

INTERNAL COMBUSTION ENGINE
DATA LOGGING

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ABSTRACT

The Imperial College Engine Data logging system is in the process of being upgraded into a powerful, multi-processor system with formidable transient and steady-state testing facilities for internal combustion engines. The control and data logging functions on the existing system have been separated. Control is now implemented on a TI 9900 microcomputer whilst data logging, test sequencing and communications is undertaken by a PDP 11/03 computer. This work describes the specification, design and implementation of data logging function within the new system.

The specification for the new system was based upon the established principles developed on the existing PDP 15 computer. The analogue to digital convertors were retained together with the digital interfaces of engine and turbocharger speed measurements logic. The PDP 11/03 was chosen for its good system architecture ease of interfacing onto its bus and the wealth of software provided.

New interfaces were built for the PDP 11/03. Direct memory access was used to speed up data transfer from

the fast off-line data logger. A "multi-device" selection was introduced to enable the computer to communicate with up to eight associated controllers used in the system. Diagnostic software was designed to exercise the new hardware and was integrated into the new system.

Steady state data acquisition software was designed and implemented with a common "user-friendly" interface. The programs include routines to calibrate the analogue to digital convertors, configure messages output, save data files and display the results as listings or histogram plots. The existing Imperial College apparant fuel burning rate calculation program was integrated into the system using common data structures on disk files.

Finally, the system was tested on a Perkins 4.236 diesel engine by deriving heat release results at various load and speed settings. These results were checked for repeatability and compared with values collected on the previous system.

The text concludes that the exercise was successful and recommends that the principle of the distributed

system be adhered to. The new data logging system should be easily integrated into the concept of the system as a whole.

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NOTATION

ADC	Analogue to Digital Convertor
BDC	Bottom Dead Centre
BMEP	Brake Mean Effective Pressure
DAC	Digital to Analogue Convertor
DEC	Digital Equipment Corporation
DMA	Direct Memory Access
IMEP	Indicated Mean Effective Pressure
IVC	Inlet Valve Closing
KB	Kilo-byte
LSI	Large Scale Integration
MB	Mega-byte
MKP	Meter Kilopound
MOS	Metal-oxide-silicon
PDP	Trademark of Digital Equipment Corporation
QBUS	Trademark of Digital Equipment Corporation
RAM	Random Access Memory
ROM	Read Only Memory
RPM	Revolutions per Minute
TDC	Top Dead Centre
TI	Texas Instruments Incorporated
TTL	Transistor Transistor Logic
UNIBUS	Trademark of Digital Equipment Corporation
VDU	Visual Display Unit.

The internal combustion engine, for so long the mainstay of the world's power generation from oil, has become the subject of increasing discussion over the last decade. It has seen mounting competition from other types of power plants (notably the gas turbine), and a general market demand for better fuel economy and an improved power-to-weight ratio. Government legislation demanded reduced noise and exhaust gas emissions allied to a minimum power output for vehicle applications. This has forced engine manufacturers to review their traditional research methods of costly trial-and-error and seek a more fundamental understanding of the processes within the power unit. The theoretical approach to engine development must, however, be based upon a sound practical knowledge of engine behaviour and its operating characteristics. A data logging system to collect this information from an engine test bed is required if a comprehensive data base is to be compiled. Such a data base is essential to verify theoretical predictive models and to direct engine design and development efforts towards the more fruitful avenues.

Imperial College developed a data logging system in the early seventies based around a Digital Equipment Corporation PDP 15 mini computer. The system was

gradually enhanced to cover both transient data acquisition and engine control (Ref 1, 2, 3). Marzouk (3, 4) outlines how it was successfully used to test a diesel engine under transient load conditions (4) and the value of the results in supporting the transient performance model constructed concurrently. Watson and Marzouk (7) describe the system being used to derive the experimental fuel burning rate (heat release) curves for diesel combustion, illustrating the accuracy (essential for this procedure) that is obtained by a computer based system.

The pace of technological development within the computer industry and the advent of the microprocessor has left the PDP 15 mini computer obsolete in less than ten years. Coupled with annually increasing maintenance costs, it was decided to replace the PDP 15 by a more modern machine to take advantage of improved hardware performance. At the same time, this change-over offered the College an opportunity to experiment with a new concept of distributed computing (i.e. to have more than one computer in the system) together with advances in software techniques. To this end, the control and data logging functions, performed entirely by the PDP 15 were divorced. A system concept was evolved where one computer looked after the control of the engine on the test bed whilst the other computer

supervised the data logging and test scheduling functions and provided the general facilities normally associated with a computer system (e.g. printer, graphics, etc). The two computers have to be able to communicate with each other in order to synchronise tests with the engine operating condition.

The development of this new system was divided into three phases:-

1. Develop the control computer
2. Develop the data logging computer
3. Develop the communication between the two computers so that transient tests can be performed

The overriding priority during the whole project was that there should be no loss of facility on the new system as compared with the existing PDP 15 system. Phase 1 is documented in Reference 5. The current work describes the progress of Phase 2 which was conducted in parallel with Phase 1. Phase 3 is on-going at the time of writing and will be reported in 1982.

The present work describes the design development and verification of the software data logging system. Chapter 2 outlines the requirements of the overall system

which is crystallised into a specification in Chapter 3. Chapter 4 describes the support hardware and computer interfaces. The software development process is traced in Chapter 5 with overviews of the programming techniques employed. The integrity of the system was demonstrated by deriving experimental heat release results from a Perkins 4.236 diesel engine (Chapter 6). Finally some conclusions are drawn in Chapter 7; the rest of the text being devoted to References (Chapter 8) and Appendices.

The author's contribution to this stage of the data logging implementation involved the analysis and detailing of the computer system specification. The current PDP 15 data logging capabilities had to be defined and carried over onto the new system (Chapter 3). The analogous work done on the PDP 15 control specification was undertaken by another researcher. The author was involved in choosing the data logging computer and designing the steady-steady data logging software (Chapter 5). Testing and documenting this software was also his responsibility. The heat release calculation software described in Chapter 5 was an implementation of the existing software by the same name on the PDP 15 system.

2.

SYSTEM REQUIREMENTS

This chapter details the general requirements of computerised engine test installations and follows on with a summary of the existing Imperial College test rig (Ref, 4 18).

2.1

GENERAL REQUIREMENTS

The basic requirements may be itemised as follows:-

- . variable and accurate control of engine speed and load with time. This, coupled to the monitoring of engine water temperature, is essential to secure repeatability of results. For transient tests, i.e. where the engine is taken through a change in load/speed, there must be a strict synchronisation between control and the data acquisition procedures. Control of the engine must also be flexible and user-orientated implying a programmed or 'soft' approach, almost invariably implemented on a general purpose digital computer.
- . an alarm system to monitor critical engine parameters, e.g. oil pressure, water jacket

temperature and overspeed. This system must override the normal control function and provide a prompt but controlled shutdown of the engine in an emergency such as a loss of oil pressure. The system must provide for temporary surges in such parameters, e.g. low oil pressure on engine startup but failure to allow a correct priority to those safety values could lead to severe engine damage due to abnormal wear rates and eventual seizure of the engine.

there should be two data logging systems. One to cater for those parameters that essentially vary over an engine revolution, e.g. smoke, air flow, etc. The other must record parameters that change within an engine revolution, e.g. cylinder pressure, exhaust pressure, etc. The latter must be resolved to around $1/8^\circ$ crank angle. Capture of data is relative to engine crank angle hence the acquisition rates will be proportional to engine speed. The system must be capable of full data logging to a maximum engine speed of around 3000 rpm for diesel engines. The resultant data acquired should reflect an accuracy of about 0.1%.

- . the data logger should be capable of multi-channel operation; normally eight channels to $1/8^\circ$ CA resolution and 16 channels to 1 revolution resolution. It should have the versatility to enable variable angular resolution and to offer a "windowing" facility to the incoming data. The latter is of paramount importance for a computer based system since the data rates will be too high for continuous on line acquisitions. The machine will be able to execute its various data processing tests between each window of data captured. This so-called window must be large enough to accommodate one four stroke engine cycle, i.e. two complete revolutions.
- . the input data should be checked for faulty instrumentation, e.g. broken wires, and for incorrect instrument settings, e.g. amplifier offsets, etc. One important check would be reading the cylinder pressure transducer during the gas exchange process to ensure that it is not drifting.

- . full data processing, reduction and storage should be available, ideally, on-line. The captured data would then be processed immediately enabling the operator to view the results and check them for reasonableness. A graphics facility is essential if large amounts of data are to be presented legibly. Such an on-line system provides a short turnaround time between testing an engine and the presentation of results, consequently making the whole process more manageable and efficient.

Finally the system should provide a degree of flexibility to cater for differing projects which inevitably occur in a research environment. This requirement can be satisfied only by a computer based system with an adaptable hardware and software configuration.

2.2. EXISTING IMPERIAL COLLEGE SYSTEM

The existing Imperial College System was based around a Digital Equipment Corporation PDP 15 mini computer (see Fig 2.1) (Ref 1, 2, 3, 4, 6, 7, 18). The general

arrangement consisted of the engine coupled to an eddy-current brake and an electrical stepping motor connected to the fuel pump to set demand speed. (Appendix B). The PDP 15 computer was used to control the engine as well as monitor the data acquisition process.

Engine control (Fig 2.1) was effected by means of varying the load on the brake and the set speed position on the engine governor. The brake load was set by a three-term controller on the brake excitation unit. The analogue closed loop controller received a set torque from the computer via the brake control logic and controlled the brake excitation to give the required torque, which was measured by a strain gauge load cell on the dynamometer. The brake excitation unit supplied the stator coil with a highly stable direct current to maintain a fixed field strength. Power dissipated in the brake as heat was absorbed by cooling water inside the stator jacket. The brake excitation unit provided a manual override via a potentiometer as an alternative to remote control. Load cell output was also displayed as a torque reading on a galvanometer for manual recording.

Engine speed adjustment was effected by a digital stepping motor (Appendix B) driving through a reduction

gear box and interfaced with the PDP 15 via a control logic card. The motor was capable of rotating at two step sizes giving an overall positional tolerance of 1/2000 of full range.

The data logging system captured parameters varying within the cycle (e.g. cylinder pressure), by means of the off-line data logger and parameters that vary from cycle to cycle (e.g. air flow) on the on-line data logger. Safety variables (e.g. oil pressure) were monitored locally and turbocharger speeds were measured by the digital data logger.

2.1 DIGITAL DATA LOGGER

This consisted of three modules

- . measurement of engine speed
- . measurement of two turbocharge speeds
- . engine revolution counting

Engine speed measurement was effected by a 12-bit counter registering the number of pulses from a 25KHz crystal clock between successive crankshaft revolution marker pulses. This counter was read by the computer which calculated the speed from the reciprocal of this time

interval measurement. The two turbocharger speeds (for low pressure and high pressure turbochargers) were measured in an identical manner to the above but with a higher frequency crystal clock of 500KHz. Engine revolution counting was done by a digital counter incremented by marker pulses from the engine crankshaft. This was essential for checking the synchronisation of data logging with the firing revolution, particularly during transient tests.

2.2 ON LINE DATA LOGGER (See also 4.2)

This was a medium speed analogue to digital convertor (ADC) with a sample and hold amplifier having a conversion time of around 10u.s. (Appendix B). It has a 0-10V input voltage range and a resolution of 0.1% (i.e. 10 bits). The unit was furnished with 32 input channels addressable individually by the computer. Sampling was timed from an external pulse generator set to around 20 KHz. When conversion of the signal was complete, the ADC set a flag which indicated to the computer its readiness to be read.

2.3 OFF LINE LOGGER (See also 4.1)

The system featured a fast ADC (1.2u.s. conversion time) with a sample and hold amplifier and an eight channel multi-plexer. An addressable sequence generator controlled the multi-plexer in single channel or multi-

plexed channel mode. Converted data was dumped into the system's own 8K rotating memory with a first in first out (FIFO) 256 word buffer. The 'recording' mode was initiated by the computer via an instruction which cleared the memory and set the indexing down counter to the number of conversions required. This was followed by the selection of the multi-plexing sequence whence recording could start. The data logger was then left, enabling the computer to attend to other tasks. When the down counter reached zero, the logger raised a completion flag which signalled the computer to 'playback' or read the 8K store. Data transfer from the 8K store to the computer memory was on a word by word basis.

2.4 DATA LOGGING CONTROL UNIT

This package allows the computer to synchronise data logging with angular position of the engine crankshaft. By manipulating the marker and digitizer pulse trains derived from a shaft encoder mounted on the front of the engine crankshaft, the off-line data logger samples analogue signals in intermittent batches or 'windows'. This windowing effect enables the computer to execute its various other functions and actually reduces the total data storage requirements (see Figs, 4.5, 4.6). The DLCU allowed for the following operations:-

- . variation of sampling rate of analogue signals (e.g. cylinder pressure) in relation to engine speed.
- . sampling a batch from one engine cycle then miss a preset number of cycles.
- . recording discrete parts within individual cycles.

Fig 4.6 shows a schematic block diagram on the basic control mechanism of the unit. By dividing the once per revolution pulse by two, a once per cycle (i.e. four stroke cycle) pulse was obtained. Further division of this cycle pulse by the variable divider N1 yielded a master timing pulse once every N engine cycles, i.e. missing N-1 cycles. N1 was manually presettable by means of a thumbwheel two decade switch from 1 to 99.

A four decade counter C1 delayed the encoder digitizer pulses from the master pulse N1. The effective data logging frequency at any engine speed was determined by the two decade switch N2 which enabled the sampling interval to be increased by up to 99 times the digitizer pulse period. The ADC trigger batch counter C2 (a four decade switch) allowed a pre-settable number of ADC convert pulses through to the off-line data logger.

The DLCU could be started and stopped either manually via push-buttons or remotely by the computer. Phase synchronisation between start of batch and firing TDC was enabled by means of a push button. A typical sequence diagram of the DLCU function is shown in Figure 4.5.

2.5 SHAFT ENCODER

The shaft encoder used was a commercial, heavy duty, optical position encoder (Ferranti type 28 H2/M4). This was coupled directly onto the crankshaft pulley by a miniature carden shaft with flexible yet torsionally stiff couplings. The device was based on a Moire-fringe glass disc with a solid state light source and light sensitive pick-up on either side. As the disc rotated, the resulting pattern gave a conditioned TTL square wave output having a period of $1/4^\circ$. An additional track gave the once per revolution marker pulse. These TTL pulses were shaped and conditioned ahead of the data logging control unit.

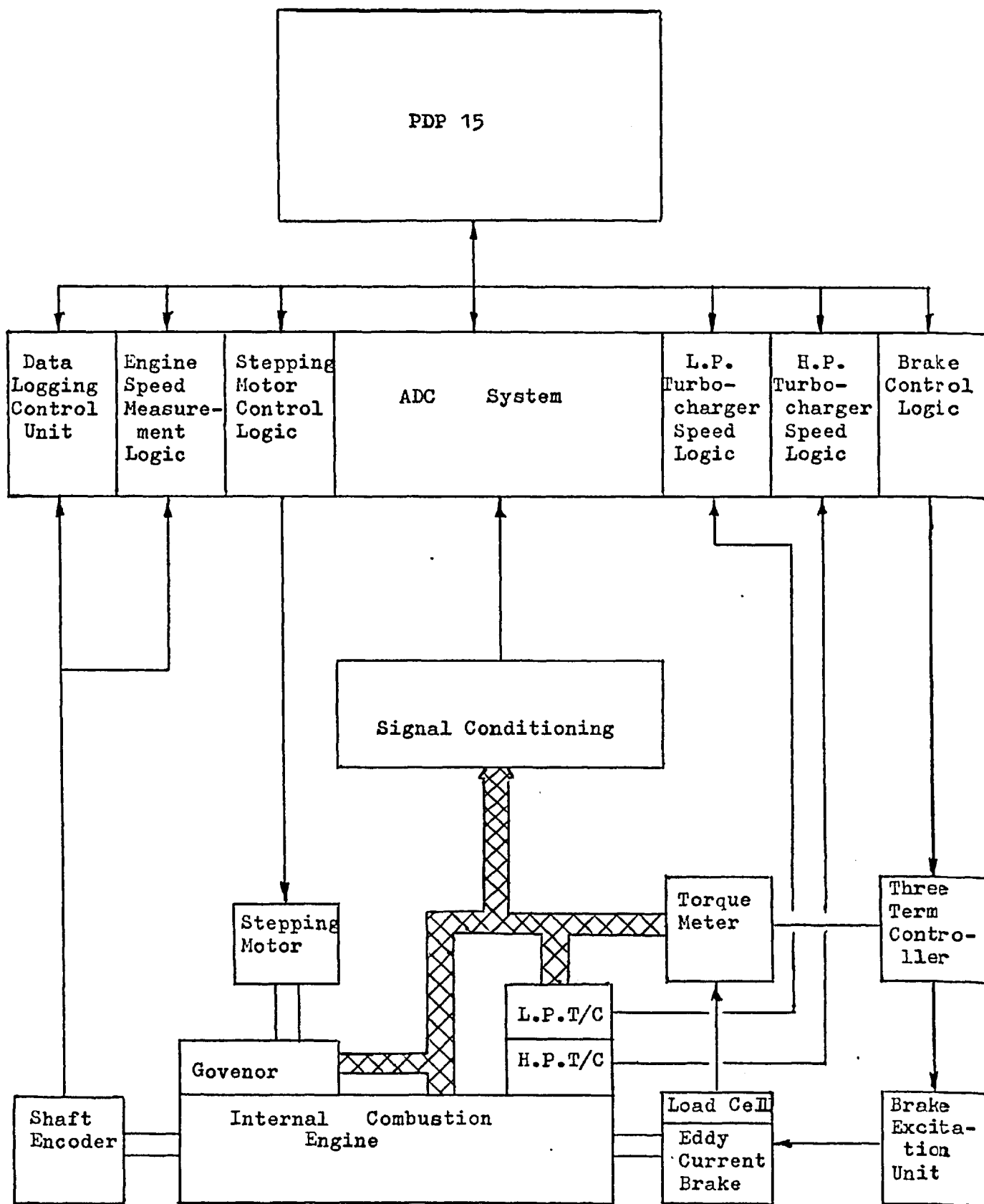


Fig 2.1 PDP 15 Data Logging & Control System

The existing Imperial College PDP 15 data logging system satisfied all the basic requirements demanded of a research type engine test system (Chapter 2). The new system (Chapter 1) would therefore need to match the PDP 15 capabilities and possibly provide some enhancements. The concept of separating the control and data logging functions previously executed by the PDP 15 computer alone into two separate system enables the system requirements to be satisfied in a more modular manner. . A protocol would be developed to link the two systems together thus assuring a reliable communication so essential to distributed computing systems.

3.1

CONTROL SYSTEM

The control system (Fig 3.1) was based around a Texas Instruments TMS 9900 microprocessor with 8KB of RAM memory and the TIBUG monitor in ROM (Ref 5). It has a 20MA loop interface to a teletype terminal and a serial interface to a cassette tape recorder for storage of programs. Engine speed was recorded by a logic unit which measured the time interval between successive revolution pulses from the engine shaft encoder. The speed was computed from the reciprocal of this recording. The governor setting for demand speed was controlled via a stepping motor driving through a reduction gearbox.

The microprocessor issued pulses to the stepping motor interface to control speed and direction of rotation. Limit switches were used to detect the extremities of the motor drive. These switches were connected directly to the microprocessor and were serviced by interrupt routines.

The main purpose of the control system was to replace the analogue three term controller on the brake (Chapter 2) by a more versatile and flexible software direct digital control (DDC) loop. Figure 3.1 shows that the microprocessor reads the torque directly from the brake load cell via a 10 bit ADC, and sets the desired torque via a 10 bit DAC to the brake excitation unit (Ref Fig 2.1).

The set torque is computed from a software algorithm which takes into account the current speed and desired engine load. Both governor position and brake load can be varied to accommodate transient demands as well as normal steady state testing.

The control system provides all the safety monitoring facilities demonstrated on the PDP 15. An oil pressure trip transducer as well as a water jacket temperature

thermocouple are connected to the microprocessor via interrupt lines. The transducers are pre-settable and hence can be adjusted to trip and warn the computer of a potentially dangerous engine condition. Engine overspeed is monitored by a software routine working from the speed measurement logic.

The system is capable of remote control operation with a manual override. For the latter, a brake excitation potentiometer adjustment is provided with a galvanometer reading of measured torque. The stepping motor on the governor can also be actuated in both forward and reverse directions with light emitting diodes (LED) to warn the user that end of travel has been reached.

Work on the control system is reported in Reference 5. The system will be interfaced to the data logging system by 1982 and will be the subject of further work.

3.2 DATA LOGGING SYSTEM

The new data logging system was to embrace all the acquisition tasks undertaken by the PDP 15 (Chapter 2) as well as providing the graphics and printing facility for presentation of data and results. Since the on-line and off-line data loggers and the data logging control

unit (Chapter 2) were functioning adequately on the PDP 15 system, it was decided that they should be transferred in their entirety onto the new system. This was also the most cost effective solution since the analogue to digital converters (ADC) form the most expensive part of any data logging system. The digital interfaces such as the engine speed and turbocharger speed measurement logic were also to be preserved across the change over, although these units are much less expensive than the analogue to digital convertors (ADC).

In addition to being easily interfaced to the existing PDP 15 data loggers, the new computer system should have the following features:-

- . It should be easily interfaced to a RACAL seven track magnetic tape unit currently associated to the PDP 15. This unit provides a back-up medium for long term results storage as well as offering a method to transfer programs and data to the CDC mainframe computer at the Imperial College Computing Centre.
- . A visual display unit (VDU) should be provided for easy data entry and convenient, fast dialogue between user and computer.

- . This should have a 24 x 80 display with a full ASCII keyboard. The system should also be capable of supporting a Tektronix 4010 graphics terminal, currently associated with the PDP 15. To this end, an RS232C serial interface was required together with the relevant software graphics package.
- . A line printer was required to provide a hard copy output of programs and results. A medium speed, 132 column, impact dot-matrix unit would be suitable.
- . The system should be capable of supporting the American National Standard version of Fortram IV development language to maintain compatibility with existing programs within the College - most of which are written in FORTRAN. This language is also preferred due to its popularity within the Engineering profession and because it is specifically designed to numeric computation. The computer should also be supplied with a disk operating system with a keyboard monitor, file handling utilities, text editor, assembler, and a linker as well as a full FORTRAN run-time system. The operating system should be easy to use (i.e. user friendly), reliable and amply documented.

3.3

PROCESSOR SPECIFICATION

The following is a summary of the main specification for a processor for the data logging system:-

- . 16 bit word architecture. An 8 bit processor would be rather slow in handling the data from the off-line logger 8K store (Chapter 2). Benchmark programs showed that although it is possible to split the 10 bit data word from the ADC into two bytes (8 bit words) it does, nevertheless, impose a time penalty.
- . The processor should have at least 30K words of random access memory (RAM) for efficient data capture. This figure is arrived at from the amount of data dumped into the computer from the data loggers during a transient test. This amount of memory is also normally required to run a FORTRAN overlay system effectively.
- . A throughput rate of about 200KHz is required between the off-line data logger 8K store and computer memory and around 40KHz

between the memory and a back-up medium.

Due to these high transfer rates, the latter would necessarily need to be a hard disk.

Such rates are necessary to enable the system to clean up the 8K store, dump the data onto back-up disk and still maintain control over procedural activities before servicing the 8K store once more.

The 8K store is, of course, filled up in response to the settings on the data logging control unit (2.4) at a rate determined by the current engine speed. For example, a diesel engine running at 3000 rpm, sampling 4 channels on the off-line data logger at a half degree crank angle over one four-stroke cycle (two revolutions) collects the following amount of data:

$$4 \times 2 \times 720 = 5760 \text{ words}$$

If, say, we had a window (2.4) on one cycle in every nine, this would allow the computer 7ms idle time in between servicing the 8K store and dumping data

onto disk. If the processor had processing duties on the data which took more than 7ms, an "over-run" condition or a loss of synchronisation between the computer and the data logger would result. This situation leads to corruption of captured data which must be recognised and flagged as a fatal error condition.

The computer chosen for the task was a Digital Equipment Corporation PDP 11/03 (Ref 8, 9, 10, 11 and 17). This incorporated the LSI-11/2 16 bit word microprocessor with a comprehensive instruction set, 64KB words of memory and a built in 5MB hard disk system (Appendix A). The latter provided a throughput of 60HKz from memory onto disk whilst a direct memory access (DMA) card (Chapter 4) provided a 250HKz interface between the 8K store and the computer. A general purpose parallel interface card (Chapter 4) was used for communication between the computer and other devices, such as the on-line data logger, etc. A 24 line by 80 column visual display unit together with a 132 column line printer were interfaced via a standard RS232C serial link with the LSI-11/2.

The operating software for the system was the well proven and excellently documented RT-11 version 3B single user operating system (Chapter 5). RT-11 has extensive disk file handling capabilities and an assembly language called MACRO-11 which produced relocatable object code. The operating system also supported a well thought of implimentation of FORTRAN 4 with some powerful enhancements over the American National Standard version.

The only major disadvantage of the new machine over the PDP 15 was the reduction in instruction speed. Benchmark programs showed the LSI-11/2 to be approximately three to four times slower than the PDP 15 despite the former's more modern architecture. This is explained by the electronic technology used in the two computers. The PDP 15 uses very fast discrete TTL components whereas the LSI-11 has much slower integrated MOS devices. This disadvantage, however, could be minimised by good software design.

The main advantages of the PDP 11 system over the existing PDP 15 system may be summarised as follows:-

- . the PDP 11 offers easier and more modular interfacing through the memory mapped QBUS (Chapter 4). The PDP 15 system used a different and more complex method of input and output where one could not easily "plug in" or remove devices onto the system. With the PDP 11 one can connect up devices to the QBUS with ease to obtain any desired configuration of peripherals and dedicated controllers.

- due to improved hardware technology, packing density on the PDP 11 is vastly improved. The PDP 15 system occupied 4 full sized 17 inch by 6 foot cabinets whereas the PDP 11 is housed in one half-size cabinet. This represents a reduction in volume of nearly 90%!
- The PDP 11 has twice as much random access memory as the PDP 15 and ten times more disk storage. Moreover the disks are faster, more reliable and removable for archiving and program transfers, etc.,
- RT-11 on the PDP 11 is an improvement over DOS 15 on the PDP 15. Although the latter affords user protected disk areas, it is much less powerful in terms of monitor commands and disk file handling capabilities. The FORTRAN compiler running under RT-11 is also more sophisticated than the PDP 15 version. Overall, the system and software documentation on the PDP 11 is more comprehensive, better indexed and easier to read than the DOS 15 manuals.

- . The PDP 11 is much more economical to maintain and (inherently more reliable) due to its more modern technology. This was one of the prime reasons for replacing the original PDP 15 (Chapter 1).

Viewing the whole system, i.e. data logging, PDP 11 and control TI9900 systems; one has resolved the timing conflict within the PDP 15 system between control and data acquisition functions. This was an important factor in opting for a distributed system of having independent processors to monitor each major task within the overall system.

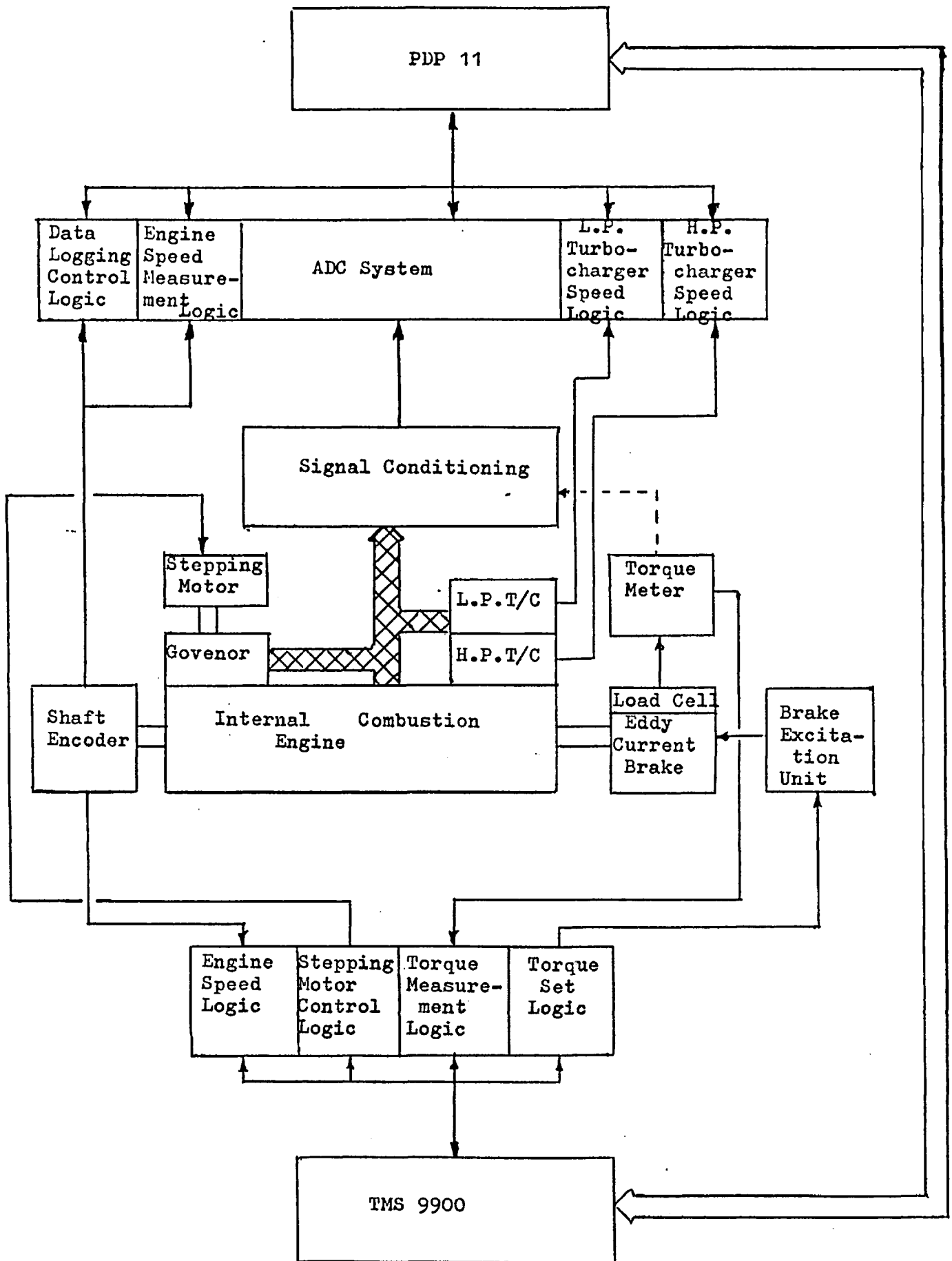


Fig 3.1 PDP 11 Data Logging & Control System

4.

HARDWARE DESIGN

The hardware design exercise involved interfacing the existing on-line and off-line data logging systems to the PDP 11 computer (Chapters 2, 3) as well as re-building the turbocharger speed and engine revolution counter interfaces. The existing data logging control unit was also connected up to the computer. The hardware exercise was undertaken by Thermal Power Group staff.

The DEC PDP LSI-11 computer has a system bus known as the QBUS. This is a sub set of the main PDP 11 family bus known as the UNIBUS. All PDP 11's use memory mapped input-output with device registers in high memory (Fig 5.3) and interrupt vectors in low memory. The PDP LSI-11 has a single level interrupt with an enable and disable interrupt facility. It can address up to 32K words of memory and its instruction set is upwardly compatible with the mini computers PDP 11/34, 11/45 and the new PDP 11/23.

It was decided to group together most of the input/output operations on the general purpose QBUS parallel interface card, the DRV11 (Ref. 9). In general with PDP 11 interfacing philosophy, this card has a control and status register to synchronize operations and separate

input and output buffers for the actual data transfer.

To speed up data collection in real-time, the off-line ADC 8K store was interfaced via a QBUS Direct memory access interface card, the DRV11B (Ref 9). This card assumes the role of "bus controller" when the 8K store is ready to dump its contents into the computer memory (Chapter 3). The DRV11B keeps the central processing unit suspended whilst data transfer is in progress and ensures that the dynamic memory used in the computer has sufficient time to refresh inbetween memory cycles. (Ref 9, 12, 13).

Before discussing the interfaces in detail, the on-line and off-line ADC systems as implemented on the PDP 11 (Chapter 2) will be described.

4.1 OFF-LINE DATA LOGGING SYSTEM

Fig 4.1 shows the organisation of the off-line ADC system. The only difference to the PDP 15 system (2.3) is that use of direct memory access to transfer data from the 8K store into the computer.

The multiplexer on the 8 analogue input channels is controlled via internal logic to give either single channel or sequential channel mode. The multiplexer itself is an Analog Devices MPX8A unit which

feeds into an Analog Devices SHA-2A 10ns aperture time sample and hold amplifier. Convert pulses from the data logging control unit are fed via a 1 to 8 pulse multiplier (for multichannel operation) into a software controlled down-counter. This unit allows for the detection of an over-run error condition - i.e. the data rate is too fast for the computer to assimilate (Chapter 3). Input pulses decrement the down counter and feed into an Analog Devices ADC 1103 10 bit, 12us conversion time analogue-to-digital converter.

The conversion data is transferred to an 8K rotating memory store preceded by a first-in-first out 256 word buffer. Data acquisition rates of 500KHz were reliably recorded into the 8K store. When the down counter has decremented to zero, a flag is raised after an internal hardwired delay of one millisecond. This delay allows the rotating memory store to settle prior to playback or read operation. Playback is directed by the direct memory access logic initiated by software.

A throughput rate of about 220KHz was recorded between 8K store and computer memory.

4.2

ON LINE ADC

Fig 4.2 shows the organisation of the on-line ADC system (2.2). The thirty-two channel multiplexer is software controlled, organised into a 4 row by 8 column matrix. The unit is an Analog Devices MOSES8 with single ended channels.

A SHA-2A Analog Devices sample and hold amplifier with an aperture time of 10us freezes the signal to be sampled. A 10 bit, 8us conversion time Analog Devices ADC 10QU analog to digital converter converts the signal, pulsed from a time based pulse generator. Typical throughput rates were about 40KHz.

The following two sections summarise the communication structure between the data logging system and the computer via the DRV11 (parallel interface) and DRV11B (DMA interface) cards.

4.3

DRV11 INTERFACE

Fig 4.3 shows the architecture of the devices connected to this card. Three bits from the DRV11 are employed for device selection allowing up to eight devices to be accessed. It should be noted that the term "device" here is used to refer to a physical unit which,

when selected, is connected exclusively to the computer. Of the two flags associated with the card, one is used as a general purpose request flag, the other as an error flag. The error flag indicates the occurrence of an "over-run" condition which is caused by the data acquisition rate being greater than the data processing rate. The flag is raised when a convert pulse arrives at the down counter and the latter's reading is zero. It is cleared only by loading a number into the down counter by software (4.3.6).

The general purpose flag is raised by a device when it has been selected by the computer. It is cleared when another device is selected. Device selection is controlled by software setting two bits in the DRV11 control and status register and manipulating the most significant bit of the output buffer. The latter operation issues a "new data ready" signal by the DRV11 to the device selection logic (Ref 9). It is this signal that triggers the interface system. The complementary signal, "data transmit", issued when the computer reads the DRV11, has exactly the same effect. Both signals can, in fact, clear the general purpose flag referred to above.

