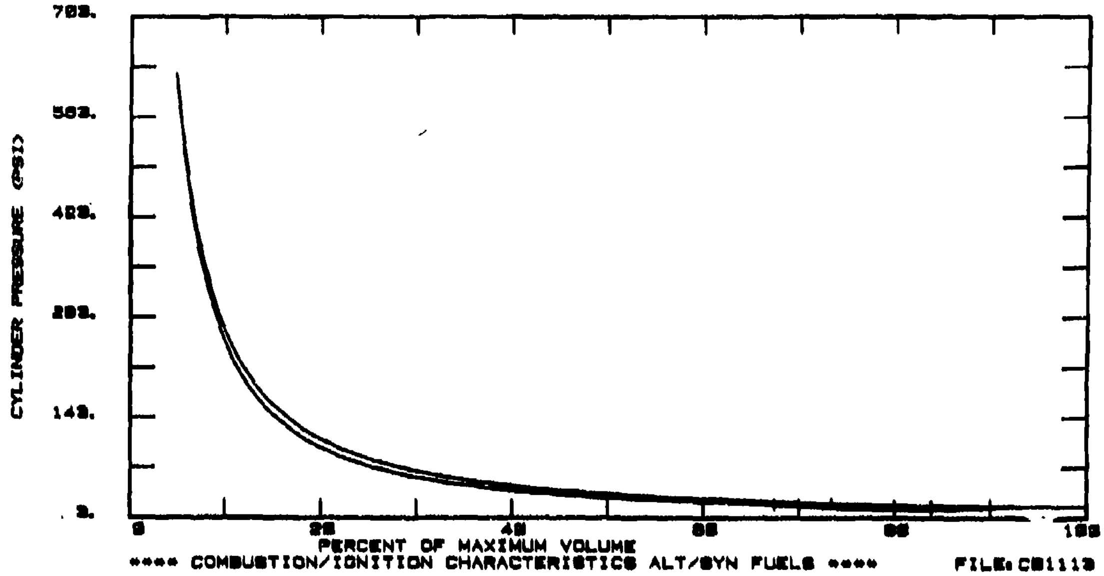
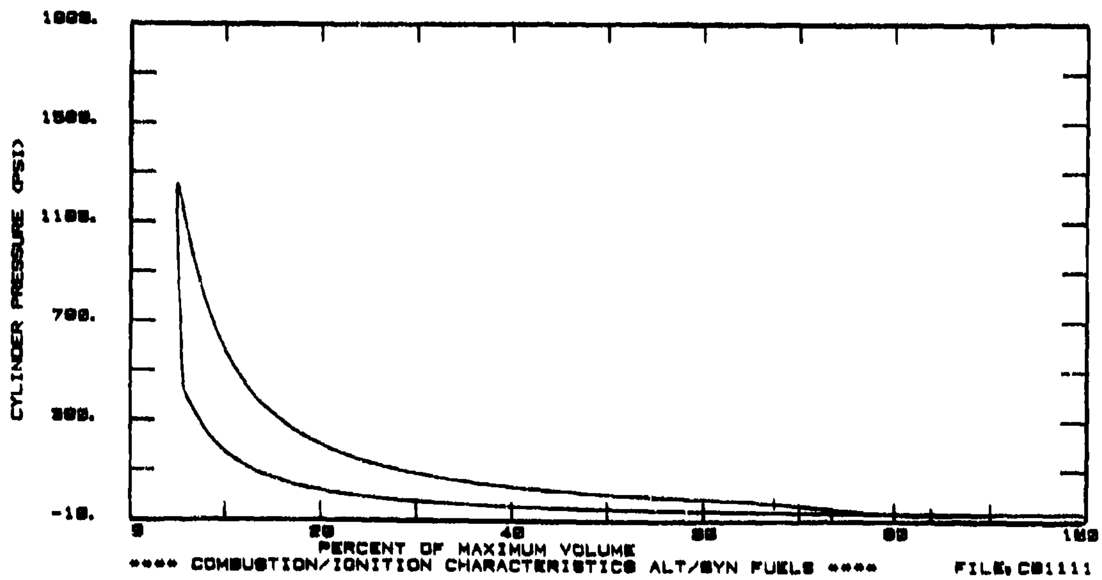


FIGURE 9. EFFECT OF CRANKANGLE PHASING ON A FIRING CYCLE; 1000 RPM, 51.4 FT-LB, LOG P-LOG V



Hot Motoring Cycle



Firing Cycle
1000 RPM
51.4 ft-lb

FIGURE 10. PRESSURE-VOLUME RELATIONSHIPS FOR HOT MOTORING AND FIRING CYCLES

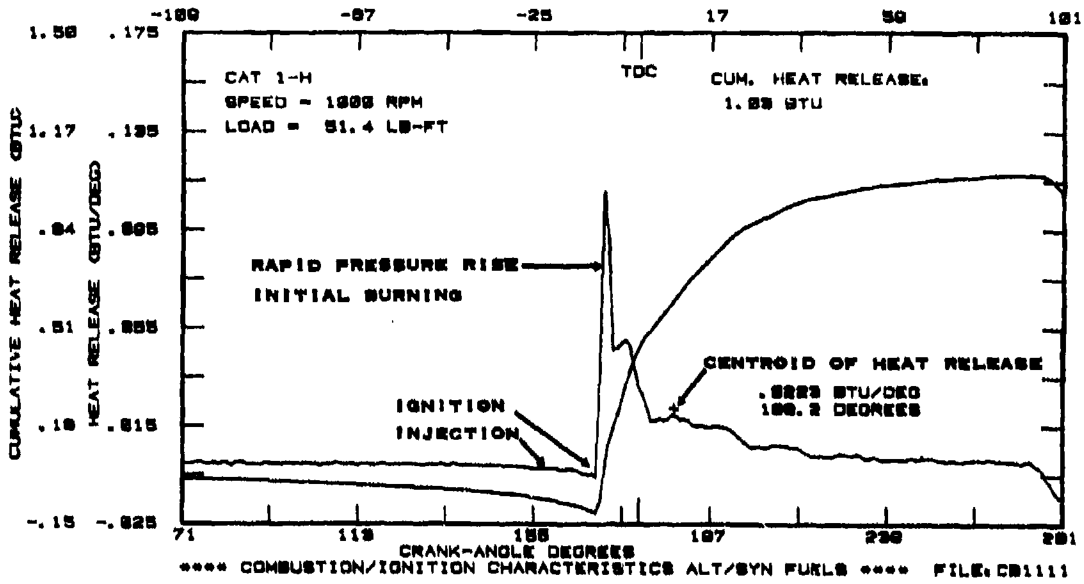


FIGURE 11. RATE OF HEAT RELEASE AND CUMULATIVE HEAT RELEASE FOR AN AVERAGED FIRING CYCLE

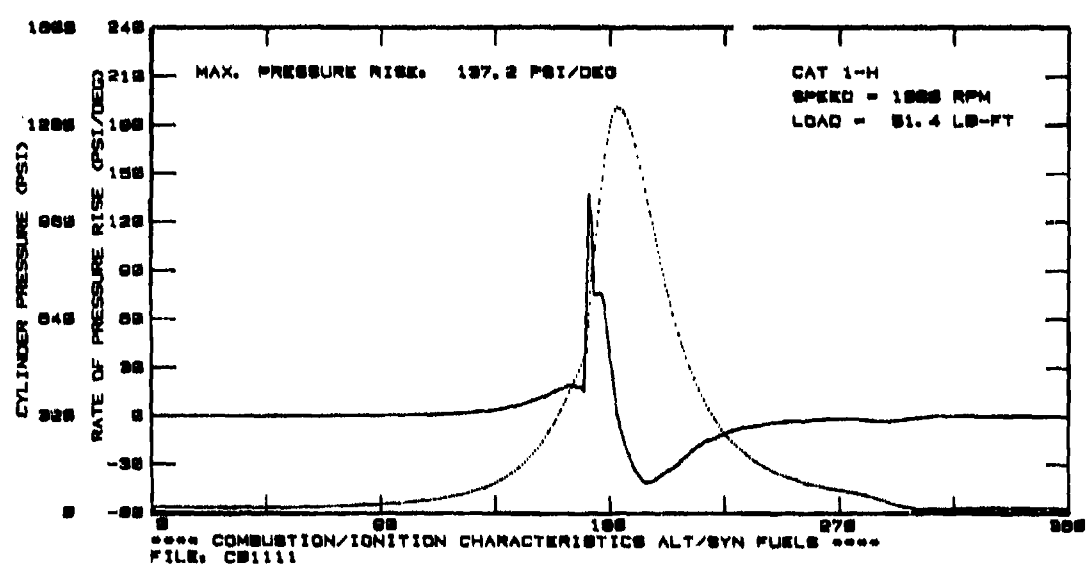


FIGURE 12. DERIVATIVE OF PRESSURE, ALONG WITH PRESSURE VERSUS CRANKANGLE

heat supplied by the fuel will not be fully accounted for by the cumulative heat release calculation. This error in the heat balance will be monitored in future work, with the objectives of attempting to detect differences in heat transfer due to fuel effects, and to develop a heat transfer model to help account for the losses.

CALO data acquisition system specifications are shown in Appendix C, while the equations used to calculate performance variables are located in Appendix D.

III. CONCLUSIONS

The combustion data acquisition system, along with the associated pressure analysis software, has been installed and checked successfully.

The time from the initiation of the data acquisition process to the presentation of the data on the terminal for the test engineer is approximately 2 minutes. This rapid analysis capability will significantly reduce the costs associated with combustion analysis by reducing both waiting time, fuel costs, and delays in determining the need for repeat tests.

The system accuracy has been shown to be sufficient to quantitize differences in the combustion performance due to minor variations in fuel composition. The basic resolution of the digitizer is 0.083 percent. Repeatability of pressure measurements is such that differences of 1.5 percent can be resolved with 95 percent confidence.

IV. RECOMMENDATIONS

The CALO data acquisition system was designed as a useful tool for examining combustion data. It is recommended that provisions be made to further utilize its capabilities in the development of future mobility fuels. The systems flexibility will make it useful for interfacing to other test cells in order to examine test fuels in different engine and combustion chamber configurations. Software and hardware enhancements should also be continued in order to achieve the state-of-the-art technology required in the analysis of high-speed combustion data. Software enhancements should include operating system upgrades, application program refinements, and provisions for heat transfer calculations to develop a more accurate burning rate model. Hardware enhancements should provide for a reliable method to determine injection rate data, in order to better understand fuel property effects on diesel engine performance.

V. REFERENCES

1. LePera, M.E., "The U.S. Army's Alternative and Synthetic Fuel's Program," Army Research, Development, and Acquisition Magazine, 18-20 Sept-Oct 1980.

2. Lancaster, D. R., Kruger, R. B., and Lienesch, J. H., "Measurement and Analysis of Engine Pressure Data," SAE paper 750026, 1975 SAE Automotive Engineering Congress, Detroit, MI, 24-28 February 1975.

