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TECHNICAL REPORT NO. 11977

ATE/ICEPM Development Report and Function Demonstration Test

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CONTRACT NO. DAAE07-73-C-0268

by TRW SYSTEMS GROUP

TACOM

PROPULSION SYSTEMS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

TACOM TECHNICAL REPORT NO. 11977

ATE/ICEPM DEVELOPMENT REPORT AND FUNCTION DEMONSTRATION TEST

FINAL REPORT

Contract No. DAAE07-73-C-0268

Prepared by

TRW Systems Group, TRW Incorporated
Redondo Beach, California 90278

For

U. S. Army Tank Automotive Command
Warren, Michigan

G.H. GELB, Project Manager
TRW Systems

W. HNATCZUK, Project Engineer
AMSTA - RGD

Foreword

This report was prepared by the Systems and Energy Group of TRW, Incorporated, Redondo Beach, California under contract DAAE07-73-C-0268 from the U.S. Army Tank-Automotive Command, Warren, Michigan. The period of performance was 11 June 1973 through 31 January 1975.

Dr. G. H. Gelb was program manager for the effort. The major program participants at TRW were: D. Stoehr. Assistant program manager; B. Berman, hardware coordinator; E. von Delden, engineering tests; C. Oki, experiment planning and data handling; R. Shapiro, software coordinator; L. Moede and R. Rea, instrumentation development and coordination; R. Billet, ATE system packaging; and Dr. E. Koutsoukos, hydrocarbon sensor development.

TRW's major subcontractor was the Government and Commercial Systems, Government Communications and Automated Systems Division of RCA, Burlington, Massachusetts, under subcontract 081DH3F.

Set Theoretics Information Systems of Ann Arbor, Michigan performed software program transcription services.

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ABSTRACT

TRW Systems and Energy Group~~, under~~ contract DAAE07-73-0-0268, from the U. S. Army Tank Automotive Command (TACOM)~~,~~ undertook a program to bring the Automatic Test Equipment for Internal Combustion Engines (ATE/ICE) system to a developmental level which would be sufficient to demonstrate the functional capabilities of the system and to allow operational assessment by Army management and vehicle technicians as to the benefits of such a system.

The ATE/ICE system~~, initially~~ constructed by Dynasciencies Corporation under contract DAAE07-71-C-0029~~,~~ had several deficiencies; a data base upon which diagnostic decisions could be made was lacking, the hardware exhibited numerous problems - poor tape control and reading, excessive electronic noise, inconsistencies in the hardware among the six units, inadequate transducers and interface electronics, and finally there was no self contained diagnostic program.

TRW's effort therefore carried out the program development in several parallel - coupled tasks. They were:

- o Program Management
- o Diagnostic Engineering
- o Advanced sensor and diagnostic technique development
- o Software Programming
- o Hardware Improvement
- o Engineering Testing
- o Systems Support

Program management included those tasks necessary for program coordination between TRW, TACOM, RCA and STIS such as work allocation and scheduling, program reviews and report preparation.

In the diagnostic engineering tasks, TRW established a firm diagnostic data

base on the M151A2 engine. Data was gathered on the effects of ignition, compression, starter and air/fuel system faults in terms of measureable parameters - engine speed, ignition and starter circuit voltages and currents, intake and crankcase pressure levels. Faults were explored singly and in combination to determine the cause and effect relationships which would result in the engine being unserviceable. Serviceability was defined as:

- o the inability to start
- o poor idling in terms of idle roughness and misfire
- o peak power less than 75% of nominal engine power

The test data was analyzed and from it were derived go/no go limits for diagnostic decisions and an understanding of the relative contributions of each fault to serviceability. The tests also showed the usefulness of ignition interruption technique as a means of evaluating engine horsepower and the correlation between variation in instantaneous engine speed and idle quality.

In the advanced sensor and diagnostic technique tasks, TRW reviewed the transducer requirements for ATE from the standpoints of function, sensitivity and stability, cost and electrical interface. TRW either developed or procured suitable devices for inclusion in a revised Transducer Kit (TK). The new instruments included a redesigned ignitor probe and number one cylinder probe, and a totally new instrument capable of passively detecting hydrocarbons in the exhaust of a no-start engine. A review of Dynascience instruments showed serious defects primarily in pressure transducers. An alternate source was located and new instruments were procured, tested and integrated into the TK.

New diagnostic techniques were established. These included the use of starter current waveform correlated to #1 cylinder firing as a measure of engine timing during cranking, starter current as a measure of relative compression, correlation of intake manifold waveforms with #1 cylinder firing to give engine timing during idle and the use of ignition interruption as a means of artifically loading the engine for wide open throttle testing.

The software programming effort involved tasks of defining diagnostic flow diagrams, development of an operating system for handling the diagnostic test programs, preparation and validation of test programs, development of programs for handling the cassette system (software loader) and the transcription of diagnostic programs unto cassettes.

In the hardware improvement task, reviews and analyses were carried out to define the hardware problems experienced by Dynasciences and TACOM. Major problem areas were identified and corrected. These included:

- o Reduction of electronic noise by filtering and elimination of non-functional noise-producing elements
- o Mechanical redesign of the cassette system (program loader) to give better alignment and less drag
- o A hermetically sealed reel-to-reel magnetic tape memory unit was integrated into two ATE/ICE units
- o Electronic redesign of the program loader to improve tape handling
- o New design of a brass board junction box to interface with the new transducer compliment
- o Detailed design of a transportable cart for carrying and deploying the ATE/ICE system. This design, however, was never built.