The eight devices selectable by the computer constitute the digital data logger, on-line data logger and off-line data logger described earlier in this Chapter and in Chapter 2. The function of each device will now be described.

4.3.1 LOW PRESSURE TURBOCHARGE SPEED MEASUREMENT

This device counts the number of pulses from a 500KHz crystal clock between successive revolutions of the turbocharger rotor (2.1). A magnetized nut on the rotor generates the revolution pulse which is shaped and conditioned prior to updating the current counter reading. When the device is ready to be read, it raises the general purpose flag.

4.3.2 HIGH PRESSURE TURBOCHARGER SPEED MEASUREMENT

This device is identical to the low pressure turbocharger speed measurement described in 4.3.1

4.3.3 ON-LINE DATA LOGGING SYSTEM

The multiplexer channel for the 32 channel on-line data logging system device is selected by manipulating the DRV11 output buffer (fig 4.2). The column number is decoded from the first three bits and the row order from the following three bits. The general purpose flag is raised when the ADC conversion is complete thus indicating to the computer that it can be read.

4.3.4 DATA LOGGING CONTROL UNIT (DLCU)

This package (Chapter 2) is driven by a shaft encoder on the engine and provides the off-line data logger with intermittent batches of convert pulses.

(Fig 4.6). The period in between batches allows computer to clean up the 8K store and execute data reduction tasks, etc. Remote control of the data logging control unit is provided by this device. Setting the least significant bit in the DRV11 stops and resets it, whilst clearing the bit starts the unit. The general purpose flag is raised by the device when a skipped cycle pulse arrives (see Fig 4.5). The PDP 15 system uses this pulse to read the on-line data logger (ref 4). The new system uses the off-line data logger completion flag to synchronise the readings taken from the on-line data logging system (see program flow chart in Fig 5.4).

4.3.5 ENGINE CRANKSHAFT REVOLUTION COUNTER

This device counts the number of revolution pulses from the engine shaft encoder (Fig 3.2). It is a 12 bit counter with overflow to zero. The general purpose flag is raised whenever the counter is incremented by a revolution pulse. The device is cleared by setting the least significant bit in the DRV11 output buffer.

4.3.6 8K STORE DOWNCOUNTER

This device is subdivided into two by the setting of bit 13 in the DRV11 output buffer. When this bit is set, the downcounter can be loaded with an 11 bit word. The downcounter controls the number of ADC words transferred to the 8K store (Fig 4.1) by decrementing to zero and then inhibiting further transfers. By clearing bit 13 on this device, the software can poll the general purpose flag which indicates that the downcounter is empty and includes the internal one millisecond delay (4.1). Should a convert pulse be sent by the data logging control unit when the downcounter is empty, the error flag is raised indicating the "over-run" condition (4.3).

4.3.7 OFF-LINE ADC MULTIPLEXER SELECTION

This device selects the multiplexing sequence on the 8 channel off-line data logger. Single channel mode can be selected by setting bit 3 in the DRV11 output buffer; Multiplexed channel mode by clearing bit 3. The channel number is decoded from the remaining low order bits. For multiplexed modes (bit 3 clear), the indicated channel will be the first channel in a sequence that ends on channel 8. Thus multiplexing on channel 5 will result in channels 5, 6 7, and 8 being sampled in that order.

4.3.8 8K STORE READ/WRITE CONTROL

This device sets the 8K rotating memory into either a "write" mode (to accept ADC data) or "read" mode (for DMA into computer memory). The former is achieved by clearing the least significant bit in the DRV11 output buffer, the latter by setting it.

4.4 DRV11B INTERFACE

The DRV11B card (Fig 4.4) is semi-intelligent (i.e. capable of being a "bus controller") and requires some program activity before it can be initiated. The two's complement of the number of word transfers from the 8K store is loaded into the word count register. The target address of the data in computer memory is set up in the Bus address register. Finally, the 8K store control logic must be reset via the control and status register before direct memory access can begin. Once the process is underway, the central processing unit is set to a "wait" state thereby not competing with the DRV11B for the bus. This improves the direct memory access rate over an "active" central processor state.

When data transfer is complete and the word count register has incremented to zero, the DRV11B relinquishes control of the bus and forces the central processor into an interrupt routine. The computer can then begin its

various tasks on the data collected in memory.

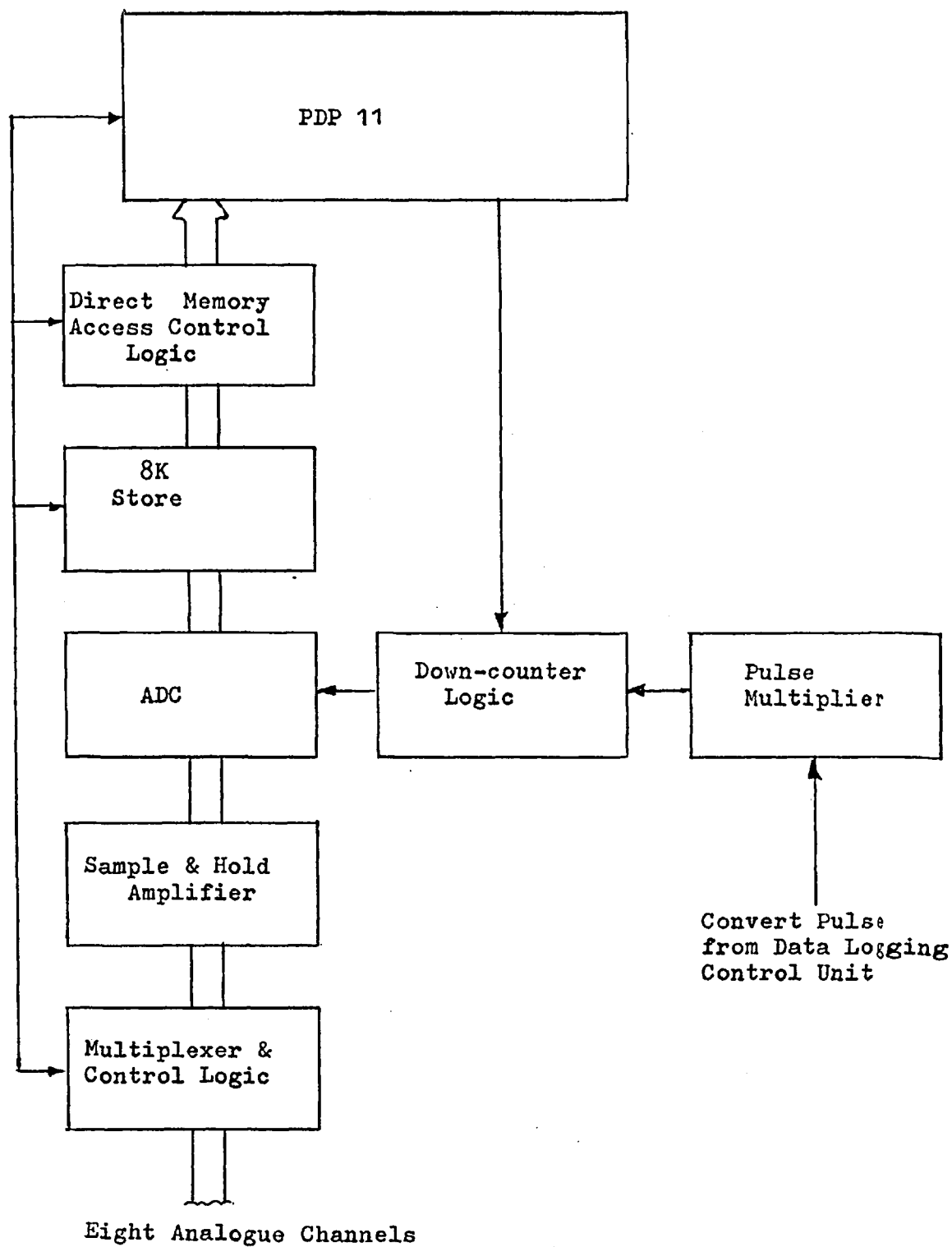


Fig 4.1 Off-line Data Logging System

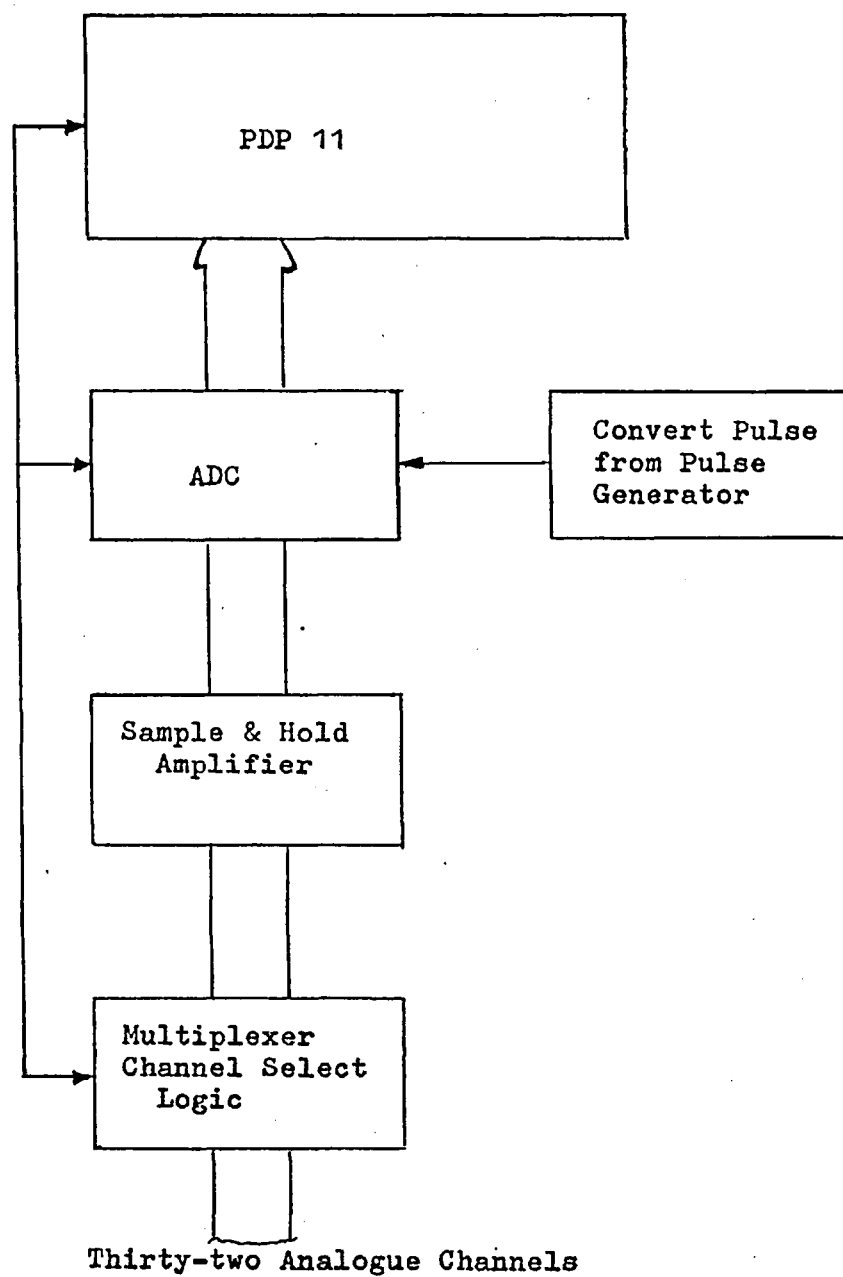
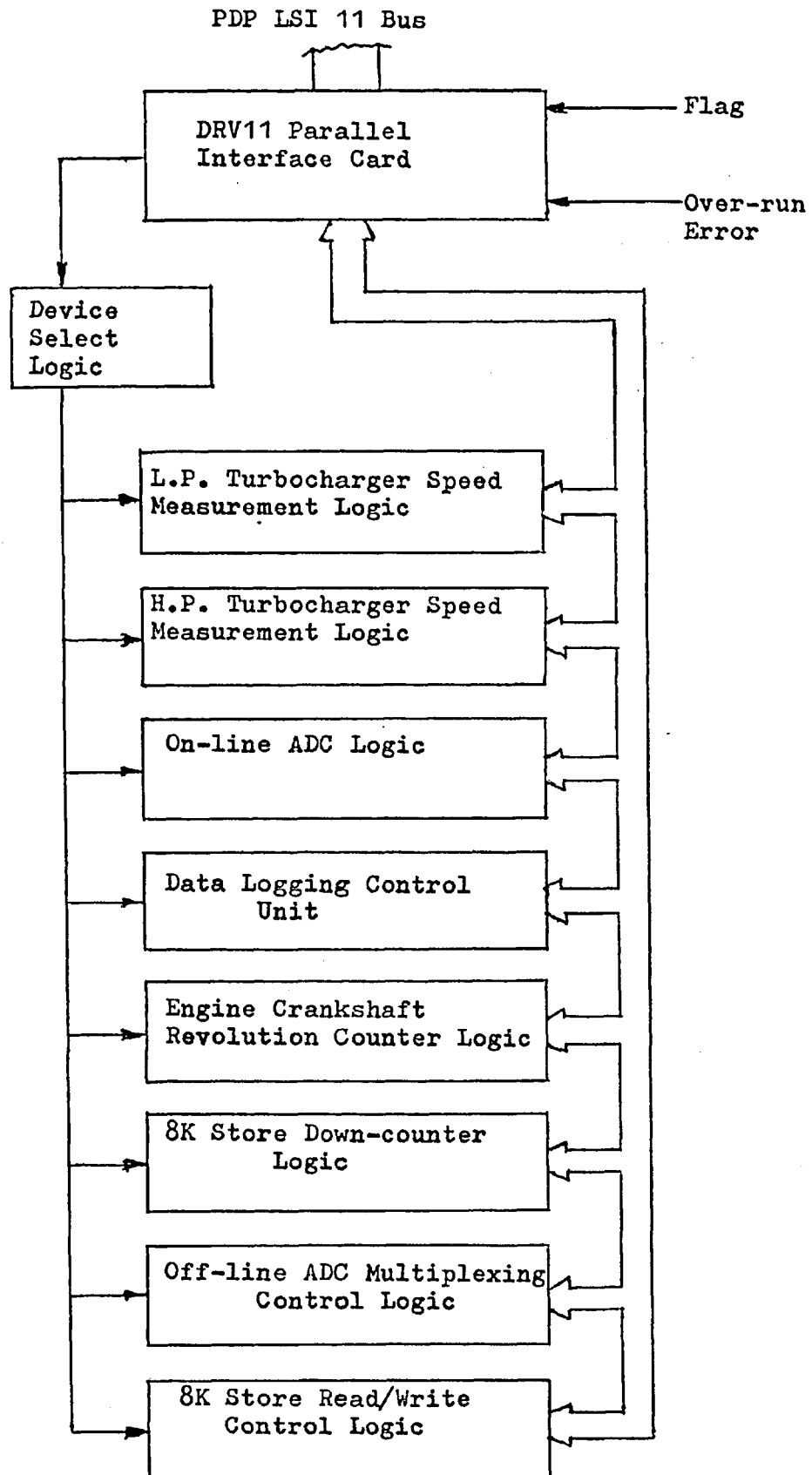


Fig 4.2 On-line Data Logging System

Fig 4.3 Parallel Interface Hardware



PDP LSI 11 Bus

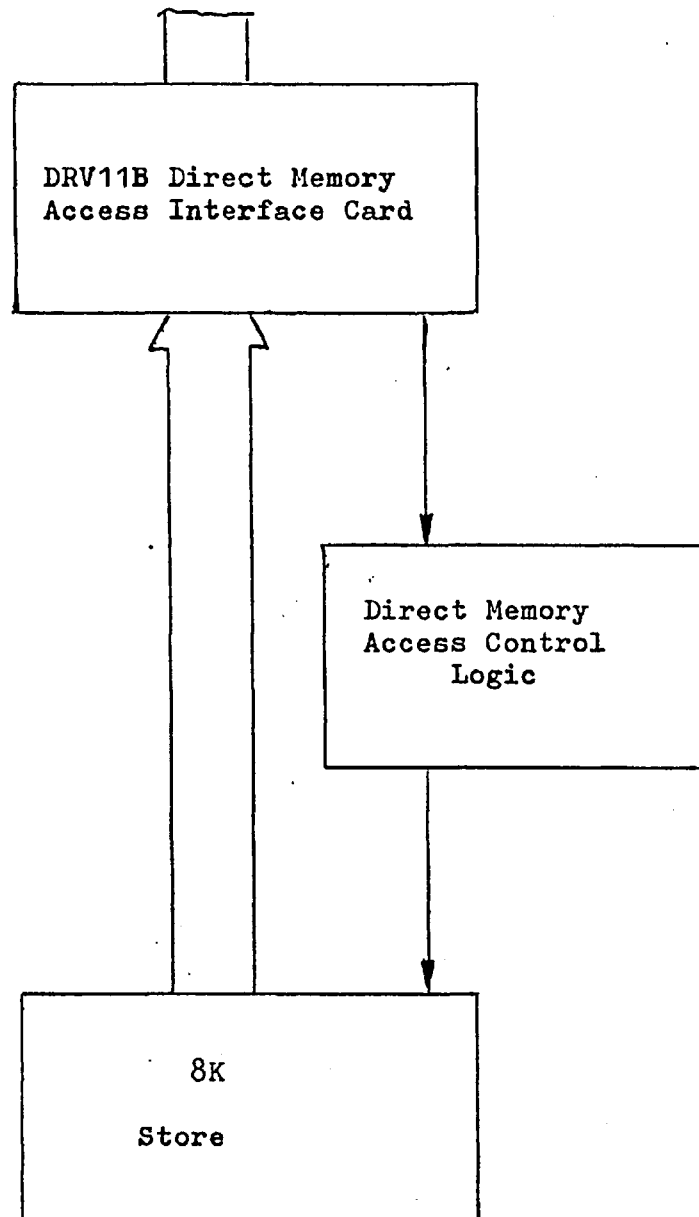


Fig 4.4 Direct Memory Access Hardware

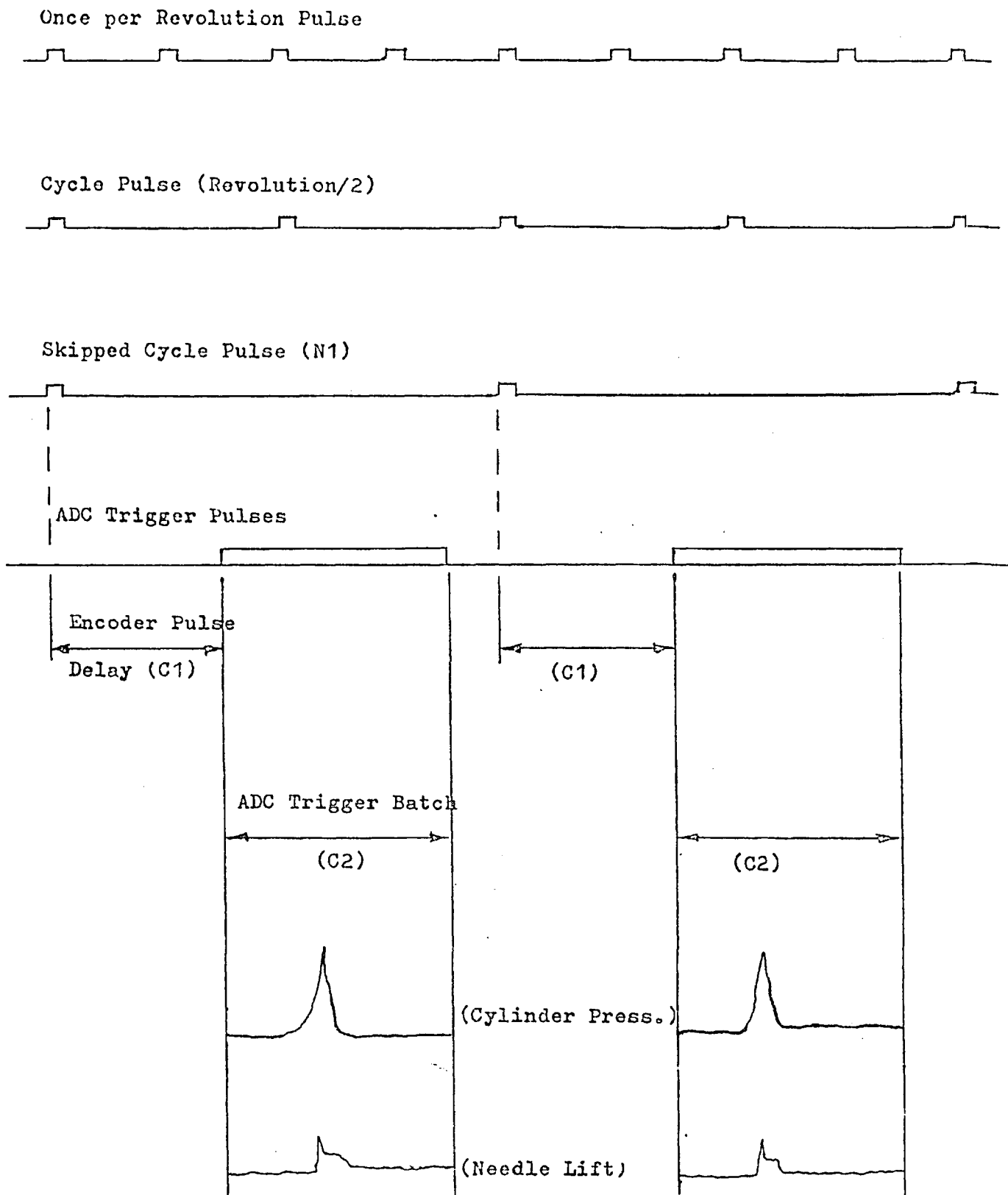


Fig 4.5 Data Logging Control Unit(DLCU) Function

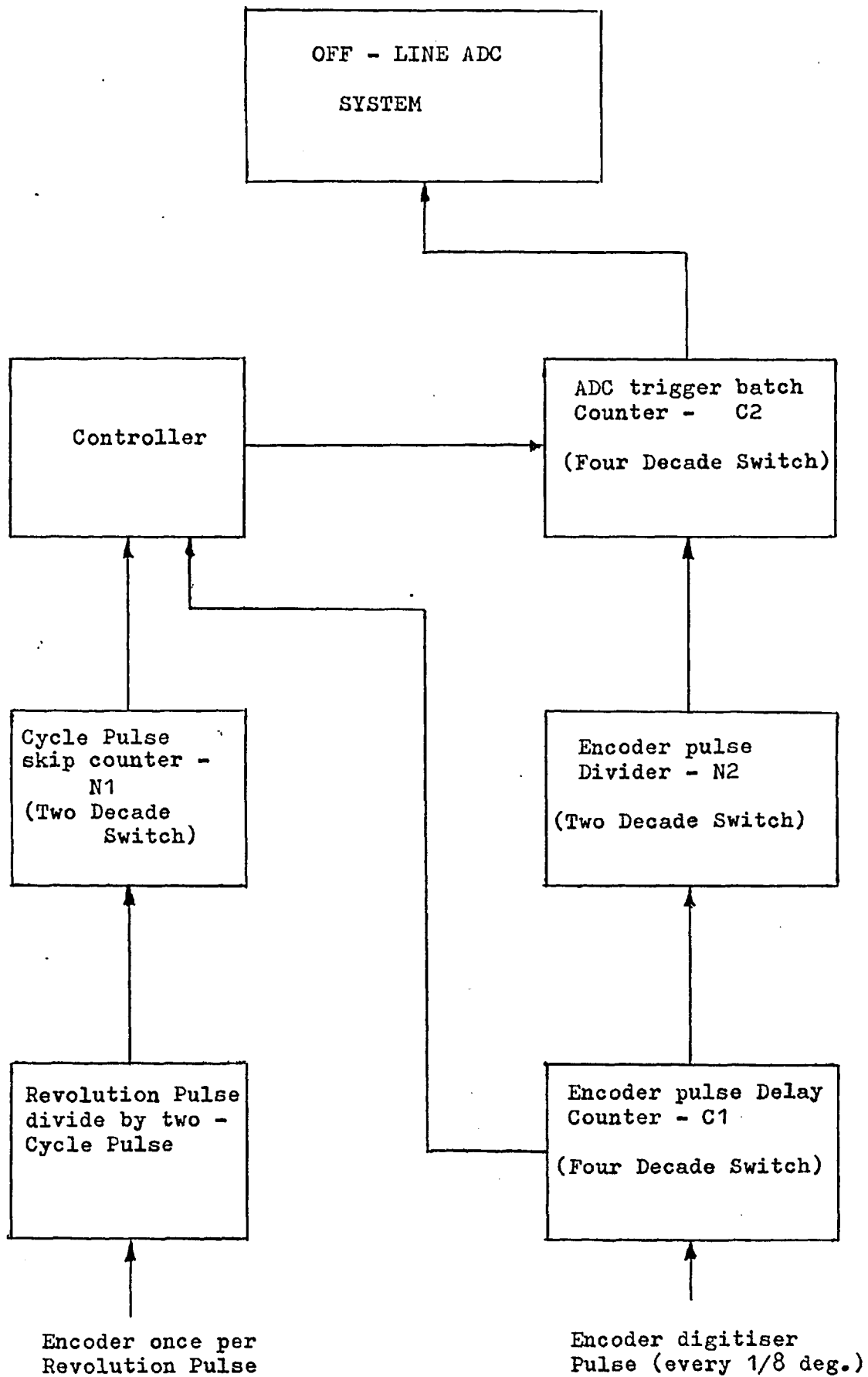


Fig 4.6 Data Logging Control Unit(DLCU)

The software was designed using a modern technique commonly known as "structured programming" (Ref 16). Structured programs have a well defined logical organisation and use a small number of simple control sequences. Such routines have a high degree of predictability which makes them easy to read, understand and subsequently modify. An effort was made to keep each program "modular" (asynamous with "structured") utilizing common interfacing characteristics. The more frequently called routines were packaged into an utility library whilst the main programs were developed using the "top-down" method of progressively refining the problem into a set of sequenced operations.

In a further attempt to produce readable programs, all non-time critical routines were coded in FORTRAN IV (American National Standard Fortran X3.9-1966 with DEC enhancements). The use of high level languages, such as FORTRAN, enables programs to be better documented, easier to debugg and maintain. (i.e. updated etc.) The use of the assembler language MACRO-11 (Chapter 3) was unavoidable when confronted with the task of reading the ADC's real time clocks (see Chapter 4), servicing interrupts, etc. In fact all the code for acquiring the data from those interfaces was written in assembler.

This was found to be the most elegant solution to the memory constraint of effectively 26K (after allowing room for the operating system resident monitor). The source programs within the Assembler were, however, provided with liberal comment statements to enable future users to understand the logic, data structures and deployment of the machine hardware.

The system software (Fig 1) can be split into three main sections:-

- . COMMON USER INTERFACE
- . DIAGNOSTICS
- . DATA ACQUISITION
- . RESULTS PROCESSING

5.1 USER INTERFACE

A common user interface called "MONLIB" is provided for all three packages, diagnostics, data acquisition and results processing. It is a flexible command driven interface which affords some "protected field" capability to the visual display unit (Chapter 4) and produces a consistent "user friendly" environment. "MONLIB" incorporates a "HELP" function and sophisticated error handling capabilities. The following is a summary of the modules contained within MONLIB. Unless otherwise stated, these routines are written in FORTRAN.

5.1.1

YKMON

This module is called by a system program to initialize the common blocks within MONLIB from a map of the available commands in a file called MONLIB.DAT. This file contains a list of all the commands which MONLIB is to offer the user together with the arguments (if any) available with each command. For example, ACQUIS (5.3), the following command lines are valid:

CHANNEL COLUMN 5

The command keyword is "CHANNEL" and the arguments are "COLUMN" and "5". The latter two will be set as valid arguments for the command "Channel" in the ACQUIS map for MONLIB.

5.1.2.

JKMON

This routine is called by YKMON. It reads the MONLIB.DAT file and checks the command/argument structure for any errors.

5.1.3.

ZKMON

ZKMON is the main module called by systems programs. A YKMON call must be executed prior to ZKMON to initialize the common arrays. ZKMON is responsible for the "HELP" command, prompting the user for input and reporting any errors. It processes the "MONITOR" command by displaying the current version number of MONLIB being used. The system program calling ZKMON sets a variable

in the argument list which is a limit on error entries to MONLIB. Thus, if a user consistently fails to enter a correct input to MONLIB, control can return to the system program, enabling it, for instance, to print out a help line.

On a clean exit from ZKMON the command string entered by the user is encoded into a command variable and a one-dimensional argument array (since there may be more than one argument). This allows the system program to act on the input using a simple "CASE OF" instruction (Ref 14). Hence the main function of MONLIB; relieving the system program of all the error checking and encoding of the user input.

5.1.4. AKMON

This routine, called from ZKMON, removes superfluous blanks from the users input command string (i.e. line of alphanumeric characters). "MONLIB" is thus tolerant to excessive blanks in the entry, allowing the user to tabulate the input into any form, providing there is at least one de-limiting blank separating each word.

5.1.5. BKMON

This routine, called from ZKMON, identifies the command word (i.e. the first word in the input string) against

the map of commands in MONLIB.DAT. (see 5.1.1.). If the command exists, it is encoded to its preset value. If it does not exist, then an error message is displayed on the screen. A useful facility provided by BKMON and also FKMON (See 5.1.7) is that it can recognise words in the map from their first few letters. For example, the command "CHANNEL" may be recognised from the first letter "C". The proviso here, of course, is that there should be no other command word starting with "C", e.g. "CALIBRATE". An appropriate error message is given when a word may be ambiguous. By entering "CH" for "CHANNEL", BKMON is able to identify the CHANNEL command in the map.

5.1.6.

CKMON

CKMON is a utility routine called by both BKMON and FKMON. It shifts a string either left or right depending upon the value of a switch in the argument list. CKMON is necessary since both BKMON and FKMON interpret a word only when it has reached the left hand margin. This is analogous to a person reading a book where, instead of rotating his eyes to follow the line, he moves the book from left to right!

5.1.7.

FKMON

FKMON identifies arguments in the input string in a similar manner to BKMON (5.1.5.). It checks the string for arguments and codes each one in turn into an integer array (5.1.3.).

5.1.8.

DKMON

This routine, called from ZKMON, checks that an argument (already vetted by FKMON) is valid with the command (already vetted by BKMON). If no argument is submitted in the string, DKMON will check whether an argument is required. This is very important since some commands cannot function without an argument. If such an argument is required, DKMON prompts ZKMON to ask the user to enter an argument.

5.1.9.

LKMON

LKMON, called from ZKMON, executes the "HELP" command. This involves reading the map obtained from MONLIB.DAT (5.1.1.) sorting out all the commands and their respective arguments, then displaying (or printing on the printer - Chapter 3) a list of all the commands and their valid arguments.

5.1.10.

EKMON and MKMON

EKMON, called from XKMON, calls up the assembly routine MKMON. This routine breaks the "soft" link made by the operating system between the keyboard and the screen on the visual display unit. MKMON records strings keyed in and displays on the screen only those characters that are normal ASCII alphanumeric. The "rubout" facility is supported with the cursor being moved left in the normal manner. MKMON also controls the length of the input line, preventing the cursor from moving beyond the left hand and right hand margins. Thus a "protected field" facility is offered to MONLIB via this assembly language routine which is fully interfaced into the FORTRAN MONLIB system.

5.2.

DIAGNOSTICS

The module "DINT" undertakes the diagnostics function on the system. It is capable of testing all eight devices associated with the parallel interface card, DRV11 (see Chapter 4) and also checks the integrity of the 8K store DMA. It accepts input from the keyboard through MONLIB, the general purpose user interface (5.1). "DINT" can be set to test a single device, multiple devices in both one-off and repetitive modes. It is possible to call up the acquisition or the results processing programs directly from "DINT"

together with the documentation text, which is included in Appendix C.

The following is a summary of the modules contained within "DINT".

5.2.1. DINTZ

This routine, written in FORTRAN interfaces DINT to the MONLIB (5.1) user interface. DINTZ decodes the directive from MONLIB to

- . test devices (1 to 8)
- . set messages to be output to either VDU or printer or to be inhibited (i.e. no messages)
- . set channel configuration on the off-line and on-line data loggers (Chapter 4)
- . call up the data acquisition or results processing programs
- . return to RT-11 operating system

- . force the computer into ODT mode (Ref 8).
This halts the system and allows the user to open registers and memory locations, etc.
- . call up the documentation file.

DINTZ allows the user to repeat a test simply by pressing the "return" key on the keyboard. This is very useful when diagnosing the on-line and off-line data loggers. Alternatively, DINTZ may be set to execute tests in the following manner:-

- . once only
- . repeat continuously
- . execute the tests and loop in any test that fails
- . execute the tests and stop on any test that fails

5.2.2. DIDOC

This routine prints the documentation file for DINT called DINT.TXT on either the VDU or printer. Output to the screen may be suspended by keying in "control S". Typing continues when the user enters "control Q".

5.2.3.

DINTT, DII

These two modules test the device selection logic on the DRV11 interface (Chapter 4). DINTT is a FORTRAN routine that executes error message handling and is the interface between DINTZ and the assembler routine DII. The latter performs the device selection by manipulating the bits on the control and status register and output buffer on the DRV11 card. The user specifies the number of devices to be tested for selection, always starting with device 1. DINTT is responsible for calling DII for each device that is to be selected.

5.2.4.

DINTO, DIO

These two routines test the low pressure turbocharger speed measurement logic (Chapter 4). DINTO is a FORTRAN program responsible for error handling and interfacing DINTZ with DIO, an assembler routine. The latter executes the following tasks:

- . tests that the general purpose flag is raised when the speed buffer is updated by the turbocharger rotor pulse
- . tests that the flag is cleared by the DRV11 interface signals "data ready" and "data transmit".

- . takes a reading of the buffer which is subsequently displayed in decimal and octal form on the VDU by DINTO.

5.2.5 DINT1

DINT1 is due to be identical to DINTO testing the high pressure turbocharger speed measurement logic. As the time of writing, hardware for this unit has not been completed.

5.2.6 DINT2, DI2

These two routines test the on-line data logging system. DINT2 handles error messages and calls up DI2, the assembler routine, to check each of 32 channels available in sequence. The user may optionally condition DINT2 to wait for a "carriage return" from the keyboard in between channels before proceeding. This facility is offered via the "WAIT" command within DINT. DI2 selects the on-line data logger device through the DRV11 card and executes the following tasks:

- . tests that the general purpose flag is raised when the ADC has finished conversion
- . tests that the flag is cleared by the DRV11 interface signals, "data ready" and "data transmit"

- . takes a reading off the ADC which is subsequently displayed in decimal and octal form on the VDU by DINT2

5.2.7 DINT3, DI3

These two routines test the DLCU control functions.

DINT3 handles error messages and the interfacing between DINT2 and the assembler routine, DI3. The latter executes the following tests on the DLCU:-

- . stops the DLCU and checks that the general purpose flag is not set
- . starts the DLCU and flags an error if the flag is not set within 3.2 seconds. The flag here is raised by the first skipped cycle pulse (Chapter 4).
- . tests that the flag is cleared by the DRV11 interface signals, "data transmit" and "data ready"
- . ensures that the flag is not raised when the DLCU has been stopped.