3. Wehrman, R. J., Mitchell, H. R., and Turunen, W. A., "Measuring Rate of Fuel Injection in an Operating Engine," SAE reprint, SAE Annual Meeting, Detroit, MI, 12-16 January 1953.

APPENDIX A
RESEARCH ENGINE DATA

ENGINE INSTRUMENTATION

AVL	model 12QP-300cvk	piezoelectric pressure transducer
Kistler	model 504E	charge amplifier
Lebow	model 1105M-5K	in-line torque meter
Vishay	model 2310	strain-gauge amplifier
Daytronics	model 300D	strain-gauge amplifier
GSE	model 615	weigh-scale system
BLH	model U1	300-lb load cell
Doric	model 420	transducer indicator (load)
RLC	model DITAK II	digital tachometer
DIGALOG	model DL-A1	dynamometer controller
DIGALOG	model DL-M1	motoring option
Wallace & Tiernan	model G1A-18-0100	absolute pressure gage (in. Hg)
Neptune/Eastech	model 2120	vortex-shedding flowmeter
Hewlett-Packard	model 5300A	measuring system (Hz)
Trump-Ross	model T-0360-D13M-5D5	optical shaft encoder
Leeds & Northrup	model 177304	24-input thermocouple recorder

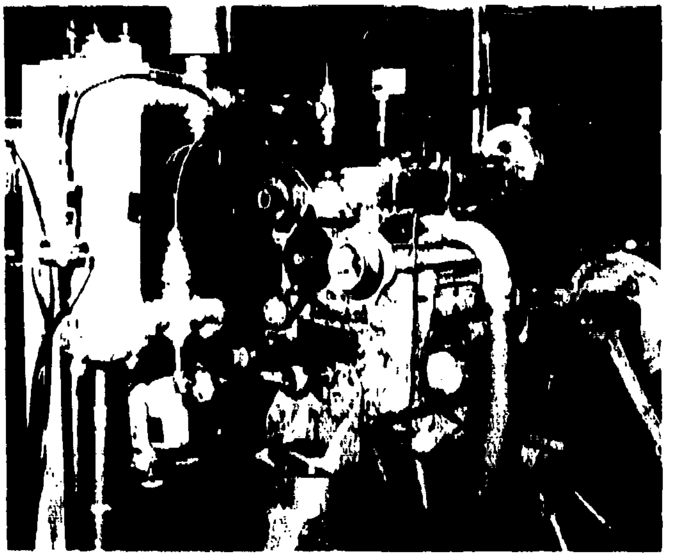


FIGURE A-1: SINGLE-CYLINDER INSTRUMENTED RESEARCH ENGINE

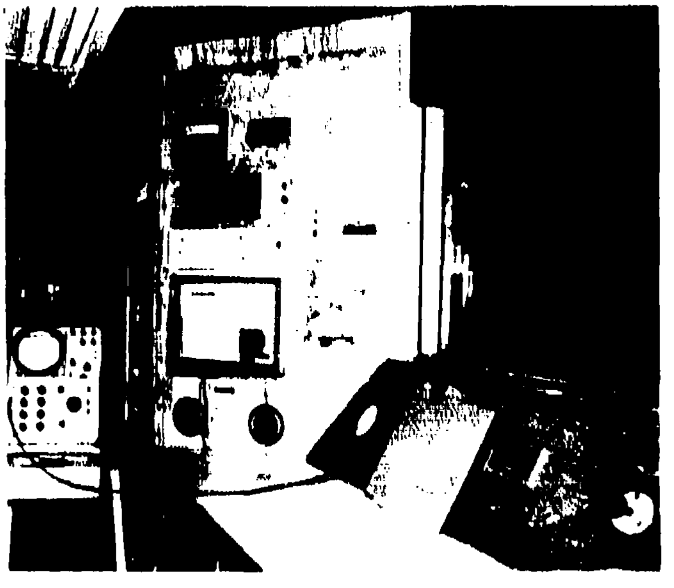


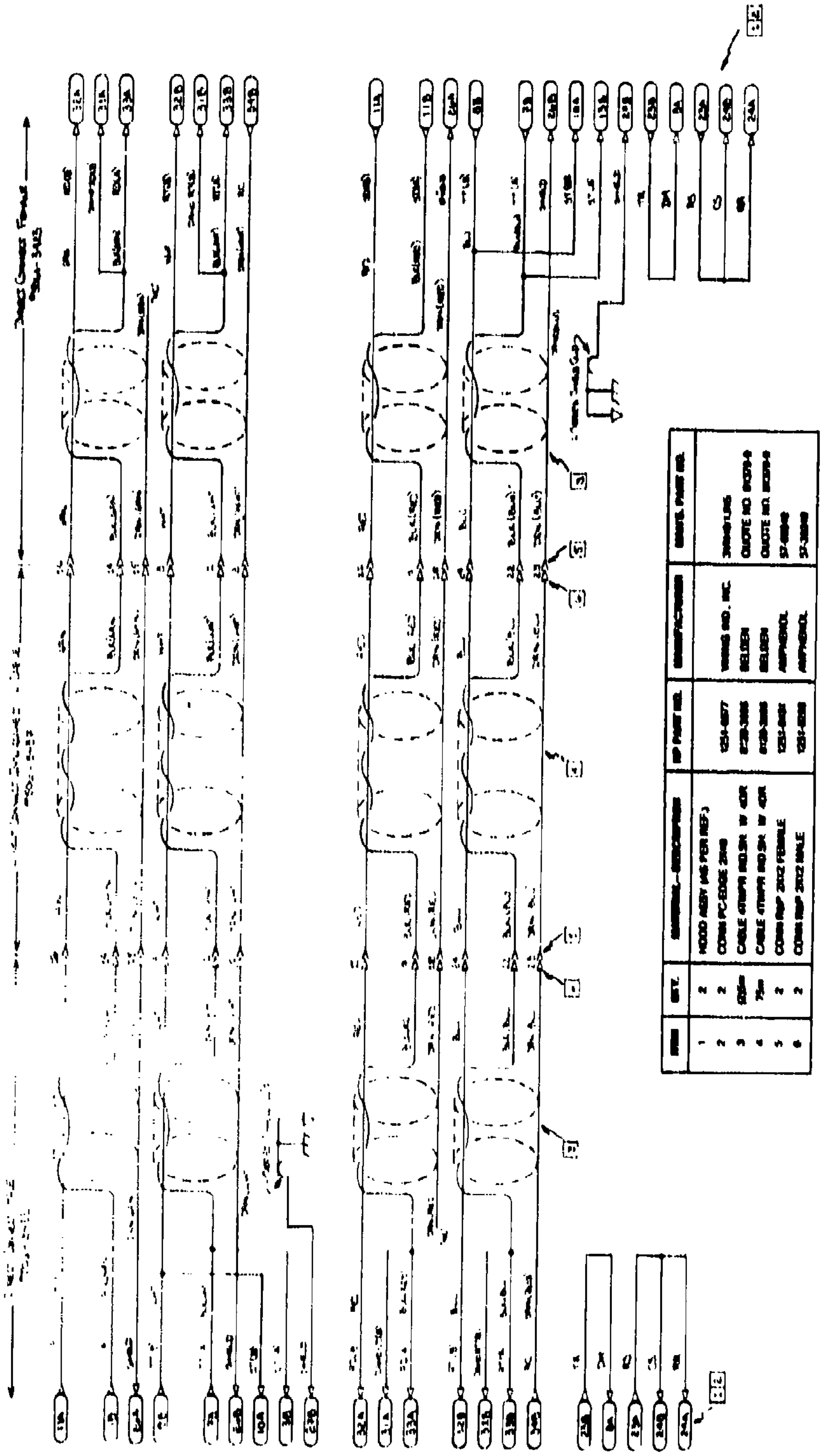
FIGURE A-2. INSTRUMENTATION CONTROL PANEL

APPENDIX B

WIRING AND CABLING DIAGRAMS

HP 1000E (CALO) I/O PORTS

Port No.	Description
25	Jumper
24	Jumper
23	Jumper
22	Jumper
21	Jumper
20	Jumper
17	Jumper
16	Jumper
15	Distributed Systems Interface Card Female Direct Connect 5061-4908-cable
14	BACI 12966A Asynchronous Data Interface 12966-60008-cable
13	93596-60018 HS ADC HI SC 93596-60017-cable
12	12566B-002 +True IN/OUT Preston ADC 93596-60017-cable
11	2100 Interface-Disc Controller 13037-60030-cable
10	Time Base Generator



HP12825A HDLC Direct Connect Interface Kit
installation and service manual
HP part no. 12825-90001 Sept. 1980

HP1000 F series
SwRI Div 05 computer
I/O port no. 14

HP 12966A Buffered Asynchronous Data Communications Interface to HP2648 Terminal. CALO data system, port no. 14

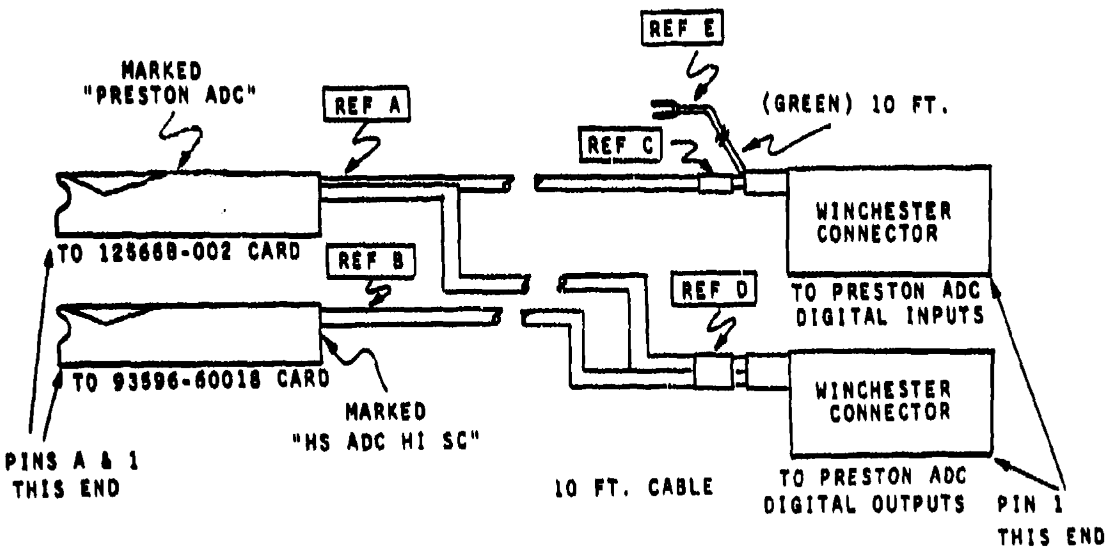
Interface Cable (HP 264X Terminal), part no. 12966-60008, Wire List