Engineering tests were conducted to demonstrate the ability of the system to isolate faults. These tests included placing various faults combination into the engine and observation of how well the system could identify them. These tests confirmed that the ATE/ICE system could perform self-contained diagnosis.

TRW also prepared a full documentation list of all parts, drawings, and vendors associated with the ATE/ICE program from the Dynasciences work through this contract.

The diagnostic program developed for the M151A2 vehicle is composed of five operationally independent test programs serially linked on a single cassette tape. This program when used with the transducer complement for that vehicle can diagnose no start and poorly performing vehicles as well as aiding the mechanic in tune up operations.

A total of six ATE/ICE systems were delivered to TACOM. Four of the units had cassette type program loaders; one had the hermetically sealed magnetic memory. The sixth unit was not operational at delivery. An additional magnetic memory was procured and delivered to TACOM. A 100% spare complement of each transducer was supplied.

1.0 INTRODUCTION

The U.S. Army has recognized the need for accurate, rapid and reliable means for detecting and isolating vehicle power train failures. Several problems generally exist in the maintenance of any vehicle fleet system. These relate to:

- The lack of qualified mechanics who can utilize standard diagnostic tools and procedures to isolate faults and then take corrective action.
- The inability of mechanics to make repairs and adjustments properly, coupled with the probability that in the course of repair, other components or subsystems may be damaged.
- Quantitative measures of engine performance on which to base the need and the degree to which satisfactory repair has been made.

As an approach to reducing the maintenance problem, the Army adopted an approach of "repair only as necessary". However, in the late 1950's when this approach was selected, adequate tools to perform the inspection and diagnostic functions were not available. The Army Materiel Command employed the Frankford Arsenal and Tank-Automotive Command to develop a program to design and construct a system which could perform self-contained engine diagnoses.

This report presents the results of work performed by the Systems Group of TRW Inc. for the U.S. Army Tank-Automotive Command under contract DAAE07-73-C-0268, "Automatic Test Equipment for Internal Combustion Engine Powered Materiel." The contract period of performance ran from June 1973 through October 1974, during which time TRW Systems provided the engineering effort needed to delineate the functional capabilities of the Automatic Test Equipment (ATE) system to isolate and identify engine faults on the M151A2 vehicle.

This work was a continuation of work originally sponsored by TACOM to Dynasciences Corporation, Contract DAAE07-71-C-0029. During that contract, ATE system hardware was designed and constructed. Although some limited environmental tests were performed, the system was not sufficiently exercised to completely demonstrate functional capabilities. At the conclusion of that contract, eight ATE systems in various operational states were delivered to TACOM along with a complement of spare components. Aside from a very limited diagnostic program which allowed the ATE to make measurements and display several engine operating parameters, there was no self-contained diagnostic logic or program which could carry a user through a series of procedures and tests with the equipment making the diagnostic decisions.

TACOM also identified serious defects in the original hardware complement which needed correction. There were major problems with the input/output data and signal handlers, program loading hardware, and several of the transducers. Due to the variety of problems existing in the system, it initially was difficult to prioritize the problem areas and thus, as an initial goal, TACOM elected to undertake a program which could bring the ATE system through an Engineering Design Test (EDT) phase.

1.1 Object of the Program

Although the beginning goal of the program was to demonstrate the functional and reliability features of the ATE system in an EDT, it was apparent after the start of the contract that these goals would be difficult, perhaps impossible to meet. Thus, effort was redirected to the demonstration that the ATE could function in an automatic test mode as originally conceived. It was therefore TRW's role as a program contractor to provide TACOM with modified ATE systems including a complete diagnostic program. For these tasks, TRW employed the Communications and Automated Systems Division of RCA as a major software and hardware subcontractor and Set Theoretic Information Systems (STIS) to provide program transcription services.

2.0 SUMMARY OF PROGRAM

The program has resulted in the successful demonstration of the ATE system's ability to perform diagnostics on the M151A2 vehicle. The system is capable of defining the serviceability status of the vehicle's engine, and locating major engine subsystem/component faults or out-of-specification conditions which contribute to non-serviceability. In addition, the ATE system may be employed as an aid to vehicle tune-up in a manner similar to conventional shop diagnostic equipment.

TRW has delivered to TACOM the hardware/software materiel shown in Figure 2-1 and Table 2-1. The ATE/ICE system includes: A Programmable Diagnostic Unit (PDU) with improved noise immunity, cassette loader, interrupt processing, and operator communication; operating and test software; and new interface hardware transducers and cables. Diagnostic programs developed and written for the M151A2 vehicle are contained on Phillips cassettes included with each TK or are transcribed onto magnetic tapes contained within the hermetically sealed program loader units.