5.2.8

DINT4, DI4

These two routines test the engine revolution counter logic. DINT4, the FORTRAN module, handles the error messages and the interfacing with DI4, the assembler routine. The latter performs the following tasks on the revolution counter (Chapter 4):-

- . ensures that the counter can be cleared
- . tests to see whether the counter is incrementing
- . ensures that the general purpose flag is raised when the counter is incremented
- . ensure that the flag is cleared by the DRV11 interface signals, "data ready" and "data transmit"
- . test that the 12 bit counter overflows to zero
- . takes a reading from the counter that is subsequently displayed in decimal and octal on the VDU by DINT3

5.2.9. DINT5, DI5

These two modules exercise the 8K store downcounter (Chapter 4). DINT5 performs the error handling and interfaces with the assembler module DI5. The latter executes the following tasks:-

- . ensures that the general purpose flag is raised when the downcounter is empty
- . ensures that the flag and the error flag are cleared when the downcounter is loaded with a number
- . that the error flag is raised when an over-run situation arises.
- . checks that the downcounter is decrementing properly.

5.2.10 DINT6, DI6

These two modules test the multiplexing sequence on the off-line data logger. DINT6 handles the error messages and interfaces to the assembler routine, DI6. The latter selects single channel and multichannel mode and invites the user to view the sequencing action on LED's adjacent to the channel BNC sockets.

5.2.11.

DFDMA, DIDMA

These two modules test the 8K store DMA function via the DRV11B card (Chapter 4). DFDMA, the FORTRAN routine, handles the messages and ensures that a channel had been previously selected for the off-line data logger. DIDMA is an assembler routine that executes the following tasks:-

- . sets the off-line data logger multiplexer
- . sets the 8K store to "record" and loads the downcounter with 20, and waits for it to decrement to zero.
- . set up the DRV11B register and the 8K store to "playback".
- . start the DMA operation and wait for it to be completed.
- . display the 20 readings in column form on the VDU screen.

5.3.

DATA ACQUISITION

This function is executed by "ACQUIS" which is a name given to a family of modules which acquire data and then subsequently display it on the VDU or line printer.

"ACQUIS" is much larger than "DINT", e.g. each section of ACQUIS (Fig. 5.2) is larger than all of "DINT", occupying most of the computer memory (about 24K words each). To link such large programs together, a technique called "CHAINING" is used. When one module of "ACQUIS" (say "ACQAVS", see Fig 5.2) has finished processing it is flushed out of computer memory and another module called in (in this case "ACQRLT"). Common data between modules is transferred in low memory (a small part at the bottom of the computer memory map) or in data files on disk (for large amounts of data). Chaining offers an elegant and versatile method of sequentially calling up modules. It is, however, slower than normal overlay calls and more restrictive in terms of argument transfer. Fig 5.3 shows the RT-11 chained memory map.

The structural concept of ACQUIS is shown in Fig. 5.2. "ACQZ" is the keyboard monitor program. The monitor is responsible for setting the results configuration, calibrating both ADC's and setting up data structures prior to a data acquisition run. "ACQZ" utilizes "MONLIB" (5.1) the "friendly" user interface in a similar manner to "DINT", the diagnostics module. "MONLIB" handles all the error reporting for ACQZ and provides a consistent interface with the user.

"ACQZ" can call up the results module "ACQRLT" directly (to interrogate results already obtained) or automatically at the end of a data logging test. Version VO1.01 of ACQMS has three steady state logging modes; viz, MODE1, MODE2 and SS. The latter allows the user to select whatever data structure he chooses (i.e. any number of channels in any configuration). MODE1 and MODE2 are two standard 50 cycle tests, well established within the Thermal Power Group. Fig 5.4 shows their operational flowchart. Data for the fuel burning rate calculation is gathered by MODE1 whilst MODE2 is a more general data logging program. Both these programs have optimised codes and operate faster than "SS", the general program. This means that fewer cycles need to be skipped (Fig 3.2) to allow for data processing (3). All three data logging modules SS, MODE1 and MODE2 are written in assembler for reasons of input-output and efficient memory management outlined earlier.

At the end of the data logging run, "ACQAVS" is called upon to calculate the mean and standard deviation from the data collected. The algorithms used within this module are:-

$$\text{Mean } \sigma = \frac{\sum_{i=1}^m X_i}{m}$$

standard deviation (the so-called "text-book algorithm")

$$S^2 = \frac{\sum_{i=1}^m X_i^2}{m-1} - \frac{m}{m-1} \sigma^2$$

where m = number of cycles logged
(commonly 50)

X_i = sampled parameter at a
specific crank position

See reference (15.4).

"ACQAVS" dumps its results onto disk files and then calls up "ACQRLT" to display the figures. This module allows the user to interrogate the mean or standard deviation results for each channel in sequence. Listings can be obtained on the VDU or line printer. A histogram plot (resolution 21 x 79) is also available for each channel. "ACQRLT" returns to the ACQUIS monitor, "ACQZ" (again by chaining) at the user's discretion (Fig 5.2).

A further capability of ACQUIS is file saving. The user may data log the engine at a particular operating point, save the results file and immediately resume data logging. This facility is useful when a user is mapping an engine.

The documentation on ACQUIS is included in Appendix D. The data structure is defined as the method of arranging the results on disk files. Fig. 5.5 shows the representation of mean values in one file, the standard deviation values in another. The reason for separating the standard deviation results is that they do not form an integral part of the tests. They are used for diagnostics and for the calculation of fuel burning rate only.

The mean values file has the off-line ADC results arranged in channel order, then engine and turbocharger speeds and finally the on-line ADC results, again arranged in channel order. This pattern is consistent with previous data structures used within the Thermal Power group. The following is a brief summary of all the modules within ACQUIS.

5.3.1.

ACQZ

ACQZ is the monitor control program which interfaces ACQUIS to MONLIB. It is responsible for running the data acquisition modules, setting the messages output, saving data files, calibrating the ADC's and a variety of other utilities. ACQZ incorporates the "autorepeat" facility of DINTZ in that a single carriage return will repeat the previous command.

5.3.2.

ACQDOC

This module is called by ACQZ to display the documentation file ACQUIS.TXT on the VDU screen. Listing can be suspended by the "control" "S" keys and restarted by the "Control" "Q" keys. Once listing is finished, control returns to ACQZ

5.3.3

ACQFIL

ACQFIL provides ACQUIS with the file saving facility. The calculation programs dump their results into scratch files on disk. To prevent these files being overwritten, ACQFIL renames them, forcing ACQUIS to create new scratch files on the next run. The routine verifies the user's input before attempting the rename option and offers two filetype extension defaults.

5.3.4. CALON, CON

These routines calibrate the on-line data logger.

CALON is a FORTRAN routine that sets the multiplexed channel and displays the results in decimal and octal.

CON is an assembler routine that reads the ADC 1024 times, records the highest and lowest readings and calculates the average value.

5.3.5. CALOFF, COFF

These two modules calibrate the off-line data logger.

CALOFF sets the multiplexed channel, handles error messages and displays the results in octal and decimal radix (i.e. index base). COFF, an assembler routine, takes 1024 readings from the off-line data logger, records the minimum and maximum and evaluates the mean.

5.3.6. ACQSET

This module sets up the chain information area and the common data structure which controls the results obtained by the acquisition routines. It has default values for MODE1 and MODE2 but will prompt the user for a data structure when run in "SPECIAL" mode. It validates the entries prior to returning to ACQZ.

5.3.7

ACQGO

This routine prepares the system for data logging run and calls up the relevant logging program.

5.3.8.

ACQRUT

ACQRUT calls up the results display module ACQRLT from ACQZ when the user wishes to look at an existing data file. The routine uses ACQSET (5.3.6) to generate the appropriate data structure for the data file under investigation.

5.3.9

SS, MODE1, MODE2

As explained earlier, these three assembler programs are chained into the computer by ACQZ to perform the data acquisition. Fig. 5.4 shows the logic behind the software. Having initialised the system, the routines poll the 8K store downcounter empty flag prior to further action. This flag is used to synchronise the whole logging process with the engine crankshaft rotation. Data collected during the steady state tests is thrown onto disk prior to the program chaining out to ACQAVS, the pre-processing module (Fig. 5.2).

5.3.10.

ACQAVS

This routine analyses the data collected by SS, Mode1 and Mode2. It floats the integer values into real numbers and performs the mean and standard deviation arithmetic. It can also contain offset and scaling factors should a user need to condition the figures further. Finally, ACQAVS writes all the results back onto disk, but this time in a standard FORTRAN data structure.

5.3.11.

ACQRLT

ACQRLT is the main module for displaying the results developed by ACQAVS (Fig. 5.2). It can also be called by ACQZ to process an already existing file. Sequential indexing is provided through each channel in the mean file and standard deviation file immediately after a test. When called up from ACQZ, ACQRLT indexes through one file only. The program calls up a summary results display, histogram plot display and a full results display or print out at the user's discretion.

5.3.12.

ACQR1

This module is called up by ACQRLT to prompt the user on the name of a unique file which the user wishes to investigate (see 5.3.11). The file name is saved in an ASC11 byte string for use later in the renaming process.

5.3.13. ACQR2

This module, again called by ACQRLT, displays an introductory summary of the results. Figures displayed are number of readings, maximum value, file name, etc, etc.

5.3.14. ACQR4, ACQR4C

These two modules read the disk file data into common arrays in ACQRLT. Integer type arrays are floated into real number to ensure that the common floating point arithmetic is functional.

5.3.14. ACQR5

This routine takes a typical 1440 element array and scales it to a 79 element array. This is necessary for the histogram plotting routines (5.3.16) to display a representative pattern of the results. ACQR5 includes an algorithm that takes two dimensional (X and Y) weightings for each element of the array to ensure an accurate model.

5.3.16. HISF, HIS

These two routines display a full screen histogram plot on the VDU. HISF is a FORTRAN interface routine which maps the 79 element array into a one dimensional

array for HIS, an assembler routine. The latter interrogates the map produced by HISF and moves the cursor left to right and down the screen. The map is encoded such that HIS displays a "dimmed", "reverse video" blank (appears white on a black background) for each -1 on the map. Both X and Y axis are drawn together with an optional asterix marker on each axis. The latter is useful for providing a reference point on each axis. ACQRLT used this facility to indicate the approximate TDC position on the X axis.

5.3.17.

ACQR6

This programme outputs the results in a four column tabular form on the VDU or alternatively in an eight column form on the line printer. It also includes an option whereby the user can specify any contiguous portion of the results to be printed. By entering the appropriate offset and length of listing, the user can, for instance, obtain a print of only the values about TDC; useful when analysing fuel burning results.

5.4

RESULTS PROCESSING

Version V01.01 of the system has an apparent fuel burning rate calculation program. This is the well tried Imperial College version of the Borman/Streit routine (Refs. 4, 7 and 18). The program is interfaced to the system via "PROCES" (Fig. 5.1) which forms

the third and final part of the system. "PROCES" works on files collected by "ACQUIS", the only constraint being that cylinder pressure must be logged on channel number 1 at a resolution of 1/2 degree crank angle with a record of its standard deviation.

"PROCES" has the facility to evaluate IMEP and fuel burning rate on both the Perkins 4.236 and Leyland 500 direct injection, diesel engines. The input data required is as follows:-

- . Engine speed
- . Air Flow to evaluate trapped mass at IVC.
- . Manifold or boost pressure used as a reference for cylinder pressure. The pressure at BDC gas exchange is equated to this pressure, hence calibrating the ADC results.
- . Names of pressure and standard deviation files respectively

The program is Menu driven (i.e. each command is coded into a number) and the results may be displayed in either Imperial or S.I. Units as listings on either VDU or line printer or, alternatively, as histogram plots on the VDU screen. "PROCES" uses the same plotting routines as "ACQUIS", the resolution of the display being 21 x 79.

"PROCES" can evaluate heat release values from a number of runs during one session or it can chain back to "ACQUIS" after a calculation, thus enabling the user to continue data logging.

The documentation for "PROCES" is given in Appendix E.

The following is a brief summary of all the modules within "PROCES".

5.4.1. PROCES

PROCES is a FORTRAN program which chains the package into the whole system thus completing the integrated system (Fig. 5.1). The module currently calls the heat release calculation program solely but it can be modified to call up additional functions.

5.4.2.

HR

This module is called by PROCES (5.4.1). Written in FORTRAN, HR is the "driver" for the heat release calculation software. The latter is too large to reside in computer memory in its entirety. It has been divided into a number of programs which are overlayed (Ref. 16) in memory. Overlaying requires a root segment (in this case HR) which calls up modules into segments of memory one at a time. When a module has finished its computation, it is replaced or "overlayed" by the linker with the next module. The root segment must contain the FORTRAN COMMON areas as well as the control path between overlayed segments. The overlay linker places FORTRAN library routines in the root segment. Great care had to be exercised in the use of these libraries lest the root segment became too large, restricting the size of the overlaying segments.

5.4.3.

READIN

This routine reads in the engine data (e.g. bore, stroke, etc) from either the keyboard, disk file or default values within the program. Pressure and standard deviation values are then read from a disk file, calibrated against cylinder pressure at BTD gas exchange and dumped into the COMMON area within the root segment. READIN is an overlay segment called by HR (5.4.2).

5.4.4

SPLINE

SPLINE uses a Cholesky decomposition to perform data fitting by SPLINE functions (Ref 4) on the pressure values. The standard deviation is used to fit a curve between the data points. The routine also incorporates variable smoothing. SPLINE is an overlay segment called by HR and returns its results in the COMMON area.

5.4.5.

AHRR

This routine performs the main calculations. It evaluates the gas properties at half degree intervals from the pressure record using the routine PROP (5.4.6). The heat transfer is computed from the Woschni formula (Ref 4) and the apparent fuel burning rate evaluated from the resultant thermodynamic states. AHRR, together with PROP are called from HR (5.4.2.) as an overlay segment.

5.4.6.

PROP

This routine is called from AHRR (5.4.5) to evaluate gas properties (i.e. gas constant, equivalence ratio, etc). It is based around an iterative loop and takes into account disociation effects above a certain temperature.

5.4.7.

HROUT

This routine forms the results output overlay segment with HROUT1 (5.4.8). HROUT presents the user with a menu of commands such as plot heat release rate, print heat transfer values or repeat calculation procedure on another file, etc. It checks the user's input for errors and takes appropriate action. If the user wishes to display the results, HROUT loads an array in a named common and calls up HROUT1. The latter prepares the data for display on the screen. Finally, HISF (5.3.16) is called to plot the values on the VDU screen as a histogram.

5.4.8.

HROUT1

This routine, called from HROUT (5.4.7.) scales the data values into an array that can be processed and displayed by HISF (5.3.16). Scaling is performed in both X and Y dimensions. All display factors required by HISF are also evaluated.

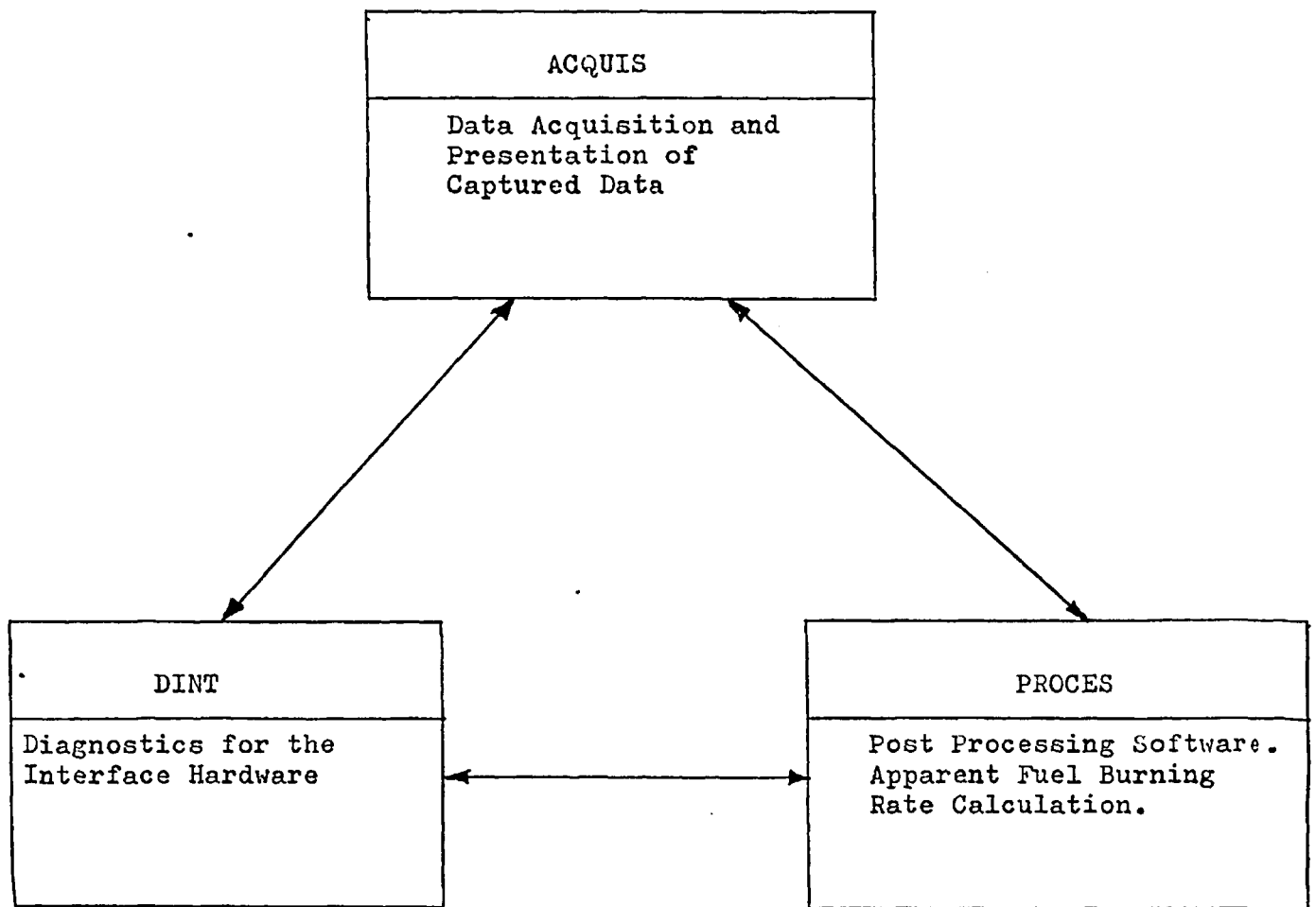


Fig 5.1 System Software

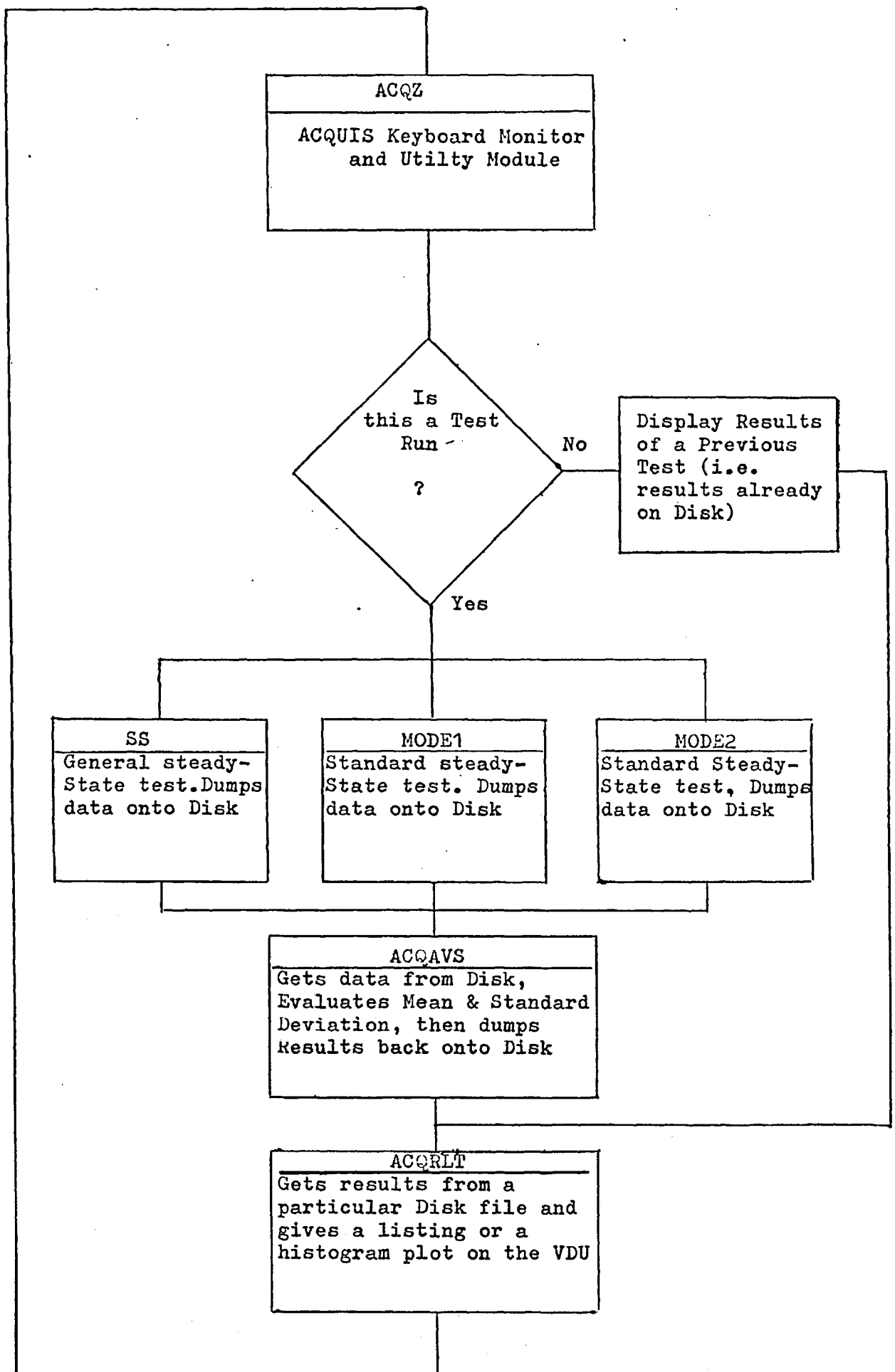


Fig 5.2 'ACQUIS' Software

RT-11/FORTRAN SYSTEM MEMORY MAP

Device Registers
Resident Monitor
Chain Modules DINT . ACQZ, ACQAVS, ACQRLT (ACQUIS) . PROCES
User Service Routine swapped into memory from Disk as required.
Job Stack
Device Interrupt Vectors
System Communication
Hard/Soft Traps

32K

28K

26K

24K

2.5K

512

126

0

RT-11/MACRO-11 SYSTEM MEMORY MAP

Device Registers
Resident Monitor
User Service Routine swapped into memory from Disk as required.
Chain Modules SS . MODE1 . MODE2
Job Stack
Device Interrupt Vectors
System Communication
Hard/Soft Traps

Fig 5.3 RT-11 Memory Map

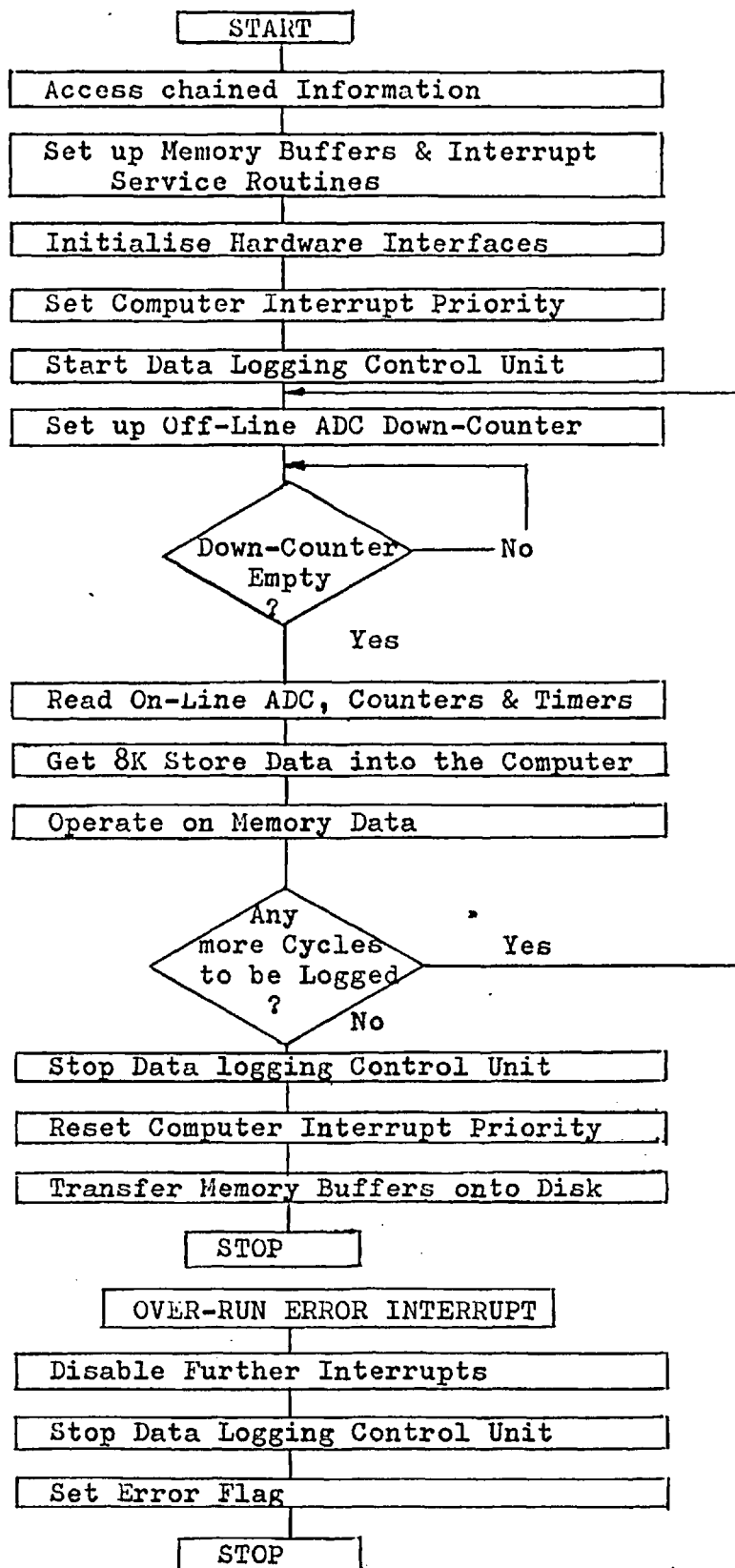


Fig 5.4 Data Logging Software

STEADY-STATE DATA FILE STRUCTURE

(1) Mean Values

Channel 1
Channel 2
Channel 3
etc.
.
.
Average Engine Sp.
H.P. T/C Speed
L.P. T/C Speed
Channel 1
Channel 2
etc.
.
.

(2) Standard Deviation Values

Channel 1
Channel 2
Channel 3
etc.
.
.

Off-Line
ADC Values

On- Line ADC values

Fig 5.5 Data Strucutres

The testing process may be divided into

Software Testing

Engine Testing

An integral part of the structured approach to software development (Chapter 5) is the vigorous testing of each individual module. This was adhered to throughout the design process; numerous test routines having been written to test each part of the three main modules, "DINT" "ACQUIS" and "PROCESS" (Fig. 5.1). The practise of using common routines in an utility library facilitated the testing process since each tested module could be called up with confidence by other programs, without the need to re-test already written code.

Having written the complete package, numerous dry runs were tried with sample valid data and erroneous data. This gave some indication of how well the system reacted to imperfect data.

Satisfied with the above tests, the next stage was to try the system out in real-time on a digitizer emulator with a constant source voltage applied to the ADC input.

The emulator generated the same pulses as a digitizer would produce mounted on an engine running at a steady 3000 rpm (Chapters 2, 4). These pulses were used to trigger the off-line data logging system supplied with the reference signal. A simulated speed of 3000 rpm was chosen to verify the response of the system at high engine speeds. (Because data is collected relative to crank angle, lower speeds would allow more time for data acquisition).

This period saw the testing of both software (now in an advanced stage) and the hardware interfaces. The on-line ADC, off-line ADC with DMA were both checked as well as various other interfaces. For example, the turbocharger speed read was tested with a pulse generator and similarly the engine revolution counter. The initial testing work was to evolve into the diagnostics package, "DINT" (5.2).

Having proven the hardware and with confidence in the diagnostic software, the full ACQUIS package was tested with the digitizer emulator. The steady state logging functions of ACQUIS in Mode 1, Mode 2 and the special Mode (Chapter 5) were tested in various channel configurations and with differing sampled values. The

algorithms within the results calculation program ACQAVS were exposed to extreme values to verify their integrity. Finally, the results display and plotting program ACQRLT was tested in much the same way, exercising rigorously all the dialogues between user and system in an attempt to expose any frailties in the system.

PROCESS was tested with sample data to check its file manipulation algorithms as well as the general IMEP and apparent fuel burning rate calculations. The results display and histogram plotting routine were tested for completeness and accuracy of units conversion.

A software product is not complete until the documentation has been written. Documentation is essential for the product's maintainability, allowing programmers to read and modify the code to allow for future version and enhancements. It is even more important for the user of the system and should describe all regular behaviour of the product as well as the irregular features, such as error messages. Detailed explanations of what input is required in normal circumstances as well as during error conditions should be provided.

A documentation file was written for each of the main software modules, viz DINT, ACQUIS and PROCESS (Chapter 5). These files were written in clear, simple language

with the most relevant sections, e.g. how to start the programs, etc, underlined. By making such sections prominent, the first-time user was offered an effective introduction to the documentation. As he gathered confidence in the system, he was able to return to the documentation and read it through in more detail. An attempt was thus made to extend the "friendly" user environment in the software interfaces (Chapter 5) into the documentation area. To help the user further, the documentation files were available to be displayed on the screen when the system was running. For example, if the user were working on ACQUIS and he was uncertain how to proceed, he could call up the documentation file on ACQUIS which give him a full description of the available options. Having chosen his next move, the user returns immediately to ACQUIS, enabling him to proceed without further interruptions.

Copies of the three documentation files are contained in Appendices C, D and E.

6.2 ENGINE TESTING

With the system functioning reliably on the emulator (6.1), it was necessary to test it on a real engine with proper instrumentation to fully verify all the software. The results of this exercise would be compared against results logged previously on the PDP 15

system. Should the two sets of results correspond, it would confirm that the PDP 11 system had been fully commissioned and tested.

The engine used for the purpose was a Perkins 4.236 four cylinder, direct injection diesel engine (Appendix B.1). With a bore of 0.0984m, stroke of 0.127m and compression ratio of 16:1, it was rated at 59.7KW at 2,800 rpm. A SIGMA E3.78 stopping motor and gearbox was connected to the engine's CAV DPA fuel pump governor control. The position of the stepping motor controlled the governor position (Chapter 2), the former being under manual control of the Texas Instruments 9900 control computer (Chapter 3). The dynamometer connected to the engine was a Vibrometer eddy current brake type 3WB15 (Appendix B.2). A BEC unit provided the excitation for the brake which was manually controlled via a potentiometer (Chapter 3) and not via the TI computer. Engine torque was measured by a strain gauge load cell on the brake and displayed as a galvanometer reading on a PBA - 1/A meter calibrated in MKP. The brake also provided an analogue readout of engine speed on a ARI - 1/A meter calibrated in RPM. Figure B.1 shows a map of engine torque and brake torque against speed. The brake curve envelopes the engine curve hence this brake can test the complete Perkins 4.236 engine map.

Two transducers were connected to the engine. A cylinder pressure transducer to measure IMEP and evaluate apparent fuel burning rate and fuel line pressure transducer to estimate the point of fuel injection. An AVL 8QP500C water-cooled transducer (Ref 4) was used to measure cylinder pressure. Errors due to drift of the transducer output were minimised by keeping all electrical connections clean to prevent charge leakage. The standard deviation of the pressure during the induction stroke was used as a criterion for checking drift. A standard deviation over 7KN/m^2 for a test over 50 cycles was considered unacceptable. The test was abandoned and repeated. The datum of the cylinder pressure diagram was obtained by relating it to inlet manifold pressure at the bottom dead centre (BDC) crankshaft position following the induction stroke. This equation automatically catered for any offset in the amplifiers or ADC.

The effects of thermal shock (4) were reduced by recessing the transducer a few millimeters into the cylinder head. Static calibration problems were reduced by connecting the transducer to a high impedance charge amplifier, a Kistler E568. The amplifier gain was set to unity to prevent an internal drift being generated. An offset of 1 volt was introduced to the pressure signal on a Fylde Electronics unit gain amplifier.

This positive zero offset was necessary to prevent the occurrence of negative signal values during the induction stroke (the off-line ADC had an input range of 0 to +10 Volts).

The fuel line pressure on number 1 cylinder was measured by means of a standard AVL strain guage transducer type 31DP500 E.2. Although this installation was not considered to represent a truthful picture of valve injection pressures (Ref. 4) it did, nevertheless, satisfy the need to estimate the approximate point of fuel injection.

The off-set values from both transducers were checked on an oscilloscope prior to connection to the data logging system. The engine was started and ~~run~~ for about half an hour to warm up. No testing was undertaken until the water jacket temperature reached 80°C. Manual control of both governor position and brake load was exercised throughout the tests.

When the engine was ready for testing, it was taken up to a speed of 1000 rpm and a torque of 12.7MKP applied by the brake. This represented approximately half full load at this speed on a BMEP of 4.1 BAR. ACQUIS was then called to data log the two parameters (cylinder pressure and needle lift) in all modes, i.e. Mode 1, Mode 2 and special Mode (Chapter 5). The cylinder

pressure (Fig. 6.2) and standard deviation were comparable to previous tests, the latter showing the sudden surge during point of fuel injection as described by Marzouk (Ref. 4). The results for this operating condition were saved in a file on the back-up disk and more load put on the engine. The engine was subsequently set to three-quarters full load, 19 MKP or 6.2 BAR BMEP. Both parameters were again data logged, the standard deviation analysed and found to be acceptable. These results were saved on another file on the back-up disk. The engine was then taken to 2000 rpm and a torque of 12.5 MKP representing half load at 4.1 BAR BMEP. Having data logged and saved the results the engine was finally set to three-quarters full load at 2000 rpm giving a torque of 15.8 MKP and a BMEP of 5.1 BAR. Data was acquired and stored for this operating condition. The engine was again set to 1000 rpm at half load and the whole procedure of testing the four operating conditions repeated ten times. The results were analysed and showed that repeatability was to within 7%. This value is of the order of magnitude of cyclic variations within the combustion process in diesel engines. The phenomenon is caused by thermodynamic instability inside the cylinder during the compression stroke, causing the delay period to vary from cycle to cycle, sometimes quite significantly. These natural variations also change

with engine operating condition, being damped considerably by applied load and are often compounded by other more mechanical variations such as those of the governor. The level of repeatability showed by the new system is thus masked by that of the compression ignition engine, but compares favourably with the PDP 15 system.

PROCESS was called up from ACQUIS to process the data obtained from the engine (Chapter 5). The indicated mean effected pressure (IMEP) was evaluated for each operating condition (see Tables 6.1 to 6.4). The friction losses (BMEP - IMEP) were found to be around 3 BAR increasing with load and speed. (see Table 6.5).