HOOD CONNECTOR P1 JUMPERS	(PCA) P1 PIN	SIGNAL NAME (SEE NOTE)	(DEVICE) P2 PIN	WIRE COLOR	RS-232-C CIRCUIT	SIGNAL SOURCE
	A	Signal Ground (EIA)	H	GRN	AB	Common
	B	F				
	C	CA Inhibit				
	D	Transmit Data (EIA)	C	RED	BA	Intfc
	E	Request to Send (EIA)			CA	
	F	Data Terminal Ready (EIA)			CD	
	H	Ext Freq				
	J	F/4				
	K	F/8				
	L	F/16				
	M	F/2				
	N	F/Ext				
	P	BSBA				
	R	Ext Clock	L	BLU		Device
	S	Received Data (EIA)	B	BRN	BB	Device
	T	Secondary Line Sig Det (EIA)			SCF	
	U	(spare) (EIA)				
	V	Secondary Receive Data (EIA)			SBB	
	W	BSCA				
	X	Clear to Send (EIA)			CB	
	Y	Data Set Ready (EIA)			CC	
	Z	Ring Indicator (EIA)	D	YEL	CE	Device
	AA	Receive Line Sig Det (EIA)			CF	
	BB	Signal Ground				
	1	Signal Ground				
	2	CCNT 7				
	3	SXX (Secondary Chan) (EIA)	E,J	ORN	SBA/SCA	Intfc
	4	BSCF				
	5	SIN				
	6	Xmit Data In				
	7	TTY OUT				
	8	+5 volts				
	9	TTY IN				
	10	+12 volts				
	11	UCLK0				
	12	CLKP2				
	13	CLKP1				
	14	CLKP0				
	15	CLKP3				
	16	Recd Data Out				
	17	BSBB				
	18	DIAG				
	19	Spare				
	20	Run Disable				
	21	BSXX				
	22	UCLK				
	23	-12 volts				
	24	Signal Ground				

Note: Signals identified by "(EIA)" after the signal name operate at signal levels specified by EIA Standard RS232C (i.e., OFF < -3V, ON > +3V). All other signals operate at TTL logic levels (i.e., approximately, OFF < +1V, ON > +1.6V)

HP 12966A Buffered Asynchronous Data Communications Interface Installation, Service, and Reference Manual
HP port no. 12966-90001 Jan, 1979

Interface from Preston ADC to CALO
data system I/O ports no!s 12 and 13

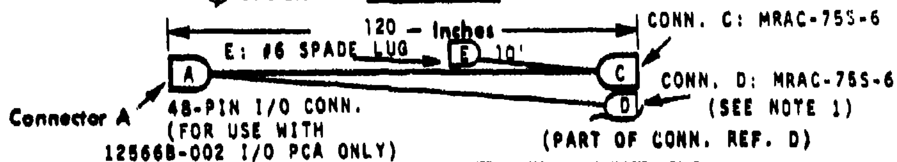


Supplement to: HP 93596L Preston A/D converter
operating and service manual
supplement Part No. 93596-90020, May 1980

Interface to CALO data system
I/O port no. 12
digital input to Preston ADC

BASIC CABLE DATA

STOCK NO. 8120-2086



CONN. A PIN	CONN. D PIN*	REMARKS
1	65/73	COINCIDENCE JD
2	56/63	DATA BIT:LSB+ ***
3	54/60	
4	52/58	
5	44/50	
6	42/48	
7	40/46	
8	32/38	
9	30/36	
10	28/34	
11	20/26	
12	17/24	
13	15/22	
14	05/13	
15	03/11	DATA BIT:MSB+
16	02/10	DATA BIT:SIGN-
24,BB	80/82	LOGIC GROUND JD
		(SEE NOTE 2)

CONN. A PIN	CONN. C PIN*	REMARKS
A	17/24	ADD LINES:LSB JC
B	16/23	
C	15/22	
D	07/14	
E	05/13	
F	04/12	
H	03/11	
J	02/10	
K	40/46	ADD LINES:MSB
L	41/47	AUX CONT2(SSH)
M	42/48	AUX CONT1(PACER)
N	29/35	CMD4
P	28/34	CMD3
R	21/27	CMD2
S	18/25	CMD1
T	32/38	RESET
22,Z**	20/26	DEV CMD
23,AA**	01/08	FLAG (EOC)
24,BB**	80/82	LOGIC GROUND JC
	CONN. E	
•	39	TRANSFORMER JE
		SHIELD

NOTES: * THE WHITE LEAD OF EACH TWISTED PAIR IS CONNECTED TO THE PIN AFTER THE SLASH ON CONNECTOR C&D AND BUSSED TOGETHER AND CONNECTED TO PINS 24/BB AT CONNECTOR A.

** PINS CONNECTED TOGETHER ON PCA. LETTER HOOD "PRESTON ADC"

*** UNUSED DATA BITS ARE GROUNDED IN I/O CONNECTOR HOOD AS REQUIRED.

1. CABLE 93596-60017 CONNECTOR D HAS ADDITIONAL WIRING, SEE FIGURE 4-3
2. TWO PAIRS IN CABLE ARE SPARE: FOLDED BACK AND INSULATED.

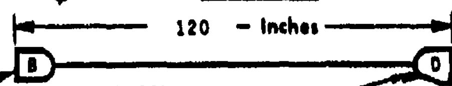
Revised: May 1980

Supplement to: HP 93596L Preston A/D Converter
Operating and Service Manual
Supplement Part No. 93596-90020, May 1980

Interface to CALO data system
I/O port no. 13
digital input to CALO

NOTE THAT THIS DIAGRAM SHOWS PARTIAL WIRING FOR CABLE 93596-60017

STOCK NO. 8120-2086



(PART OF CONN. REF D) (SEE NOTE 1)

Connector B: 48-PIN, I/O CONN. (FOR USE WITH 93596-60018 I/O PCA ONLY)

Connector D: MRAC - 75S-6 (EXISTING CONN. REF D)

CONN. B PIN	CONN. D PIN*	REMARKS	CONN. B PIN	CONN. D PIN	REMARKS
1	*	GRD	A	*	GRD
2	-	(SEE NOTE 3)	B	*	IFN2 READ ENABLE JUMPERS
3	-		C	*	IFN3
4	-		D	45/51	DATA BIT 4
5	-		E	43/49	5
6	-		F	41/47	6
7	*	(OVERRUN FF RESET-DONE ON I/O PCA)	H	33/39	7
8	-		J	*	GRD
9	*	GRD	K	*	GRD
10	*	GRD	L	*	GRD
11	71/77	COIN EXOR OVERRUN (BIT 0)	M	*	GRD
12	57/64	DATA BIT 1 (LSB)	N	*	GRD
13	55/62	2	P	*	GRD
14	53/59	3	R	-	
15	-		S	70/76	INTOR (STATE OF CONTROL FF)
16	67/75	IFCLK (EOC)	T	*	+5V (GATE BIAS FROM CPU)
17	*	GRD	U	*	GRD
18	*	GRD	V	*	GRD
19	31/37	DATA BIT 8	W	16/23	DATA BIT 12
20	29/35	9	X	7/14	13
21	21/27	10	Y	4/12	14 (MSB)
22	18/25	11	Z	01/08	15 (SIGN)
23	-		AA	72/78	OVERRUN (STATE OF OVERRUN FF)
24	-		BB	-	
		(SEE NOTE 2)			

NOTES: * The white lead of each twisted pair is connected to the pin after the slash on CONNECTOR D, bussed together as required, and connected to nearest ground pin(s) on CONN B. Mark Hood "B" this DWG "HS ADC HI SC"

1. Additional wiring on this connector, see figure 4-2.
2. All signals are ground true this PCA only. (Pos. logic convention).
3. Make no connections to dashed pins (designated above), they are used for other applications.

Revised: May 1980

Supplement to: HP 93596L Preston A/D Converter Operating and Service Manual
Supplement Part No. 93596-90020, May 1980

Interface to Disc Controller from
CALO data system. I/O port no. 11

Interface PCA/Controller Signals

SIGNAL	DESCRIPTION
CLEAR	This signal is generated by passing the computer's Power-On Preset I/O (POPIO) signal to the controller whenever the preset jumper (see paragraph 2-4) is set to enable. The Clear signal resets the controller to its power-on state. If all interfaces can generate this signal, operation of other interfaces may be affected. For this reason, the Clear signal can be disabled on any or all interfaces by setting the preset jumper to disable.
IBUS0-15	Interface Bus. Sixteen bit bi-directional data bus used to transmit all data information between the interface and controller.
ENID	Enable Interface Drivers. Allows interface drivers to place data on IBUS for transmission to the controller. Interface must have been previously selected.
ENIR	Enable Interface Receivers. Enables reception of data from IBUS on the interface.
IFN0-3	Interface Function Bus. Four-bit bus carrying the coded function commands from the controller. Decoded functions are valid only if the IFVLD signal is true.
IFCLK	Interface Clock. Validates data and status word transfers word-by-word.
IFVLD	Interface Function Valid. Validates functions on the interface function bus. A function is valid only if this line is true.
CMRDY	Command Ready. Held true while a command to the controller is on the interface bus. Cleared by IFGTC from controller. Interface must be selected.
DTRDY	Data Ready. Held true whenever the FIFO buffer is not empty. Interface must be selected.
EOD	End of Data. True on read when DMA has completed a block transfer. True on write when DMA has completed a block transfer and the FIFO buffer is empty. Interface must be selected. Cleared by CLCSC from computer.
OVRUN	Read Overrun. True if the data buffer FIFO is full and the controller or the computer tries to send another word or true if the data buffer FIFO is empty and controller or computer attempts to fetch a word. Interface must be selected. Cleared by CLCSC from computer.
INTOK	Interrupt OK. True if interface is selected and the control bit is set.