The PDU's computer is used to store and process all of the tests for vehicle performance evaluation and servicing requirements, without the need for meters and other instrumentation. Checks and balances are included to ensure that these tests are conducted rapidly and accurately. Executive, self test, zero offset calibration, data acquisition, amplitude statistics processing, time and frequency analysis processing, linear systems analysis and interactive input-output processing software are contained in 44,000 words of stored program. The engine, ignition, electrical, fuel and intake subsystems are tested in a manner which allows the operator to self-test the ATE hardware or perform engine tune-up and/or adjustment.

There are five operationally independent test programs serially connected on the program tapes. Each group is normally sequenced in the order given below:

(1) Confidence Test
(2) Automated Inspection List
(3) No start
(4) Performance
(5) Tune-up

The operator is given the option to reorder the test sequence to run any of these tests independently. Within each test group, the operator is given abbreviated (phonetic) instructions for all required operator actions. Each test group will process its own summary test status for operator display and printout. Hard copy printout of the data taken to reach a diagnostic conclusion is possible by connecting a Centronics Model 101 Line Printer to the system. The printout includes intermediate test results of each performance, diagnostic and/or operator adjustment made during an individual test run.

The diagnostic capabilities of the current system are summarized in Table 2-2 by vehicle subsystem. The programs are designed to isolate and indicate faults only if the vehicle is found unserviceable, i.e. does not pass the specified starting and performance criteria. If the vehicle fails to start, components/faults identified in the No-Start column are diagnosed. If the vehicle fails to perform in the idle or powered modes of operation, components/faults identified in the Performance column are diagnosed. Components that can be adjusted with the aid of the ATE/ICE System are identified in the Tune-Up column. Automatic "A" means the diagnostic procedure is fully automatic and interactively communicates with the operator if operator actions are required. Semi-automatic means that the system interactively communicates with the operator, but responses require that the operator performs inspections and/or make decisions and enter them in the computer as part of the operational procedure.

System operation and description is described in detail in the User's Manual for Automatic Test Equipment/Internal Combustion Engine (ATE/ICE), July 1974.

To bring the ATE System to this point, several major program tasks had to be undertaken. These tasks are summarized below along with their major accomplishments. The body of this report contains a more detailed examination of those tasks along with supporting data and explanations. The tasks were:

- o Development of the diagnostic engineering structure
- o Preparation of the diagnostic software program
- o Improvement of system hardware
- o Preparation of systems support material

2.1 Development of the Diagnostic Engineering Structure

The major thrust of the contract was to develop a complete diagnostic structure for the M151A2 vehicle. There were a number of sub-tasks which had to be performed in order that a final, automatic system would result. The steps which took place serially or in parallel were:

- o Development of diagnostic flow paths
- o Data base experiments
  - screening experiments
  - matrix tests
  - component characterization
  - EDT verification
- o Diagnostic validation tests

2.1.1 Diagnostic Flow Paths

Section 6 describes the logic flow paths which were developed. A preliminary logic served as a road map to focus on fault isolation techniques and identify diagnostic parameters. For example, given a no-start vehicle, the diagnostic logic will first attempt to see if there are obvious reasons such as a low voltage battery. If the battery voltage is sufficiently high, the next logical step is to see how well the engine can be cranked. If cranking takes place, cranking speed is examined to see if it is sufficiently high. If it is too low, the logic must branch to determine the cause--stuck starter, open or high impedance starter circuit. It is clear that at each decision point, parameter values (voltages, current and speed) must be measured and compared with pre-determined values in order that succeeding branches may be chosen.

The flow paths also are helpful in identifying the operator's part in terms of operator response and displays. Examination of the paths tend to point out dead-ended procedures and hardware and transducer sensitivity requirements. The preliminary logic structure was upgraded as the program progressed, reflecting the results of the experimental portion of the program.

2.1.2 Data Base Experiments

With a diagnostic path in mind, it was necessary to develop a broad data base upon which go/no-go limits could be based. In the case of the present work, it was necessary to investigate not only the range of parameters which could cause the vehicle to be unserviceable, but also to validate the techniques of determining serviceability.

Screening experiments were performed to understand the limits of carburetion (air-fuel ratio), compression, ignition timing and misfire on idle and wide open throttle power as well as startability. Once a parameter was found to cause unserviceability, it was flagged and used in the later matrix tests. Implicit in the screening experiments was serviceability criteria established by TACOM. A No-Start condition is clearly unserviceable; however, other criteria had to be used for idle and full power.

In the former, serviceability was defined in terms of average idle speed, idle tailpipe pressure variation, and misfire. Since the installation of a tailpipe pressure transducer presented cost, installation and reliability problems, means for using engine idle speed variation alone were developed.

The serviceability of the engine at full throttle was, according to TACOM specifications, to be based upon the engine developing 75% of its peak, nominal power. In the absence of a dynamometer, an interrupter technique was developed and validated.

Matrix tests were performed to understand the single and multiple effects of engine parameters (air-fuel, compression and ignition) on idle and full power serviceability. From these tests the engine parameters were ordered into first, second and higher order factors. For example, idle air-fuel ratio had a pronounced effect on idle roughness while low compression caused by intake valve problems had only a minor effect.

Component characterization tests were performed to establish the diagnostic information which would describe the state of a component or subsystem. Each set of data was carefully analyzed to come up with go/no-go decision limits. The following is a partial list of components and key data which is measured, according to the final diagnostics, to evaluate the state of the component.