The fuel burning rate calculation program was run on each operating point and the results are shown in Tables 6.1 and 6.4. The cylinder pressures and instantaneous rate of heat release are plotted for each condition in Figures 6.1 to 6.4. The maximum smoothing factor for the spline function (Chapter 5) which fits a curve onto the cylinder pressure was chosen. The figures show the characteristic peak on the instantaneous rate of heat release during the period of rapid rise in cylinder pressure (Ref. 4). The latter is caused by the sudden and violent burning of the fuel injected

into the cylinder during the so-called delay period. For normal injection systems, one finds that the longer the delay period, the more pronounced is the first peak on the instantaneous heat release curve. This period in the combustion cycle is called "pre-mixed" burning. The remaining fuel injected into the cylinder reacts in a much more controlled manner during the "diffusion" burning period. This is represented on Figs. 6.1 to 6.4 as the shallow hump following the initial peak.

The initial value of instantaneous heat release around ten degrees before TDC is shown on all the graphs (Figs. 6.1 to 6.4) to be non-zero. A very small value should be calculated during the delay period at this crank position. The error is probably caused by mathematical irregularities around this first limit. The spline function (Chapter 5) smooths out the pressure signal based on rate of change of pressure both before and after the sampled point. Similarly, the iterative process upon which the heat release calculation is based can be unstable near the two limits, i.e. beginning and end of the pressure sample. These errors however, apply only at the extreme limits of the record; values computed a few points within the batch will be correct.

The full results computed (Tables 6.1 to 6.4) were:-

- . Cylinder pressure in BARS (P)
- . Cylinder temperature in deg. Kelvin (T)
- . Cylinder contents equivalence ratio (F)
- . Rate of change of cylinder mass in kg per second (DM). This represented the theoretical rate of fuel injected into the cylinder.
- . Heat transfer rate in Joles per second (HTR). This was evaluated using the Woschin formula (Chapter 5).
- . Instantaneous heat release rate in Joles per degree crank angle (HRR).
- . Cumulative heat release in Joles (HR). This is the sum over the burning period of the instantaneous heat release.

The computer predicts the total amount of fuel burnt by integrating the instantaneous change in cylinder mass

over the burning period. Dividing this into the trapped mass derived from the engine air flow yields the predicted air/fuel ratio (See Tables 6.1 to 6.5).

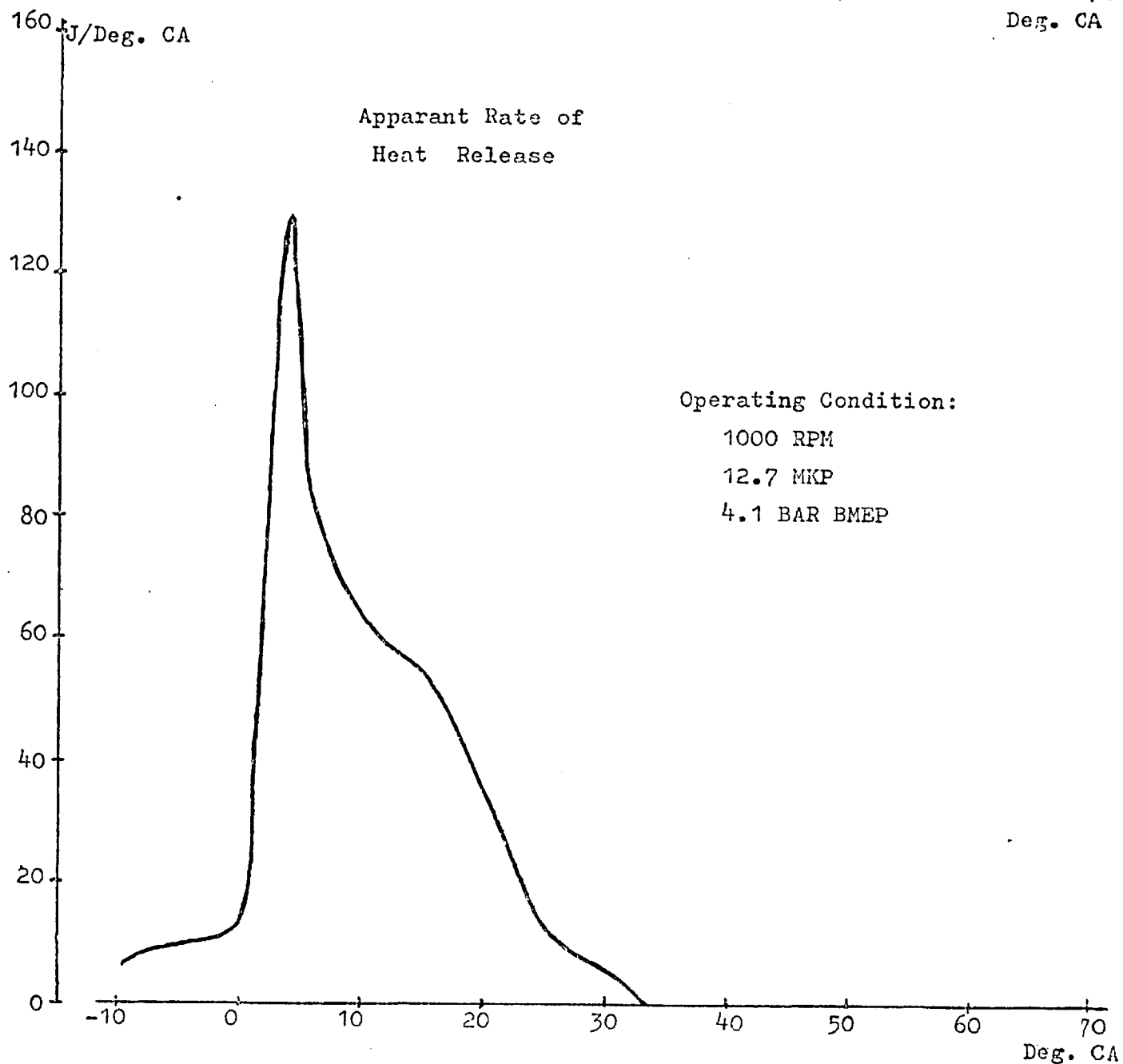
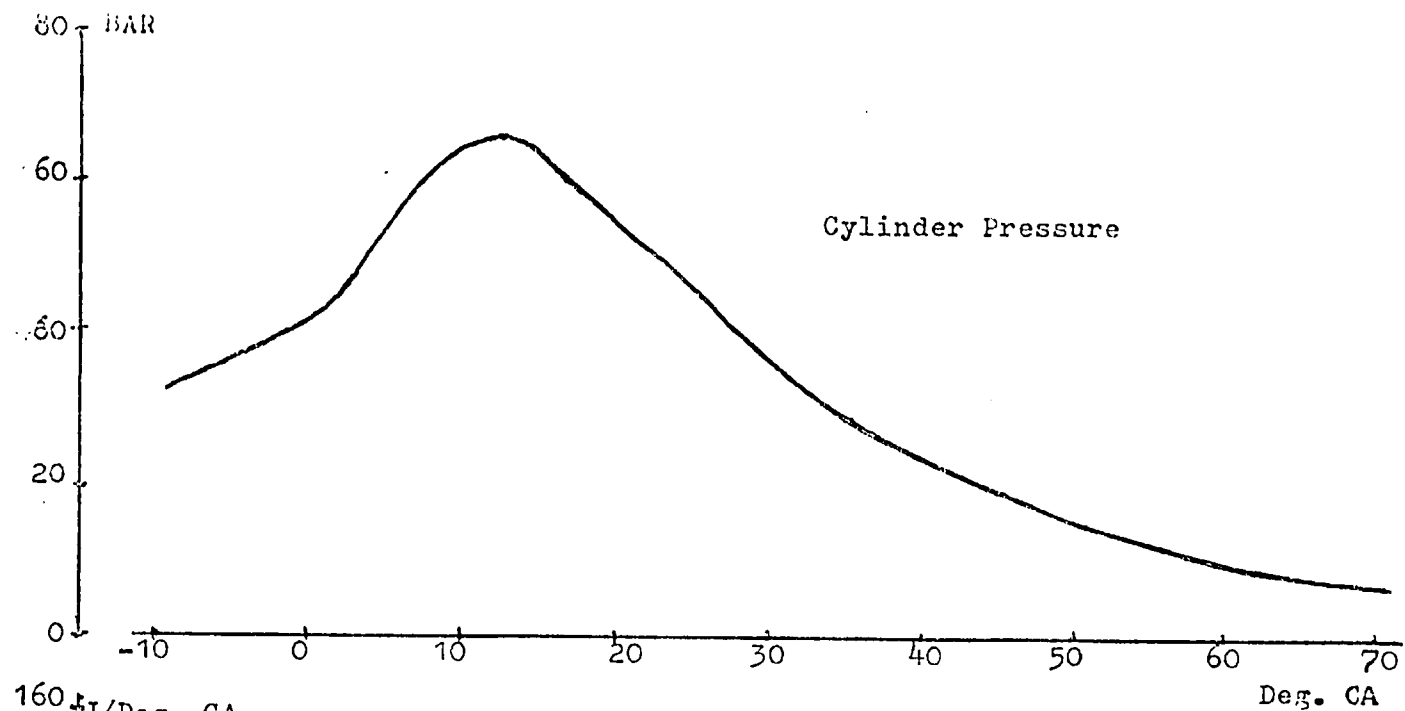


Fig 6.1 System Results

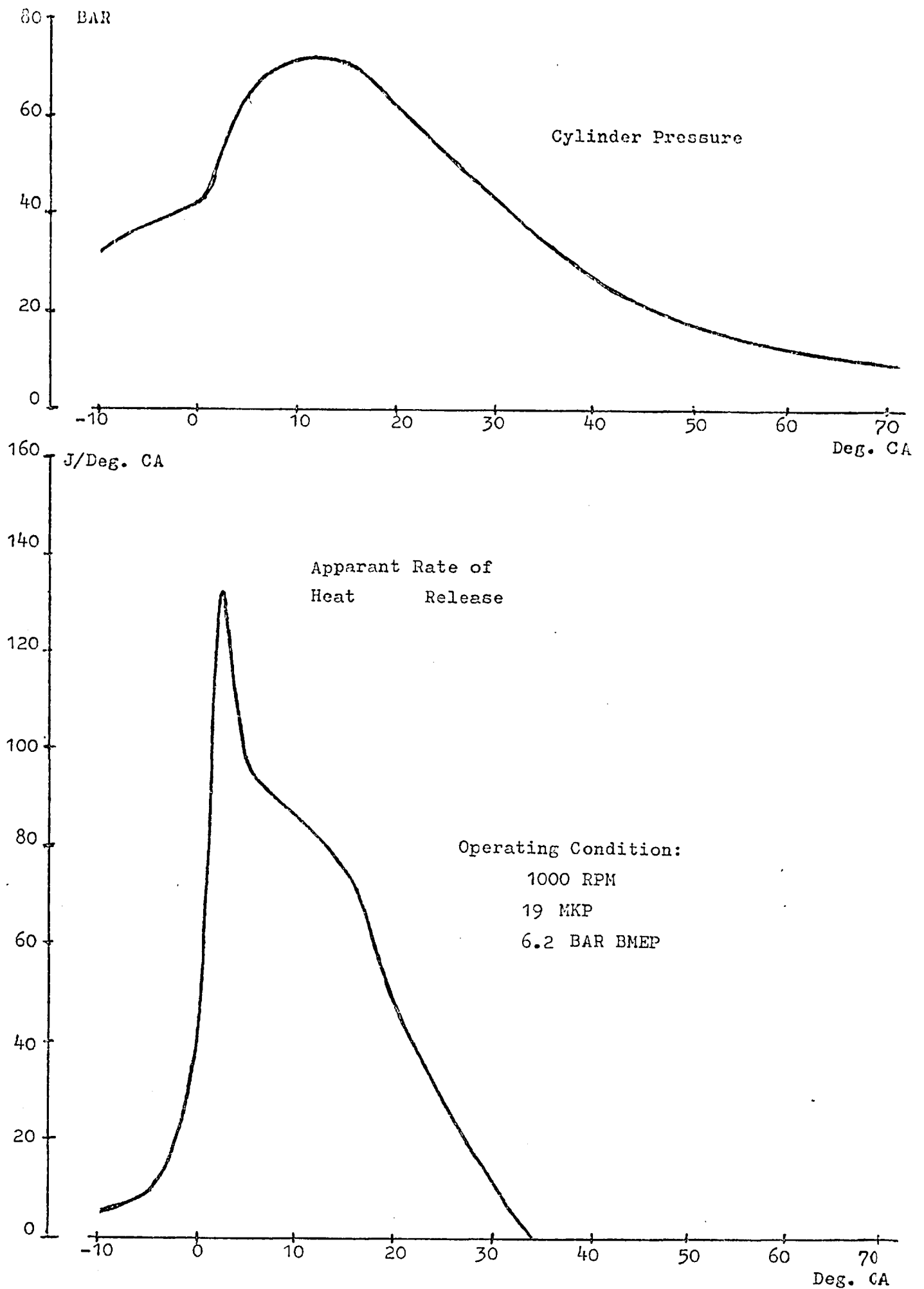


Fig 6.2 System Results

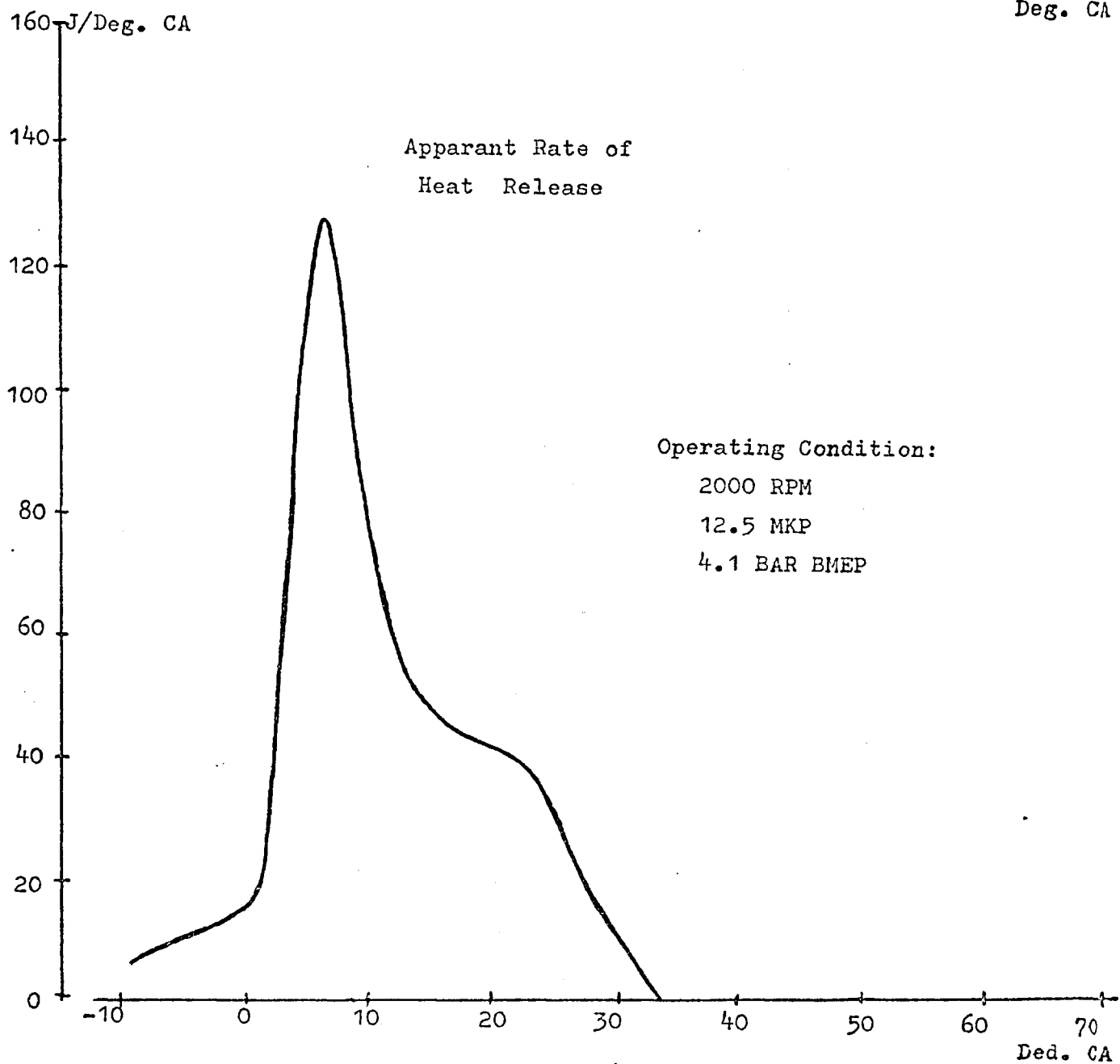
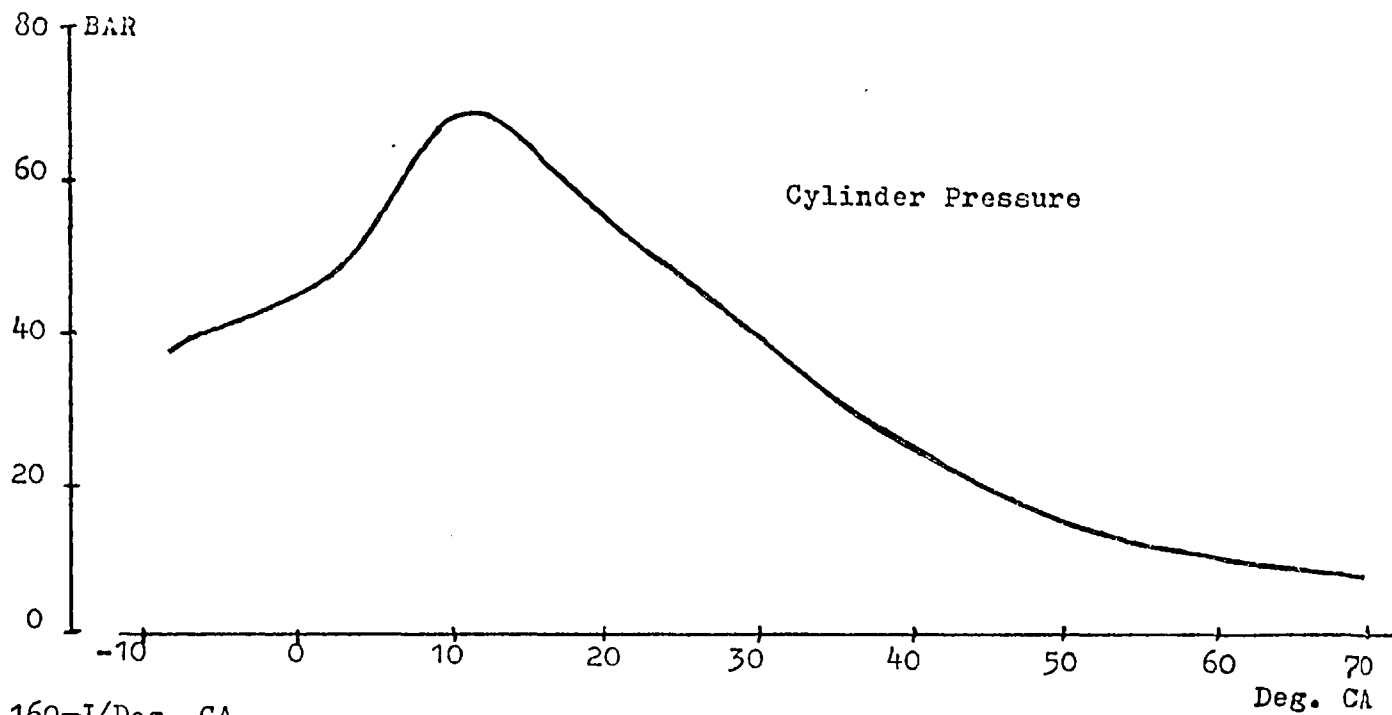


Fig 6.3 System Results

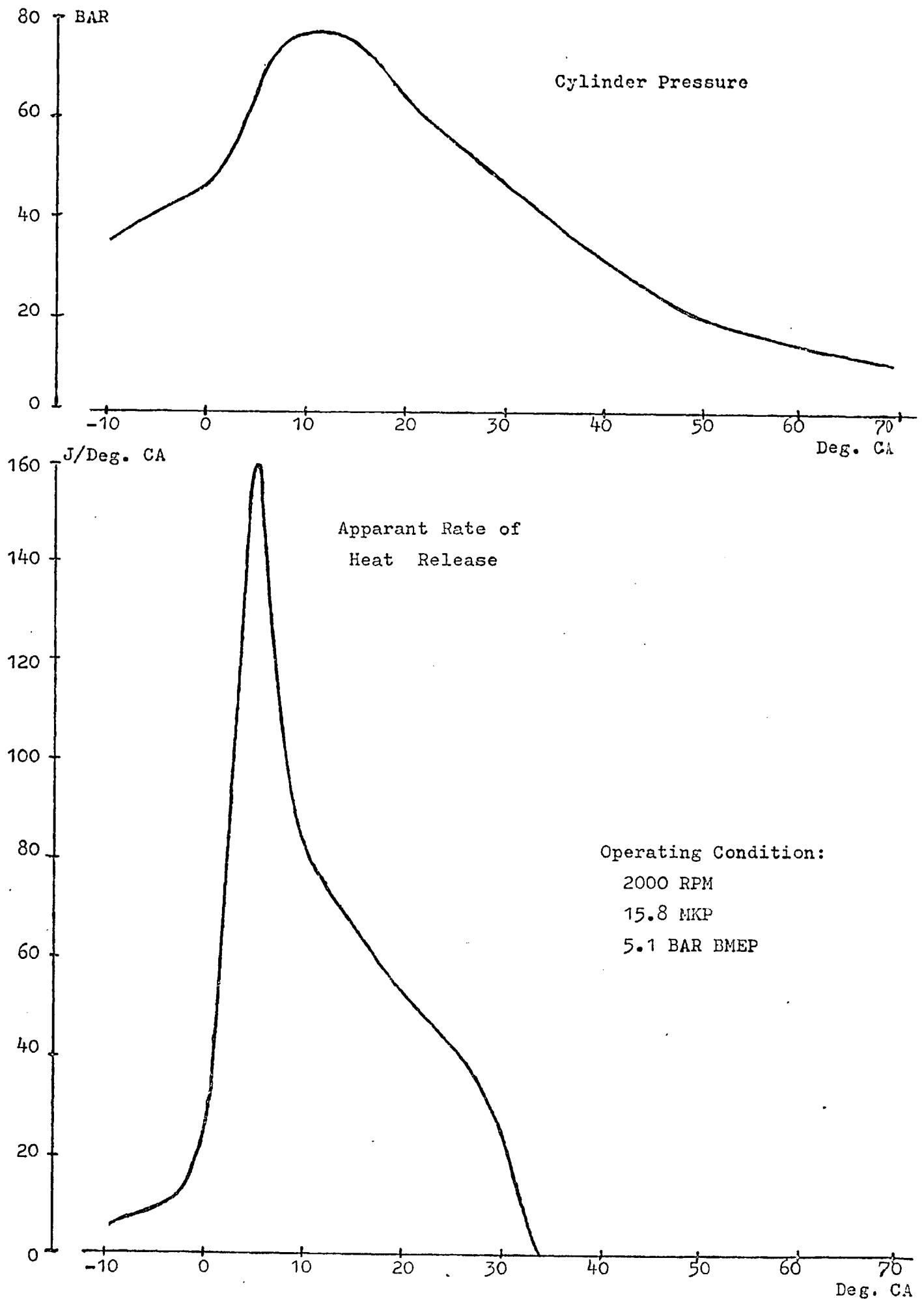


Fig 6.4 System Results

Table 6.1 System Results - 1000rpm, 4.1 BAR BMEP

30-SEP-80

HR - VERSION V01.02

PRESSURE DATA FILE : RK1:HM1000.DAT
 STANDARD DEV. FILE : RK1:HS1000.DAT

ESPD= 1000.00 RPM ; MAN.PRESS=0.1014E+01 BAR

CYCLE RESULTS ...

IMEP= 7.08 BAR, TOTAL WORK= 470490.94 J

HEAT RELEASE RESULTS ...

TRAPPED CONDITIONS :

TR.MASS= 0.00093 KG

PREDICTED MASS OF FUEL BURNT= 0.36348E-04 KG/CYC/CYL
 FUEL CALORIFIC VALUE = 0.42912E+08 J/KG
 PREDICTED AIR/FUEL RATIO = 25.46

CA	P(BAR)	T(DEG.K)	F	DM(KG/S)	HTR(J/S)	HRR(J/D)	HF(J)
-15.0	25.45	819.98	0.148E-01	0.000E+00	0.356E+02	0.000E+00	0.000E+00
-14.5	26.08	826.71	0.148E-01	0.757E-07	0.366E+02	0.325E+01	0.811E+00
-14.0	26.70	832.93	0.157E-01	0.706E-07	0.374E+02	0.303E+01	0.238E+00
-13.5	27.31	838.93	0.162E-01	0.627E-07	0.383E+02	0.269E+01	0.382E+00
-13.0	27.92	844.61	0.167E-01	0.558E-07	0.392E+02	0.240E+01	0.508E+00
-12.5	28.53	850.14	0.171E-01	0.587E-07	0.400E+02	0.252E+01	0.631E+00
-12.0	29.14	855.78	0.176E-01	0.697E-07	0.409E+02	0.299E+01	0.769E+00
-11.5	29.77	861.66	0.182E-01	0.815E-07	0.418E+02	0.350E+01	0.931E+00
-11.0	30.40	867.76	0.189E-01	0.964E-07	0.427E+02	0.414E+01	0.112E+01
-10.5	31.04	874.27	0.197E-01	0.118E-06	0.437E+02	0.507E+01	0.135E+01
-10.0	31.70	881.25	0.208E-01	0.137E-06	0.447E+02	0.588E+01	0.163E+01
-9.5	32.36	888.47	0.219E-01	0.146E-06	0.458E+02	0.627E+01	0.193E+01
-9.0	33.02	895.71	0.232E-01	0.150E-06	0.469E+02	0.644E+01	0.225E+01
-8.5	33.68	902.87	0.244E-01	0.151E-06	0.480E+02	0.648E+01	0.257E+01
-8.0	34.32	909.85	0.256E-01	0.149E-06	0.490E+02	0.640E+01	0.289E+01
-7.5	34.94	916.61	0.268E-01	0.148E-06	0.501E+02	0.635E+01	0.321E+01
-7.0	35.54	923.18	0.279E-01	0.148E-06	0.511E+02	0.637E+01	0.353E+01
-6.5	36.12	929.65	0.291E-01	0.157E-06	0.521E+02	0.674E+01	0.386E+01
-6.0	36.71	936.38	0.304E-01	0.180E-06	0.531E+02	0.774E+01	0.422E+01
-5.5	37.30	943.66	0.320E-01	0.212E-06	0.542E+02	0.910E+01	0.464E+01
-5.0	37.89	951.51	0.338E-01	0.234E-06	0.554E+02	0.100E+02	0.512E+01
-4.5	38.47	959.44	0.357E-01	0.236E-06	0.566E+02	0.101E+02	0.562E+01
-4.0	39.02	967.08	0.376E-01	0.233E-06	0.577E+02	0.999E+01	0.613E+01
-3.5	39.53	974.38	0.395E-01	0.227E-06	0.588E+02	0.974E+01	0.662E+01
-3.0	40.01	981.29	0.413E-01	0.225E-06	0.598E+02	0.967E+01	0.710E+01
-2.5	40.44	987.97	0.431E-01	0.224E-06	0.607E+02	0.960E+01	0.759E+01
-2.0	40.84	994.20	0.449E-01	0.212E-06	0.616E+02	0.910E+01	0.805E+01
-1.5	41.18	999.84	0.465E-01	0.200E-06	0.624E+02	0.859E+01	0.849E+01
-1.0	41.47	1004.97	0.481E-01	0.193E-06	0.631E+02	0.827E+01	0.892E+01
-0.5	41.72	1009.75	0.496E-01	0.197E-06	0.638E+02	0.845E+01	0.933E+01
0.0	41.95	1014.79	0.512E-01	0.235E-06	0.644E+02	0.101E+02	0.980E+01
0.5	42.21	1021.29	0.532E-01	0.333E-06	0.652E+02	0.143E+02	0.104E+02
1.0	42.58	1031.19	0.562E-01	0.519E-06	0.665E+02	0.223E+02	0.113E+02
1.5	43.17	1046.99	0.611E-01	0.806E-06	0.684E+02	0.346E+02	0.127E+02
2.0	44.08	1071.36	0.687E-01	0.122E-05	0.715E+02	0.523E+02	0.149E+02
2.5	45.45	1107.42	0.801E-01	0.174E-05	0.761E+02	0.748E+02	0.181E+02
3.0	47.32	1156.27	0.962E-01	0.228E-05	0.823E+02	0.979E+02	0.224E+02

Table 6.1 (continued)

3.5	49.61	1216.21	0.117E+00	0.273E-05	0.902E+02	0.117E+03	0.272E+03
4.0	52.14	1283.18	0.140E+00	0.299E-05	0.990E+02	0.128E+03	0.339E+03
4.5	54.69	1351.85	0.165E+00	0.304E-05	0.108E+03	0.130E+03	0.404E+03
5.0	57.06	1417.43	0.190E+00	0.291E-05	0.117E+03	0.125E+03	0.468E+03
5.5	59.10	1474.37	0.212E+00	0.266E-05	0.125E+03	0.114E+03	0.527E+03
6.0	60.75	1525.69	0.233E+00	0.235E-05	0.132E+03	0.101E+03	0.581E+03
6.5	62.01	1569.13	0.250E+00	0.207E-05	0.137E+03	0.887E+02	0.628E+03
7.0	62.95	1605.98	0.266E+00	0.185E-05	0.142E+03	0.792E+02	0.670E+03
7.5	63.63	1638.00	0.279E+00	0.170E-05	0.146E+03	0.728E+02	0.708E+03
8.0	64.14	1666.79	0.292E+00	0.161E-05	0.149E+03	0.690E+02	0.744E+03
8.5	64.50	1693.45	0.305E+00	0.156E-05	0.152E+03	0.667E+02	0.778E+03
9.0	64.77	1718.68	0.317E+00	0.153E-05	0.155E+03	0.655E+02	0.811E+03
9.5	64.95	1742.83	0.329E+00	0.151E-05	0.157E+03	0.647E+02	0.843E+03
10.0	65.05	1766.03	0.341E+00	0.149E-05	0.160E+03	0.638E+02	0.876E+03
10.5	65.07	1788.22	0.353E+00	0.146E-05	0.162E+03	0.628E+02	0.907E+03
11.0	65.02	1809.38	0.365E+00	0.144E-05	0.163E+03	0.617E+02	0.938E+03
11.5	64.89	1829.54	0.376E+00	0.141E-05	0.165E+03	0.606E+02	0.969E+03
12.0	64.69	1848.76	0.387E+00	0.139E-05	0.166E+03	0.596E+02	0.999E+03
12.5	64.44	1867.21	0.398E+00	0.138E-05	0.168E+03	0.591E+02	0.103E+04
13.0	64.14	1885.03	0.409E+00	0.137E-05	0.169E+03	0.587E+02	0.106E+04
13.5	63.79	1902.28	0.420E+00	0.136E-05	0.170E+03	0.583E+02	0.109E+04
14.0	63.40	1918.93	0.431E+00	0.134E-05	0.171E+03	0.577E+02	0.112E+04
14.5	62.96	1934.87	0.442E+00	0.132E-05	0.171E+03	0.568E+02	0.114E+04
15.0	62.48	1949.97	0.452E+00	0.129E-05	0.172E+03	0.555E+02	0.117E+04
15.5	61.95	1964.11	0.462E+00	0.125E-05	0.172E+03	0.538E+02	0.120E+04
16.0	61.37	1977.08	0.472E+00	0.120E-05	0.173E+03	0.515E+02	0.123E+04
16.5	60.73	1988.71	0.482E+00	0.114E-05	0.173E+03	0.490E+02	0.125E+04
17.0	60.04	1998.96	0.491E+00	0.108E-05	0.172E+03	0.463E+02	0.128E+04
17.5	59.31	2007.82	0.499E+00	0.102E-05	0.172E+03	0.436E+02	0.130E+04
18.0	58.53	2015.42	0.507E+00	0.959E-06	0.171E+03	0.412E+02	0.132E+04
18.5	57.72	2021.91	0.514E+00	0.911E-06	0.171E+03	0.391E+02	0.134E+04
19.0	56.89	2027.44	0.521E+00	0.869E-06	0.170E+03	0.373E+02	0.136E+04
19.5	56.04	2032.11	0.528E+00	0.830E-06	0.169E+03	0.356E+02	0.138E+04
20.0	55.16	2035.99	0.535E+00	0.790E-06	0.168E+03	0.339E+02	0.139E+04
20.5	54.28	2039.03	0.541E+00	0.747E-06	0.167E+03	0.320E+02	0.141E+04
21.0	53.38	2041.13	0.547E+00	0.693E-06	0.165E+03	0.298E+02	0.143E+04
21.5	52.45	2042.13	0.552E+00	0.628E-06	0.164E+03	0.270E+02	0.144E+04
22.0	51.51	2041.84	0.557E+00	0.556E-06	0.162E+03	0.239E+02	0.145E+04
22.5	50.55	2040.26	0.561E+00	0.488E-06	0.161E+03	0.210E+02	0.146E+04
23.0	49.57	2037.59	0.564E+00	0.432E-06	0.159E+03	0.185E+02	0.147E+04
23.5	48.59	2034.00	0.568E+00	0.385E-06	0.157E+03	0.165E+02	0.148E+04
24.0	47.61	2029.66	0.571E+00	0.343E-06	0.155E+03	0.147E+02	0.149E+04
24.5	46.63	2024.63	0.573E+00	0.305E-06	0.153E+03	0.131E+02	0.150E+04
25.0	45.66	2019.02	0.575E+00	0.277E-06	0.151E+03	0.119E+02	0.150E+04
25.5	44.70	2013.06	0.578E+00	0.259E-06	0.149E+03	0.111E+02	0.151E+04
26.0	43.75	2006.89	0.580E+00	0.249E-06	0.147E+03	0.107E+02	0.151E+04
26.5	42.82	2000.63	0.581E+00	0.240E-06	0.145E+03	0.103E+02	0.152E+04
27.0	41.91	1994.23	0.583E+00	0.230E-06	0.143E+03	0.986E+01	0.153E+04
27.5	41.02	1987.73	0.585E+00	0.219E-06	0.141E+03	0.941E+01	0.153E+04
28.0	40.15	1981.06	0.587E+00	0.205E-06	0.139E+03	0.879E+01	0.153E+04
28.5	39.29	1974.19	0.588E+00	0.189E-06	0.137E+03	0.812E+01	0.154E+04
29.0	38.44	1967.11	0.590E+00	0.175E-06	0.135E+03	0.752E+01	0.154E+04
29.5	37.62	1959.87	0.591E+00	0.162E-06	0.134E+03	0.697E+01	0.155E+04
30.0	36.81	1952.46	0.593E+00	0.150E-06	0.132E+03	0.642E+01	0.155E+04
30.5	36.01	1944.91	0.594E+00	0.138E-06	0.130E+03	0.592E+01	0.155E+04
31.0	35.23	1937.17	0.595E+00	0.118E-06	0.128E+03	0.505E+01	0.156E+04
31.5	34.47	1929.03	0.596E+00	0.861E-07	0.126E+03	0.370E+01	0.156E+04
32.0	33.71	1920.34	0.596E+00	0.511E-07	0.124E+03	0.219E+01	0.156E+04
32.5	32.96	1911.03	0.596E+00	0.725E-08	0.123E+03	0.311E+00	0.156E+04
33.0	32.21	1900.90	0.596E+00	0.000E+00	0.121E+03	0.000E+00	0.156E+04
33.5	31.47	1889.96	0.596E+00	0.000E+00	0.119E+03	0.000E+00	0.156E+04
34.0	30.74	1878.62	0.596E+00	0.000E+00	0.117E+03	0.000E+00	0.156E+04
34.5	30.03	1867.25	0.596E+00	0.000E+00	0.115E+03	0.000E+00	0.156E+04
35.0	29.33	1855.91	0.596E+00	0.000E+00	0.113E+03	0.000E+00	0.156E+04