Installation and service manual
13175/13178 Disc Controller Interface kits
Manual part no. 13037-90015, Feb 1980

Interface to Disc Controller from
CALO data system. I/O port no. 11
continued

Interface PCA Connector J1 Pin Assignments

J1 PIN	SIGNAL	J1 PIN	SIGNAL
A	GND	1	GND
B	IFN2	2	IFN0
C	IFN3	3	IFN1
D	IBUS4	4	NOT USED
E	IBUS5	5	CMRDY
F	IBUS6	6	EOD
H	IBUS7	7	IFVLD
J	GND	8	NOT USED
K	GND	9	GND
L	GND	10	GND
M	GND	11	IBUS0
N	GND	12	IBUS1
P	GND	13	IBUS2
R	CLEAR	14	IBUS3
S	INTOK	15	ENID
T	+5V from controller	16	IFCLK
U	GND	17	GND
V	GND	18	GND
W	IBUS12	19	IBUS8
X	IBUS13	20	IBUS9
Y	IBUS14	21	IBUS10
Z	IBUS15	22	IBUS11
AA	OVRUN	23	ENIR
BB	NOT USED	24	DTRDY

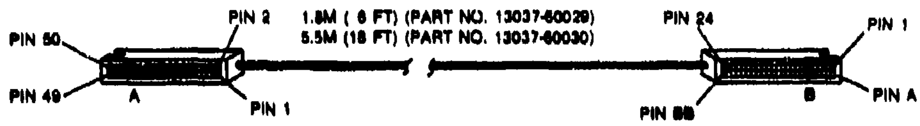
Device Controller PCA Connector IFJ1 Pin Assignments

IFJ1 PIN	SIGNAL	IFJ1 PIN	SIGNAL
1	+5V	2	+5V
3	IFN0	4	IFN2
5	IFN1	6	IFN3
7	NOT USED	8	IBUS4
9	CMRDY	10	IBUS5
11	EOD	12	IBUS6
13	IFVLD	14	IBUS7
15	GND	16	GND
17	NOT USED	18	NOT USED
19	GND	20	GND
21	IBUS0	22	+5V
23	IBUS1	24	NOT USED
25	IBUS2	26	NOT USED
27	IBUS3	28	CLEAR
29	ENID	30	NOT USED
31	IFCLK	32	NOT USED
33	GND	34	GND
35	+5V	36	+5V
37	IBUS8	38	IBUS12
39	IBUS9	40	IBUS13
41	IBUS10	42	IBUS14
43	IBUS11	44	IBUS15
45	ENIR	46	OVRUN
47	DTRDY	48	INTOK
49	GND	50	GND

Installation and service manual
13175/13178 Disc Controller Interface kits
Manual part no. 13037-90015, Feb 1980

Interface to Disc Controller from
CALO data system. I/O port no. 11
continued

Interface Cable (Part Numbers 13037-60029 and 13037-60030), Wiring List



50-PIN CONNECTOR,
PART NO. 1251-3106

(TO DEVICE CONTROLLER PCA)

48-PIN CONNECTOR,
PART NO. 1251-0335

(TO INTERFACE PCA)

WIRING LIST

CONNECTOR A PIN ASSIGNMENT	SIGNAL	CONNECTOR B PIN ASSIGNMENT	CONNECTOR A PIN ASSIGNMENT	SIGNAL	CONNECTOR B PIN ASSIGNMENT
21	IBUS0	11	9	CMRDY	5
23	IBUS1	12	11	EOD	6
25	IBUS2	13	13	IFVLD	7
27	IBUS3	14	29	ENID	15
8	IBUS4	D	31	IFCLK	16
10	IBUS5	E	45	ENIR	23
12	IBUS6	F	47	DTRDY	24
14	IBUS7	H	28	CLEAR	R
37	IBUS8	19	46	OVRUN	AA
39	IBUS9	20	48	INTOK	S
41	IBUS10	21			
43	IBUS11	22	19	GND	9
38	IBUS12	W	33	GND	17
40	IBUS13	X	49	GND	18
42	IBUS14	Y	16	GND	A
44	IBUS15	Z	20	GND	10, U
			34	GND	P
3	IFN0	2	50	GND	P, V
5	IFN1	3	15	GND	1
4	IFN2	B			
6	IFN3	C	1	+5V	T
			2	+5V	T

NOTES: 1. Pins 7, 17, 18, 22, 24, 26, 30, 32, 35, and 36 are not used on connector A.
2. Pins 4, 8, J, K, L, M, N, and BB are not used on Connector B.
3. The above information is for continuity testing only and does not reflect the special shielding utilized.

Analog and Digital Inputs to Preston ADC, and Digital Outputs to HP1000E(CALO)

FROM	TO

WIRE LIST GMAD-2-13B, 4 CHAN GMD-1
4 CHAN GMM MUX, RFL, PROGRAMMABLE CLOCK
0 TO +10 VOLTS FULL SCALE,

P/N 78652-01

NOTE UNLESS OTHERWISE SPECIFIED
ALL WIRE IS TO BE 22 AWG WHITE

NOTE 01. TWO CONDUCTOR SHIELDED
NOTE 02. RG 174/U
NOTE 03. FOR SWITCH S31 SEE DWG 52581
NOTE 04. FOR FRONT PANEL REFERENCE DESIGNATIONS SEE DWG 53749
NOTE 05. 22 AWG BUSS WIRE WITH TEFLON SLEEVING BETWEEN TERMINALS
NOTE 06. FOR AC PWR WIRING SEE DWG 54856-00 &53601-01
NOTE 07. $ INDICATES DOUBLE TAPER PIN
NOTE 08. * INDICATES THE COMPLEMENT

CONNECT TWO 22 AWG WIRES FROM GROUND
POST ON REAR CONNECTOR PLATE TO B04-02

Analog inputs to Preston ADC
from engine test cell

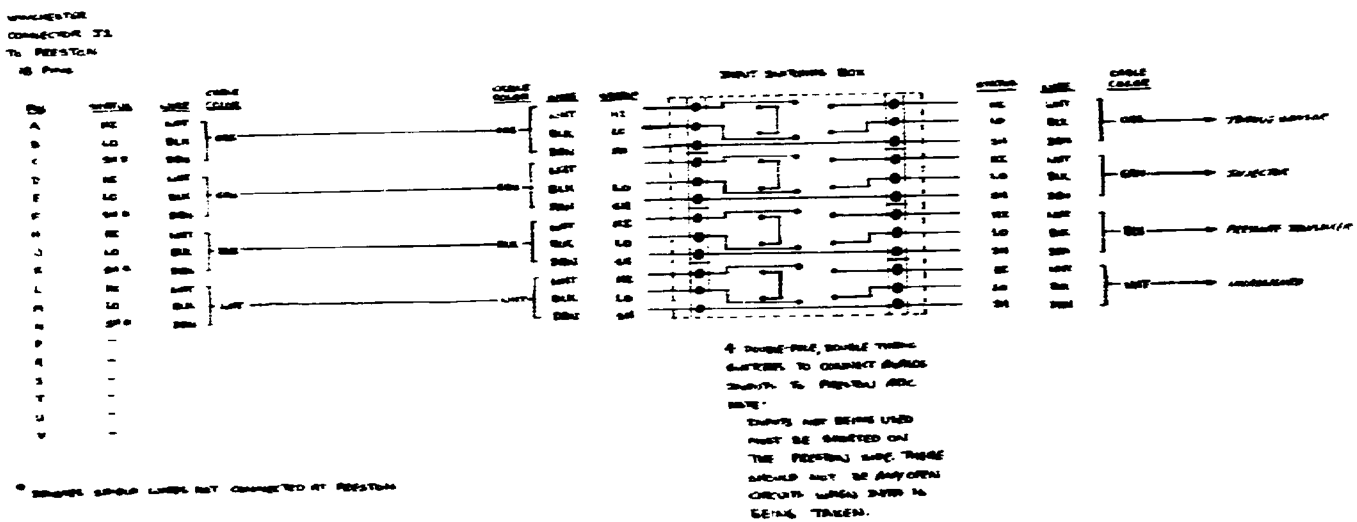
WIRE LIST NO. 78652-01 REPRINT DATE 10/15/80 PAGE 3

FROM		TO		

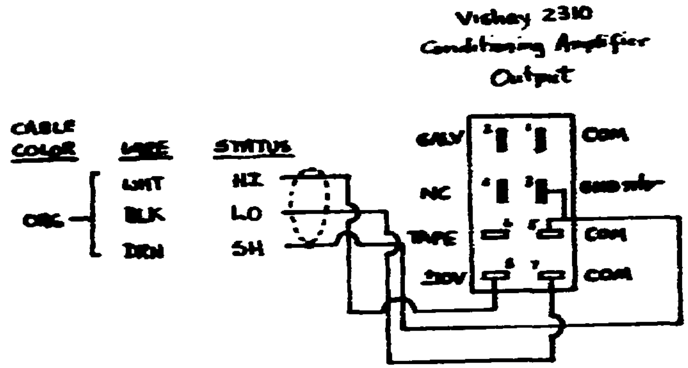
CONNECTOR J1 ANALOG INPUTS 00 TO 03
MRAC 188-J6

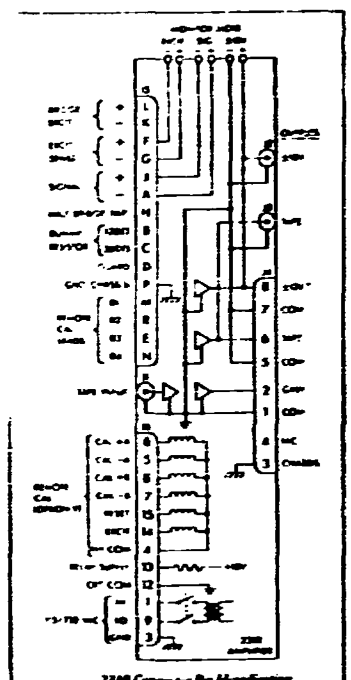
ANAIN 00 HI	J1	A	ANAIN 00 HI	C01 04	NOTE 01
ANAIN 00 LO	J1	B	ANAIN 00 LO	C01 08	NOTE 01
ANAIN 00 SH	J1	C	ANAIN 00 SH	C01 06	NOTE 01
ANAIN 01 HI	J1	D	ANAIN 01 HI	C02 04	NOTE 01
ANAIN 01 LO	J1	E	ANAIN 01 LO	C02 08	NOTE 01
ANAIN 01 SH	J1	F	ANAIN 01 SH	C02 06	NOTE 01
ANAIN 02 HI	J1	H	ANAIN 02 HI	C03 04	NOTE 01
ANAIN 02 LO	J1	J	ANAIN 02 LO	C03 08	NOTE 01
ANAIN 02 SH	J1	K	ANAIN 02 SH	C03 06	NOTE 01
ANAIN 03 HI	J1	L	ANAIN 03 HI	C04 04	NOTE 01
ANAIN 03 LO	J1	M	ANAIN 03 LO	C04 08	NOTE 01
ANAIN 03 SH	J1	N	ANAIN 03 SH	C04 06	NOTE 01
BLANK	J1	P	BLANK		
BLANK	J1	R	BLANK		
BLANK	J1	S	BLANK		
BLANK	J1	T	BLANK		
ANAGRD	J1	U	ANAGRD	C01 12	
ANAGRD	J1	V	ANAGRD	C02 12	

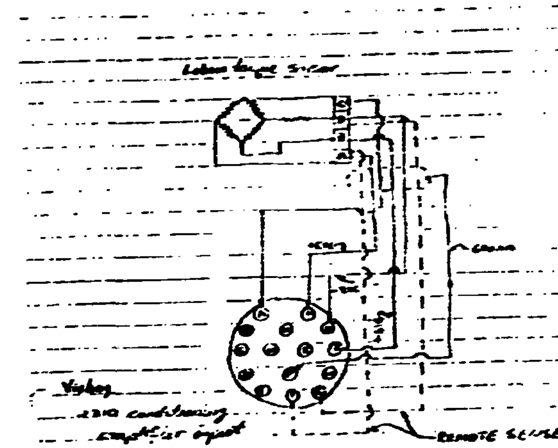
GM series Analog-to-Digital Conversion Systems
reference manual, Preston Scientific Inc., Nov. 10, 1980



Analog inputs to Preston ADC
from Engine test cell. (CONT'D)