Battery - open circuit voltage, and voltage under current load or charge
Compression - starter current peak and minimum levels
Ignition - secondary circuit spark voltage, firing zone voltage and spark duration
Intake Manifold - intake manifold vacuum during cranking, waveform during idle
Points - voltage at point closure and opening

Tests were also carried out to support and validate each of the decision levels as it might affect the successful outcome of an Engineering Design Test (EDT). Faults which were thought to result in unserviceability were inserted and studied to see if in fact an unserviceable engine would result. If the fault had no effect, it was dropped from the EDT fault list. If it did affect serviceability, the method of component failure isolation was reviewed to insure the diagnostic logic and go/no-go limits would have located it.

2.1.3 Diagnostic Validation Tests

A major effort was also directed at diagnostic validation. This was a combined hardware/software test program in which each module of the diagnostic structure was programmed and made to play with the actual hardware to see if the response was proper and if unforeseen hardware or software compatibility problems existed. The following are some examples of validation tests.

- o Determination of cranking speed by counting the number and the time between point openings
- o Development of programs to identify maximum and minimum values of starter current, intake manifold vacuum
- o Sampling and curve fit of firing zone voltages
- o Offset correction for igniter probe secondary signal
- o Correlation of crankshaft acceleration and deceleration levels with misfire

Within the time and cost level of the contract, approximately 70% of the diagnostic modules underwent complete validation--that is, all the presumed fault levels and possible confounding effects were introduced and the diagnostic approach shown to be viable. In the remainder of the modules, sufficient validation had progressed to give a high degree of confidence that the approach was sound.

2.2 Preparation of the Diagnostic Software Program

The diagnostic software programming effort was divided into four major portions; software loader development, operating system development, software validation and software transcription.

The software loader, composed of two sub-programs, is the program which takes over control of tape operation and follows the direction of the operating system in locating and loading records into the computer core and checking the validity of loaded records. The loader was developed in conjunction with the operating system requirements, the read-only-memory (ROM) of the computer and the interface requirements with both the computer and the tape control system. The first portion of the finalized loader, the bootstrap loader, is read into core by control of the ROM. The bootstrap in turn loads the operating system and cassette loader. Both the bootstrap and cassette reader contain program information as to:

- How to handle end-of-tape signals
- How to search and locate record segments
- How to check the validity of loaded records
- How to generate displays to the operator related to loading errors

The operating system consists of a test executive which contains the task scheduler and stack handler. The operating system was built upon the PDU/BITE system developed under previous TACOM sponsorship, Contract DAAE07-73-C-0035. The function of the executive is to allocate and sequence task control blocks which contain the actual computational steps needed to make diagnostic decisions. The task scheduler may receive interrupt commands from the set communicator or operation of the ignition interrupter; and, in turn, the set communicator can re-establish the scheduler's function by the "enter" button on the set communicator.

The stack handler interfaces with a number of input/output devices - a teletype interface, cassette program loader, high speed paper tape reader, high speed printer, set communicator display and the J-box.

The software validation phase took place in two steps. First, diagnostic programs containing a number of logically chained task control blocks, TCB, were written on paper tape and loaded into core through the stack handler. Each program could therefore be analyzed as to its performance prior to its incorporation in the total system.

The second phase of the validation required the cassette with the software loader. In this validation phase not only were segments tested but the ability to transfer control from the operating system to the software loader and then back to the operating system after completion of a segment load was demonstrated.

Software transcription, performed by STIS, took the source program containing the software loader and operating system and transcribed it onto the magnetic tape cassettes or the hermetically sealed program loader. Recordings were made in a "non-return to zero incremental complemented code, NZRI, on each of two tracks. Each record is separated by a "mark" bit. A record contains a four-word header (each word contains 16 bits), followed by the record information of up to 256 additional words. STIS was responsible for transcription level, control of inter-record gaps and data channel skew.

2.3 Improvement of the System Hardware

As previously mentioned, during the initial phases of the program, major hardware problems were uncovered which in the past had prevented the successful operation of the ATE. Although there were problems associated with the packaging and environmental protection quality of the equipment, these were small compared to those deficiencies which led to a non-functional system.

The primary hardware problems could be grouped into the following areas:

- o Problems with the PDU itself
  - noise from the DC-DC converter, battery charger, fans and elapsed time meter
  - design deficiencies in the set communicator
  - program loader design deficiencies which lead to poor cassette read capabilities and tape damage
- o Transducer problems
  - poor performance of the ignitor probe and pressure transducers
  - faulty number one cylinder probe
  - lack of a means for detecting no-start carburetion problems
- o Need for re-designed J-box and cables to reflect the new diagnostic path and upgraded transducers

It was apparent that without satisfactory hardware performance, software checkout and diagnostic verification were impossible. The hardware development was therefore broken into the following responsibilities. TRW solved the program loader problems and developed and procured new transducers. RCA identified some of the sources and, if possible,corrected noise problems in the PDU as well as to design and construct new J-boxes and cable sets.

Solutions to the PDU noise problems included filtering of all the outputs of the DC-DC converter along with filters at critical points in the read electronics and analog-digital converters. Components not needed for functional performance--battery charger, fan and elapsed time meter were removed. In some cases, faulty CDC 469 computers were identified and returned for repair.