Table 6.1 (continued)

35.5	28.66	1844.43	0.596E+00	0.000E+00	0.111E+03	0.000E+00	0.156E+04
36.0	27.99	1832.67	0.596E+00	0.000E+00	0.110E+03	0.000E+00	0.156E+04
36.5	27.34	1820.19	0.596E+00	0.000E+00	0.108E+03	0.000E+00	0.156E+04
37.0	26.68	1806.78	0.596E+00	0.000E+00	0.106E+03	0.000E+00	0.156E+04
37.5	26.04	1792.99	0.596E+00	0.000E+00	0.104E+03	0.000E+00	0.156E+04
38.0	25.41	1779.29	0.596E+00	0.000E+00	0.102E+03	0.000E+00	0.156E+04
38.5	24.81	1766.02	0.596E+00	0.000E+00	0.100E+03	0.000E+00	0.156E+04
39.0	24.23	1753.18	0.596E+00	0.000E+00	0.986E+02	0.000E+00	0.156E+04
39.5	23.67	1740.50	0.596E+00	0.000E+00	0.969E+02	0.000E+00	0.156E+04
40.0	23.11	1727.54	0.596E+00	0.000E+00	0.953E+02	0.000E+00	0.156E+04
40.5	22.57	1714.24	0.596E+00	0.000E+00	0.937E+02	0.000E+00	0.156E+04
41.0	22.04	1700.63	0.596E+00	0.000E+00	0.920E+02	0.000E+00	0.156E+04
41.5	21.51	1686.76	0.596E+00	0.000E+00	0.904E+02	0.000E+00	0.156E+04
42.0	21.01	1672.98	0.596E+00	0.000E+00	0.888E+02	0.000E+00	0.156E+04
42.5	20.52	1659.99	0.596E+00	0.000E+00	0.873E+02	0.000E+00	0.156E+04
43.0	20.06	1648.33	0.596E+00	0.000E+00	0.859E+02	0.000E+00	0.156E+04
43.5	19.63	1637.64	0.596E+00	0.000E+00	0.847E+02	0.000E+00	0.156E+04
44.0	19.22	1627.84	0.596E+00	0.000E+00	0.835E+02	0.000E+00	0.156E+04
44.5	18.82	1618.66	0.596E+00	0.000E+00	0.824E+02	0.000E+00	0.156E+04
45.0	18.43	1609.00	0.596E+00	0.000E+00	0.812E+02	0.000E+00	0.156E+04
45.5	18.04	1598.15	0.596E+00	0.000E+00	0.800E+02	0.000E+00	0.156E+04
46.0	17.64	1586.31	0.596E+00	0.000E+00	0.788E+02	0.000E+00	0.156E+04
46.5	17.25	1574.19	0.596E+00	0.000E+00	0.775E+02	0.000E+00	0.156E+04
47.0	16.88	1562.74	0.596E+00	0.000E+00	0.764E+02	0.000E+00	0.156E+04
47.5	16.52	1552.37	0.596E+00	0.000E+00	0.753E+02	0.000E+00	0.156E+04
48.0	16.19	1542.63	0.596E+00	0.000E+00	0.743E+02	0.000E+00	0.156E+04
48.5	15.86	1533.23	0.596E+00	0.000E+00	0.733E+02	0.000E+00	0.156E+04
49.0	15.55	1524.04	0.596E+00	0.000E+00	0.723E+02	0.000E+00	0.156E+04
49.5	15.23	1514.25	0.596E+00	0.000E+00	0.713E+02	0.000E+00	0.156E+04
50.0	14.91	1503.53	0.596E+00	0.000E+00	0.703E+02	0.000E+00	0.156E+04
50.5	14.61	1492.86	0.596E+00	0.000E+00	0.693E+02	0.000E+00	0.156E+04
51.0	14.32	1483.33	0.596E+00	0.000E+00	0.684E+02	0.000E+00	0.156E+04
51.5	14.04	1474.60	0.596E+00	0.000E+00	0.676E+02	0.000E+00	0.156E+04
52.0	13.77	1465.66	0.596E+00	0.000E+00	0.667E+02	0.000E+00	0.156E+04
52.5	13.50	1456.07	0.596E+00	0.000E+00	0.658E+02	0.000E+00	0.156E+04
53.0	13.23	1446.24	0.596E+00	0.000E+00	0.649E+02	0.000E+00	0.156E+04
53.5	12.97	1436.56	0.596E+00	0.000E+00	0.641E+02	0.000E+00	0.156E+04
54.0	12.71	1426.52	0.596E+00	0.000E+00	0.632E+02	0.000E+00	0.156E+04
54.5	12.45	1415.30	0.596E+00	0.000E+00	0.623E+02	0.000E+00	0.156E+04
55.0	12.19	1403.78	0.596E+00	0.000E+00	0.613E+02	0.000E+00	0.156E+04
55.5	11.95	1392.68	0.596E+00	0.000E+00	0.604E+02	0.000E+00	0.156E+04
56.0	11.71	1382.13	0.596E+00	0.000E+00	0.596E+02	0.000E+00	0.156E+04
56.5	11.48	1371.74	0.596E+00	0.000E+00	0.587E+02	0.000E+00	0.156E+04
57.0	11.25	1361.21	0.596E+00	0.000E+00	0.579E+02	0.000E+00	0.156E+04
57.5	11.03	1351.14	0.596E+00	0.000E+00	0.571E+02	0.000E+00	0.156E+04
58.0	10.82	1342.06	0.596E+00	0.000E+00	0.564E+02	0.000E+00	0.156E+04
58.5	10.63	1333.67	0.596E+00	0.000E+00	0.557E+02	0.000E+00	0.156E+04
59.0	10.43	1325.13	0.596E+00	0.000E+00	0.550E+02	0.000E+00	0.156E+04
59.5	10.24	1315.80	0.596E+00	0.000E+00	0.543E+02	0.000E+00	0.156E+04
60.0	10.04	1305.33	0.596E+00	0.000E+00	0.535E+02	0.000E+00	0.156E+04
60.5	9.83	1293.87	0.596E+00	0.000E+00	0.527E+02	0.000E+00	0.156E+04
61.0	9.64	1282.45	0.596E+00	0.000E+00	0.519E+02	0.000E+00	0.156E+04
61.5	9.45	1272.31	0.596E+00	0.000E+00	0.512E+02	0.000E+00	0.156E+04
62.0	9.28	1263.95	0.596E+00	0.000E+00	0.506E+02	0.000E+00	0.156E+04
62.5	9.13	1256.62	0.596E+00	0.000E+00	0.500E+02	0.000E+00	0.156E+04
63.0	8.97	1248.67	0.596E+00	0.000E+00	0.495E+02	0.000E+00	0.156E+04
63.5	8.81	1239.75	0.596E+00	0.000E+00	0.488E+02	0.000E+00	0.156E+04
64.0	8.65	1230.80	0.596E+00	0.000E+00	0.482E+02	0.000E+00	0.156E+04
64.5	8.50	1222.38	0.596E+00	0.000E+00	0.476E+02	0.000E+00	0.156E+04
65.0	8.35	1214.91	0.596E+00	0.000E+00	0.471E+02	0.000E+00	0.156E+04
65.5	8.21	1207.57	0.596E+00	0.000E+00	0.466E+02	0.000E+00	0.156E+04
66.0	8.07	1198.80	0.596E+00	0.000E+00	0.460E+02	0.000E+00	0.156E+04
66.5	7.91	1188.22	0.596E+00	0.000E+00	0.453E+02	0.000E+00	0.156E+04
67.0	7.76	1176.69	0.596E+00	0.000E+00	0.446E+02	0.000E+00	0.156E+04

Table 6.1 (continued)

67.5	7.61	1165.70	0.596E+00	0.000E+00	0.439E+02	0.000E+00	0.156E+00
68.0	7.47	1156.86	0.596E+00	0.000E+00	0.433E+02	0.000E+00	0.156E+00
68.5	7.35	1150.03	0.596E+00	0.000E+00	0.429E+02	0.000E+00	0.156E+00
69.0	7.24	1143.87	0.596E+00	0.000E+00	0.425E+02	0.000E+00	0.156E+00
69.5	7.12	1136.94	0.596E+00	0.000E+00	0.421E+02	0.000E+00	0.156E+00
70.0	7.01	1129.32	0.596E+00	0.000E+00	0.416E+02	0.000E+00	0.156E+00
70.5	6.89	1121.43	0.596E+00	0.000E+00	0.411E+02	0.000E+00	0.156E+00
71.0	6.78	1113.50	0.596E+00	0.000E+00	0.406E+02	0.000E+00	0.156E+00
71.5	6.66	1105.62	0.596E+00	0.000E+00	0.401E+02	0.000E+00	0.156E+00
72.0	6.55	1097.86	0.596E+00	0.000E+00	0.397E+02	0.000E+00	0.156E+00
72.5	6.45	1090.42	0.596E+00	0.000E+00	0.392E+02	0.000E+00	0.156E+00
73.0	6.35	1083.50	0.596E+00	0.000E+00	0.388E+02	0.000E+00	0.156E+00
73.5	6.25	1077.37	0.596E+00	0.000E+00	0.384E+02	0.000E+00	0.156E+00
74.0	6.17	1071.99	0.596E+00	0.000E+00	0.381E+02	0.000E+00	0.156E+00
74.5	6.08	1066.18	0.596E+00	0.000E+00	0.377E+02	0.000E+00	0.156E+00
75.0	5.99	1059.84	0.596E+00	0.000E+00	0.374E+02	0.000E+00	0.156E+00
75.5	5.90	1053.51	0.596E+00	0.000E+00	0.370E+02	0.000E+00	0.156E+00
76.0	5.81	1047.48	0.596E+00	0.000E+00	0.367E+02	0.000E+00	0.156E+00
76.5	5.73	1041.30	0.596E+00	0.000E+00	0.363E+02	0.000E+00	0.156E+00
77.0	5.64	1034.53	0.596E+00	0.000E+00	0.359E+02	0.000E+00	0.156E+00
77.5	5.55	1027.05	0.596E+00	0.000E+00	0.355E+02	0.000E+00	0.156E+00
78.0	5.46	1018.70	0.596E+00	0.000E+00	0.350E+02	0.000E+00	0.156E+00
78.5	5.37	1009.97	0.596E+00	0.000E+00	0.346E+02	0.000E+00	0.156E+00
79.0	5.27	1000.81	0.596E+00	0.000E+00	0.341E+02	0.000E+00	0.156E+00
79.5	5.18	991.76	0.596E+00	0.000E+00	0.336E+02	0.000E+00	0.156E+00
80.0	5.10	983.42	0.596E+00	0.000E+00	0.331E+02	0.000E+00	0.156E+00
80.5	5.02	976.84	0.596E+00	0.000E+00	0.328E+02	0.000E+00	0.156E+00
81.0	4.96	971.89	0.596E+00	0.000E+00	0.325E+02	0.000E+00	0.156E+00
81.5	4.90	967.63	0.596E+00	0.000E+00	0.323E+02	0.000E+00	0.156E+00
82.0	4.83	962.89	0.596E+00	0.000E+00	0.320E+02	0.000E+00	0.156E+00
82.5	4.77	957.00	0.596E+00	0.000E+00	0.317E+02	0.000E+00	0.156E+00
83.0	4.70	950.62	0.596E+00	0.000E+00	0.314E+02	0.000E+00	0.156E+00
83.5	4.63	944.85	0.596E+00	0.000E+00	0.311E+02	0.000E+00	0.156E+00
84.0	4.58	940.32	0.596E+00	0.000E+00	0.308E+02	0.000E+00	0.156E+00
84.5	4.52	935.81	0.596E+00	0.000E+00	0.306E+02	0.000E+00	0.156E+00
85.0	4.46	930.83	0.596E+00	0.000E+00	0.303E+02	0.000E+00	0.156E+00

Table 6.2 System Results - 1000rpm, 6.2 BAR BMEP

30-SEP-80

HR - VERSION V01.02

PRESSURE DATA FILE : RK1:FM1000.DAT
 STANDARD DEV. FILE : RK1:FS1000.DAT

ESPD= 1000.00 RPM ; MAN.PRESS=0.1014E+01 BAR

CYCLE RESULTS ...

IMEP= 9.34 BAR, TOTAL WORK= 620767.94 J

HEAT RELEASE RESULTS ...

TRAPPED CONDITIONS :

DEG.CA, TR.MASS= 0.00093 KG

PREDICTED MASS OF FUEL BURNT= 0.48783E-04 KG/CYC/CYL

FUEL CALORIFIC VALUE = 0.42912E+08 J/KG

PREDICTED AIR/FUEL RATIO = 18.97

CA	P(BAR)	T(DEG.K)	F	DM(KG/S)	HTR(J/S)	HRR(J/D)	HR(J)
-15.0	25.48	820.94	0.148E-01	0.000E+00	0.357E+02	0.000E+00	0.000E+00
-14.5	26.06	826.34	0.148E-01	0.589E-07	0.365E+02	0.253E+01	0.630E+00
-14.0	26.67	832.15	0.155E-01	0.602E-07	0.374E+02	0.258E+01	0.191E+01
-13.5	27.28	838.06	0.160E-01	0.675E-07	0.382E+02	0.289E+01	0.308E+01
-13.0	27.91	844.08	0.165E-01	0.744E-07	0.391E+02	0.319E+01	0.480E+01
-12.5	28.53	850.20	0.172E-01	0.805E-07	0.400E+02	0.345E+01	0.646E+01
-12.0	29.17	856.42	0.178E-01	0.893E-07	0.409E+02	0.383E+01	0.838E+01
-11.5	29.81	862.85	0.186E-01	0.103E-06	0.419E+02	0.442E+01	0.103E+02
-11.0	30.46	869.55	0.195E-01	0.114E-06	0.429E+02	0.489E+01	0.127E+02
-10.5	31.12	876.37	0.204E-01	0.124E-06	0.439E+02	0.530E+01	0.152E+02
-10.0	31.78	883.39	0.214E-01	0.136E-06	0.450E+02	0.584E+01	0.180E+02
-9.5	32.44	890.53	0.226E-01	0.140E-06	0.460E+02	0.599E+01	0.210E+02
-9.0	33.09	897.44	0.237E-01	0.132E-06	0.471E+02	0.568E+01	0.239E+02
-8.5	33.72	904.01	0.247E-01	0.127E-06	0.481E+02	0.546E+01	0.267E+02
-8.0	34.33	910.35	0.257E-01	0.127E-06	0.491E+02	0.545E+01	0.294E+02
-7.5	34.94	916.61	0.268E-01	0.135E-06	0.501E+02	0.579E+01	0.322E+02
-7.0	35.53	923.06	0.279E-01	0.154E-06	0.511E+02	0.662E+01	0.353E+02
-6.5	36.14	929.99	0.292E-01	0.184E-06	0.521E+02	0.788E+01	0.389E+02
-6.0	36.76	937.60	0.308E-01	0.216E-06	0.533E+02	0.927E+01	0.432E+02
-5.5	37.38	945.68	0.326E-01	0.230E-06	0.545E+02	0.988E+01	0.480E+02
-5.0	37.98	953.60	0.345E-01	0.224E-06	0.557E+02	0.962E+01	0.529E+02
-4.5	38.54	961.01	0.363E-01	0.208E-06	0.568E+02	0.891E+01	0.575E+02
-4.0	39.05	967.74	0.379E-01	0.197E-06	0.578E+02	0.847E+01	0.619E+02
-3.5	39.52	974.18	0.394E-01	0.199E-06	0.587E+02	0.856E+01	0.661E+02
-3.0	39.97	980.34	0.410E-01	0.191E-06	0.596E+02	0.820E+01	0.703E+02
-2.5	40.36	985.88	0.425E-01	0.175E-06	0.605E+02	0.749E+01	0.742E+02
-2.0	40.70	990.87	0.439E-01	0.173E-06	0.612E+02	0.741E+01	0.780E+02
-1.5	41.02	995.95	0.452E-01	0.202E-06	0.619E+02	0.865E+01	0.820E+02
-1.0	41.36	1002.24	0.470E-01	0.290E-06	0.628E+02	0.125E+02	0.872E+02
-0.5	41.81	1011.92	0.496E-01	0.486E-06	0.641E+02	0.208E+02	0.956E+02
0.0	42.52	1028.29	0.543E-01	0.824E-06	0.662E+02	0.353E+02	0.110E+03
0.5	43.62	1054.89	0.622E-01	0.129E-05	0.696E+02	0.554E+02	0.132E+03
1.0	45.23	1094.09	0.744E-01	0.184E-05	0.746E+02	0.789E+02	0.166E+03
1.5	47.37	1146.50	0.913E-01	0.238E-05	0.815E+02	0.102E+03	0.211E+03
2.0	49.93	1209.93	0.113E+00	0.282E-05	0.899E+02	0.121E+03	0.267E+03
2.5	52.74	1279.84	0.137E+00	0.306E-05	0.994E+02	0.131E+03	0.330E+03
3.0	55.55	1351.18	0.162E+00	0.311E-05	0.109E+03	0.133E+03	0.396E+03

Table 6.2 (continued)

3.5	58.17	1419.23	0.187E+00	0.297E-05	0.119E+03	0.127E+03	0.441E+02
4.0	60.46	1478.21	0.211E+00	0.271E-05	0.127E+03	0.116E+03	0.522E+02
4.5	62.36	1531.87	0.231E+00	0.245E-05	0.134E+03	0.105E+03	0.578E+02
5.0	63.93	1578.99	0.250E+00	0.224E-05	0.141E+03	0.962E+02	0.628E+02
5.5	65.23	1621.28	0.267E+00	0.211E-05	0.146E+03	0.905E+02	0.675E+02
6.0	66.34	1660.35	0.283E+00	0.203E-05	0.152E+03	0.872E+02	0.719E+02
6.5	67.31	1697.28	0.299E+00	0.199E-05	0.156E+03	0.856E+02	0.762E+02
7.0	68.15	1732.79	0.315E+00	0.198E-05	0.161E+03	0.850E+02	0.805E+02
7.5	68.91	1767.34	0.331E+00	0.198E-05	0.165E+03	0.851E+02	0.847E+02
8.0	69.57	1801.11	0.347E+00	0.199E-05	0.169E+03	0.853E+02	0.890E+02
8.5	70.15	1834.22	0.363E+00	0.200E-05	0.173E+03	0.858E+02	0.933E+02
9.0	70.66	1866.78	0.379E+00	0.201E-05	0.177E+03	0.864E+02	0.976E+02
9.5	71.09	1898.76	0.395E+00	0.202E-05	0.181E+03	0.869E+02	0.102E+03
10.0	71.45	1930.14	0.411E+00	0.203E-05	0.184E+03	0.872E+02	0.106E+03
10.5	71.74	1960.89	0.427E+00	0.204E-05	0.187E+03	0.876E+02	0.111E+03
11.0	71.95	1991.03	0.444E+00	0.205E-05	0.190E+03	0.880E+02	0.115E+03
11.5	72.10	2020.57	0.460E+00	0.206E-05	0.193E+03	0.883E+02	0.119E+03
12.0	72.18	2049.37	0.477E+00	0.205E-05	0.196E+03	0.881E+02	0.124E+03
12.5	72.19	2077.19	0.493E+00	0.203E-05	0.199E+03	0.871E+02	0.128E+03
13.0	72.11	2103.76	0.509E+00	0.199E-05	0.201E+03	0.855E+02	0.133E+03
13.5	71.94	2128.89	0.525E+00	0.195E-05	0.203E+03	0.835E+02	0.137E+03
14.0	71.69	2152.49	0.540E+00	0.189E-05	0.205E+03	0.812E+02	0.141E+03
14.5	71.36	2174.50	0.555E+00	0.183E-05	0.206E+03	0.787E+02	0.145E+03
15.0	70.95	2194.94	0.570E+00	0.177E-05	0.207E+03	0.761E+02	0.149E+03
15.5	70.46	2213.84	0.584E+00	0.171E-05	0.208E+03	0.735E+02	0.153E+03
16.0	69.90	2231.23	0.597E+00	0.165E-05	0.209E+03	0.707E+02	0.156E+03
16.5	69.29	2247.09	0.610E+00	0.158E-05	0.209E+03	0.679E+02	0.160E+03
17.0	68.61	2261.49	0.622E+00	0.152E-05	0.209E+03	0.651E+02	0.163E+03
17.5	67.87	2274.44	0.634E+00	0.145E-05	0.209E+03	0.622E+02	0.166E+03
18.0	67.09	2285.99	0.646E+00	0.138E-05	0.209E+03	0.593E+02	0.169E+03
18.5	66.27	2296.26	0.656E+00	0.132E-05	0.208E+03	0.567E+02	0.172E+03
19.0	65.40	2305.35	0.667E+00	0.126E-05	0.208E+03	0.541E+02	0.175E+03
19.5	64.51	2313.28	0.676E+00	0.120E-05	0.207E+03	0.516E+02	0.177E+03
20.0	63.59	2320.14	0.686E+00	0.114E-05	0.206E+03	0.491E+02	0.180E+03
20.5	62.64	2325.90	0.695E+00	0.108E-05	0.205E+03	0.464E+02	0.182E+03
21.0	61.67	2330.58	0.703E+00	0.102E-05	0.203E+03	0.436E+02	0.185E+03
21.5	60.69	2334.17	0.711E+00	0.955E-06	0.202E+03	0.410E+02	0.187E+03
22.0	59.68	2336.80	0.718E+00	0.899E-06	0.200E+03	0.386E+02	0.189E+03
22.5	58.67	2338.59	0.725E+00	0.847E-06	0.199E+03	0.364E+02	0.191E+03
23.0	57.65	2339.58	0.732E+00	0.801E-06	0.197E+03	0.344E+02	0.192E+03
23.5	56.63	2339.90	0.738E+00	0.761E-06	0.195E+03	0.327E+02	0.194E+03
24.0	55.61	2339.66	0.744E+00	0.727E-06	0.193E+03	0.312E+02	0.196E+03
24.5	54.60	2338.93	0.750E+00	0.693E-06	0.192E+03	0.297E+02	0.197E+03
25.0	53.59	2337.66	0.755E+00	0.654E-06	0.190E+03	0.280E+02	0.199E+03
25.5	52.58	2335.79	0.760E+00	0.608E-06	0.188E+03	0.261E+02	0.200E+03
26.0	51.58	2333.24	0.765E+00	0.553E-06	0.186E+03	0.237E+02	0.201E+03
26.5	50.58	2329.88	0.769E+00	0.496E-06	0.184E+03	0.213E+02	0.202E+03
27.0	49.58	2325.75	0.773E+00	0.441E-06	0.182E+03	0.189E+02	0.203E+03
27.5	48.59	2320.99	0.776E+00	0.397E-06	0.179E+03	0.170E+02	0.204E+03
28.0	47.61	2315.69	0.779E+00	0.363E-06	0.177E+03	0.156E+02	0.205E+03
28.5	46.64	2310.05	0.782E+00	0.343E-06	0.175E+03	0.147E+02	0.206E+03
29.0	45.69	2304.24	0.785E+00	0.325E-06	0.173E+03	0.140E+02	0.206E+03
29.5	44.76	2298.15	0.787E+00	0.297E-06	0.171E+03	0.127E+02	0.207E+03
30.0	43.84	2291.64	0.789E+00	0.259E-06	0.169E+03	0.111E+02	0.208E+03
30.5	42.93	2284.61	0.791E+00	0.217E-06	0.167E+03	0.932E+01	0.208E+03
31.0	42.03	2277.05	0.793E+00	0.175E-06	0.164E+03	0.752E+01	0.209E+03
31.5	41.14	2268.95	0.794E+00	0.134E-06	0.162E+03	0.573E+01	0.209E+03
32.0	40.26	2260.24	0.795E+00	0.780E-07	0.160E+03	0.335E+01	0.209E+03
32.5	39.38	2250.64	0.795E+00	0.721E-08	0.158E+03	0.309E+00	0.209E+03
33.0	38.51	2240.05	0.795E+00	0.000E+00	0.156E+03	0.000E+00	0.209E+03
33.5	37.65	2228.50	0.795E+00	0.000E+00	0.153E+03	0.000E+00	0.209E+03
34.0	36.79	2216.44	0.795E+00	0.000E+00	0.151E+03	0.000E+00	0.209E+03
34.5	35.96	2204.15	0.795E+00	0.000E+00	0.149E+03	0.000E+00	0.209E+03
35.0	35.14	2191.63	0.795E+00	0.000E+00	0.146E+03	0.000E+00	0.209E+03

Table 6.2 (continued)

35.5	34.34	2178.87	0.795E+00	0.000E+00	0.144E+03	0.000E+00	0.209E+00
36.0	33.56	2165.77	0.795E+00	0.000E+00	0.143E+03	0.000E+00	0.209E+00
36.5	32.79	2152.24	0.795E+00	0.000E+00	0.139E+03	0.000E+00	0.209E+00
37.0	32.03	2138.64	0.795E+00	0.000E+00	0.137E+03	0.000E+00	0.209E+00
37.5	31.31	2125.47	0.795E+00	0.000E+00	0.135E+03	0.000E+00	0.209E+00
38.0	30.61	2112.83	0.795E+00	0.000E+00	0.133E+03	0.000E+00	0.209E+00
38.5	29.93	2100.34	0.795E+00	0.000E+00	0.131E+03	0.000E+00	0.209E+00
39.0	29.26	2087.77	0.795E+00	0.000E+00	0.129E+03	0.000E+00	0.209E+00
39.5	28.62	2075.14	0.795E+00	0.000E+00	0.127E+03	0.000E+00	0.209E+00
40.0	27.99	2062.78	0.795E+00	0.000E+00	0.125E+03	0.000E+00	0.209E+00
40.5	27.38	2051.06	0.795E+00	0.000E+00	0.123E+03	0.000E+00	0.209E+00
41.0	26.81	2040.13	0.795E+00	0.000E+00	0.122E+03	0.000E+00	0.209E+00
41.5	26.25	2029.58	0.795E+00	0.000E+00	0.120E+03	0.000E+00	0.209E+00
42.0	25.70	2018.73	0.795E+00	0.000E+00	0.118E+03	0.000E+00	0.209E+00
42.5	25.16	2007.00	0.795E+00	0.000E+00	0.117E+03	0.000E+00	0.209E+00
43.0	24.61	1994.21	0.795E+00	0.000E+00	0.115E+03	0.000E+00	0.209E+00
43.5	24.07	1980.43	0.795E+00	0.000E+00	0.113E+03	0.000E+00	0.209E+00
44.0	23.53	1966.15	0.795E+00	0.000E+00	0.112E+03	0.000E+00	0.209E+00
44.5	23.01	1952.07	0.795E+00	0.000E+00	0.110E+03	0.000E+00	0.209E+00
45.0	22.52	1939.04	0.795E+00	0.000E+00	0.108E+03	0.000E+00	0.209E+00
45.5	22.05	1927.06	0.795E+00	0.000E+00	0.107E+03	0.000E+00	0.209E+00
46.0	21.59	1915.72	0.795E+00	0.000E+00	0.105E+03	0.000E+00	0.209E+00
46.5	21.16	1904.98	0.795E+00	0.000E+00	0.104E+03	0.000E+00	0.209E+00
47.0	20.74	1894.19	0.795E+00	0.000E+00	0.103E+03	0.000E+00	0.209E+00
47.5	20.32	1882.97	0.795E+00	0.000E+00	0.101E+03	0.000E+00	0.209E+00
48.0	19.90	1871.20	0.795E+00	0.000E+00	0.999E+02	0.000E+00	0.209E+00
48.5	19.49	1858.86	0.795E+00	0.000E+00	0.985E+02	0.000E+00	0.209E+00
49.0	19.09	1846.05	0.795E+00	0.000E+00	0.971E+02	0.000E+00	0.209E+00
49.5	18.69	1832.87	0.795E+00	0.000E+00	0.957E+02	0.000E+00	0.209E+00
50.0	18.30	1819.62	0.795E+00	0.000E+00	0.943E+02	0.000E+00	0.209E+00
50.5	17.92	1807.04	0.795E+00	0.000E+00	0.929E+02	0.000E+00	0.209E+00
51.0	17.57	1795.75	0.795E+00	0.000E+00	0.917E+02	0.000E+00	0.209E+00
51.5	17.23	1785.58	0.795E+00	0.000E+00	0.906E+02	0.000E+00	0.209E+00
52.0	16.91	1775.81	0.795E+00	0.000E+00	0.896E+02	0.000E+00	0.209E+00
52.5	16.59	1765.99	0.795E+00	0.000E+00	0.885E+02	0.000E+00	0.209E+00
53.0	16.28	1755.67	0.795E+00	0.000E+00	0.875E+02	0.000E+00	0.209E+00
53.5	15.97	1744.53	0.795E+00	0.000E+00	0.863E+02	0.000E+00	0.209E+00
54.0	15.66	1733.08	0.795E+00	0.000E+00	0.852E+02	0.000E+00	0.209E+00
54.5	15.36	1722.53	0.795E+00	0.000E+00	0.842E+02	0.000E+00	0.209E+00
55.0	15.09	1713.49	0.795E+00	0.000E+00	0.833E+02	0.000E+00	0.209E+00
55.5	14.82	1705.27	0.795E+00	0.000E+00	0.824E+02	0.000E+00	0.209E+00
56.0	14.57	1697.04	0.795E+00	0.000E+00	0.816E+02	0.000E+00	0.209E+00
56.5	14.31	1688.10	0.795E+00	0.000E+00	0.807E+02	0.000E+00	0.209E+00
57.0	14.06	1678.58	0.795E+00	0.000E+00	0.798E+02	0.000E+00	0.209E+00
57.5	13.81	1668.85	0.795E+00	0.000E+00	0.789E+02	0.000E+00	0.209E+00
58.0	13.55	1658.48	0.795E+00	0.000E+00	0.780E+02	0.000E+00	0.209E+00
58.5	13.30	1647.37	0.795E+00	0.000E+00	0.770E+02	0.000E+00	0.209E+00
59.0	13.05	1635.87	0.795E+00	0.000E+00	0.760E+02	0.000E+00	0.209E+00
59.5	12.81	1624.43	0.795E+00	0.000E+00	0.750E+02	0.000E+00	0.209E+00
60.0	12.57	1613.43	0.795E+00	0.000E+00	0.741E+02	0.000E+00	0.209E+00
60.5	12.35	1602.83	0.795E+00	0.000E+00	0.732E+02	0.000E+00	0.209E+00
61.0	12.12	1592.29	0.795E+00	0.000E+00	0.723E+02	0.000E+00	0.209E+00
61.5	11.91	1582.19	0.795E+00	0.000E+00	0.715E+02	0.000E+00	0.209E+00
62.0	11.71	1573.04	0.795E+00	0.000E+00	0.707E+02	0.000E+00	0.209E+00
62.5	11.51	1564.56	0.795E+00	0.000E+00	0.700E+02	0.000E+00	0.209E+00
63.0	11.32	1556.05	0.795E+00	0.000E+00	0.693E+02	0.000E+00	0.209E+00
63.5	11.14	1547.22	0.795E+00	0.000E+00	0.686E+02	0.000E+00	0.209E+00
64.0	10.95	1537.70	0.795E+00	0.000E+00	0.678E+02	0.000E+00	0.209E+00
64.5	10.76	1527.53	0.795E+00	0.000E+00	0.670E+02	0.000E+00	0.209E+00
65.0	10.57	1517.21	0.795E+00	0.000E+00	0.662E+02	0.000E+00	0.209E+00
65.5	10.39	1507.45	0.795E+00	0.000E+00	0.655E+02	0.000E+00	0.209E+00
66.0	10.22	1498.16	0.795E+00	0.000E+00	0.648E+02	0.000E+00	0.209E+00
66.5	10.05	1488.95	0.795E+00	0.000E+00	0.641E+02	0.000E+00	0.209E+00
67.0	9.88	1479.68	0.795E+00	0.000E+00	0.634E+02	0.000E+00	0.209E+00

Table 6.2 (continued)

67.5	9.72	1470.20	0.795E+00	0.000E+00	0.627E+02	0.000E+00	0.209E+
68.0	9.56	1460.88	0.795E+00	0.000E+00	0.620E+02	0.000E+00	0.209E+
68.5	9.41	1452.26	0.795E+00	0.000E+00	0.614E+02	0.000E+00	0.209E+
69.0	9.26	1444.50	0.795E+00	0.000E+00	0.608E+02	0.000E+00	0.209E+
69.5	9.12	1436.96	0.795E+00	0.000E+00	0.602E+02	0.000E+00	0.209E+
70.0	8.98	1428.91	0.795E+00	0.000E+00	0.596E+02	0.000E+00	0.209E+
70.5	8.84	1419.26	0.795E+00	0.000E+00	0.590E+02	0.000E+00	0.209E+
71.0	8.68	1408.08	0.795E+00	0.000E+00	0.582E+02	0.000E+00	0.209E+
71.5	8.53	1396.23	0.795E+00	0.000E+00	0.574E+02	0.000E+00	0.209E+
72.0	8.38	1384.43	0.795E+00	0.000E+00	0.566E+02	0.000E+00	0.209E+
72.5	8.23	1373.71	0.795E+00	0.000E+00	0.559E+02	0.000E+00	0.209E+
73.0	8.10	1364.35	0.795E+00	0.000E+00	0.553E+02	0.000E+00	0.209E+
73.5	7.98	1356.00	0.795E+00	0.000E+00	0.547E+02	0.000E+00	0.209E+
74.0	7.86	1348.47	0.795E+00	0.000E+00	0.542E+02	0.000E+00	0.209E+
74.5	7.74	1340.77	0.795E+00	0.000E+00	0.537E+02	0.000E+00	0.209E+
75.0	7.63	1332.39	0.795E+00	0.000E+00	0.532E+02	0.000E+00	0.209E+
75.5	7.51	1323.73	0.795E+00	0.000E+00	0.526E+02	0.000E+00	0.209E+
76.0	7.40	1315.25	0.795E+00	0.000E+00	0.520E+02	0.000E+00	0.209E+
76.5	7.29	1307.40	0.795E+00	0.000E+00	0.515E+02	0.000E+00	0.209E+
77.0	7.18	1299.75	0.795E+00	0.000E+00	0.510E+02	0.000E+00	0.209E+
77.5	7.08	1291.82	0.795E+00	0.000E+00	0.505E+02	0.000E+00	0.209E+
78.0	6.98	1284.12	0.795E+00	0.000E+00	0.501E+02	0.000E+00	0.209E+
78.5	6.88	1277.24	0.795E+00	0.000E+00	0.496E+02	0.000E+00	0.209E+
79.0	6.79	1271.23	0.795E+00	0.000E+00	0.492E+02	0.000E+00	0.209E+
79.5	6.70	1265.34	0.795E+00	0.000E+00	0.489E+02	0.000E+00	0.209E+
80.0	6.61	1258.84	0.795E+00	0.000E+00	0.485E+02	0.000E+00	0.209E+
80.5	6.52	1252.09	0.795E+00	0.000E+00	0.480E+02	0.000E+00	0.209E+
81.0	6.44	1245.42	0.795E+00	0.000E+00	0.476E+02	0.000E+00	0.209E+
81.5	6.35	1238.84	0.795E+00	0.000E+00	0.472E+02	0.000E+00	0.209E+
82.0	6.27	1231.65	0.795E+00	0.000E+00	0.468E+02	0.000E+00	0.209E+
82.5	6.18	1223.51	0.795E+00	0.000E+00	0.463E+02	0.000E+00	0.209E+
83.0	6.08	1214.91	0.795E+00	0.000E+00	0.458E+02	0.000E+00	0.209E+
83.5	5.99	1206.37	0.795E+00	0.000E+00	0.453E+02	0.000E+00	0.209E+
84.0	5.91	1197.97	0.795E+00	0.000E+00	0.448E+02	0.000E+00	0.209E+
84.5	5.82	1190.02	0.795E+00	0.000E+00	0.443E+02	0.000E+00	0.209E+
85.0	5.75	1182.97	0.795E+00	0.000E+00	0.439E+02	0.000E+00	0.209E+

Table 6.3 System Results - 2000rpm, 4.1 BAR BMEP

30-SEP-80

HR - VERSION V01.02

PRESSURE DATA FILE : RK1:HM2000.DAT

STANDARD DEV. FILE : RK1:HS2000.DAT

ESPD= 2000.00 RPM ; MAN.PRESS=0.1014E+01 BAR

CYCLE RESULTS ...