Note 1. Remote sensor maintains constant excitation at torque sensor regardless of lead resistance

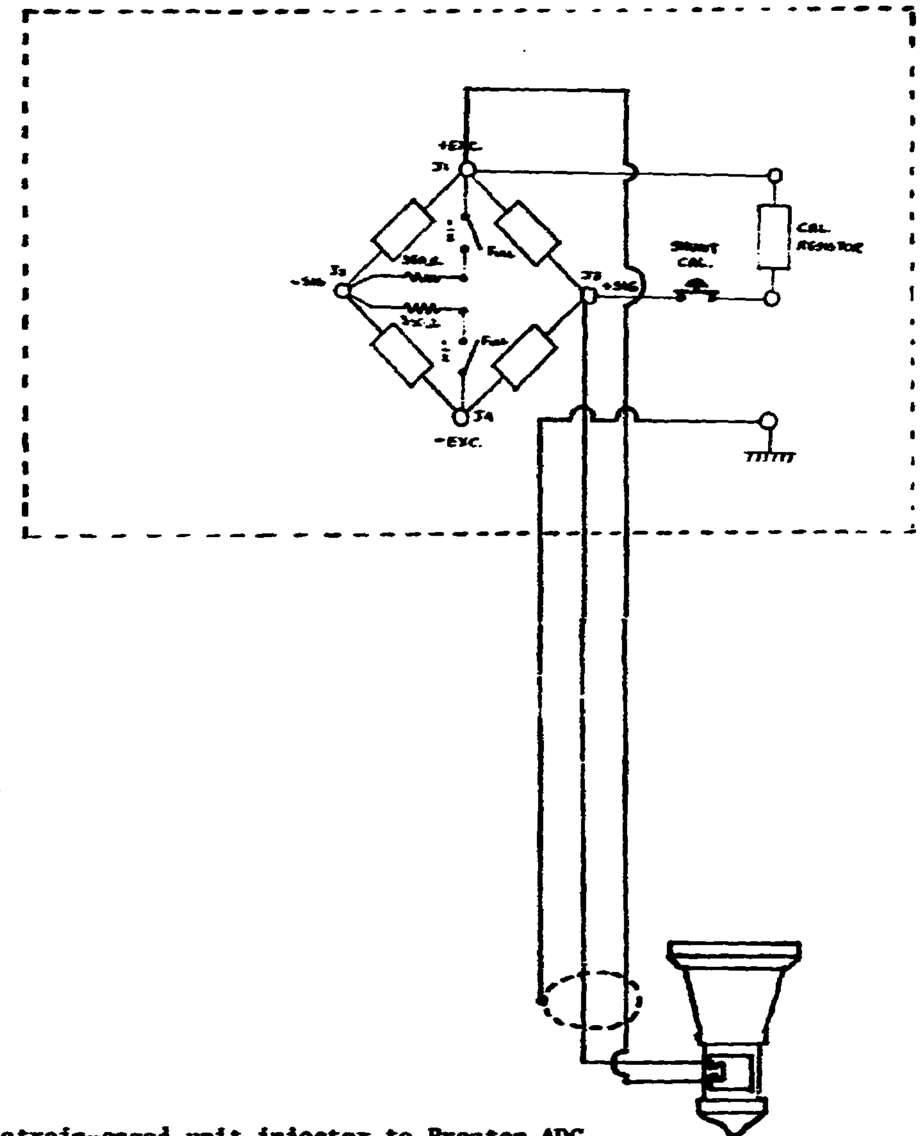
Use twisted multiconductor wire, with shielding.

Shield should be grounded at one (and only one) end; ground at the input plug, and left disconnected at torque sensor end.

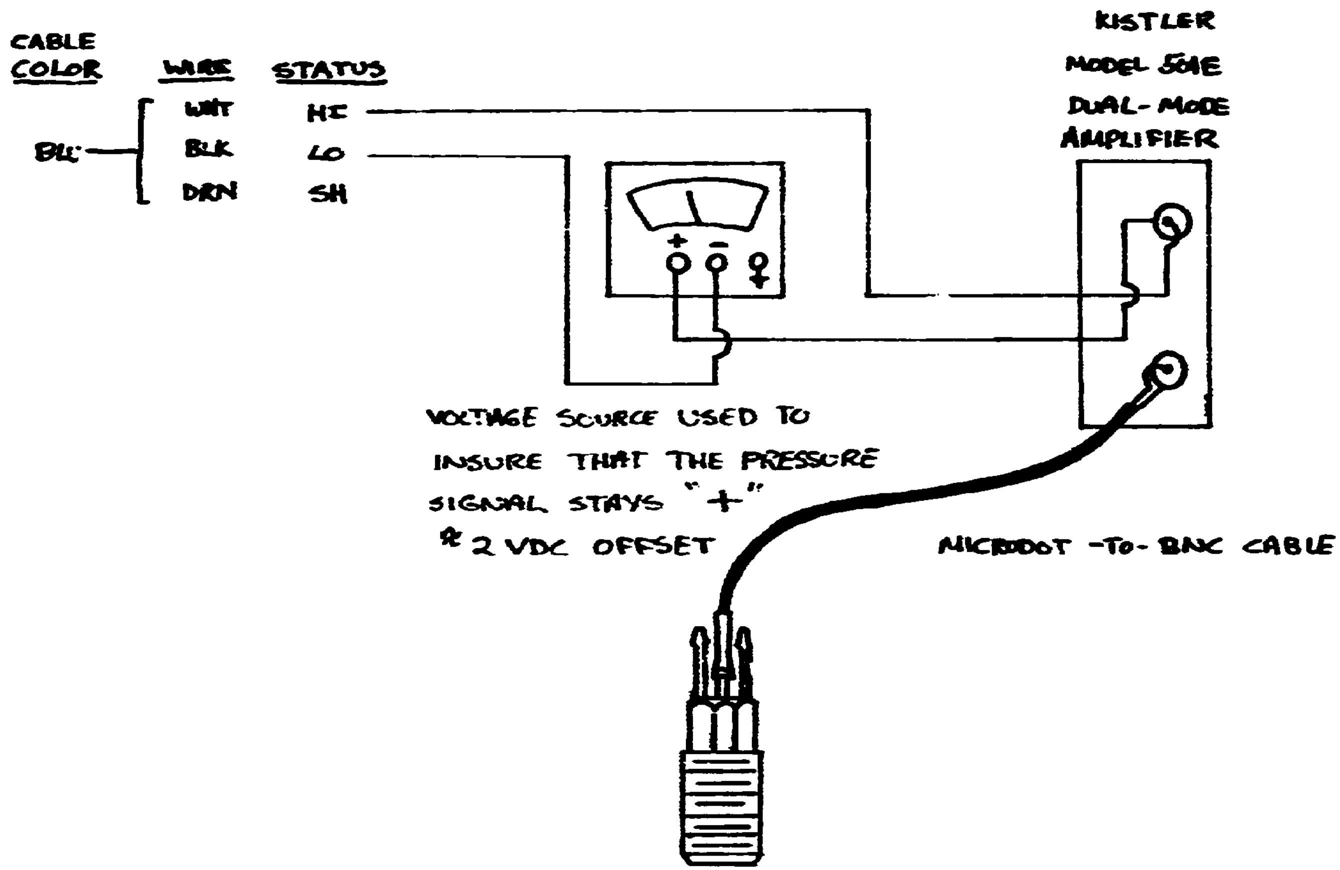
Torque Sensor should be electrically connected to good ground.

Analog Input from Torque Sensor to Preston ADC

CABLE COLOR	WIRE	STATUS
GRN	WHT	HI
	BLK	LO
	DRN	GH



Analog input from strain-gaged unit injector to Preston ADC



Analog input from pressure transducer to Preston ADC

Digital inputs from HP1000E (CALO)
to Preston Hi-Speed ADC

```
WIRE LIST NO. 78492-01      REPRINT DATE 10/15/80      PAGE   4

------------------------------------------------------------------
                 FROM                   TO
------------------------------------------------------------------

          CONNECTOR J2 DIGITAL INPUTS & CONTROLS
          MRAC 758-J6

          EOC                J2 01 EOC          A16 23 NOTE 02
          EOC          SH    J2 08 EOC       SH A16 24 NOTE 02
          ADD 07             J2 02 NOT USED
          ADD 07       SH    J2 10 NOT USED
          ADD 06             J2 03 NOT USED
          ADD 06       SH    J2 11 NOT USED
          ADD 05             J2 04 NOT USED
          ADD 05       SH    J2 12 NOT USED
          ADD 04             J2 05 NOT USED
          ADD 04       SH    J2 13 NOT USED
          ADD 03             J2 07 NOT USED
          ADD 03       SH    J2 14 NOT USED
          ADD 02             J2 15 NOT USED
          ADD 02       SH    J2 22 NOT USED
          ADD 01             J2 16 F/LMAD 02    B19 02 NOTE 02
          ADD 01       SH    J2 23 F/LMAD 02SH  B19 29 NOTE 02
          ADD 00             J2 17 F/LAMD 01    B19 01 NOTE 02
          ADD 00       SH    J2 24 F/LAMD 01SH  B19 29 NOTE 02
          ADD 14             J2 18 CONTROL 1    B18 32 NOTE 02
          ADD 14       SH    J2 25 CONTROL 1SH  B19 29 NOTE 02
          COMMAND            J2 20 COMMAND      B18 04 NOTE 02
          COMMAND      SH    J2 26 COMMAND   SH B19 29 NOTE 02
          ADD 13             J2 21 CONTROL 2    B18 33 NOTE 02
          ADD 13       SH    J2 27 CONTROL 2SH  B17 29 NOTE 02
          ADD 12             J2 28 CONTROL 3    B18 02 NOTE 02
          ADD 12       SH    J2 34 CONTROL 3SH  B19 29 NOTE 02
          ADD 11             J2 29 CONTROL 4    B18 01 NOTE 02
          ADD 11       SH    J2 35 CONTROL 4SH  B19 29 NOTE 02
          BLANK              J2 30 BLANK
          BLANK              J2 36 BLANK
          BLANK              J2 31 BLANK
          BLANK              J2 37 BLANK
          ADD 15             J2 32 RESET        B14 20 NOTE 02
          ADD 15       SH    J2 38 RESET     SH B17 29 NOTE 02
          NORM MODE          J2 33 NORMAL       A16 28
          XFMR     SHLD      J2 39 XFMR   SHLD  C12 17
          ADD 08             J2 40 NOT USED
          ADD 08       SH    J2 46 NOT USED
          ADD 09             J2 41 SIM HOLD EN  B14 03 NOTE 02
          ADD 09       SH    J2 47 SIM HOLD SH  B17 29 NOTE 02
          ADD 10             J2 42 INT PAC  EN*B14 22 NOTE 02
          ADD 10       SH    J2 48 INT PAC   SH B17 29 NOTE 02
          BLANK              J2 43 BLANK
          BLANK              J2 49 BLANK
          BLANK              J2 44 BLANK
          BLANK              J2 50 BLANK
          BLANK              J2 45 BLANK
```