The program loader was completely rebuilt with special attention paid to accurately locating the tape relative to the read head. The motor control system and beginning of tape sensor were improved and modified to insure non-catastrophic malfunctioning. Special reference tapes were located and used during head alignment to insure minimum skewness and good amplitude match between digital channels.

As a further improvement, Raymond Engineering hermetically sealed program loaders were obtained and integrated into the PDU. While the integration was not completely successful due to interface problems with the J-boxes, the approach was validated and read accuracy improved.

Totally new ignitor probes, number one cylinders probes, and intake and crank-case pressure transducers were developed or procured. A search for a low cost hydro-carbon sensor led to the use of a Dolan Absorptive Sensor,DAS, as a means of isolating fuel faults in a no-start vehicle.

A completely new J-box and cable system was developed, reflecting the sensor complement, diagnostic structure and new diagnostic procedures. A major development was the incorporation of an interrupter circuit which could detect point closing and inhibit the ignition on a 80% firing basis - necessary for the full power serviceability test.

3.0 Hardware Improvements

Major design deficiencies were identified early in the program and other changes were deemed necessary to interface new or improved diagnostic techniques with the system. TRW undertook to solve these problems in several ways. First, existing TK equipment was analyzed and calibrated by TRW and RCA to ascertain whether or not it would meet the expected performance levels. In many cases, the equipment was lacking and replacement or totally new equipment had to be specified.

TRW undertook to redesign the cassette loader and to handle the cassette transcription interface problem. Major improvements in tape tension control, alignment and transcription standardization were made.

RCA reviewed portions of the PDU circuitry and recommended design improvements. A new Signal Conditioning Unit (SCU) or J-box was designed and built according to commercial practice. Wire wrap and cabling techniques were employed so that design changes could be readily made. Wherever possible, printed wire circuit modules were employed.

The cassette program loader, while it was made to function during the contract, remained with major design problems. TACOM directed TRW to institute a design feasibility study to establish the suitability of a hermetically sealed program loader, HSPL. TRW located a military qualified unit manufactured by Raymond Engineering and connected it in a breadboard fashion to a PDU. While the integration was not 100% perfect due to design interface problems with the J-box, the work showed that such an approach was possible and should be undertaken in the redesign phase of the ATE.

3.1 Programmable Diagnostic Unit (PDU)

The PDU, #11733817, was found to have unacceptable performance due to the variety of states in which the materiel was furnished, unknown or unreported modifications made to the equipment and design deficiencies. A major task, therefore, was undertaken to improve the PDU so that it would function sufficiently well to demonstrate the capabilities of the ATE system. The modifications are summarized below.

3.1.1 Reduction of spurious electronic noise by removal of equipment not needed for functional demonstration.

Three components were identified as possible sources which could introduce noise into the read electronics of the cassette program loader or into the computer. These components were:

- o Blower fan
- o Battery charger
- o Elapsed time meter

The blower fan was originally installed to proviede a measure of system cooling. However, tests showed that these motors were inadequately electrically filtered. Moreover, thermal tests indicated that these fans were incapable of reducing the internal temperature of the PDU to a level that would give a sufficient thermal margin to the CDC 469 computer. Given that the computer has a 140^{o}F ambient maximum, the blowers could not be counted upon to provide a 15^{o}F cooling effect when the air surrounding the PDU was raised to 125^{o}F. Therefore, the fans were removed from all the PDU's.

The PDU's were supplied with a nickel-cadmium battery and a battery charger. The battery was to be used in case the ATE system was called upon to diagnose a vehicle which had no battery, a weakened battery, or in case the operator wanted to perform an internal check of the ATE system without a vehicle or other source of external power. The battery and charger were found to be significant thermal sources, and potential noise generators. The PDU can be powered from a 60 Hz, 110-120 VAC source through the AC/DC converter of the ATE system, and therefore each PDU was modified by eliminating the batteries and chargers.

Each PDU had an elapsed time meter on it which indicated the total time the PDU was on. On several of the PDU's, the motor drive for the meter produced electrical noise which appeared on the output of the cassette read head electronics. Again, since the meters had no bearing on functional performance, they were eliminated from each unit.

3.1.2 Improvement of PDU Operation by Noise Reduction and Current Redesign

EMI filters were added to every line which came from the DC-DC converter plug. This eliminated the low frequency ripple from the inverter circuits in the DC-DC converter. Noise reduction of up to 40 db was observed in the 100 kHz to 10 mhz frequency range.

A 1.8K 1/2 watt resistor was added from U32-14 to IO-53 on board A6. This allowed the CH8 register to drive the TK power control line in the DC-DC converter (refer to drawing #F11734015).

The backplane was modified to correct for interrupt handling deficiencies of the CDC 469. When Level 2 interrupt was enabled, CH4, the signal conditioner unit control register, was unable to be outputted. The modifications below change this control register, programming wise to CH8.

Remove:

A2-27	A6-89
A6-89	A5-18

And add:

A2-27	A5-18
A2-24	A6-89

The CH4 analog amplifier U7 on board A3 was changed to a gain of 1.00 (refer to drawing #F11734026).

Board A5 was modified to reduce false level 2 interrupts caused by noise (refer to drawing #D11734016).