IMEP= 7.40 BAR; TOTAL WORK= 491690.25 J

HEAT RELEASE RESULTS ...

TRAPPED CONDITIONS :

TR.MASS= 0.00093 KG

PREDICTED MASS OF FUEL BURNT= 0.39952E-04 KG/CYC/CYL

FUEL CALORIFIC VALUE = 0.42912E+08 J/KG

PREDICTED AIR/FUEL RATIO = 23.16

CA	P(BAR)	T(DEG.K)	F	DM(KG/S)	HTR(J/S)	HRR(J/D)	HR(J
-15.0	27.11	873.60	0.148E-01	0.000E+00	0.356E+02	0.000E+00	0.000E+
-14.5	27.74	879.38	0.148E-01	0.440E-07	0.364E+02	0.189E+01	0.471E+
-14.0	28.36	884.98	0.153E-01	0.425E-07	0.372E+02	0.182E+01	0.140E+
-13.5	28.99	890.54	0.156E-01	0.456E-07	0.380E+02	0.196E+01	0.235E+
-13.0	29.63	896.17	0.160E-01	0.540E-07	0.387E+02	0.232E+01	0.343E+
-12.5	30.27	902.00	0.165E-01	0.658E-07	0.396E+02	0.282E+01	0.470E+
-12.0	30.92	908.06	0.171E-01	0.779E-07	0.404E+02	0.334E+01	0.625E+
-11.5	31.59	914.34	0.177E-01	0.897E-07	0.413E+02	0.385E+01	0.804E+
-11.0	32.25	920.81	0.185E-01	0.999E-07	0.422E+02	0.429E+01	0.101E+
-10.5	32.93	927.39	0.193E-01	0.106E-06	0.431E+02	0.454E+01	0.123E+
-10.0	33.59	933.93	0.202E-01	0.108E-06	0.440E+02	0.463E+01	0.146E+
-9.5	34.25	940.39	0.211E-01	0.111E-06	0.449E+02	0.476E+01	0.169E+
-9.0	34.91	946.86	0.220E-01	0.121E-06	0.459E+02	0.518E+01	0.194E+
-8.5	35.56	953.56	0.230E-01	0.139E-06	0.468E+02	0.595E+01	0.222E+
-8.0	36.23	960.63	0.242E-01	0.160E-06	0.478E+02	0.688E+01	0.254E+
-7.5	36.90	968.11	0.255E-01	0.181E-06	0.488E+02	0.779E+01	0.291E+
-7.0	37.57	975.94	0.271E-01	0.201E-06	0.499E+02	0.861E+01	0.332E+
-6.5	38.24	984.03	0.288E-01	0.216E-06	0.510E+02	0.925E+01	0.376E+
-6.0	38.90	992.26	0.305E-01	0.226E-06	0.521E+02	0.972E+01	0.424E+
-5.5	39.54	1000.52	0.324E-01	0.234E-06	0.532E+02	0.100E+02	0.473E+
-5.0	40.17	1008.73	0.343E-01	0.242E-06	0.543E+02	0.104E+02	0.524E+
-4.5	40.78	1017.00	0.363E-01	0.254E-06	0.554E+02	0.109E+02	0.577E+
-4.0	41.37	1025.30	0.383E-01	0.262E-06	0.565E+02	0.112E+02	0.633E+
-3.5	41.93	1033.45	0.405E-01	0.261E-06	0.575E+02	0.112E+02	0.689E+
-3.0	42.45	1041.23	0.426E-01	0.255E-06	0.586E+02	0.109E+02	0.744E+
-2.5	42.93	1048.56	0.446E-01	0.249E-06	0.595E+02	0.107E+02	0.798E+
-2.0	43.37	1055.59	0.465E-01	0.253E-06	0.604E+02	0.109E+02	0.852E+
-1.5	43.77	1062.62	0.486E-01	0.267E-06	0.613E+02	0.115E+02	0.908E+
-1.0	44.16	1069.79	0.508E-01	0.285E-06	0.621E+02	0.122E+02	0.967E+
-0.5	44.52	1077.17	0.531E-01	0.306E-06	0.630E+02	0.131E+02	0.103E+
0.0	44.86	1084.82	0.556E-01	0.328E-06	0.639E+02	0.141E+02	0.110E+
0.5	45.18	1092.82	0.584E-01	0.357E-06	0.648E+02	0.153E+02	0.117E+
1.0	45.50	1101.54	0.613E-01	0.411E-06	0.658E+02	0.176E+02	0.125E+
1.5	45.85	1111.90	0.648E-01	0.512E-06	0.669E+02	0.220E+02	0.135E+
2.0	46.30	1125.31	0.693E-01	0.677E-06	0.683E+02	0.291E+02	0.148E+
2.5	46.92	1143.47	0.754E-01	0.914E-06	0.703E+02	0.392E+02	0.165E+
3.0	47.76	1167.99	0.837E-01	0.121E-05	0.730E+02	0.521E+02	0.188E+

Table 6.3 (continued)

3.5	48.87	1199.97	0.946E-01	0.155E-05	0.765E+02	0.666E+02	0.218E+01
4.0	50.27	1239.75	0.108E+00	0.190E-05	0.810E+02	0.816E+02	0.255E+01
4.5	51.92	1286.82	0.125E+00	0.223E-05	0.863E+02	0.956E+02	0.299E+01
5.0	53.77	1340.00	0.144E+00	0.251E-05	0.923E+02	0.108E+03	0.350E+01
5.5	55.75	1397.70	0.165E+00	0.273E-05	0.989E+02	0.117E+03	0.408E+01
6.0	57.79	1455.53	0.188E+00	0.289E-05	0.106E+03	0.124E+03	0.466E+01
6.5	59.79	1516.74	0.212E+00	0.296E-05	0.113E+03	0.127E+03	0.529E+01
7.0	61.69	1576.98	0.236E+00	0.295E-05	0.120E+03	0.127E+03	0.592E+01
7.5	63.42	1634.60	0.259E+00	0.288E-05	0.126E+03	0.123E+03	0.655E+01
8.0	64.93	1688.35	0.282E+00	0.274E-05	0.132E+03	0.118E+03	0.715E+01
8.5	66.18	1737.25	0.303E+00	0.255E-05	0.138E+03	0.110E+03	0.772E+01
9.0	67.15	1780.69	0.323E+00	0.233E-05	0.143E+03	0.100E+03	0.824E+01
9.5	67.84	1818.51	0.341E+00	0.211E-05	0.147E+03	0.905E+02	0.872E+01
10.0	68.27	1850.98	0.357E+00	0.189E-05	0.150E+03	0.812E+02	0.915E+01
10.5	68.47	1878.67	0.371E+00	0.170E-05	0.152E+03	0.730E+02	0.954E+01
11.0	68.46	1902.20	0.384E+00	0.154E-05	0.154E+03	0.659E+02	0.988E+01
11.5	68.29	1922.26	0.395E+00	0.140E-05	0.155E+03	0.601E+02	0.102E+02
12.0	67.98	1939.51	0.406E+00	0.129E-05	0.156E+03	0.555E+02	0.105E+02
12.5	67.56	1954.63	0.416E+00	0.122E-05	0.157E+03	0.523E+02	0.108E+02
13.0	67.06	1968.23	0.425E+00	0.117E-05	0.157E+03	0.502E+02	0.110E+02
13.5	66.51	1980.77	0.435E+00	0.114E-05	0.158E+03	0.490E+02	0.113E+02
14.0	65.91	1992.62	0.444E+00	0.113E-05	0.158E+03	0.485E+02	0.115E+02
14.5	65.28	2004.05	0.453E+00	0.113E-05	0.158E+03	0.483E+02	0.117E+02
15.0	64.63	2015.17	0.462E+00	0.113E-05	0.158E+03	0.483E+02	0.120E+02
15.5	63.95	2026.04	0.471E+00	0.113E-05	0.158E+03	0.483E+02	0.122E+02
16.0	63.26	2036.64	0.480E+00	0.112E-05	0.157E+03	0.483E+02	0.125E+02
16.5	62.56	2046.93	0.489E+00	0.112E-05	0.157E+03	0.480E+02	0.127E+02
17.0	61.83	2056.83	0.498E+00	0.111E-05	0.157E+03	0.475E+02	0.130E+02
17.5	61.08	2066.27	0.506E+00	0.109E-05	0.157E+03	0.468E+02	0.132E+02
18.0	60.32	2075.20	0.515E+00	0.107E-05	0.156E+03	0.460E+02	0.134E+02
18.5	59.54	2083.59	0.524E+00	0.105E-05	0.156E+03	0.451E+02	0.136E+02
19.0	58.75	2091.38	0.532E+00	0.102E-05	0.155E+03	0.440E+02	0.139E+02
19.5	57.93	2098.53	0.540E+00	0.996E-06	0.154E+03	0.427E+02	0.141E+02
20.0	57.11	2105.05	0.548E+00	0.969E-06	0.154E+03	0.416E+02	0.143E+02
20.5	56.27	2110.99	0.555E+00	0.944E-06	0.153E+03	0.405E+02	0.145E+02
21.0	55.43	2116.39	0.563E+00	0.918E-06	0.152E+03	0.394E+02	0.147E+02
21.5	54.57	2121.20	0.570E+00	0.888E-06	0.151E+03	0.381E+02	0.149E+02
22.0	53.72	2125.41	0.577E+00	0.854E-06	0.150E+03	0.367E+02	0.151E+02
22.5	52.85	2128.90	0.584E+00	0.816E-06	0.149E+03	0.350E+02	0.153E+02
23.0	51.98	2131.67	0.590E+00	0.777E-06	0.148E+03	0.333E+02	0.154E+02
23.5	51.10	2133.77	0.596E+00	0.740E-06	0.147E+03	0.318E+02	0.156E+02
24.0	50.22	2135.21	0.602E+00	0.704E-06	0.146E+03	0.302E+02	0.157E+02
24.5	49.33	2136.00	0.608E+00	0.667E-06	0.145E+03	0.286E+02	0.159E+02
25.0	48.45	2136.11	0.613E+00	0.625E-06	0.143E+03	0.268E+02	0.160E+02
25.5	47.57	2135.48	0.618E+00	0.579E-06	0.142E+03	0.249E+02	0.162E+02
26.0	46.68	2134.09	0.622E+00	0.534E-06	0.141E+03	0.229E+02	0.163E+02
26.5	45.80	2132.01	0.626E+00	0.495E-06	0.139E+03	0.212E+02	0.164E+02
27.0	44.92	2129.35	0.630E+00	0.459E-06	0.138E+03	0.197E+02	0.165E+02
27.5	44.05	2126.15	0.633E+00	0.426E-06	0.136E+03	0.183E+02	0.166E+02
28.0	43.18	2122.45	0.637E+00	0.396E-06	0.135E+03	0.170E+02	0.167E+02
28.5	42.33	2118.31	0.640E+00	0.367E-06	0.133E+03	0.158E+02	0.168E+02
29.0	41.48	2113.77	0.643E+00	0.339E-06	0.132E+03	0.146E+02	0.168E+02
29.5	40.65	2108.80	0.645E+00	0.311E-06	0.130E+03	0.133E+02	0.169E+02
30.0	39.82	2103.36	0.648E+00	0.276E-06	0.129E+03	0.119E+02	0.170E+02
30.5	39.00	2097.34	0.650E+00	0.234E-06	0.127E+03	0.100E+02	0.170E+02
31.0	38.19	2090.62	0.651E+00	0.186E-06	0.125E+03	0.798E+01	0.171E+02
31.5	37.38	2083.13	0.653E+00	0.136E-06	0.124E+03	0.582E+01	0.171E+02
32.0	36.58	2074.85	0.653E+00	0.853E-07	0.122E+03	0.366E+01	0.171E+02
32.5	35.78	2065.80	0.654E+00	0.346E-07	0.120E+03	0.148E+01	0.171E+02
33.0	34.99	2055.94	0.654E+00	0.000E+00	0.118E+03	0.000E+00	0.171E+02
33.5	34.20	2045.25	0.654E+00	0.000E+00	0.117E+03	0.000E+00	0.171E+02
34.0	33.42	2033.75	0.654E+00	0.000E+00	0.115E+03	0.000E+00	0.171E+02
34.5	32.65	2021.53	0.654E+00	0.000E+00	0.113E+03	0.000E+00	0.171E+02
35.0	31.89	2008.69	0.654E+00	0.000E+00	0.111E+03	0.000E+00	0.171E+02

Table 6.3 (continued)

35.5	31.14	1995.39	0.654E+00	0.000E+00	0.109E+03	0.000E+00	0.171E+4
36.0	30.40	1981.83	0.654E+00	0.000E+00	0.107E+03	0.000E+00	0.171E+4
36.5	29.68	1968.15	0.654E+00	0.000E+00	0.106E+03	0.000E+00	0.171E+4
37.0	28.99	1954.42	0.654E+00	0.000E+00	0.104E+03	0.000E+00	0.171E+4
37.5	28.30	1940.62	0.654E+00	0.000E+00	0.102E+03	0.000E+00	0.171E+4
38.0	27.64	1926.64	0.654E+00	0.000E+00	0.100E+03	0.000E+00	0.171E+4
38.5	26.98	1912.50	0.654E+00	0.000E+00	0.986E+02	0.000E+00	0.171E+4
39.0	26.35	1898.33	0.654E+00	0.000E+00	0.969E+02	0.000E+00	0.171E+4
39.5	25.73	1884.26	0.654E+00	0.000E+00	0.953E+02	0.000E+00	0.171E+4
40.0	25.13	1870.29	0.654E+00	0.000E+00	0.937E+02	0.000E+00	0.171E+4
40.5	24.54	1856.37	0.654E+00	0.000E+00	0.921E+02	0.000E+00	0.171E+4
41.0	23.97	1842.52	0.654E+00	0.000E+00	0.905E+02	0.000E+00	0.171E+4
41.5	23.42	1828.86	0.654E+00	0.000E+00	0.890E+02	0.000E+00	0.171E+4
42.0	22.89	1815.59	0.654E+00	0.000E+00	0.876E+02	0.000E+00	0.171E+4
42.5	22.38	1802.77	0.654E+00	0.000E+00	0.862E+02	0.000E+00	0.171E+4
43.0	21.88	1790.26	0.654E+00	0.000E+00	0.849E+02	0.000E+00	0.171E+4
43.5	21.40	1777.87	0.654E+00	0.000E+00	0.836E+02	0.000E+00	0.171E+4
44.0	20.93	1765.50	0.654E+00	0.000E+00	0.823E+02	0.000E+00	0.171E+4
44.5	20.47	1753.16	0.654E+00	0.000E+00	0.810E+02	0.000E+00	0.171E+4
45.0	20.02	1740.76	0.654E+00	0.000E+00	0.798E+02	0.000E+00	0.171E+4
45.5	19.58	1728.27	0.654E+00	0.000E+00	0.786E+02	0.000E+00	0.171E+4
46.0	19.16	1715.87	0.654E+00	0.000E+00	0.774E+02	0.000E+00	0.171E+4
46.5	18.74	1703.88	0.654E+00	0.000E+00	0.762E+02	0.000E+00	0.171E+4
47.0	18.35	1692.63	0.654E+00	0.000E+00	0.751E+02	0.000E+00	0.171E+4
47.5	17.98	1682.16	0.654E+00	0.000E+00	0.741E+02	0.000E+00	0.171E+4
48.0	17.62	1672.15	0.654E+00	0.000E+00	0.731E+02	0.000E+00	0.171E+4
48.5	17.26	1662.29	0.654E+00	0.000E+00	0.722E+02	0.000E+00	0.171E+4
49.0	16.92	1652.55	0.654E+00	0.000E+00	0.713E+02	0.000E+00	0.171E+4
49.5	16.59	1643.13	0.654E+00	0.000E+00	0.704E+02	0.000E+00	0.171E+4
50.0	16.28	1634.24	0.654E+00	0.000E+00	0.695E+02	0.000E+00	0.171E+4
50.5	15.97	1625.87	0.654E+00	0.000E+00	0.688E+02	0.000E+00	0.171E+4
51.0	15.68	1617.82	0.654E+00	0.000E+00	0.680E+02	0.000E+00	0.171E+4
51.5	15.39	1609.85	0.654E+00	0.000E+00	0.672E+02	0.000E+00	0.171E+4
52.0	15.11	1601.76	0.654E+00	0.000E+00	0.665E+02	0.000E+00	0.171E+4
52.5	14.83	1593.27	0.654E+00	0.000E+00	0.658E+02	0.000E+00	0.171E+4
53.0	14.55	1584.12	0.654E+00	0.000E+00	0.650E+02	0.000E+00	0.171E+4
53.5	14.27	1574.30	0.654E+00	0.000E+00	0.642E+02	0.000E+00	0.171E+4
54.0	14.00	1564.21	0.654E+00	0.000E+00	0.633E+02	0.000E+00	0.171E+4
54.5	13.73	1554.47	0.654E+00	0.000E+00	0.626E+02	0.000E+00	0.171E+4
55.0	13.48	1545.54	0.654E+00	0.000E+00	0.618E+02	0.000E+00	0.171E+4
55.5	13.24	1537.51	0.654E+00	0.000E+00	0.612E+02	0.000E+00	0.171E+4
56.0	13.01	1530.13	0.654E+00	0.000E+00	0.606E+02	0.000E+00	0.171E+4
56.5	12.79	1523.00	0.654E+00	0.000E+00	0.600E+02	0.000E+00	0.171E+4
57.0	12.58	1515.95	0.654E+00	0.000E+00	0.594E+02	0.000E+00	0.171E+4
57.5	12.37	1509.14	0.654E+00	0.000E+00	0.588E+02	0.000E+00	0.171E+4
58.0	12.17	1502.68	0.654E+00	0.000E+00	0.583E+02	0.000E+00	0.171E+4
58.5	11.97	1496.49	0.654E+00	0.000E+00	0.578E+02	0.000E+00	0.171E+4
59.0	11.78	1490.49	0.654E+00	0.000E+00	0.573E+02	0.000E+00	0.171E+4
59.5	11.60	1484.55	0.654E+00	0.000E+00	0.568E+02	0.000E+00	0.171E+4
60.0	11.42	1478.65	0.654E+00	0.000E+00	0.563E+02	0.000E+00	0.171E+4
60.5	11.24	1473.01	0.654E+00	0.000E+00	0.559E+02	0.000E+00	0.171E+4
61.0	11.07	1467.49	0.654E+00	0.000E+00	0.554E+02	0.000E+00	0.171E+4
61.5	10.90	1461.74	0.654E+00	0.000E+00	0.550E+02	0.000E+00	0.171E+4
62.0	10.73	1455.48	0.654E+00	0.000E+00	0.545E+02	0.000E+00	0.171E+4
62.5	10.56	1448.65	0.654E+00	0.000E+00	0.540E+02	0.000E+00	0.171E+4
63.0	10.39	1441.51	0.654E+00	0.000E+00	0.535E+02	0.000E+00	0.171E+4
63.5	10.23	1434.38	0.654E+00	0.000E+00	0.530E+02	0.000E+00	0.171E+4
64.0	10.07	1427.45	0.654E+00	0.000E+00	0.525E+02	0.000E+00	0.171E+4
64.5	9.91	1420.08	0.654E+00	0.000E+00	0.520E+02	0.000E+00	0.171E+4
65.0	9.74	1411.84	0.654E+00	0.000E+00	0.515E+02	0.000E+00	0.171E+4
65.5	9.58	1402.81	0.654E+00	0.000E+00	0.509E+02	0.000E+00	0.171E+4
66.0	9.42	1393.43	0.654E+00	0.000E+00	0.503E+02	0.000E+00	0.171E+4
66.5	9.26	1384.41	0.654E+00	0.000E+00	0.498E+02	0.000E+00	0.171E+4
67.0	9.11	1376.26	0.654E+00	0.000E+00	0.492E+02	0.000E+00	0.171E+4

Table 6.3 (continued)

67.5	8.96	1368.71	0.654E+00	0.000E+00	0.488E+02	0.000E+00	0.171E-
68.0	8.83	1361.54	0.654E+00	0.000E+00	0.483E+02	0.000E+00	0.171E-
68.5	8.69	1354.73	0.654E+00	0.000E+00	0.479E+02	0.000E+00	0.171E-
69.0	8.56	1348.02	0.654E+00	0.000E+00	0.475E+02	0.000E+00	0.171E-
69.5	8.44	1341.22	0.654E+00	0.000E+00	0.470E+02	0.000E+00	0.171E-
70.0	8.31	1334.15	0.654E+00	0.000E+00	0.466E+02	0.000E+00	0.171E-
70.5	8.18	1326.67	0.654E+00	0.000E+00	0.462E+02	0.000E+00	0.171E-
71.0	8.06	1318.87	0.654E+00	0.000E+00	0.457E+02	0.000E+00	0.171E-
71.5	7.93	1310.86	0.654E+00	0.000E+00	0.452E+02	0.000E+00	0.171E-
72.0	7.81	1302.87	0.654E+00	0.000E+00	0.448E+02	0.000E+00	0.171E-
72.5	7.69	1295.10	0.654E+00	0.000E+00	0.443E+02	0.000E+00	0.171E-
73.0	7.57	1287.47	0.654E+00	0.000E+00	0.439E+02	0.000E+00	0.171E-
73.5	7.46	1279.90	0.654E+00	0.000E+00	0.434E+02	0.000E+00	0.171E-
74.0	7.34	1272.01	0.654E+00	0.000E+00	0.430E+02	0.000E+00	0.171E-
74.5	7.23	1263.86	0.654E+00	0.000E+00	0.425E+02	0.000E+00	0.171E-
75.0	7.12	1255.83	0.654E+00	0.000E+00	0.421E+02	0.000E+00	0.171E-
75.5	7.01	1247.73	0.654E+00	0.000E+00	0.417E+02	0.000E+00	0.171E-
76.0	6.90	1239.33	0.654E+00	0.000E+00	0.412E+02	0.000E+00	0.171E-
76.5	6.80	1230.90	0.654E+00	0.000E+00	0.408E+02	0.000E+00	0.171E-
77.0	6.69	1222.88	0.654E+00	0.000E+00	0.403E+02	0.000E+00	0.171E-
77.5	6.60	1215.67	0.654E+00	0.000E+00	0.399E+02	0.000E+00	0.171E-
78.0	6.51	1209.02	0.654E+00	0.000E+00	0.396E+02	0.000E+00	0.171E-
78.5	6.42	1202.46	0.654E+00	0.000E+00	0.392E+02	0.000E+00	0.171E-
79.0	6.33	1195.67	0.654E+00	0.000E+00	0.389E+02	0.000E+00	0.171E-
79.5	6.24	1188.59	0.654E+00	0.000E+00	0.385E+02	0.000E+00	0.171E-
80.0	6.15	1181.26	0.654E+00	0.000E+00	0.381E+02	0.000E+00	0.171E-
80.5	6.06	1173.98	0.654E+00	0.000E+00	0.377E+02	0.000E+00	0.171E-
81.0	5.98	1167.22	0.654E+00	0.000E+00	0.374E+02	0.000E+00	0.171E-
81.5	5.90	1161.07	0.654E+00	0.000E+00	0.371E+02	0.000E+00	0.171E-
82.0	5.82	1155.48	0.654E+00	0.000E+00	0.368E+02	0.000E+00	0.171E-
82.5	5.75	1149.89	0.654E+00	0.000E+00	0.365E+02	0.000E+00	0.171E-
83.0	5.68	1144.15	0.654E+00	0.000E+00	0.362E+02	0.000E+00	0.171E-
83.5	5.60	1138.14	0.654E+00	0.000E+00	0.359E+02	0.000E+00	0.171E-
84.0	5.53	1132.13	0.654E+00	0.000E+00	0.356E+02	0.000E+00	0.171E-
84.5	5.46	1126.05	0.654E+00	0.000E+00	0.353E+02	0.000E+00	0.171E-
85.0	5.39	1119.74	0.654E+00	0.000E+00	0.350E+02	0.000E+00	0.171E-

Table 6.4 System Results - 2000rpm, 5.1 BAR BMEP

30-SEP-80

HR - VERSION V01.02

PRESSURE DATA FILE : RK1:FM2000.DAT

STANDARD DEV. FILE : RK1:FS2000.DAT

ESPD= 2000.00 RPM ; MAN.PRESS=0.1014E+01 BAR

CYCLE RESULTS ...

IMEP= 9.49 BAR, TOTAL WORK= 630660.44 J

HEAT RELEASE RESULTS ...

TRAPPED CONDITIONS :

TR.MASS= 0.00093 KG

PREDICTED MASS OF FUEL BURNT= 0.52971E-04 KG/CYC/CYL

FUEL CALORIFIC VALUE = 0.42912E+08 J/KG

PREDICTED AIR/FUEL RATIO = 17.47

CA	P(BAR)	T(DEG.K)	F	DM(KG/S)	HTR(J/S)	HRR(J/D)	HR(J
-15.0	27.29	879.41	0.148E-01	0.000E+00	0.362E+02	0.000E+00	0.000E+
-14.5	27.90	884.48	0.148E-01	0.719E-07	0.369E+02	0.309E+01	0.770E+
-14.0	28.55	890.87	0.156E-01	0.710E-07	0.377E+02	0.305E+01	0.230E+
-13.5	29.21	897.25	0.162E-01	0.754E-07	0.386E+02	0.323E+01	0.387E+
-13.0	29.88	903.73	0.168E-01	0.850E-07	0.394E+02	0.365E+01	0.559E+
-12.5	30.56	910.45	0.176E-01	0.976E-07	0.403E+02	0.419E+01	0.755E+
-12.0	31.24	917.37	0.184E-01	0.106E-06	0.413E+02	0.455E+01	0.973E+
-11.5	31.93	924.32	0.193E-01	0.109E-06	0.422E+02	0.468E+01	0.120E+
-11.0	32.62	931.20	0.201E-01	0.110E-06	0.432E+02	0.470E+01	0.149E+
-10.5	33.30	937.98	0.210E-01	0.111E-06	0.441E+02	0.475E+01	0.167E+
-10.0	33.98	944.70	0.219E-01	0.116E-06	0.451E+02	0.499E+01	0.192E+
-9.5	34.66	951.49	0.229E-01	0.126E-06	0.460E+02	0.541E+01	0.218E+
-9.0	35.34	958.43	0.239E-01	0.138E-06	0.470E+02	0.590E+01	0.246E+
-8.5	36.02	965.52	0.251E-01	0.149E-06	0.480E+02	0.640E+01	0.277E+
-8.0	36.69	972.74	0.263E-01	0.161E-06	0.490E+02	0.690E+01	0.310E+
-7.5	37.36	980.09	0.276E-01	0.170E-06	0.501E+02	0.730E+01	0.346E+
-7.0	38.01	987.43	0.290E-01	0.175E-06	0.511E+02	0.751E+01	0.383E+
-6.5	38.65	994.66	0.305E-01	0.177E-06	0.521E+02	0.760E+01	0.420E+
-6.0	39.27	1001.74	0.319E-01	0.179E-06	0.531E+02	0.770E+01	0.459E+
-5.5	39.87	1008.66	0.333E-01	0.182E-06	0.541E+02	0.780E+01	0.497E+
-5.0	40.44	1015.40	0.348E-01	0.181E-06	0.550E+02	0.779E+01	0.536E+
-4.5	40.97	1021.85	0.362E-01	0.177E-06	0.559E+02	0.760E+01	0.575E+
-4.0	41.47	1027.90	0.376E-01	0.170E-06	0.568E+02	0.730E+01	0.612E+
-3.5	41.93	1033.56	0.390E-01	0.167E-06	0.576E+02	0.718E+01	0.648E+
-3.0	42.36	1039.02	0.403E-01	0.173E-06	0.583E+02	0.744E+01	0.685E+
-2.5	42.75	1044.49	0.417E-01	0.188E-06	0.590E+02	0.807E+01	0.724E+
-2.0	43.13	1050.16	0.433E-01	0.206E-06	0.598E+02	0.885E+01	0.764E+
-1.5	43.49	1056.03	0.450E-01	0.224E-06	0.605E+02	0.963E+01	0.812E+
-1.0	43.83	1062.21	0.469E-01	0.254E-06	0.613E+02	0.109E+02	0.863E+
-0.5	44.18	1069.27	0.490E-01	0.317E-06	0.621E+02	0.136E+02	0.925E+
0.0	44.58	1078.39	0.518E-01	0.437E-06	0.632E+02	0.187E+02	0.101E+
0.5	45.11	1091.21	0.558E-01	0.630E-06	0.646E+02	0.270E+02	0.112E+
1.0	45.84	1109.72	0.616E-01	0.906E-06	0.667E+02	0.389E+02	0.128E+
1.5	46.86	1135.94	0.699E-01	0.127E-05	0.696E+02	0.543E+02	0.152E+
2.0	48.25	1171.52	0.815E-01	0.169E-05	0.737E+02	0.725E+02	0.183E+
2.5	50.02	1217.31	0.967E-01	0.215E-05	0.789E+02	0.921E+02	0.225E+
3.0	52.17	1273.13	0.116E+00	0.260E-05	0.854E+02	0.111E+03	0.276E+

Table 6.4 (continued)

3.5	54.65	1337.79	0.138E+00	0.301E-05	0.930E+02	0.129E+03	0.336E+03
4.0	57.36	1409.31	0.164E+00	0.334E-05	0.102E+03	0.143E+03	0.404E+03
4.5	60.20	1482.45	0.192E+00	0.358E-05	0.110E+03	0.154E+03	0.478E+03
5.0	63.04	1559.90	0.222E+00	0.371E-05	0.120E+03	0.159E+03	0.556E+03
5.5	65.78	1636.41	0.252E+00	0.372E-05	0.129E+03	0.160E+03	0.636E+03
6.0	68.32	1709.75	0.282E+00	0.364E-05	0.138E+03	0.156E+03	0.715E+03
6.5	70.59	1778.18	0.310E+00	0.348E-05	0.147E+03	0.149E+03	0.791E+03
7.0	72.53	1840.52	0.337E+00	0.325E-05	0.154E+03	0.140E+03	0.863E+03
7.5	74.12	1896.30	0.363E+00	0.300E-05	0.161E+03	0.129E+03	0.930E+03
8.0	75.38	1945.52	0.386E+00	0.275E-05	0.167E+03	0.118E+03	0.992E+03
8.5	76.32	1988.60	0.407E+00	0.251E-05	0.171E+03	0.108E+03	0.105E+04
9.0	76.98	2026.19	0.426E+00	0.229E-05	0.175E+03	0.983E+02	0.110E+04
9.5	77.39	2059.12	0.443E+00	0.211E-05	0.179E+03	0.905E+02	0.115E+04
10.0	77.60	2088.21	0.459E+00	0.197E-05	0.181E+03	0.844E+02	0.119E+04
10.5	77.64	2114.27	0.474E+00	0.186E-05	0.183E+03	0.798E+02	0.123E+04
11.0	77.55	2138.06	0.489E+00	0.179E-05	0.185E+03	0.767E+02	0.127E+04
11.5	77.36	2160.14	0.503E+00	0.174E-05	0.187E+03	0.746E+02	0.131E+04
12.0	77.07	2180.90	0.517E+00	0.170E-05	0.188E+03	0.732E+02	0.135E+04
12.5	76.72	2200.64	0.530E+00	0.168E-05	0.189E+03	0.722E+02	0.138E+04
13.0	76.30	2219.47	0.543E+00	0.166E-05	0.190E+03	0.713E+02	0.142E+04
13.5	75.82	2237.45	0.557E+00	0.164E-05	0.191E+03	0.703E+02	0.145E+04
14.0	75.28	2254.50	0.570E+00	0.161E-05	0.191E+03	0.691E+02	0.148E+04
14.5	74.69	2270.58	0.582E+00	0.158E-05	0.192E+03	0.676E+02	0.152E+04
15.0	74.05	2285.62	0.595E+00	0.154E-05	0.192E+03	0.659E+02	0.156E+04
15.5	73.35	2299.57	0.607E+00	0.149E-05	0.192E+03	0.641E+02	0.159E+04
16.0	72.60	2312.46	0.619E+00	0.145E-05	0.192E+03	0.622E+02	0.162E+04
16.5	71.80	2324.27	0.630E+00	0.140E-05	0.192E+03	0.601E+02	0.165E+04
17.0	70.97	2335.01	0.641E+00	0.135E-05	0.191E+03	0.581E+02	0.168E+04
17.5	70.10	2344.78	0.652E+00	0.131E-05	0.191E+03	0.564E+02	0.171E+04
18.0	69.20	2353.73	0.662E+00	0.128E-05	0.190E+03	0.548E+02	0.174E+04
18.5	68.27	2361.95	0.672E+00	0.125E-05	0.189E+03	0.537E+02	0.176E+04
19.0	67.34	2369.63	0.682E+00	0.124E-05	0.188E+03	0.531E+02	0.179E+04
19.5	66.39	2376.95	0.692E+00	0.123E-05	0.188E+03	0.527E+02	0.182E+04
20.0	65.45	2383.96	0.702E+00	0.122E-05	0.187E+03	0.523E+02	0.184E+04
20.5	64.50	2390.64	0.712E+00	0.121E-05	0.186E+03	0.519E+02	0.187E+04
21.0	63.55	2397.04	0.721E+00	0.121E-05	0.185E+03	0.517E+02	0.189E+04
21.5	62.61	2403.22	0.731E+00	0.120E-05	0.184E+03	0.515E+02	0.192E+04
22.0	61.66	2409.14	0.740E+00	0.119E-05	0.183E+03	0.511E+02	0.195E+04
22.5	60.72	2414.71	0.750E+00	0.117E-05	0.182E+03	0.504E+02	0.197E+04
23.0	59.78	2419.89	0.759E+00	0.115E-05	0.180E+03	0.495E+02	0.200E+04
23.5	58.85	2424.66	0.768E+00	0.113E-05	0.179E+03	0.483E+02	0.202E+04
24.0	57.91	2428.82	0.777E+00	0.109E-05	0.178E+03	0.466E+02	0.204E+04
24.5	56.96	2432.26	0.786E+00	0.103E-05	0.177E+03	0.444E+02	0.207E+04
25.0	56.01	2434.86	0.794E+00	0.975E-06	0.176E+03	0.418E+02	0.209E+04
25.5	55.06	2436.61	0.801E+00	0.910E-06	0.174E+03	0.390E+02	0.211E+04
26.0	54.10	2437.39	0.808E+00	0.841E-06	0.173E+03	0.361E+02	0.213E+04
26.5	53.13	2437.22	0.815E+00	0.770E-06	0.171E+03	0.331E+02	0.215E+04
27.0	52.16	2436.19	0.821E+00	0.708E-06	0.170E+03	0.304E+02	0.216E+04
27.5	51.20	2434.47	0.826E+00	0.662E-06	0.168E+03	0.284E+02	0.218E+04
28.0	50.24	2432.31	0.831E+00	0.633E-06	0.166E+03	0.271E+02	0.219E+04
28.5	49.30	2429.90	0.836E+00	0.610E-06	0.165E+03	0.262E+02	0.220E+04
29.0	48.37	2427.20	0.841E+00	0.585E-06	0.163E+03	0.251E+02	0.222E+04
29.5	47.46	2424.18	0.846E+00	0.553E-06	0.161E+03	0.237E+02	0.223E+04
30.0	46.55	2420.71	0.850E+00	0.509E-06	0.160E+03	0.218E+02	0.224E+04
30.5	45.66	2416.65	0.854E+00	0.449E-06	0.158E+03	0.193E+02	0.225E+04
31.0	44.76	2411.75	0.857E+00	0.368E-06	0.156E+03	0.158E+02	0.226E+04
31.5	43.87	2405.80	0.860E+00	0.269E-06	0.155E+03	0.115E+02	0.227E+04
32.0	42.97	2398.55	0.861E+00	0.162E-06	0.153E+03	0.694E+01	0.227E+04
32.5	42.06	2390.03	0.862E+00	0.607E-07	0.151E+03	0.260E+01	0.227E+04
33.0	41.16	2380.37	0.862E+00	0.000E+00	0.149E+03	0.000E+00	0.227E+04
33.5	40.26	2369.78	0.862E+00	0.000E+00	0.146E+03	0.000E+00	0.227E+04
34.0	39.37	2358.32	0.862E+00	0.000E+00	0.144E+03	0.000E+00	0.227E+04
34.5	38.49	2346.15	0.862E+00	0.000E+00	0.142E+03	0.000E+00	0.227E+04
35.0	37.62	2333.22	0.862E+00	0.000E+00	0.140E+03	0.000E+00	0.227E+04