Digital inputs from HP1000E (CALO)
to Preston ADC (cont'd)

WIRE LIST NO. 78652-01 REPRINT DATE 10/15/80 PAGE 5

FROM			TO	
BLANK	J2	51	BLANK	
BLANK	J2	52	BLANK	
BLANK	J2	58	BLANK	
BLANK	J2	53	BLANK	
BLANK	J2	59	BLANK	
BLANK	J2	54	BLANK	
BLANK	J2	60	BLANK	
BLANK	J2	55	BLANK	
BLANK	J2	62	BLANK	
BLANK	J2	56	BLANK	
BLANK	J2	63	BLANK	
BLANK	J2	57	BLANK	
BLANK	J2	64	BLANK	
BLANK	J2	65	BLANK	
BLANK	J2	73	BLANK	
BLANK	J2	66	BLANK	
BLANK	J2	74	BLANK	
BLANK	J2	67	BLANK	
BLANK	J2	75	BLANK	
BLANK	J2	70	BLANK	
BLANK	J2	76	BLANK	
BLANK	J2	71	BLANK	
BLANK	J2	77	BLANK	
BLANK	J2	72	BLANK	
BLANK	J2	78	BLANK	
BLANK	J2	79	BLANK	
DIGGRD	J2	80	DIGGRD	B17 29
DIGGRD	J2	82	DIGGRD	B17 29

GM series Analog-to-Digital Conversion Systems
reference manual, Preston Scientific Inc., Nov. 10, 1980

Digital outputs to HP1000E (CALO)
from Preston ADC

WIRE LIST NO. 78652-01 REPRINT DATE 10/15/80 PAGE 6

FROM					TO						

CONNECTOR J3 DIGITAL OUTPUTS
MRAC 758-J6

DB	SIGN +		J3	01	DB	SIGN +		A03	28	NOTE	02
DB	SIGN +	SH	J3	09	DB	SIGN +	SH	A03	26	NOTE	02
DB	SIGN -		J3	02	DB	SIGN -		A03	27	NOTE	02
DB	SIGN -	SH	J3	10	DB	SIGN -	SH	A03	26	NOTE	02
DB	2048		J3	03	DB	2048		A04	28	NOTE	02
DB	2048	SH	J3	11	DB	2048	SH	A04	26	NOTE	02
DB	2048*		J3	04	DB	2048*		A04	27	NOTE	02
DB	2048*	SH	J3	12	DB	2048*	SH	A04	26	NOTE	02
DB	1024		J3	05	DB	1024		A05	28	NOTE	02
DB	1024	SH	J3	13	DB	1024	SH	A05	26	NOTE	02
DB	1024*		J3	07	DB	1024*		A05	27	NOTE	02
DB	1024*	SH	J3	14	DB	1024*	SH	A05	26	NOTE	02
DB	512		J3	15	DB	512		A06	28	NOTE	02
DB	512	SH	J3	22	DB	512	SH	A06	26	NOTE	02
DB	512*		J3	16	DB	512*		A06	27	NOTE	02
DB	512*	SH	J3	23	DB	512*	SH	A06	26	NOTE	02
DB	256		J3	17	DB	256		A07	28	NOTE	02
DB	256	SH	J3	24	DB	256	SH	A07	26	NOTE	02
DB	256*		J3	18	DB	256*		A07	27	NOTE	02
DB	256*	SH	J3	25	DB	256*	SH	A07	26	NOTE	02
DB	128		J3	20	DB	128		A08	28	NOTE	02
DB	128	SH	J3	26	DB	128	SH	A08	26	NOTE	02
DB	128*		J3	21	DB	128*		A08	27	NOTE	02
DB	128*	SH	J3	27	DB	128*	SH	A08	26	NOTE	02
DB	64		J3	28	DB	64		A09	28	NOTE	02
DB	64	SH	J3	34	DB	64	SH	A09	26	NOTE	02
DB	64*		J3	29	DB	64*		A09	27	NOTE	02
DB	64*	SH	J3	35	DB	64*	SH	A09	26	NOTE	02
DB	32		J3	30	DB	32		A10	28	NOTE	02
DB	32	SH	J3	36	DB	32	SH	A10	26	NOTE	02
DB	32*		J3	31	DB	32*		A10	27	NOTE	02
DB	32*	SH	J3	37	DB	32*	SH	A10	26	NOTE	02
DB	16		J3	32	DB	16		A11	28	NOTE	02
DB	16	SH	J3	38	DB	16	SH	A11	26	NOTE	02
DB	16*		J3	33	DB	16*		A11	27	NOTE	02
DB	16*	SH	J3	39	DB	16*	SH	A11	26	NOTE	02
DB	08		J3	40	DB	08		A15	03	NOTE	02
DB	08	SH	J3	46	DB	08	SH	A15	04	NOTE	02
DB	08*		J3	41	DB	08*		A15	07	NOTE	02
DB	08*	SH	J3	47	DB	08*	SH	A15	04	NOTE	02
DB	04		J3	42	DB	04		A15	08	NOTE	02
DB	04	SH	J3	48	DB	04	SH	A15	09	NOTE	02
DB	04*		J3	43	DB	04*		A15	12	NOTE	02
DB	04*	SH	J3	49	DB	04*	SH	A15	09	NOTE	02
DB	02		J3	44	DB	02		A15	13	NOTE	02
DB	02	SH	J3	50	DB	02	SH	A15	14	NOTE	02
DB	02*		J3	45	DB	02*		A15	17	NOTE	02

WIRE LIST NO. 78652-01   REPRINT DATE 10/15/80   PAGE 7

FROM				TO				
DB 02*	SH	J3	51	DB 02*	SH	A15	14	NOTE 02
DB 01		J3	52	DB 01		A15	22	NOTE 02
DB 01	SH	J3	58	DB 01	SH	A15	19	NOTE 02
DB 01*		J3	53	DB 01*		A15	18	NOTE 02
DB 01*	SH	J3	59	DB 01*	SH	A15	19	NOTE 02
DIGGRD		J3	54	DIGGRD		A19	29	
BLANK		J3	60	BLANK				
BLANK		J3	55	BLANK				
BLANK		J3	62	BLANK				
DIGGRD		J3	56	DIGGRD		A19	29	
BLANK		J3	63	BLANK				
BLANK		J3	57	BLANK				
BLANK		J3	64	BLANK				
COIN		J3	65	COIN		A18	31	NOTE 02
COIN	SH	J3	73	COIN	SH	A19	29	NOTE 02
BUSY		J3	66	BUSY		A16	12	NOTE 02
BUSY	SH	J3	74	BUSY	SH	A16	38	NOTE 02
EOC *		J3	67	EOC *		B13	19	NOTE 02
EOC *	SH	J3	75	EOC *	SH	B11	29	NOTE 02
INTOK *		J3	70	INTOK *		B13	03	NOTE 02
INTOK *	SH	J3	76	INTOK *	SH	B11	29	NOTE 02
CO(XOR)OVR*		J3	71	CO(XOR)OVR*		B13	17	NOTE 02
CO(XOR)OVR*S		J3	77	CO(XOR)OVR*S		B11	29	NOTE 02
OVRUN*		J3	72	OVRUN*		B13	13	NOTE 02
OVRUN*	SH	J3	78	OVRUN*	SH	B11	29	NOTE 02
BLANK		J3	79	BLANK				
DIGGRD		J3	80	DIGGRD		A01	37	
DIGGRD		J3	82	DIGGRD		A01	37	

GM series Analog-to-Digital Conversion Systems
reference manual, Preston Scientific Inc., Nov. 10, 1980

External clock input to Preston ADC

FROM		TO	
CONNECTOR J4 EXT CLK & CLK DIVISOR INPUTS			
MRAC 348-J6			
CDB 16384	J4 A	CDB 16384	B09 21
CDB 8192	J4 B	CDB 8192	B09 18
CDB 4096	J4 C	CDB 4096	B09 15
CDB 2048	J4 D	CDB 2048	B09 12
CDB 1024	J4 E	CDB 1024	B09 09
CDB 512	J4 F	CDB 512	B09 06
CDB 256	J4 H	CDB 256	B09 03
CDB 128	J4 J	CDB 128	B11 24
CDB 64	J4 K	CDB 64	B11 21
CDB 32	J4 L	CDB 32	B11 18
CDB 16	J4 M	CDB 16	B11 15
CDB 08	J4 N	CDB 08	B11 12
CDB 04	J4 P	CDB 04	B11 09
CDB 02	J4 R	CDB 02	B11 06
CDB 01	J4 S	CDB 01	B11 03
EXT CLK EN	J4 T	EXT CLK EN	B09 24
BLANK	J4 U	BLANK	
EXT CLK HI	J4 V	EXT CLK HI	B17 02 NOTE 01
EXT CLK LO	J4 W	EXT CLK LO	B17 03 NOTE 01
EXT CLK SH	J4 X	EXT CLK SH	B17 29 NOTE 01
BLANK	J4 Y	BLANK	
BLANK	J4 Z	BLANK	
BLANK	J4 -A	BLANK	
BLANK	J4 -B	BLANK	
BLANK	J4 -C	BLANK	
BLANK	J4 -D	BLANK	
BLANK	J4 -F	BLANK	
BLANK	J4 -G	BLANK	
BLANK	J4 -H	BLANK	
BLANK	J4 -I	BLANK	
BLANK	J4 -J	BLANK	
BLANK	J4 -K	BLANK	
DIGGRD	J4 -M	DIGGRD	B09 29
DIGGRD	J4 -N	DIGGRD	B09 29

GM series Analog-to-Digital Conversion Systems
reference manual, Preston Scientific Inc., Nov. 10, 1980