The real time clock was modified so that a programmer could select the upper or lower 8 bits of the real time clock by means of CH8, PDU to J-box control register (refer to drawing F11734015).

The SC voltage probe circuitry was modified and an added breadboard element was located below the plate which covers the area where the battery was removed. The SC keyboard electronics was also modified (refer to drawing #D11734076).

Some of the PDU's had been modified for a previous (PDU-BITE) program. Some of the modifications were retained and implemented in those units which do not have them, while others were removed from all PDU's.

- o Master clear switch circuitry removal
  - SN7400 IC, located near depot socket was removed and all wires which go to it including toggle switch mounted near blower.
  - 2 wires on A6-52 were disconnected and connected to A6-60.
  - MRS from DC-DC converter was reconnected
    J07-R to A6-52

- o Level 3 interrupt function was restored
  - P03-20 to A5-77 reconnected
  - J01-99 to A5-77 reconnected
  - 1.1K resistor from A5-98 to A5-77 retained

- o Load NDRO function was restored
  - P03-19 to A5-26 reconnected
  - J01-105 to A5-26 reconnected
  - 1.1K resistor from A5-98 to A5-26 retained

Finally, the CDC computers were modified by CDC so the systems would start in read-only-memory (ROM).

3.1.3 Program Loader Modifications

The program loader portion of the PDU's was identified early in the contract as a major source of PDU malfunction. For example, due to poor program loader performance, the capacity of the cassette had been reduced from a theoretical 300,000 - 16 bit words to approximately 18,000 words. The reduction was due to:

- o The inability to read reliably at the beginning and end of tape meant only the middle section of the cassette could be used.

- o Triplicate recordings of each record were previously used to attempt to build read reliability.

- o The recordings were made at low bit densities - approximately one-half that commonly used in similar applications.

Another severe problem was associated with the failure of the beginning of tape (BOT) sensor. In many cases, the program loader would fail to recognize the beginning of tape and the tape would continue to the beginning of the reel and then rewind the tape backward. The problem was solved by improving the detection circuitry, making a more definitive demarkation between oxide and clear leader on the tape, installation of a better reflective surface in the cassette for scattering the infra-red source radiation back into the photo detector of the BOT and by redesign of the mechanical arrangement of the source and detection to reduce the background radiation.

Major mechanical redesign of the program loader resulted in:

- Establishment of accurate reference surfaces so that the tape was positioned relative to the tape head, rather than non-controlled, non-machined surfaces having no relationship to the tape head.
- An over-center mechanism which allowed the tape and cassette holder to be lowered directly onto the drive spindles without binding.
- Complete redesign of the cassette holders, #11734928, to incorporate accurate location of the cassette, dust proofing and drive motor/ cassette spindle jamming problems.

The electrical improvements in the program loader are to be found in the engineering change notices (ECN's). The major improvements were in the area of transport control and operation. The previous method of tension control relied on two active motor systems. One motor, the tension or drag motor, was controlled to operate at constant armature current and thus provide nearly constant uni-direction torque, independent of speed. The result was to produce a tension in the tape inversely proportional to the tape radius on the tension motor spindle. The other motor, the speed control or drive motor, was controlled to maintain constant emf and thus ran at constant speed. Its direction reversed between load and rewind. Since the tape radius changes, the tape speed was slowest at the beginning of tape and increased by nearly 100 percent by the end of tape. In the event of tension motor jamming, the speed control motor in the load direction would continue to spill tape off causing bunchup and failure.

Review of the requirements indicated that implementing the drive motor amplifier with a pushpull capability was not only unnecessary but had to be prevented. Circuit functional analysis further showed that the rewind leg of the drive amplifier (Q11, Q10) was not connected. The speed of the drive motor during rewind is maintained by the forward leg (Q9 and Q8) which control the restraining torque to the drive motor to maintain the tape taut and motor speed constant. The rewind leg of the drive amplifier (Q11 and Q10) was disconnected.

Further, due to the reflected motor inertia through the high gear reduction built in the speed control motor, the motor would, after a stop command in the load direction, continue to turn and cause a loop or slack in the tape to occur. Subsequent restart would "snap". The slack passes the read head and causes record header read errors (improper identification of the record number). During stop, the tension motor was commanded to retain a tension on the tape to take up the slack.

3.1.4 Alternate Program Loader

3.1.4.1 Introduction

Although the modifications described resulted in a usable program loader, several shortcomings remained:

1. The cassette holder prevents use of a capstan drive and leads to large tape speed variations between the beginning and end of tape.

2. Alignment of the read head is a difficult and time consuming process, and the tolerances required to locate the Phillips-type cassette adequately in its environmental holder are difficult to hold.

3. The opposing-torque motor system is sensitive to frictional variations and changes in control system electronic component values, so that as these change with age or components are replaced, rebalancing of the system becomes necessary to avoid drifting while nominally stopped.

4. The drive subsystem has wear problems in the gear train and Velcro clutches.

5. The search and read speeds are relatively slow.

6. A relatively low bit density is necessary to avoid read errors.

3.1.4.2 Available Alternates

Accordingly, the possibility of substituting a commercially available tape deck of proven reliability was re-investigated by TACOM direction, The principal requirement resulting in the existing design was the environmental one leading to the holder for the Phillips cassette. If this were to be relaxed, several proven tape readers for the Phillips cassette are available.