Table 6.4 (continued)

35.5	36.76	2319.46	0.862E+00	0.000E+00	0.138E+03	0.000E+00	0.227E+0
36.0	35.91	2304.94	0.862E+00	0.000E+00	0.136E+03	0.000E+00	0.227E+0
36.5	35.07	2289.68	0.862E+00	0.000E+00	0.133E+03	0.000E+00	0.227E+0
37.0	34.24	2273.62	0.862E+00	0.000E+00	0.131E+03	0.000E+00	0.227E+0
37.5	33.42	2256.72	0.862E+00	0.000E+00	0.129E+03	0.000E+00	0.227E+0
38.0	32.60	2238.98	0.862E+00	0.000E+00	0.126E+03	0.000E+00	0.227E+0
38.5	31.80	2220.50	0.862E+00	0.000E+00	0.124E+03	0.000E+00	0.227E+0
39.0	31.01	2201.47	0.862E+00	0.000E+00	0.122E+03	0.000E+00	0.227E+0
39.5	30.24	2182.07	0.862E+00	0.000E+00	0.119E+03	0.000E+00	0.227E+0
40.0	29.49	2162.69	0.862E+00	0.000E+00	0.117E+03	0.000E+00	0.227E+0
40.5	28.76	2143.62	0.862E+00	0.000E+00	0.115E+03	0.000E+00	0.227E+0
41.0	28.05	2124.97	0.862E+00	0.000E+00	0.113E+03	0.000E+00	0.227E+0
41.5	27.38	2106.92	0.862E+00	0.000E+00	0.111E+03	0.000E+00	0.227E+0
42.0	26.73	2089.67	0.862E+00	0.000E+00	0.109E+03	0.000E+00	0.227E+0
42.5	26.11	2073.34	0.862E+00	0.000E+00	0.107E+03	0.000E+00	0.227E+0
43.0	25.51	2057.91	0.862E+00	0.000E+00	0.105E+03	0.000E+00	0.227E+0
43.5	24.94	2043.20	0.862E+00	0.000E+00	0.104E+03	0.000E+00	0.227E+0
44.0	24.39	2029.01	0.862E+00	0.000E+00	0.102E+03	0.000E+00	0.227E+0
44.5	23.86	2015.11	0.862E+00	0.000E+00	0.100E+03	0.000E+00	0.227E+0
45.0	23.34	2001.29	0.862E+00	0.000E+00	0.990E+02	0.000E+00	0.227E+0
45.5	22.84	1987.44	0.862E+00	0.000E+00	0.975E+02	0.000E+00	0.227E+0
46.0	22.35	1973.64	0.862E+00	0.000E+00	0.960E+02	0.000E+00	0.227E+0
46.5	21.87	1960.16	0.862E+00	0.000E+00	0.946E+02	0.000E+00	0.227E+0
47.0	21.41	1947.35	0.862E+00	0.000E+00	0.933E+02	0.000E+00	0.227E+0
47.5	20.98	1935.40	0.862E+00	0.000E+00	0.920E+02	0.000E+00	0.227E+0
48.0	20.56	1924.33	0.862E+00	0.000E+00	0.909E+02	0.000E+00	0.227E+0
48.5	20.16	1914.07	0.862E+00	0.000E+00	0.898E+02	0.000E+00	0.227E+0
49.0	19.78	1904.52	0.862E+00	0.000E+00	0.887E+02	0.000E+00	0.227E+0
49.5	19.41	1895.54	0.862E+00	0.000E+00	0.877E+02	0.000E+00	0.227E+0
50.0	19.06	1886.86	0.862E+00	0.000E+00	0.868E+02	0.000E+00	0.227E+0
50.5	18.71	1878.12	0.862E+00	0.000E+00	0.859E+02	0.000E+00	0.227E+0
51.0	18.37	1869.02	0.862E+00	0.000E+00	0.849E+02	0.000E+00	0.227E+0
51.5	18.03	1859.50	0.862E+00	0.000E+00	0.840E+02	0.000E+00	0.227E+0
52.0	17.69	1849.75	0.862E+00	0.000E+00	0.830E+02	0.000E+00	0.227E+0
52.5	17.37	1840.05	0.862E+00	0.000E+00	0.821E+02	0.000E+00	0.227E+0
53.0	17.05	1830.65	0.862E+00	0.000E+00	0.812E+02	0.000E+00	0.227E+0
53.5	16.74	1821.56	0.862E+00	0.000E+00	0.803E+02	0.000E+00	0.227E+0
54.0	16.45	1812.68	0.862E+00	0.000E+00	0.795E+02	0.000E+00	0.227E+0
54.5	16.16	1804.09	0.862E+00	0.000E+00	0.787E+02	0.000E+00	0.227E+0
55.0	15.88	1795.82	0.862E+00	0.000E+00	0.779E+02	0.000E+00	0.227E+0
55.5	15.61	1787.67	0.862E+00	0.000E+00	0.771E+02	0.000E+00	0.227E+0
56.0	15.34	1779.33	0.862E+00	0.000E+00	0.763E+02	0.000E+00	0.227E+0
56.5	15.08	1770.56	0.862E+00	0.000E+00	0.756E+02	0.000E+00	0.227E+0
57.0	14.82	1761.47	0.862E+00	0.000E+00	0.748E+02	0.000E+00	0.227E+0
57.5	14.56	1752.39	0.862E+00	0.000E+00	0.740E+02	0.000E+00	0.227E+0
58.0	14.31	1743.62	0.862E+00	0.000E+00	0.733E+02	0.000E+00	0.227E+0
58.5	14.07	1735.16	0.862E+00	0.000E+00	0.725E+02	0.000E+00	0.227E+0
59.0	13.84	1726.75	0.862E+00	0.000E+00	0.718E+02	0.000E+00	0.227E+0
59.5	13.61	1718.05	0.862E+00	0.000E+00	0.711E+02	0.000E+00	0.227E+0
60.0	13.38	1708.76	0.862E+00	0.000E+00	0.704E+02	0.000E+00	0.227E+0
60.5	13.14	1698.70	0.862E+00	0.000E+00	0.696E+02	0.000E+00	0.227E+0
61.0	12.91	1687.90	0.862E+00	0.000E+00	0.688E+02	0.000E+00	0.227E+0
61.5	12.68	1676.60	0.862E+00	0.000E+00	0.679E+02	0.000E+00	0.227E+0
62.0	12.45	1665.08	0.862E+00	0.000E+00	0.671E+02	0.000E+00	0.227E+0
62.5	12.22	1653.67	0.862E+00	0.000E+00	0.663E+02	0.000E+00	0.227E+0
63.0	12.01	1642.62	0.862E+00	0.000E+00	0.655E+02	0.000E+00	0.227E+0
63.5	11.80	1632.05	0.862E+00	0.000E+00	0.647E+02	0.000E+00	0.227E+0
64.0	11.60	1622.00	0.862E+00	0.000E+00	0.640E+02	0.000E+00	0.227E+0
64.5	11.41	1612.38	0.862E+00	0.000E+00	0.633E+02	0.000E+00	0.227E+0
65.0	11.22	1603.07	0.862E+00	0.000E+00	0.627E+02	0.000E+00	0.227E+0
65.5	11.04	1593.95	0.862E+00	0.000E+00	0.620E+02	0.000E+00	0.227E+0
66.0	10.86	1584.94	0.862E+00	0.000E+00	0.614E+02	0.000E+00	0.227E+0
66.5	10.68	1575.87	0.862E+00	0.000E+00	0.608E+02	0.000E+00	0.227E+0
67.0	10.51	1566.65	0.862E+00	0.000E+00	0.602E+02	0.000E+00	0.227E+0

Table 6.4 (continued)

67.5	10.34	1557.17	0.862E+00	0.000E+00	0.595E+02	0.000E+00	0.227E+
68.0	10.17	1547.63	0.862E+00	0.000E+00	0.589E+02	0.000E+00	0.227E+
68.5	10.01	1538.12	0.862E+00	0.000E+00	0.583E+02	0.000E+00	0.227E+
69.0	9.85	1528.48	0.862E+00	0.000E+00	0.577E+02	0.000E+00	0.227E+
69.5	9.69	1518.64	0.862E+00	0.000E+00	0.570E+02	0.000E+00	0.227E+
70.0	9.53	1508.94	0.862E+00	0.000E+00	0.564E+02	0.000E+00	0.227E+
70.5	9.38	1499.54	0.862E+00	0.000E+00	0.558E+02	0.000E+00	0.227E+
71.0	9.23	1490.45	0.862E+00	0.000E+00	0.552E+02	0.000E+00	0.227E+
71.5	9.09	1481.38	0.862E+00	0.000E+00	0.547E+02	0.000E+00	0.227E+
72.0	8.95	1472.12	0.862E+00	0.000E+00	0.541E+02	0.000E+00	0.227E+
72.5	8.81	1462.86	0.862E+00	0.000E+00	0.535E+02	0.000E+00	0.227E+
73.0	8.67	1453.82	0.862E+00	0.000E+00	0.530E+02	0.000E+00	0.227E+
73.5	8.54	1444.92	0.862E+00	0.000E+00	0.524E+02	0.000E+00	0.227E+
74.0	8.41	1436.11	0.862E+00	0.000E+00	0.519E+02	0.000E+00	0.227E+
74.5	8.28	1427.24	0.862E+00	0.000E+00	0.514E+02	0.000E+00	0.227E+
75.0	8.15	1418.32	0.862E+00	0.000E+00	0.509E+02	0.000E+00	0.227E+
75.5	8.03	1409.54	0.862E+00	0.000E+00	0.504E+02	0.000E+00	0.227E+
76.0	7.91	1400.85	0.862E+00	0.000E+00	0.498E+02	0.000E+00	0.227E+
76.5	7.80	1392.56	0.862E+00	0.000E+00	0.494E+02	0.000E+00	0.227E+
77.0	7.69	1385.14	0.862E+00	0.000E+00	0.489E+02	0.000E+00	0.227E+
77.5	7.58	1378.31	0.862E+00	0.000E+00	0.485E+02	0.000E+00	0.227E+
78.0	7.48	1371.33	0.862E+00	0.000E+00	0.481E+02	0.000E+00	0.227E+
78.5	7.38	1363.76	0.862E+00	0.000E+00	0.477E+02	0.000E+00	0.227E+
79.0	7.27	1355.68	0.862E+00	0.000E+00	0.472E+02	0.000E+00	0.227E+
79.5	7.17	1347.38	0.862E+00	0.000E+00	0.468E+02	0.000E+00	0.227E+
80.0	7.07	1339.15	0.862E+00	0.000E+00	0.463E+02	0.000E+00	0.227E+
80.5	6.97	1331.04	0.862E+00	0.000E+00	0.459E+02	0.000E+00	0.227E+
81.0	6.87	1323.13	0.862E+00	0.000E+00	0.454E+02	0.000E+00	0.227E+
81.5	6.78	1315.52	0.862E+00	0.000E+00	0.450E+02	0.000E+00	0.227E+
82.0	6.69	1308.39	0.862E+00	0.000E+00	0.446E+02	0.000E+00	0.227E+
82.5	6.60	1301.85	0.862E+00	0.000E+00	0.443E+02	0.000E+00	0.227E+
83.0	6.52	1295.77	0.862E+00	0.000E+00	0.440E+02	0.000E+00	0.227E+
83.5	6.44	1289.81	0.862E+00	0.000E+00	0.436E+02	0.000E+00	0.227E+
84.0	6.36	1283.73	0.862E+00	0.000E+00	0.433E+02	0.000E+00	0.227E+
84.5	6.28	1277.56	0.862E+00	0.000E+00	0.430E+02	0.000E+00	0.227E+
85.0	6.20	1271.12	0.862E+00	0.000E+00	0.426E+02	0.000E+00	0.227E+

TABLE 6.5 COMPARATIVE RESULTS

	Speed 1000 rpm		Speed 2000 rpm	
	$\frac{1}{2}$ load	$\frac{3}{4}$ load	$\frac{1}{2}$ load	$\frac{3}{4}$ load
Torque (MEP)	12.7	19.0	12.5	15.8
BMEP (BAR)	4.1	6.2	4.1	5.1
IMEP (BAR)	7.1	9.3	7.4	9.5
Max Pressure (BAR)	65.1	72.2	68.5	77.6
Predicted mass fuel burnt (kg/cyc/cyl)	$.363 \cdot 10^{-4}$	$.488 \cdot 10^{-4}$	$.399 \cdot 10^{-4}$	$.529 \cdot 10^{-4}$
Predicted air/fuel ratio	25.5	19.0	23.2	17.5

7. CONCLUSIONS AND RECOMMENDATIONS

The data logging function of the PDP 15 has been installed on a PDP 11/3 computer and all the software rewritten.

The objectives as set out in Chapter 1 have been realised for Phase 2 of the new system. The control function of the PDP 15 will soon be implemented on a Texas Instruments 9900 microcomputer (Chapters 1 and 3). The final task of incorporating the two systems together to perform transient engine tests will be the subject of further work.

The existing on-line and off-line data loggers were successfully interfaced to the PDP 11/3 using only two input/output cards. The device selection logic (Chapter 4) proved to be very reliable and easy to implement by software. New speed measurement logic circuits were devised based upon existing designs and successfully integrated into the system. Both low pressure turbocharger speed measurement and engine revolution counter were tested using the diagnostic software and were found to be satisfactory.

The on-line data logger showed that its data acquisition rate would be limited only by the software and the data transfer rate through the general purpose input/output card,

the DRV11 (about 40KHz). The multiplexer selection logic enabled all 32 channels to be accessed by software (Chapter 4). The off-line data logger was modified considerably yet reflected the main design aims of the previous PDP 15 system. Full control was obtained over the multiplexing sequence of the ADC and a rate of 500KHz recorded for transfers into 8K rotating store memory. A performance of 220KHz was obtained by the direct memory access function in transferring data from 8K store to computer memory.

Software on the PDP 11/3 proved to be up to four times slower than the PDP 15 (Chapter 3). However, by optimising the code (Chapter 5), an overall performance very much comparable to the PDP 15 was obtained. For example, during steady state tests, the data logging control unit cycle skip counter (Chapter 2) was set to 6 for most of the engine speed range; whereas the PDP 15 system could obtain a skipped sequence of 1 in 4. Overall the software was finished with a "friendly" user interface incorporating numerous options (Chapter 5). A diagnostic package was developed to exercise all the new interfaces. A data acquisition program was designed which catered for all test configurations in steady state together with full results printout on an 80 column or 132 column printer. A plotting

option was also furnished for results output in the form of a 79 x 20 matrix histogram. A version of the Imperial College apparent fuel burning rate program was implemented on the system which provided heat release results from logged cylinder pressure records. Full documentation was written for all three packages, copies of which appear in the Appendix.

Finally, the whole system was successfully tested on a Perkins 4.236 diesel engine driving an eddy current brake (Chapter 6). The heat release results derived from this engine compared well with results off the PDP 15 system obtained by other researchers. This confirmed the overall integrity of the system and gave confidence in its use for future research projects.

The following are recommendations for future work in this field:

7.1. TRANSIENT SOFTWARE

The data acquisition software "ACQUIS" should be enhanced to include engine transients data logging. Similarly, results display and processing should be adapted to include transients capability. This should not be a difficult task in view of the modular structure of "ACQUIS" (Chapter 5).

7.2. OVERALL SYSTEM DEVELOPMENT

The overall system development in terms of interfacing the various peripherals (Tektronix terminal and magnetic tape unit) and the Texas Instrument 9900 control micro-computer (Chapter 3) should continue. The software on the control computer is complete and should be married to the PDP 11 system during the transient work development.

Further possible enhancements to the PDP 11 system would be updating the central processing unit card to the PDP LSI-11/23. The LSI11/23 is about twice as fast as the existing unit and would speed up the software considerably. Moreover, the LSI11/23 can address over the 32K memory limit on the existing version. Hence more memory may be added thereby making the system more effective (e.g. the slow process of "chaining" (Chapter 5) may be eliminated by making all the routines in ACQUIS memory resident).

The data logging system chosen is thus adaptable and should be able to accommodate all requirements that will be met in a diesel engine research environment. This flexibility, both in hardware and software, will serve it well as new fields are explored in engine transients performance, combustion and electronic governing.

8.

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APPENDIX

- A Plessey Peripheral Systems Micro-1 System
- B System Testing Hardware
- C "DINT" (Diagnostics) Software Documentation
- D. "ACQUIS" (Data Logging) Software Documentation
- E. "PROCES" (heat Release Calculation) Software
Documentation

APPENDIX A : PLESSEY PERIPHERAL SYSTEMS MICRO-1 SYSTEM

Computer Hardware Configuration (Ref 17)

Digital Equipment Corporation PDP LSI 11/2
microprocessor with KEV11 extended arithmetic
chip.

PM SV32A 32K word dynamic memory with on-
board refresh

REV11 automatic bootstrap

RK05 Disk controller (one fixed 2.5MB disk
and one removable 2.5MB disk).

DLV115 4 port RS232C serial interface.

DRV11 general purpose parallel interface card

DRV11B direct memory access (DMA) interface card

DT2769 real time clock card.

DECwriter LA36 132 column dot matrix line printer

Datamedia Elite 3052 Visual Display Unit (VDU)
with scrolling 24 x 80 character format and DEC
VT52 emulation

Computer Software Configuration (Ref 16)

RT-11 V03B single user utility operating system

Fortran V2.1 compiler with system library
running under RT-11.

B.1 Engine

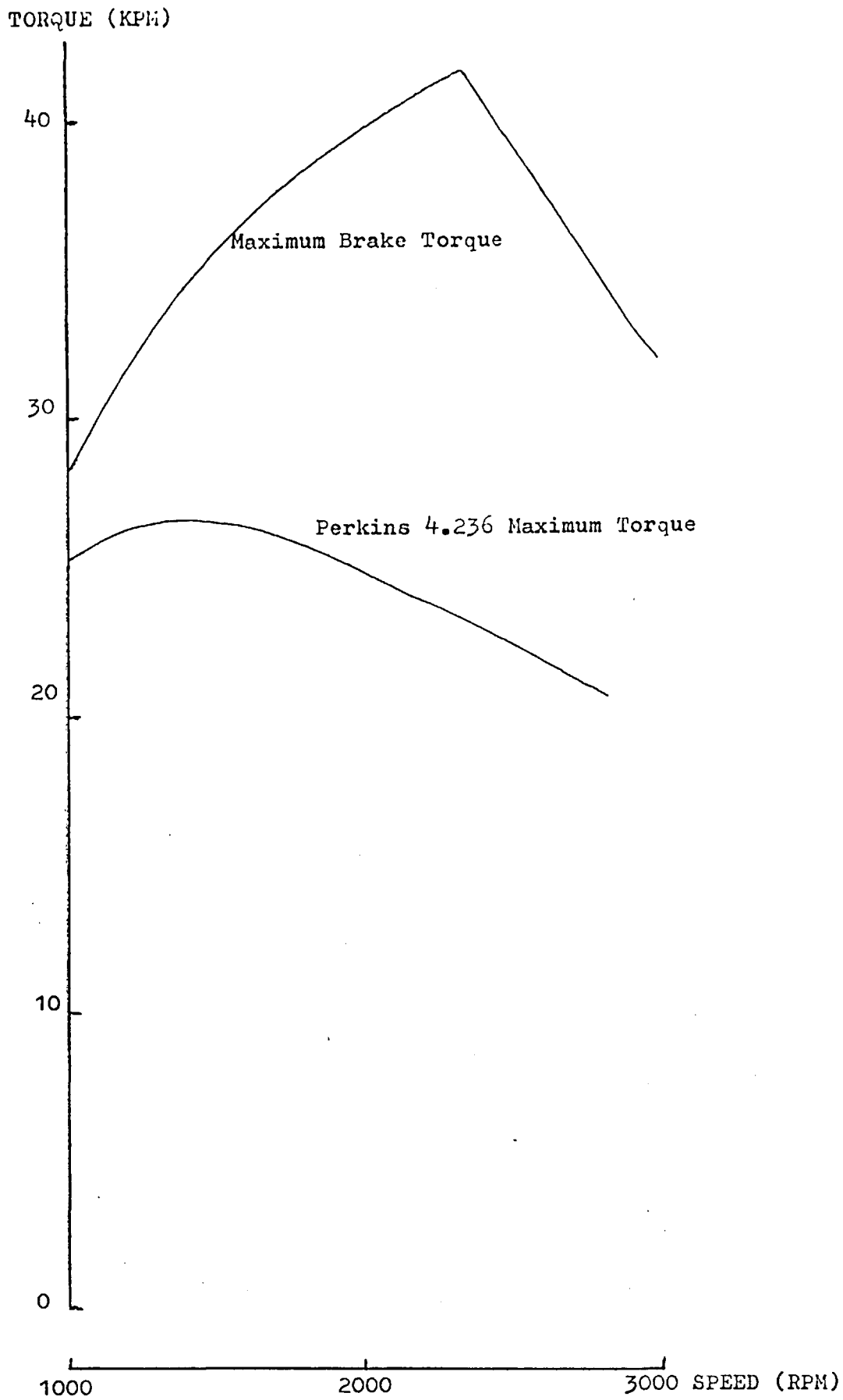
16:1 compression ratio

Govenor set by manual control of a SIGMA E3.78
stepping motor connected to the fuel pump control

B.2 DYNAMOMETER

See Fig B.1 for brake torque map

Fig. B.1 Engine and Brake Performance



B.3 TRANSDUCERS AND SIGNAL CONDITIONING

B.3.1 Cylinder Pressure

A water-cooled piezoelectric pressure transducer (AVL 12QP500C) recessed from the cylinder head wall (number 1 cylinder) to minimise thermal shock (Ref 4) was used. The transducer was connected to a Kisler E568 high impedance charge amplifier. A one volt offset to the signal (to prevent occurrence of negative values) was introduced by a Fylde Electronics Amplifier set to unity gain.

B.3.2 Fuel Line Pressure

The injection or fuel line pressure was measured by a standard AVL strain gauge transducer (21DP500E.2) set immediately in front of number 1 injector.

B.4 Engine crankshaft angular measurement

A commercial, heavy-duty, optical position encoder (Ferranti 28 H2/M4) was coupled to the engine via a minature carden shaft (Ref 4). The unit gave an output which could be resolved to $1/8^\circ$. An additional track gave a once per revolution pulse. These signals were connected to the data logging control unit (Chapter 4).

Determination of TDC in relation to the train of pulses was found from a motored cylinder pressure diagram (Ref 4); taking note of the point of maximum pressure. This was consistent over a speed range of 1000 to 2800 rpm.

THIS FILE IS CALLED "DINT.TXT"

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*****
*
* I.C. DATA LOGGING SYSTEM DIAGNOSTICS
*
*****

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NAME - DINT PACKAGE, VERSION V01.02

AUTHOR - LEWIS ROBERTS

DATE - MARCH 1980

SUMMARY -

'DINT' IS A COMPLETE DIAGNOSTIC PACKAGE FOR THE
DATA ACQUISITION INTERFACES ASSOCIATED
WITH THE PDP LSI-11 IN ROOM 122, MED, IMPERIAL COLLEGE.
THE PRODUCT TESTS ALL 8 CHANNELS CONNECTED TO THE
DRV11 AS WELL AS THE 8K STORE DMA VIA THE DRV11B.
'DINT' INTERFACE WITH THE USER IS THROUGH A SIMPLE DIALOGUE
ON THE VDU.

FIRST-TIME USERS -

YOU SHOULD READ THE SECTIONS WITH UNDERLINED HEADINGS
BEFORE READING THE WHOLE FILE THROUGH. KEEP A LISTING OF THIS
DOCUMENT IN FRONT OF YOU WHILE YOU RUN 'DINT'

HARDWARE REQUIREMENTS -

PDP LSI-11, CONSOLE, DT2769 (RT-CLOCK), DRV11, DRV11B,
I.C. INTERFACES

SOFTWARE REQUIREMENTS -

RT-11 V03B

FORTRAN 77

UTILITY.OBJ (UTILITY LIBRARY) V01.01
MONLIB.OBJ (USER INTERFACE LIBRARY) V01.01

OPERATION(SWITCH ON/SWITCH OFF) -

ENSURE PDP-11 BOOTED ON RK0: WITH 'WRITE PROTECT' SWITCH OFF ON REM. DISK
POWER UP I.C. INTERFACES & CONNECT PULSE GENERATOR AS
NECESSARY(SEE LATER). SOME TESTS, E.G. ADC CONVERSION,
MAY ALSO REQUIRE AN ACCURATE VOLTAGE SOURCE.
TYPE IN AT THE CONSOLE:
"R DINT" ("CARRIAGE RETURN")
PROGRAM WILL NOW RUN
TO RETURN TO RT-11, ENTER:
"EXIT" ("CARRIAGE RETURN")

LIMITATIONS -

V01.02 DOES NOT TEST -
. T/C 2 SPEED READ, DEVICE #1(NOT BUILT)

DINT/MONLIB INTERFACE -

DINT IS INTERFACED TO THE USER VIA 'MONLIB', THE GENERAL PURPOSE
USER INTERFACE SYSTEM. MONLIB IS A FLEXIBLE, 'FRIENDLY', VDU
INTERFACE WHICH AFFORDS SOME PROTECTED FIELD CAPABILITY TO
THE CONSOLE. FOR FURTHER DETAILS, PLEASE REFER TO "MONLIB.TXT",
THE DOCUMENTATION FILE FOR MONLIB.

DINT COMMANDS -

THE FOLLOWING IS A DESCRIPTION OF THE POSSIBLE COMMANDS(TO THE PROMPT ">")
AVAILABLE TO THE USER WHEN RUNNING 'DINT'

("CARRIAGE RETURN" ONLY): REPEATS THE PREVIOUS TEST. THIS IS NOT
ACCEPTABLE FOR SOME PRIOR COMMANDS(E.G. "CHANNEL") AND AN APPROPRIATE
ERROR MESSAGE WILL BE GIVEN

"HELP": GIVES A LISTING OF ALL THE VARIOUS COMMAND/ARGUMENT(S)
COMBINATIONS AVAILABLE IN THE PACKAGE. USE "CS" (CTRL) (S) KEYS TO
TEMPORARY STOP SCREEN OUTPUT, THENCE "CQ" (CTRL) (Q) TO RESTART.
ACCEPTS THE FOLLOWING ARGUMENTS

(NO ARGUMENT)=DEFAULT, TYPE TO VDU

"TYPE"=TYPE TO VDU

"PRINT"=OUTPUT TO PRINTER

"MONITOR": TYPES ON VDU THE VERSION NUMBER OF 'MONLIB', THE GENERAL USER INTERFACE
WHICH IS USED BY THIS PROGRAM

"DEVICE": SELECTS A DEVICE & PAUSES(ARGUMENTS 0-7, DEFAULT IS ALL)

"CARRIAGE RETURN" TO RETURN TO MONLIB.

"TEST": RUNS A DIAGNOSTIC ON A DEVICE(S) ONCE ONLY(Arguments 0-7, Default is All) THEN RETURNS TO MONLIB.

"REPEAT": REPEATS A DIAGNOSTIC CONTINUOUSLY(Arguments 0-7, Default is All)
NOTE: TO BREAK THIS TEST, ENTER "C" & RE-RUN DINT BY TYPING IN: "R DINT"

"LOOP": EXERCISES A DEVICE AND LOOPS ON ANY TEST THAT SHOWS AN ERROR (Arguments 0-7, Default is All). SAME PROCEDURE TO BREAK THE LOOP AS "REPEAT" ABOVE

"STOP": EXERCISES A DEVICE(S) AND PAUSES ONCE AN ERROR IS DETECTED (Arguments 0-7, Default is All) TEST RETURNS TO MONLIB

"MESSAGES": CAN ACCEPT 3 ARGUMENTS-
"TYPE"=MESSAGES APPEAR ON THE VDU(Also the Default-No Arg.)
"PRINT"=MESSAGES PRINTED ON THE LA36
"INHIBIT"=NO MESSAGE OUTPUT, EXCEPT PAUSE & MONLIB MESSAGES

"HALT": FORCES THE CPU INTO ODT MODE. ENTER "P" TO CONTINUE THEREAFTER.
FOR INFORMATION ON ODT MODE, REFER TO DEC LSI-11 PROCESSOR HANDBOOK

"EXIT": RETURNS TO RT-11 MONITOR

"WAIT": SETS A PAUSE BETWEEN EACH CHANNEL TEST ON THE SLOW ADC(DEVICE #2)
FOR A SINGLE TEST RUN ONLY, I.E. RETURNS TO NORMAL AFTER ONE COMPLETE TEST (NO PAUSES BETWEEN CHANNEL TESTS)

"DOCUMENTATION": PRODUCES A LISTING ON EITHER VDU OR LINE PRINTER
(SEE MESSAGES COMMAND) OF THIS FILE "DINT.TXT". USE "S" (CTRL) (S) TO SUSPEND LISTING AND "C" (CTRL) (Q) TO CONTINUE THEREAFTER

"ACQUISITION": CHAINS 'DINT' TO THE ACQUISITION PACKAGE 'ACQUIS'(SEE "ACQUIS.TXT" DOCUMENTATION)

"PROCESS": CHAINS 'DINT' TO THE PROCESSING PACKAGE 'PROCES'(SEE "PROCES.TXT" DOCUMENTATION)

"CHANNEL": SELECTS FAST ADC MULTIPLEXING SEQUENCE. THIS COMMAND MUST BE ISSUED PRIOR TO TESTING #7(FAST ADC AND DMA TEST)
"CHANNEL" COMMAND MUST BE FOLLOWED BY 2 ARGUMENTS IN THE ORDER -
("SINGLE" OR "MPX") (ANY CHANNEL "0" TO "7")
NOTE THAT A MULTIPLEXING SEQUENCE ALWAYS ENDS AT CHANNEL 7

NOTE: MONLIB(THE USER INTERFACE PROGRAM) WILL ACCEPT ABBREVIATIONS
*** OF COMMANDS & ARGUMENTS, FOR EXAMPLE:
'T' WILL BE ACCEPTED AS THE COMMAND 'TEST'

WHAT TO DO IF DINT ENTERS A "LOOP" -
IF DINT FALLS INTO A "LOOP" OR "HANGS" (NOTHING SEEMS TO HAPPEN)
TYPE IN "C" ("CTRL" & "C" KEYS TOGETHER). YOU SHOULD THEN RETURN TO RT-11 MONITOR. IF A BELL TONE IS HEARD, DEPRESS RED 'RESET' BUTTON ON THE VDU THEN "C".
IF ALL ELSE FAILS, RE-BOOT RT-11 & START AGAIN
TO RE-START DINT, TYPE IN:
"R DINT" ("RETURN")

DEVICE TESTS --

NOTE: "DATA TRANS." & "DATA READY" DRV11 SIGNALS CLEAR
THE REQA FLAG USED BY THE I.C. INTERFACE
REQB FLAG(OVERRUN ERROR) CAN BE CLEARED BY LOADING THE
DOWNCOUNTER(DEVICE #5) BUT BEWARE OF THE 1 MS DELAY !

#0 - T/C 1 SPEED READ

TYPICAL T/C SPEEDS WOULD BE AROUND 60,000 RPM
(ABOUT 1.0 KHZ). THE CLOCK COUNT AT 500 KHZ
BETWEEN REVOLUTIONS OF THE ROTOR SHAFT IS
READABLE ON THIS DEVICE. THE COUNTER IS UPDATED
EVERY ROTOR REVOLUTION, KICKING UP REQA FLAG.
FOR THIS DIAGNOSTIC, YOU SHOULD HAVE A PULSE GENERATOR
@ 1KHZ CONNECTED UP TO THE T/C1 BNC SOCKET. THIS
SHOULD GIVE A READING OF 500 DECIMAL, 764 OCTAL

#1 - T/C 2 SPEED READ

THIS UNIT WILL NOT BE BUILT TILL LATE 1980. ITS
OPERATIONAL CHARACTERISTIC WILL, HOWEVER, BE SIMILAR
TO T/C 1 SPEED READ ABOVE.

#2 - SLOW ADC (10BIT,30KHZ)

THIS IS A 32 SINGLE-ENDED CHANNEL MULTIPLEXED UNIT.
THE CHANNELS ARE ARRANGED IN 8 COLUMNS BY 4 ROWS.
COLUMN NUMBER IS DECODED FROM BITS 0-2, ROW NUMBER SIMILARLY FROM
BITS 3-5. REQA IS SET WHEN ADC CONVERSION IS COMPLETE.

#3 - DLCU STOP/START CONTROL

CLEARING BIT0 IN DROUT STARTS DLCU. SETTING BIT0 STOPS IT.
THE FIRST SKIPPED CYCLE PULSE AFTER STARTING THE DLCU SETS
REQA. FOR THIS DIAGNOSTIC YOU SHOULD HAVE A FERRANTI ENCODER
CONNECTED TO THE DLCU(OR SIMULATED BY A PULSE GENERATOR)
WITH THE ENGINE RUNNING AT IDLE(APPROX 400 RPM). THE SKIPPED
CYCLE SHOULD BE SET TO '5'. THUS -

REV PULSE RATE = 6.6 HZ

CYCLE PULSE RATE = 3.3 HZ

SKIPPED CYCLE PULSE RATE = 0.55 HZ (MISS 5- 1 IN 6)

#4 - REVOLUTION PULSE COUNTER

THIS IS A 12BIT PULSE COUNTER WITH OVERFLOW TO 0.
IT COUNTS THE NUMBER OF ENGINE REVOLUTION PULSES.
THE MAXIMUM NORMAL RATE FOR DIESELS IS 3000 RPM.