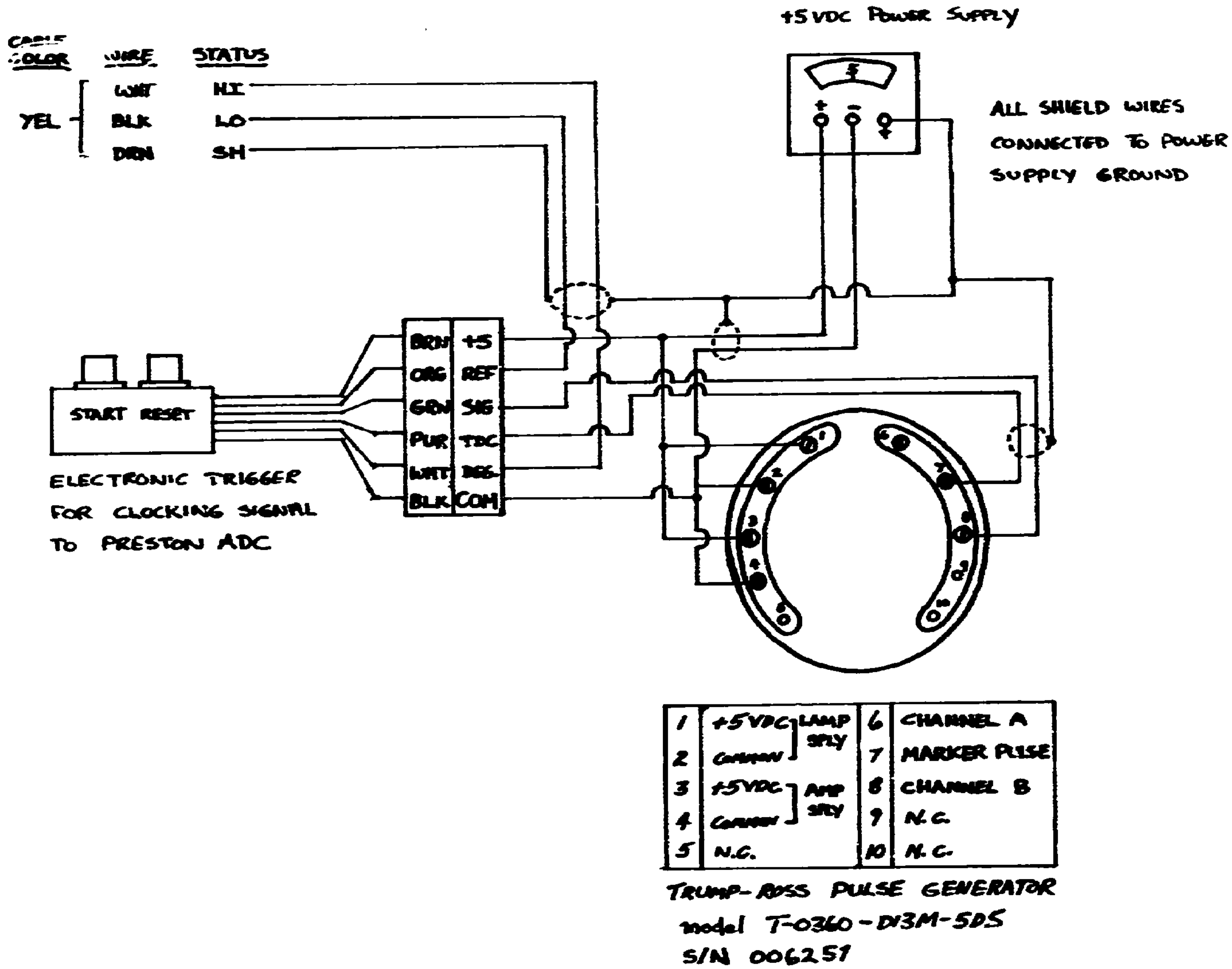
External clock input to Preston ADC (cont'd)

WINCHESTER
CONNECTOR J1
34 PINS

A THRU S & -M, -N ALL JUMPERED TOGETHER

PIN	STATUS	WIRE	CABLE COLOR
A			
B			
C			
D			
E			
F			
H			
J			
K			
L			
M			
N			
P			
R			
S			
T	—		
U	—		
V	HI	WHT	YEL → CLOCKING SIGNAL
W	LO	BLK	YEL → CLOCKING SIGNAL
X	SH *	DRN	YEL → CLOCKING SIGNAL
Y	—		
Z	—		
-A	—		
-B	—		
-C	—		
-D	—		
-E	—		
-F	—		
-G	—		
-H	—		
-I	—		
-J	—		
-K	—		
-M			
-N			

* DENOTES SHIELD WIRE NOT CONNECTED AT PRESTON



External clock input to Preston ADC (cont'd)

FROM		TO

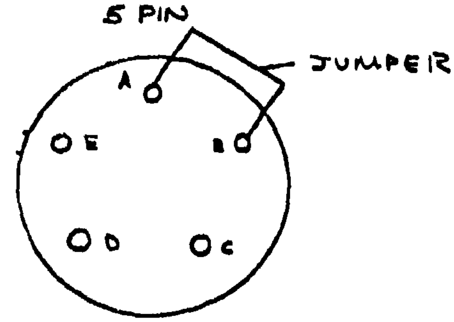
CONNECTOR J5 EXT PACER ENABLE *
MS3102A-14S-5P

```
EXPACEN* HI   J5  A EXPACEN* HI B17 05 NOTE 01
EXPACEN* LO   J5  B EXPACEN* LO B17 04 NOTE 01
EXPACEN* SH   J5  C EXPACEN* SH B17 29 NOTE 01
BLANK         J5  D BLANK
BLANK         J5  E BLANK
```

CONNECTOR J6 OUTPUT PACER BIT
TROMPETER BJ-27

```
PACER OUT     J6'C' PACER OUT   B14 32 NOTE 02
PACER OUT SH  J6'B' PACER OUT SHB11 29 NOTE 02
```

MIL-S-3102A-14S-5P
CONNECTOR J5
5 PIN



APPENDIX C

CALO-DATA ACQUISITION SYSTEM INFORMATION

CALO-DATA ACQUISITION SPECIFICATIONS

Hewlett-Packard	model #2113E	HP1000E series computer
	option 014	delete 128K memory
Hewlett-Packard	model #12786B	256 k byte memory module
Hewlett-Packard	model #12992C	Loader ROM
Hewlett-Packard	model #7906 MR	19.6 Mbyte Disc
	option 020	rack mounts for disc
Hewlett-Packard	model #1375B	Disc Controller
Hewlett-Packard	model #92068R	RTE-IVB right to copy & Firmware
Hewlett-Packard	model #12539C	Time Base Generator
Hewlett-Packard	model #12966A	RS232C Interface
	option 001	264X Interface cable
Hewlett-Packard	model #2649C	Graphics Terminal
	option 007	mini-tape drives
	option 032	Asyncronous data interface
Hewlett-Packard	model #13296A	HP-IB Interface for 264X
	option 048	Above for 2648
Hewlett-Packard	model #2631G	Graphics printer plotter
Hewlett-Packard	model #26098A	Stand for 2631G
	option 001	casters
	option 002	paper catcher
Hewlett-Packard	model #12991B	Power Fail
Hewlett-Packard	model #13306A	Processor
Hewlett-Packard	model #935875	High-Speed Software
	option 001	Preston option
Hewlett-Packard	model #93587T	Modified Disc Driver
Hewlett-Packard	model #93596L	Preston I/F Kit
	option 005	high speed card
	option 008	Pacer
	option 010	SSH
Preston Scientific	GM series Analog-to-Digital Control System	
Preston Scientific	model GMD-1	4-channel Amplifier-Multiplexer
Preston Scientific	model GNM	4-channel Multiplexer
Preston Scientific	model GMC-RFL	Logic control system
Preston Scientific	model GMSH-100	5-channel sample and hold
Preston Scientific	model GMADZ-13B	A/D converter
Preston Scientific	interface to HP93596L	I/O Buffer (GMDSRC clock)
Preston Scientific	model GM-3	Card Module with power supply

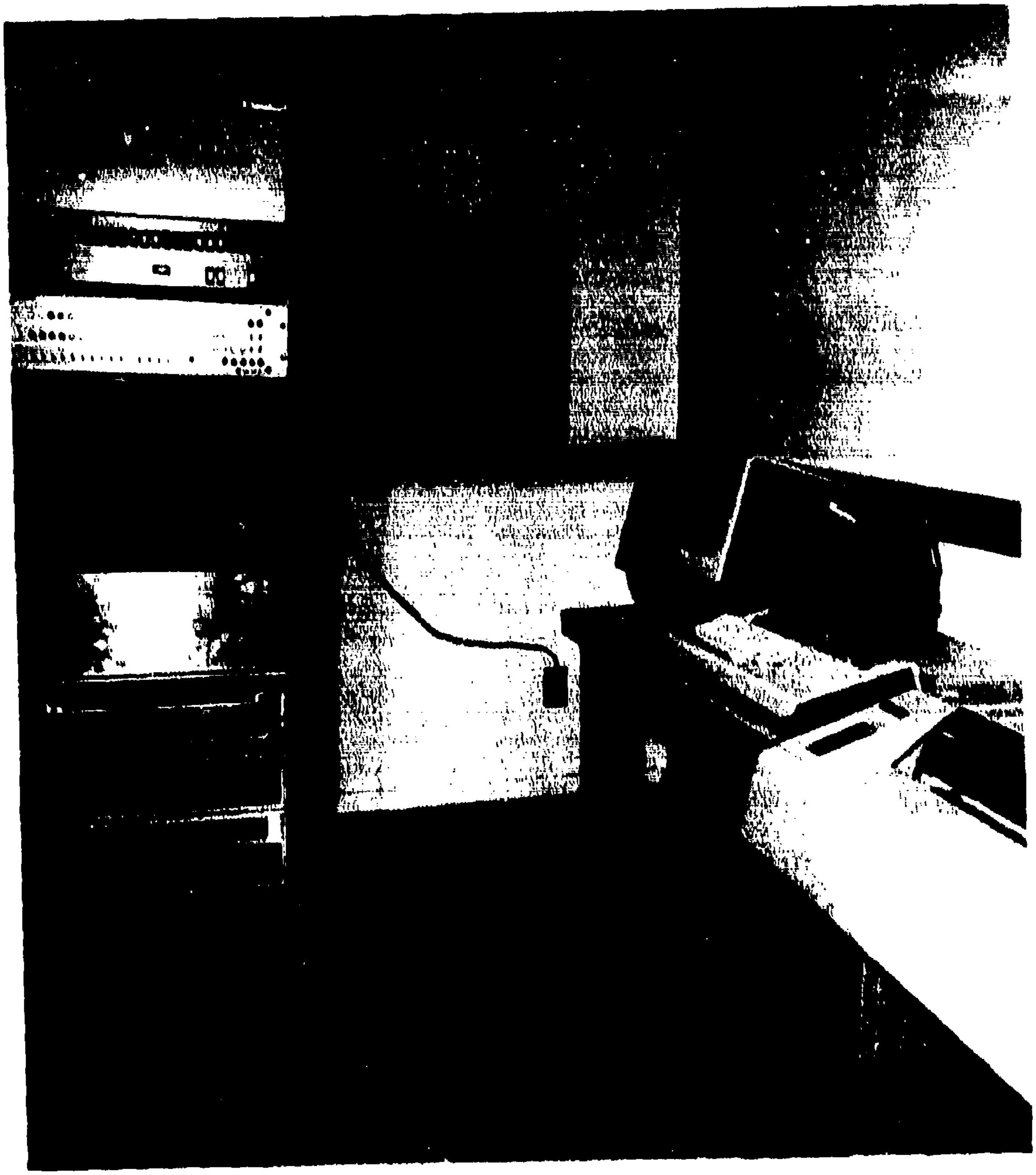


FIGURE C-1: CALO-DATA ACQUISITION SYSTEM IN
ENVIRONMENTALLY CONTROLLED ROOM

APPENDIX D
PRESSURE, TIME, AND VOLUME RELATIONSHIP CALCULATIONS

PRESSURE, TIME, AND VOLUME RELATIONSHIP CALCULATIONS

The analog voltage from the pressure transducer and charge amplifier is digitized and separated into voltage data files. The voltage data files are accessed by the application programs, and used to calculate the pressure at each crankangle by knowing the proper transducer and amplifier constants.