Another possibility was a 3-M machine using a special cassette. This unique design possessed some of the advantages of a reel-to-reel capstan drive unit, i.e., constant tape speed and greater capacity than a Phillips cassette, coupled with better environmental protection than a bare Phillips cassette, though not quite so good as the present system with environmental holder.

The ultimate solution appears to be a hermetically sealed capstan drive reel-to-reel tape deck of large capacity with internal write as well as read capability. Although expensive, such a machine qualified to Mil environmental standards was available in 28 VDC. This Raymond Engineering unit is a 4 channel machine with sufficiently capacity for several vehicle programs. This latter approach was preferred by TACOM and the contract was revised to call for building a feasibility demonstration model by modifying an existing PDU to accept a Raymond tape deck and electronics.

3.1.4.3 Raymond Unit PDU Interfacing

A Raymond Engineering Magnetic Tape Memory Unit Model 6401-04 was integrated with the PDU by:

1. Wiring the Raymond unit interface cable into connector XA1 of the PDU, using the spare pins contained thereon.

2. Removing the existing A1 board and replacing it with a new board containing the Raymond/PDU interface circuitry.

3. Remove the existing program loader tape transport unit

4. Adding a one shot to PDU board A5.

The interfacing was done in such a way as to allow the PDU to be operated with either the Raymond Unit or the original program loader by re-inserting the A1 board and the program loader.

The Raymond unit is designed to read and write up to four parallel channels of digital information, however, only a single channel (CH A) was used in interfacing with the PDU.

The following control signals to and from the Raymond unit are used in the interface circuitry.

1. Enable Command (XA1-PIN 45)

This signal is generated in the interface circuitry and is supplied to the Raymond unit. A "one" on this line allows the unit to accept the MOTION COMMAND after a delay of at least 150 millisec.

2. Raymond Unit ON (XA1-PIN 41)

This signal is Raymond unit's response to the ENABLE COMMAND. A "ONE" on the line indicates that the Raymond unit is ready to accept the MOTION COMMAND. The interface circuitry used this signal to gate the MOTION COMMAND to the Raymond unit.

3. Speed Command (XA1-PIN 30)

A "ONE" on this line conditions the control logic in the Raymond unit to move the tape at high speed and a "zero" for low speed.

4. Direction Command (XA1-PIN 28)

A "ONE" on this line conditions the logic in the Raymond unit to move the tape in the forward direction when the motion command is given. A "zero" will move the tape in the reverse direction.

5. MOTION COMMAND (XA1-PIN 29)

A "ONE" on this line will result in tape motion as specified by the DIRECTION and SPEED commands. The MOTION command will not appear until the Raymond unit on signal is "ONE".

The following signal lines to and from the Raymond unit are used in the interface circuitry.

1. BLOCK SIGNAL (XA1-PIN 50)

A "ONE" on this line indicates the presence of data on the tape. This signal goes to a "ZERO" during an inter-record gap or blank tape. This signal is used to generate the record gap signal required by the PDU.

2. CHANNEL A DATA OUTPUT (XA1, PIN-48)

This is the NRZ Data Output from the Raymond unit to the PDU.

3. CLOCK OUTPUT (XA1, PIN-47)

The clock output from the Raymond unit is used in the interface circuitry to generate the "strobe" and "MARK" pulse required by the PDU.

Recording Format for Raymond

The Raymond unit requires a Pre-Amble and Post-Amble to be recorded at the beginning and end of each record. The Pre-Amble consists of nine (9) "zeros" and one (1) "ONE" bit preceeding the data contained in each record. The Post-Amble consists of the phasing bit plus nine (9) "zeros" at the end of each record. Data is recorded on Channel A only, the other three channels (B thru D) are recorded with all "zeros". The inter-record gap should be at least three (3) inches long.

3.2 Transducer Kit (TK) Improvements

Major improvements were made in the TK by:

- Redesign of the Signal Conditioning Unit
- Cable redesign
- Elimination of unnecessary or improper transducers
- Development of new transducers

3.2.1 SCU Design

The SCU or junction box, #11734974, provides the interface electronics between the M151A2 vehicle and the PDU. Redesign of this unit was necessary for two reasons: one, either the circuits were not available in the PDU or old J-Box or two, the existing circuits were not satisfactory. Four boards comprise the J-Box. These are (1) the transducer interface, (2) final multiplexer, (3) ignition circuits, and (4) the interrupter.

3.2.2 Transducer Interface Board #1

The transducer interface board consists of two distinct sections. The first is a logic interface with the PDU; the second the differential interface for transducers mounted on the vehicle.

Logic Interface

In order to control the junction box from the PDU, nine lines are brought from the multiplexer (MUX), control register (see Table 3-7) on the A6 board within the PDU. With reference to drawing #11734982, the SA0 through SA3 lines are used as information bits and are routed to various storage registers by lines C8, C9, and C10. The tag bit is used to discriminate between operation of the internal MUX in PDU and J-box control. The I_B Hi-Lo line is used to strobe the information into the appropriate register. Details of the J-box control registers are shown in Tables 3-1 through 3-6.