50 HZ(20MS PERIOD).
SETTING BIT0 IN DROUT CLEARS THE COUNTER
FOR THIS DIAGNOSTIC, USE A SQUARE WAVE PULSE GENERATOR
SET TO 1 KHZ. THIS SHOULD GIVE A "TIMED" READING OF
APPROX 320 DECIMAL, 505 OCTAL

#5 - 8K STORE DOWNCOUNTER

LOADING THE 11 BIT COUNTER (WITH BIT13 SET) CLEARS THE D/C EMPTY
& REQB. WITH BIT13 CLEAR, REQA IS RAISED WHEN THE DOWNCOUNTER
IS EMPTY(THIS INCLUDES AN INTERNAL 1MS DELAY). SHOULD AN ADC CONVERT
PULSE ARRIVE WHILST THE D/C IS EMPTY, REOB IS AUTOMATICALLY RAISED-
THIS IS THE OVERRUN CONDITION.
THE ROUTINE REQUIRES A PULSE GENERATOR SET TO NO LESS THAN 250 HZ.
A PROMPT WILL BE GIVEN TO CHANGE THIS OVER TO MANUAL TO CHECK THAT
7 PULSES CLEAN THE PRE-SET COUNTER(ENSURE PULSE MULTIPLIER IS SET TO 1)
REMEMBER TO CHANGE PULSE GENERATOR BACK TO CONTINUOUS BEFORE CONTINUING.

#6 - FAST ADC MULTIPLEXING MODE

THIS TEST ASSUMES THE PREVIOUS TEST WAS SUCCESSFUL. THE PULSE
GENERATOR SHOULD AGAIN BE PUT IN MANUAL MODE.
A PAUSE WILL OCCUR BETWEEN EACH CHANNEL SELECTED, FIRST IN
"SINGLE" MODE THEN IN "MPX" MODE. IN THE LATTER CASE, DEPRESS
THE 'MANUAL' BUTTON ON THE PULSE GENERATOR AND VIEW THE
CHANNEL INDEXING ACTION (NOTE THAT MPX SEQUENCES ALWAYS END ON
CHANNEL 7).
BEFORE PROGRESSING TO ANOTHER TEST, RESET THE GENERATOR ON CONTINUOUS

#7 - 8K STORE READ/WRITE AND DMA

ENSURE THAT A CHANNEL SEQUENCE HAS BEEN SELECTED PRIOR TO
THIS TEST.
THE ROUTINE TAKES 20 READINGS FROM THE ADC & 8K STORE, DMA
TO PDP LSI-11 MEMORY THEN DISPLAYS THE RESULT ON THE VDU SCREEN.
(NOTE- WITH MPX CHANNELS, THE CHANNEL SELECT IS RESET TO THE
STARTING CHANNEL AT THE END)

DINT MESSAGES -

THESE ARE SELF-EXPLANATORY AND ARE INCLUDED HERE FOR
REFERENCE ONLY. REFER TO PROGRAM LISTINGS FOR MORE
DETAILS. ONLY '-F-' & '-W-' TYPE MESSAGES ARE LISTED.
THE PREFIX REFERS TO THE PROGRAM MODULE FLAGGING THE
MESSAGE.

-F- MESSAGES ARE FATAL ERROR CONDITIONS. CONTROL RETURNED
TO DINT MONITOR
-W- MESSAGES ARE WARINGS OF POSSIBLE ERRORS. EXECUTION CONTINUES
-I- MESSAGES ARE INFORMATION ONLY

NOTE: WHEN DINT IS PROCESSING YOUR COMMAND, THE MESSAGE
"WORKING" WILL FLASH ON THE RIGHT HAND SIDE OF THE
SCREEN. WAIT FOR THIS TO CLEAR BEFORE YOUR NEXT INPUT.
THE KEYBOARD IS SUSPENDED WHILST THE COMPUTER IS "WORKING".
IF YOU WISH TO TERMINATE THE PROGRAM EXECUTION, PUSH THE
RED BUTTON ON THE CONSOLE AND ENTER "CC" TO RETURN TO RT-11.

137. !DINTZ-W-DINT0 STOP
!DINTZ-W-DINT1 STOP
!DINTZ-W-DINT2 STOP
!DINTZ-W-DINT3 STOP
!DINTZ-W-DINT4 STOP
!DINTZ-W-DINT5 STOP
!DINTZ-W-DINT6 STOP
!DINTZ-W-DFDMA STOP
!DINTZ-F-MONLIB ERROR
!DINTZ-F-PREVIOUS COMMAND NOT REPEATABLE
!DINTZ-F-INVALID CHANNEL SELECTION
!DINT0-F-REQA NOT SET
!DINT0-F-REQA NOT CLEARED BY "DATA TRANS."
!DINT0-F-REQA NOT CLEARED BY "DATA READY"
!DINT1-F-T/C2 INTERFACE NOT OPERATIONAL
!DINT2-F-INVALID MPX CHANNEL SELECTION
!DINT2-F-REQA NOT SET BY DRIN UPDATE
!DINT2-F-REQA NOT CLEARED BY "DATA TRANS."
!DINT2-F-REQA NOT CLEARED BY "DATA READY"
!DINT3-F-REQA SET WHEN DLCU ARRESTED
!DINT3-F-REQA NOT RAISED WHEN DLCU STARTED
!DINT3-F-REQA NOT CLEARED BY "DATA TRANS."
!DINT3-F-REQA NOT CLEARED BY "DATA READY"
!DINT4-F-COUNTER NOT CLEARED BY LSB IN DROUT
!DINT4-F-COUNTER NOT INCREMENTING
!DINT4-F-COUNTER SHOULD NOT HAVE BEEN CLEARED BY LSB IN DROUT
!DINT4-F-REQA NOT SET WHEN COUNTER INCREMENTS
!DINT4-F-REQA NOT CLEARED BY "DATA TRANS."
!DINT4-F-REQA NOT CLEARED BY "DATA READY"
!DINT4-F-COUNTER DOES NOT OVERFLOW TO ZERO
!DINT5-F-D/C EMPTY FLAG NOT SET

!DINT5-F-D/C EMPTY FLAG NOT CLEARED
 !DINT5-F-OVERRUN FLAG NOT CLEARED
 !DINT5-F-OVRERRUN FLAG NOT SET
 !DINT6-F-INVALID MPX SELECTION
 !DFDMA-F-NO CHANNEL

DINT SOFTWARE ORGANISATION -

MONLIB -(MONLIB.DAT)

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 DINTZ
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SUPPORT -
 L. ROBERTS*, D. BLOXHAM

UPDATES -
 L. ROBERTS*

*UNTIL OCTOBER 1980, THEREAFTER OTHER ROOM 122 STAFF.

THIS FILE IS CALLED 'ACQUIS.TXT'

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*****
*
* I.C. DATA LOGGING SYSTEM PACKAGE
*
*****
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NAME - ACQUIS PACKAGE, VERSION V01.01

AUTHOR - LEWIS ROBERTS

DATE - AUGUST 1980

SUMMARY -

'ACQUIS' IS A COMPLETE DATA LOGGING SYSTEM FOR USE ON THE PDP-11 SYSTEM IN ROOM 122, IMPERIAL COLLEGE, LONDON. VERSION V01.01 IS CAPABLE OF FULL STEADY-STATE DATA ACQUISITION AT ALL ENGINE SPEEDS AND LOADS WHILST FUTURE VERSIONS WILL ALSO BE CAPABLE OF TRANSIENT DATA LOGGING. THE PACKAGE HAS VARIOUS POST-PROCESSING SOFTWARE ALGORITHMS AND HISTOGRAM PLOTTING ROUTINES TO DISPLAY RESULTS. 'ACQUIS' INTERFACE WITH THE USER IS THROUGH 'MONLIB', THE GENERAL PURPOSE USER INTERFACE.

FIRST-TIME USERS -

YOU SHOULD READ THE SECTIONS WITH UNDERLINED HEADINGS BEFORE READING THE WHOLE FILE THROUGH. KEEP A LISTING OF THIS DOCUMENT IN FRONT OF YOU WHILE YOU RUN 'ACQUIS'

HARDWARE REQUIREMENTS -

PDP LSI-11, CONSOLE, DT2769 (RT-CLOCK), DRV11, DRV11R,
I.C. INTERFACES & AN ENGINE OR EMULATOR

SOFTWARE REQUIREMENTS -

RT-11 V03B
FORTRAN F2.1
UTILITY.OBJ (UTILITY LIBRARY) V01.01
MONLIB.OBJ (USER INTERFACE LIBRARY) V01.01

OPERATION(SWITCH ON/SWITCH OFF) -

ENSURE PDP-11 BOOTED ON RKO: WITH 'WRITE PROTECT' SWITCH OFF ON BOTH DISKS
POWER UP I.C. INTERFACES & CONNECT UP ANALOGUE SIGNALS TO
THE ADC & DIGITIZER TRACK TO THE DLCU UNIT. SET THE DLCU DECADE
COUNTERS APPROPRIATE TO YOUR TEST.

TYPE IN AT THE CONSOLE:

"R ACQUIS" ("CARRIAGE RETURN")

PROGRAM WILL NOW RUN

TO RETURN TO RT-11, ENTER:

"EXIT" ("CARRIAGE RETURN")

LIMITATIONS -

V01.01 CANNOT PERFORM TRANSIENT TESTS

V01.01 DOES NOT LOG THE ON-LINE ADC

V01.01 DOES NOT READ TURBOCHARGER SPEEDS

ACQUIS/MONLIB INTERFACE -

ACQUIS IS INTERFACED TO THE USER VIA 'MONLIB', THE GENERAL PURPOSE
USER INTERFACE SYSTEM. MONLIB IS A FLEXIBLE, 'FRIENDLY', VDU
INTERFACE WHICH AFFORDS SOME PROTECTED FIELD CAPABILITY TO
THE CONSOLE. FOR FURTHER DETAILS, PLEASE REFER TO "MONLIB.TXT",
THE DOCUMENTATION FILE FOR MONLIB.

ACQUIS COMMANDS -

THE FOLLOWING IS A DESCRIPTION OF THE POSSIBLE COMMANDS(TO THE PROMPT ">")
AVAILABLE TO THE USER WHEN RUNNING 'ACQUIS'

("CARRIAGE RETURN" ONLY): REPEATS THE PREVIOUS TEST. THIS IS NOT
ACCEPTABLE FOR SOME PRIOR COMMANDS(E.G. "CHANNEL") AND AN APPROPRIATE
ERROR MESSAGE WILL BE GIVEN

"HELP": GIVES A LISTING OF ALL THE VARIOUS COMMAND/ARGUMENT(S)
COMBINATIONS AVAILABLE IN THE PACKAGE. USE "CS" (CTRL) (S) KEYS TO
TEMPORARY STOP SCREEN OUTPUT, THENCE "CQ" (CTRL) (Q) TO RESTART.
ACCEPTS THE FOLLOWING ARGUMENTS

(NO ARGUMENT)=DEFAULT, TYPE TO VDU

"TYPE"=TYPE TO VDU

"PRINT"=OUTPUT TO PRINTER

"MONITOR": TYPES ON VDU THE VERSION NUMBER OF 'MONLIB', THE GENERAL USER INTERFACE
WHICH IS USED BY THIS PROGRAM

"CALIBRATE": THIS TAKES 1024 CONSECUTIVE READINGS OF A CHANNEL (ON EITHER
SLOW OR FAST ADC). AVERAGES THEM AND DISPLAYS THE RESULT IN
DECIMAL & OCTAL ON THE VDU. IT ALSO RECORDS THE LOWEST AND
HIGHEST READING IN THE BATCH.

ACCEPTS THE FOLLOWING ARGUMENTS:

"SLOWADC"=CALIBRATES ON-LINE ADC

"FASTADC"=CALIBRATES OFF-LINE ADC

WHEN USING THIS COMMAND, PLEASE REMEMBER

. TO ALLOCATE A CHANNEL BEFOREHAND(SEE "CHANNEL" COMMAND)

. TO CHECK THAT THE ADC HAS A CONVERT PULSE CONNECTED TO IT.

"SS": SETS ACQUIS UP FOR A STEADY-STATE DATA LOGGING CYCLE AND CALLS
UP THE APPROPRIATE MODULE
ARGUMENTS ARE:

"MODE1" =MODE 1 CONFIGURATION(SEE LATER)

"MODE2" =MODE 2 (" ")

"SPECIAL"=SPECIAL CONFIGURATION(" ")

ENSURE THAT YOU HAVE SET UP THE DLCU DECADE COUNTERS AS APPROPRIATE
TO THE TEST BEFORE COMMENCING.

"HILO": THIS COMMAND IS RESERVED FOR USE IN FUTURE VERSIONS OF ACQUIS

"TRANSIENT": THIS COMMAND IS RESERVED FOR USE IN FUTURE VERSIONS OF ACQUIS

"CHANNEL": SETS UP THE CHANNEL SELECTION FOR BOTH ADCS FOR A "CALIBRATION"
COMMAND.

FOR THE FAST ADC, ONLY ONE ARGUMENT IS REQUIRED: NUMBER, "0" TO "7"

THE OFF-LINE ADC IS THEN SET TO SINGLE CHANNEL MODE ON THE SELECTED CHANNEL

FOR THE SLOW ADC, TWO LINES MUST BE INPUT: ONE TO DEFINE THE

COLUMN NUMBER("0" TO "7"), AND ONE TO DEFINE THE ROW NUMBER

("0" TO "3"). FOR EXAMPLE, TO SELECT COL 5,ROW 1, ENTER:

"CHANNEL COLUMN 5" ("RETURN")

"CHANNEL ROW 1" ("RETURN")

"MESSAGES": ACCEPTS TWO ARGUMENTS:

NO ARGUMENT=DEFAULT TYPE

"TYPE" =LISTING TO VDU

"PRINT" =LISTINGS TO LINE PRINTER

*** WHEN ACQUIS IS FIRST RUN, THE "MESSAGES" SETTING IS "PRINT"
TO CHANGE THIS,ENTER:

"MESSAGES" ("RETURN")

"RESULTS": THIS COMMAND HAS TWO FUNCTIONS:

. TO SET THE RESULTS CONFIGURATION FOR THE END OF A DATA
LOGGING CYCLE, E.G.

"RESULTS MAIN FULL" = FULL RESULTS FOR CURRENT RUN

"RESULTS MAIN SUMMARY"= SUMMARY OF CURRENT RESULTS

"RESULTS NONE" = NO RESULTS AT ALL

. TO CALL UP THE RESULTS DISPLAY MODULE ACORLT TO ANALYSE
THE DATA IN A PARTICULAR FILE TAKEN, SAY, YESTERDAY, E.G

"RESULTS SPECIAL FULL" = FULL RESULTS

"RESULTS SPECIAL SUMMARY"= SUMMARY RESULTS

"FILE": THIS IS A FILE SAVING FACILITY USEFUL WHEN YOU ARE DOING
MANY RUNS. REMEMBER THAT ACQUIS OVERWRITES ALL ITS FILES

DURING A NEW DATA LOGGING RUN THE FILES THAT SHOULD BE SAVED ARE:

RK1:MEAN.DAT (MEAN VALUES)
 RK1:STDEV.DAT (STANDARD DEVIATION VALUES)
 ARGUMENTS ARE
 NO ARGUMENT=DEFAULT IS SAVE
 "SAVE" =SAVE FILE(YOU WILL BE PROMPTED FOR NEW NAMES)
 "DELETE" =DO NOTHING,I.E. FILES WILL BE OVERWRITTEN
 "EXIT": RETURN TO RT-11 MONITOR
 "DOCUMENTATION": PRODUCES A LISTING ON EITHER VDU OR LINE PRINTER
 (SEE MESSAGES COMMAND) OF THIS FILE "ACQUIS.TXT". USE "S" (CTRL) (S)
 TO SUSPEND LISTING AND "C" (CTRL) (Q) TO CONTINUE THEREAFTER
 "DIAGNOSTICS": CHAINS 'ACQUIS' TO THE ACQUISITION PACKAGE 'DINT'(SEE "DINT.TXT" DOCUMENTATION)
 "PROCESS": CHAINS 'ACQUIS'(SEE "PROCES.TXT" DOCUMENTATION) TO THE PROCESSING PACKAGE 'PROCES'

NOTE: MONLIB(THE USER INTERFACE PROGRAM) WILL ACCEPT ABBREVIATIONS
 *** OF COMMANDS & ARGUMENTS, FOR EXAMPLE:
 "SP" WILL BE ACCEPTED AS THE COMMAND "SPECIAL"

ACQUIS DATA STRUCTURING -

ACQUIS LOGGS STEADY-STATE TESTS AND OUTPUTS THE RESULTS INTO DISK FILES
 WHICH HAVE A WELL DEFINED, YET FLEXIBLE DATA STRUCTURE. VERSION V01.01
 ONLY READS THE OFF-LINE ADC. HOWEVER THE DATA STRUCTURE CAN BE EASILY
 MODIFIED TO ACCOMODATE OTHER PARAMETERS(E.G. ON-LINE ADC VALUES.ETC.)
 IN FUTURE VERSIONS

THE FOLLOWING SUMMARISES THE DISK FILES CREATED BY THE
 MODULES SS,MODE1 & MODE2 LOGGING UNITS.

RK1:RECORD.DAT
 IMAGE OF LAST CYCLE OF DATA FROM 8K STORE
 USEFUL FOR DIAGNOSTICS,AN INTEGER FILE
 RK1:SUM.DAT
 SUM OVER N CYCLES OF FAST ADC DATA VALUES.
 AN INTEGER FILE
 RK1:SQH.DAT
 HIGH WORD PART OF SUM OF SQUARES OVER N CYCLES.
 AN INTEGER FILE
 RK1:SQL.DAT
 LOW WORD PART OF SUM OF SQUARES OVER N CYCLES.
 AN INTEGER FILE
 RK1:MEAN.DAT
 MEAN VALUES OF N CYCLES.CAN ALSO INCLUDE ADC CALIBRATION.
 A REAL FILE
 RK1:STDEV.DAT
 STANDARD DEVIATION OF N VALUES. A REAL FILE

YOU WILL NOTICE THAT WHEN YOU RUN THE SPECIAL LOGGING UNIT
 YOU WILL BE ASKED TO CREATE A DATA STRUCTURE FOR

THE TEST (I.E. NUMBER OF CHANNELS, ETC), IT IS IMPORTANT THAT THE INFORMATION YOU ENTER IS CONSISTENT WITH THE SETTINGS ON THE DLCU DECADE COUNTERS; OTHERWISE UNPREDICTABLE RESULTS CAN OCCUR. THE COMMAND "SS MODE1", "SS MODE2" CALL UP THE MODE1 & MODE2 MODULES RESPECTIVELY. THESE MODULES HAVE A FIXED DATA STRUCTURE WHICH YOU SHOULD BE FAMILIAR WITH. THESE MODULES HAVE OPTIMISED CODE AND RUN FASTER THAN THE "SPECIAL" EQUIVALENT.

THE DATA STRUCTURING PARAMETERS ARE DEFINED AS FOLLOWS:

CYCLE=NUMBER OF CYCLES LOGGED

NREC =NUMBER OF CHANNELS LOGGED. IN A MULTIPLEXING SEQUENCE THIS SHOULD CORRESPOND TO THE PULSE MULTIPLIER DECADE SETTING. REMEMBER THAT ALL MPX SEQUENCES END ON THE LAST CHANNEL.

SREC =NUMBER OF SAMPLES PER CHANNEL IN A MULTIPLEXING SEQUENCE. THIS SHOULD CORRESPOND TO THE BATCH LENGTH DECADE COUNTER ON THE DLCU.

NSUM =NUMBER OF CHANNELS ACTUALLY OPERATED ON. THIS WILL NORMALLY EQUAL NREC.

PSUM =8 ELEMENT ARRAY WITH THE OPERATING SAMPLING INTERVAL STARTING FROM CHANNEL 1, E.G. 1 IS 1 IN 1 SAMPLING, ETC

OSUM =8 ELEMENT ARRAY WITH THE OFFSET FROM START OF BATCH FOR EACH CHANNEL, STARTING WITH CHANNEL 1.

SSUM =8 ELEMENT ARRAY WITH THE NUMBER OF POINTS OPERATED ON IN EACH CHANNEL BATCH, STARTING FROM CHANNEL 1.

ISUM =8 ELEMENT ARRAY WITH A FLAG FOR SQUARING THE CHANNEL DATA FOR SUBSEQUENT STD. DEVIATION ANALYSIS. SQUARED CHANNELS MUST BE CONCATENATED WITH CHANNEL 1. I.E. YOU CANNOT SQUARE 1 & 3; 1 & 2 WOULD BE CORRECT. THE FLAG IS 1 FOR SQUARING, OTHERWISE 0

ONE POINT TO NOTE IS THAT THE DATA STRUCTURE ARRAYS AND RESULTS MODULE ACQRLT REFER TO ALL MULTIPLEXING CHANNELS STARTING FROM CHANNEL 1. IN FACT, THE HARDWARE MPX CHANNELS ALWAYS END AT CHANNEL 7 (COUNTING FROM 0). THUS A 4 CHANNEL SEQUENCE WOULD BE 4,5,6,7 ON THE MULTIPLEXER, BUT REFERRED TO AS 1,2,3,4 BY ACQRLT. THE DATA STRUCTURE FOR MODE1 IS -

CYCLE=50

NREC =4

SREC =1440

NSUM =4

PSUM =1 1 1 1 1 1 1 1

OSUM =0 380 380 380 0 0 0 0

SSUM =1440 200 200 200 0 0 0 0

ISUM =1 1 1 0 0 0 0 0

(I.E. 1/2 DEG. OVER 720 DEG. CYCLE). ALL 1440 POINTS ON CHANNEL 1 ARE LOGGED BUT ONLY 200 POINTS AT AN OFFSET OF 380 FROM THE START OF BATCH ARE READ ON CHANNELS 2,3 & 4. DATA ON CHANNELS 1,2 & 3 ARE SQUARED FOR STANDARD DEVIATION CALCULATION. SIMILARLY, THE STRUCTURE FOR MODE2 IS -

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CYCLE=50
NREC =8
SREC =720
NSUM =8
PSUM =1 1 1 1 1 1 1
OSUM =0 190 190 190 0 0 0 0
SSUM =720 100 100 100 720 720 720 720
ISUM =0 0 0 0 0 0 0 0

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USING THIS FLEXIBLE STRUCTURING SYSTEM, YOU MAY CREATE ANY DATA STRUCTURE YOU WISH WHEN RUNNING THE 'SPECIAL' LOGGING UNIT

ACQUIS MESSAGES -

THESE ARE SELF-EXPLANATORY AND ARE INCLUDED HERE FOR REFERENCE ONLY. REFER TO PROGRAM LISTINGS FOR MORE DETAILS. ONLY '-F-' TYPE MESSAGES ARE LISTED, THE PREFIX REFERS TO THE PROGRAM MODULE FLAGGING THE MESSAGE.

-F- MESSAGES ARE FATAL ERROR CONDITIONS. CONTROL RETURNED TO ACQUIS MONITOR
 -W- MESSAGES ARE WARNINGS OF POSSIBLE ERRORS. EXECUTION CONTINUES
 -I- MESSAGES ARE INFORMATION ONLY

NOTE: WHEN ACQUIS IS PROCESSING YOUR COMMAND, THE MESSAGE "WORKING" WILL FLASH ON THE RIGHT HAND SIDE OF THE SCREEN. WAIT FOR THIS TO CLEAR BEFORE YOUR NEXT INPUT. THE KEYBOARD IS SUSPENDED WHILST THE COMPUTER IS "WORKING". IF YOU WISH TO TERMINATE THE PROGRAM, PUSH THE RED BUTTON ON THE CONSOLE AND ENTER "C" TO RETURN TO RT-11

!ACQZ-F-MONLIB ERROR
 !ACQZ-F-PREVIOUS COMMAND NOT REPEATABLE
 !ACQZ-F-INVALID CHANNEL SELECTION
 !ACQZ-F-INVALID RESULTS SELECTION
 !ACQSET-F-MODE ERROR
 !ACQSET-F-INPUT DATA ERROR=N

WHERE N IS :-

-4 CYCLE INCORRECT
 5 NREC INCORRECT

- 6 SREC INCORRECT
- 7 NSUM INCORRECT
- 8 PSUM INCORRECT
- 9 PSUM,OSUM OR SSUM INCORRECT
- 10 SSUM INCORRECT
- 11 ISUM INCORRECT

!ACQGO-F-SOFTWARE NOT AVAILABLE

!ACQFIL-F-SAVE FILE ERROR

!CALON-F-NO CHANNEL SELECTED

!CALON-F-ILLEGAL COLUMN ADDR

!CALON-F-ILLEGAL ROW ADDR

!CALON-F-REQA NOT SET

!CALOFF-F-NO CHANNEL SELECTED

!CALOFF-F-ILLEGAL CHANNEL SELECTED

!CALOFF-F-D/C FAILED TO EMPTY

!CALOFF-F-IMA FAILED TO COMPLETE

!ACQRLT-F-TEST UNSUCCESSFUL..CHAIN INFORMATION ERROR

!ACQRLT-F- " ..OVER-RUN ERROR

!ACQRLT-F- " ..SUMMATION ERROR

!ACQRLT-F- " ..SUMMATION OF SQUARES ERROR

!ACQRLT-F- " ..DISK WRITE ERROR

!ACQRLT-F-ACQAVS ERROR(CODE=N)

WHERE N IS :-

- 10 RK1:SUM.DAT READ ERROR
- 20 RK1:SQH.DAT READ ERROR
- 30 RK1:SQL.DAT READ ERRPR
- 40 RK1:MEAN.DAT WRITE ERROR
- 50 RK1:STDEV.DAT WRITE ERROR
- 60 CHAIN INFORMATION ERROR

!ACQRLT ACQR2 ERROR

!ACQRLT ACQR4 ERROR

!ACQRLT ACQR5 ERROR

!ACQRLT ACQR6 ERROR

!ACQRLT ACQR1 ERROR

!ACQR6-F-ILLEGAL INPUT

146.

(B) RESULTS ANALYSIS ONLY SEQUENCE:

ACQZ
\
ACQRLT
\
ACQZ

```
MONLIB - (MONLIB.DAT)
\
ACQZ
\
```

```
*  EITHER SS,MODE1 OR MODE2
** ACQRLT
```

ACQRLT SOFTWARE -

ACQRLT
\

ACQR1	ACQR2	ACQR4	ACQR5	ACQR6	HISF	*
		ACQR4C			HIS	

* RETURNS TO ACQZ

SUPPORT -
L.ROBERTS*

UPDATES -
L. ROBERTS*

*UNTIL OCTOBER 1980, THEREAFTER OTHER ROOM 122 STAFF

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*****
*
* I.C.  POST-PROCESSING SYSTEM PACKAGE
*
*****
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NAME - PROCES PACKAGE, VERSION V01.01

AUTHOR - LEWIS ROBERTS

DATE - AUGUST 1980

SUMMARY -

'PROCES' IS AN ANALYSIS PACKAGE WHICH IS FULLY INTEGRATED INTO THE PDP-11 DATA LOGGING SYSTEM IN ROOM 122, IMPERIAL COLLEGE, LONDON. VERSION V01.01 CONTAINS A HEAT RELEASE PROGRAM WHICH EVALUATES FUEL BURNING RATES IN DIESEL ENGINES. 'PROCES' RUNS DIRECTLY ON DATA COLLECTED BY ACQUIS, THE DATA LOGGING PACKAGE.

FIRST-TIME USERS -

YOU SHOULD READ THE SECTIONS WITH UNDERLINED HEADINGS BEFORE READING THE WHOLE FILE THROUGH. KEEP A LISTING OF THIS DOCUMENT IN FRONT OF YOU WHILE YOU RUN 'PROCES'

HARDWARE REQUIREMENTS -

PDP LSI-11, CONSOLE, PRINTER

SOFTWARE REQUIREMENTS -

RT-11 V03B

FORTRAN F2.1

UTILITY.OBJ (UTILITY LIBRARY) V01.01

MONLIB.OBJ (USER INTERFACE LIBRARY) V01.01

OPERATION(SWITCH ON/SWITCH OFF) -

ENSURE PDP-11 BOOTED ON RKO: WITH 'WRITE PROTECT' SWITCH OFF ON BOTH DISKS
TYPE IN AT THE CONSOLE:

"R PROCES" ("CARRIAGE RETURN")

PROGRAM WILL NOW RUN

LIMITATIONS

U01.01 HAS HEAT RELEASE ROUTINE ONLY

RUNNING PROCES -

IMMEDIATELY AFTER TYPING THE INTRODUCTORY TEXT, 'PROCES' WILL PROMPT YOU FOR THE NAME OF THE CYLINDER PRESSURE DATA FILE.

ENTER THE DEMONSTRATION FILE NAME:

"PRESS" ("RETURN")

YOU WILL THEN BE PROMPTED FOR THE STANDARD DEVIATION FILE NAME.

ENTER:

"DPRESS" ("RETURN")

'PROCES' WILL NOW CALCULATE THE IMEP OVER THE WHOLE ENGINE CYCLE AND OUTPUT THE RESULT ON THE SCREEN.

IT WILL THEN EVALUATE THE FUEL BURNING RATE, HEAT TRANSFER, ETC. FROM THE SMOOTHED CYLINDER PRESSURE DIAGRAM, TRAPPED MASS, CYLINDER DIMENSIONS, ETC. WHEN IT HAS FINISHED IT WILL START TYPING OUT (ON THE VDU) THE HEAT RELEASE RESULTS OVER 200 DEGREES (APPROX. THE FUEL BURNING PERIOD)

WHEN THIS HAS BEEN DONE, 'PROCES' WILL GIVE YOU A MENU OF COMMANDS. THESE ARE:

149.

A	ABORT TO 'ACQUIS', THE DATA LOGGING PACKAGE
R	RETURN TO INTERREGATE A NEW FILE. RETURNS TO MENU
S	GIVES SUMMARY OF PROGRAM RESULTS. RETURNS TO MENU
P	PRINT THE RESULTS JUST TYPED. RETURNS TO MENU
T	RE-TYPE RESULTS ON VDU SCREEN. RETURNS TO MENU
1	GIVES A HISTOGRAM PLOT OF CYLINDER PRESSURE WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
2	GIVES A HISTOGRAM PLOT OF CYLINDER TEMPERATURE WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
3	GIVES A HISTOGRAM PLOT OF EQUIVALENCE RATIO WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
4	GIVES A HISTOGRAM PLOT OF CHANGE IN CYLINDER MASS WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
5	GIVES A HISTOGRAM PLOT OF CYLINDER HEAT TRANSFER WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
6	GIVES A HISTOGRAM PLOT OF CYLINDER HEAT RELEASE WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
7	GIVES A HISTOGRAM PLOT OF CUMMULATIVE HEAT RELEASE WITH THE APPROX. POSITION OF TDC MARKED ON THE X AXIS. RETURNS TO MENU.
SUFFIX	COMMAND SUFFIXED WITH M ; CHANGE TO S.I. UNITS COMMAND SUFFIXED WITH I ; CHANGE BACK TO IMPERIAL UNITS
H	GIVES LISTING AND EXPLANATION OF VALID COMMANDS. RETURNS TO MENU

HEAT RELEASE THEORY -

PLEASE REFER TO M.MARZOUK PHD THESIS FOR THEORY AND REFERENCES
ON FUEL BURNING RATE PROGRAM. 'PROCES' IS IN FACT THE WELL ESTABLISHED
STREIT/I.C. PROGRAM FOR CALCULATION OF DIESEL ENGINE HEAT RELEASE.

150. PROCES MESSAGES -

THESE ARE SELF-EXPLANATORY AND ARE INCLUDED HERE FOR
REFERENCE ONLY. REFER TO PROGRAM LISTINGS FOR MORE
DETAILS. ONLY '-F-' TYPE MESSAGES ARE LISTED.
THE PREFIX REFERS TO THE PROGRAM MODULE FLAGGING THE
MESSAGE.

- F- MESSAGES ARE FATAL ERROR CONDITIONS. CONTROL RETURNED
TO PROCES MONITOR
- W- MESSAGES ARE WARINGS OF POSSIBLE ERRORS. EXECUTION CONTINUES
- I- MESSAGES ARE INFORMATION ONLY

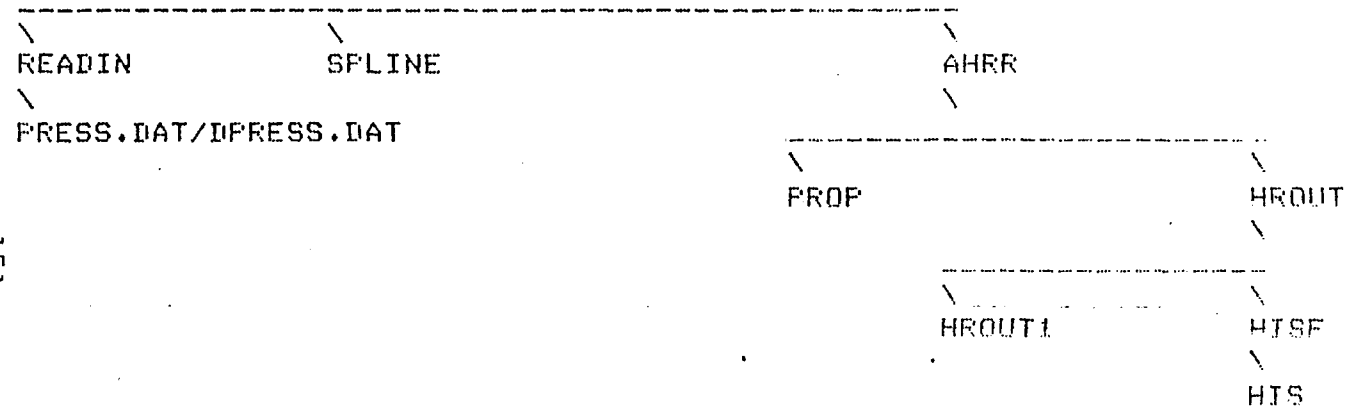
NOTE: WHEN PROCES IS PROCESSING YOUR COMMAND, THE MESSAGE
"WORKING" WILL FLASH ON THE RIGHT HAND SIDE OF THE
SCREEN. WAIT FOR THIS TO CLEAR BEFORE YOUR NEXT INPUT.
THE KEYBOARD IS SUSPENDED WHILST THE COMPUTER IS "WORKING".
IF YOU WISH TO TERMINATE THE PROGRAM EXECUTION, PUSH THE
RED BUTTON ON THE CONSOLE AND ENTER "CC" TO RETURN TO RT-11.

!READIN-F-RK1:PRESS.DAT I/O ERROR
!READIN-F-RK1:DPRESS.DAT I/O ERROR

PROCES SOFTWARE ORGANISATION -

PROCES

\
HR
\



SUPPORT -

L. ROBERTS*

UPDATES -

L. ROBERTS*; M.A. SHAHIN

*UNTIL OCTOBER 1980, THEREAFTER OTHER ROOM 122 STAFF.