$$P(in) = A_6 X^5 + A_5X^4 + A_4X^3 + A_3X^2 + A_2X + A_1 \quad (1)$$

where:
- $A_1, \ldots, A_6$ = charge amplifier constants
- X = voltage values in data file
- $P(in)$ = Pressure at crankangle IN

A pressure adjustment is calculated by knowing the airbox pressure at bottom dead center, (PCOR) and its corresponding crankangle with relationship to top dead center.

$$PCOP = PCOR * K \quad (2)$$

where:
- PCOR = absolute airbox pressure, in. Hg
- K = 0.4912 = conversion from, in Hg to psia
- PCOP = airbox pressure in psia at BDC

$$PP(I) = P(IN + NOFF) \quad (3)$$

where:
- P(IN) = pressure at crankangle IN (1)
- NOFF = pressure crankangle offset for BDC on compression stroke
- PP(I) = pressure phased to BDC on compression stroke

$$PCOR = PP(1) - PCOP \quad (4)$$

where:
- PP(1) = pressure calculated from voltage data at BDC
- PCOP = actual pressure at BDC (2)
- PCOR = pressure adjustment

Once the pressure adjustment is calculated, all pressures in the cycle are adjusted to the reference pressure.

$$PP(I) = PP(I) - PCOR \quad (5)$$

Once the pressures are calculated and adjusted, the mean effective pressures can be calculated by knowing engine geometry.

$$MEP = \left(\sum_{SMEP}^{EMEP} PP(I)\ \frac{dv(\theta)}{d\theta}\right)/(A \times S) \qquad (6)$$

where:

SMEP = angle at which MEP calculation starts
EMEP = angle at which MEP calculation ends
PP(I) = adjusted pressure at crankangle I
$dv(\theta)/d\theta$ = derivative of the volume with respect to crankangle:

$$\frac{dv(\theta)}{d\theta} = A*(E^2 \sin(2\theta)/2F(\theta) - E\sin\theta) \qquad (7)$$

Θ = crankangle degree I in radians
A = $\pi/4\ B^2$ = cylinder area
B = cylinder bore diameter, inches
E = S/2 = length of crankthrow, half of stroke
S = stroke, inches

$$F(\theta) = \sqrt{L^2 - (E^2 \sin^2\theta)} \qquad (8)$$

L = connecting rod length, inches
MEP = mean effective pressure

Cylinder volume can be calculated per crankangle degree, which along with pressure, yields the pressure-volume relationships.

$$V(\theta) = \left\{\left[L + E\ (1 + \cos\theta) - F\ (\theta)\right]A\right\} + VC \qquad (9)$$

where:

Θ = crankangle degree I in radians
L = connecting rod length, inches
E = S/2 = length of crankthrow, half of stroke
S = stroke, inches
$F(\theta) = \sqrt{L^2 - E^2 \sin^2\theta}$

A = $(\pi/4)\ B^2$ = cylinder area
B = cylinder bore diameter, inches

$$VC = VD/(CR-1.0) \qquad (10)$$

VD = A * S = displacement volume
CR = compression ratio
VC = clearance volume

By knowing pressure and engine geometry, the heat release per degree may be calculated along with the cumulative heat release for the firing cycle.

$$DQQ = \left[\frac{K}{K-1}\ PP(I) * DVO(I)\right] + \left[\frac{1}{K-1} V(I) * \ DPRE(I)\right] \tag{11}$$

where:

K = ratio of specific heats of the combustion gases

PP(I) = pressure at crankangle I (5)

$$DVO(I) = \frac{dv(\theta)}{d\,\theta}\ (5) * \frac{\pi}{180}$$

$$V(I) = V(\theta)\ (9) * \pi/180$$

DPRE(I)= derivative of pressure at crankangle (I)

$$= \frac{PP(I-2) - 8 * (PP(I-1) + 8 * PP(I+1) - PP(I+2)}{12 * (DPC/TOT)}$$

DPC = degrees/cycle

TOT = data pt./cycle

$$DQDG(I) = DQQ/(12.0 * 778.) \tag{12}$$

where:

DQQ = ft-lb-in./deg (11)

12.0 = conversion from inches to feet

778 = conversion from ft-lb to Btu's

DQDG(I) = Instantaneous heat release, Btu/deg

$$DQ(I) = DQDG(I) * (DPC/TOT) \tag{13}$$

where:

DQ(I) = heat release at increment I, Btu

$$CHR(I) = CHR(I-1) + DQ(I) \tag{14}$$

where

CHR(I) = cumulative heat release, summation over heat release interval, Btu

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ATTN: DRCLD (MR BENDER) 1
DRCDMR (MR GREINER) 1
DRCDMD-ST (DR HALEY) 1
DRCQA-E 1
DRCDE-SG 1
DRCIS-C (LTC CROW) 1
DRCSM-P 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333

CDR
US ARMY TANK-AUTOMOTIVE CMD
ATTN DRSTA-NW (TWVMO) 1
DRSTA-RG (MR HAMPARIAN) 1
DRSTA-NS (DR PETRICK) 1
DRSTA-G 1
DRSTA-M 1
DRSTA-GBP (MR MCCARTNEY) 1
WARREN MI 48090

DIRECTOR
US ARMY MATERIEL SYSTEMS ANALYSIS AGENCY
ATTN DRXSY-CM 1
DRXSY-S 1
DRXSY-L 1
ABERDEEN PROVING GROUND MD 21005

DIRECTOR
APPLIED TECHNOLOGY LAB
U.S. ARMY R&T LAB (AVRADCOM)
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DAVDL-ATL-ASV (MR CARPER) 1
FORT EUSTIS VA 23604

HQ, 172D INFANTRY BRIGADE (ALASKA)
ATTN AFZT-DI-L 1
AFZT-DI-M 1
DIRECTORATE OF INDUSTRIAL OPERATIONS
FT RICHARDSON AK 99505

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN STSGP-F (MR SPRIGGS) 1
STSGP-PE (MR MCKNIGHT),
BLDG 85-3 1
STSGP (COL CLIFTON) 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY MATERIEL ARMAMEMT
READINESS CMD
ATTN DRSAR-LEM 1
ROCK ISLAND ARSENAL IL 61299

CDR
US ARMY COLD REGION TEST CENTER
ATTN STECR-TA 1
APO SEATTLE 98733

HQ, DEPT. OF ARMY
ATTN: DAEN-RDZ-B 1
WASHINGTON, DC 20310

CDR
US ARMY RES & STDZN GROUP
(EUROPE)
ATTN DRXSN-UK-RA 1
BOX 65
FPO NEW YORK 09510

HQ, US ARMY AVIATION R&D CMD
ATTN DRDAV-GT (MR R LEWIS) 1
DRDAV-D (MR CRAWFORD) 1
DRDAV-N (MR BORGMAN) 1
DRDAV-E 1
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ST LOUIS MO 63120

CDR
US ARMY FORCES COMMAND
ATTN AFLG-REG 1
AFLG-POP 1
FORT MCPHERSON GA 30330

CDR
US ARMY ABERDEEN PROVING GROUND
ATTN: STEAP-MT 1
STEAP-MT-U (MR DEAVER) 1
ABERDEEN PROVING GROUND MD 21005

CDR
US ARMY YUMA PROVING GROUND
ATTN STEYP-MT (MR DOEBBLER) 1
YUMA AZ 85364

PROJ MGR, ABRAMS TANK SYS
ATTN DRCPM-GCM-S 1
WARREN MI 48090

PROG MGR, FIGHTING VEHICLE SYS
ATTN DRCPM-FVS-SE 1
WARREN MI 48090

PROJ MGR, M60 TANK DEVELOPMENT
USMC-LNO, MAJ. VARELLA 1
US ARMY TANK-AUTOMOTIVE CMD (TACOM)
WARREN MI 48090

PROG MGR, M113/M113A1 FAMILY
VEHICLES
ATTN DRCPM-M113 1
WARREN MI 48090

PROJ MGR, MOBILE ELECTRIC POWER
ATTN DRCPM-MEP-TM 1
7500 BACKLICK ROAD
SPRINGFIELD VA 22150

PROJ MGR, IMPROVED TOW
VEHICLE
US ARMY TANK-AUTOMOTIVE CMD
ATTN DRCPM-ITV-T 1
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CDR
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US ARMY DARCOM
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CDR
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DIRECTORATE FOR PETROL MGMT
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ZWEIBRUCKEN
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DRXRO-EG (DR SINGLETON) 1
DRXRO-CB (DR GHIRARDELLI) 1
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RSCH TRIANGLE PARK NC 27709

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NASA/AMES RSCH CTR
MAIL STP 207-5
MOFFIT FIELD CA 94035

CDR
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ATTN SDSTO-TP-S 1
TOBYHANNA PA 18466

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RSCH CTR
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DRXMR-R 1
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CDR
US ARMY DEPOT SYSTEMS CMD
ATTN DRSDS 1
CHAMBERSBURG PA 17201

CDR
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ATTN SARWY-RDD 1
WATERVLIET NY 12189

CDR
US ARMY LEA
ATTN DALO-LEP 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN STSGP-PW (MR PRICE) 1
SHARPE ARMY DEPOT
LATHROP CA 95330

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CENTER
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FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
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LEXINGTON KY 40511

HQ, US ARMY T&E COMMAND
ATTN DRSTE-TO-O 1
ABERDEEN PROVING GROUND, MD 21005

HQ, US ARMY ARMAMENT R&D CMD
ATTN DRDAR-LC 1
DRDAR-SC 1
DRDAR-AC 1
DRDAR-QA 1
DOVER NJ 07801

HQ, US ARMY TROOP SUPPORT &
AVIATION MATERIAL READINESS
COMMAND
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DRCPO-PDE (LTC FOSTER) 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120

DEPARTMENT OF THE ARMY
CONSTRUCTION ENG RSCH LAB
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CERL-ZT 1
CERL-EH 1
P O BOX 4005
CHAMPAIGN IL 61820

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BALLISTIC RESEARCH LAB
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CLEVELAND OH 44135

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US ARMY ORDNANCE CTR & SCHOOL
ATTN ATSL-CTD-MS 1
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US ARMY ENGINEER SCHOOL
ATTN ATSE-CDM 1
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CDR
US ARMY INFANTRY SCHOOL
ATTN ATSH-CD-MS-M 1
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ATTN ATZQ-OT-C 1
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CDR
US ARMY MISSILE CMD
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DRSMI-RK 1
DRSMI-D 1
REDSTONE ARSENAL, AL 35809

CRD
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PROJ MGR M60 TANK DEVELOP.
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CDR
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CDR
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NAVAL AIR DEVELOPMENT CTR
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WARMINSTER PA 18974

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CDR
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ATTN MAT-083 (DR A ROBERTS) 1
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CP6, RM 606
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CDR
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CAMERON STATION
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CDR
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