Integrated circuits U4 and U5 are used to buffer the input lines. Since the drivers in the PDU are of the open collector type, 1K pull-up resistors have been provided. The I_B Hi-Lo line which is used as a strobe is a level change which is formed into a pulse by the one shot circuit between U4 Pin 12 and U6 Pin 1. The one shot was "hand made" in order to provide noise immunity. R60 and R61 provide hysteresis to insure a clean pulse output. The strobe is "anded" with the tag bit to provide distinction between the internal PDU mux and the J-box control as mentioned earlier. This "anded" pulse is routed to one of five registers as determined by the C8, C9 and C10 lines. U7 is a binary to decimal decoder with the strobe pulse input being the least significant bit. Thus, the odd numbered outputs are used to strobe the storage registers, U8 through U12. These storage registers are clocked D latches and thus the outputs contain the status of the SA0 - SA3 lines at the time of the strobe. The outputs of these five registers are used for control of the remainder of the J-box. Within the J-box is a connector to provide an access to these points as well as power supply voltages for use as a validation aid.

Transducer Interface

With the exception of the current probe inputs, the transducer interfaces consist of differential-to-single ended gain stages since the transducers are of the bridge strain gauge type. Since precision resistors were long lead items, hand selected RN55 type resistors were used to establish the gains with a trimmer to establish the common mode rejection. The trimmer also makes use of the common mode DC output voltages of the transducers to null the effects of the input offset voltage (2 mV) of the amplifiers, thus only one adjustment is necessary. The adjustment is made by shorting the differential inputs together with the transducers connected while monitoring the final J-box output. (This will not harm the transducers since the differential output is very small compared to the excitation voltage and internal resistive values.) The outputs of AR1 through AR4 are multiplexed by U2, a solid state switch, and then amplified by a factor of 2.5 before going to the final mux board.

The current probe inputs are handled in a somewhat different manner. There are two ranges associated with the probe: a $\pm$150 amp range and a $\pm$30 amp range. Each range corresponds to $\pm$1 volt full scale output. The high or low range is selected by turning on either U3-A0 or U3-A1 solid state switches. Two operational amplifiers are used since inversion and high impedance are required. In addition, the analog-to-digital converter, ADCON, in the PDU has a range of 0 to +5 volts and cannot "see" negative inputs. Thus the current probe must be biased such that the $\pm$1V output corresponds to 2.5V $\pm$ 2.5V. This is done by setting the + input of AR8 to 0.5 VDC. AR8 multiplies this value by 2 while multiplying the input by -1, thus giving a range of +1V $\mp$ 1V. This is subsequently multiplied by AR6 by 2.5 times when switch U2 selects the AR8 output.

Self test switching is also provided on this board. A 200 mV signal is developed from the +10V reference and may be routed to the various inputs by switches U1 and U3. Since the self test voltage is coupled to the inputs through high resistance values, the self test mode may be programmed to check if particular transducers are connected. If they are, the low output impedances of the transducers will shunt the self test inputs.

3.2.3 Final Multiplexer

The final multiplexer, Board #2, consists of the following:

(1) Amplifier - X4.01 - 1.0 VDC
(2) Amplifier - X7.02 + 2.66 VDC
fo = 0.8 Hz
(3) Amplifier - X1.03
(4) 75 RPM Indicator
(5) Level 2 Interrupt Generator
(6) Exhaust Hydrocarbon Indicator
(7) Emergency stop + Kill signal
(8) 8 Channel analog multiplexer

Referring to drawing #11734983, amplifier AR3, X1.03 is the analog driver to the PDU. The amplifier gain compensates for the -3% error when it is interfaced with the PDU. AR3 is fed by the 8 channel analog multiplexer U3 which can be programmed to select 8 different analog signals from boards 1, 2 and 3. The various signals are indicated on the Board #2 schematic. Two of the 8 channels come from amplifiers on Board #2 and are the AC coupled X7.02 + 2.66 VDC amplifier AR2, and the X4.01 - 1.00 VDC amplifier AR1. The inputs of these amplifiers are connected together and to another analog MUX channel. This point is driven from the X2.5 amplifier on Board #1. The lower 3 dB point of AR2 is 0.8 Hz and the upper 3 dB point is approximately 10 kHz.

Amplifier AR4 is used as a comparator to indicate when the output of the exhaust hydrocarbon probe has gone above a certain limit. The exhaust hydrocarbon probe is essentially a variable resistor which is one of the legs in the bridge circuit at the input of AR4. The circuit is designed so that when the transducer is on and the hydrocarbon content low, the output is zero volts. If the transducer is off or the hydrocarbon content is above a certain limit as indicated by a transducer resistance of 100K ohms, the output of AR4 is five volts.

U2, Q1 and half of U1 comprise the 75 RPM indicator. This circuit is driven from the points clock signal from board #4. When the voltage at U2 - 8 is five volts, the engine speed is below 75 RPM.

Two sections of U4 and U5 are used to generate a level 2 interrupt signal. The circuit is basically a differentiator which will produce a pulse whenever there is a negative transition of the points clock signal from the ignition interrupter, Board #4 corresponding to an opening of the points. The output of this circuit is a low going signal or a level 2, whose output pulse width is primarily determined by C12 and R27 and is approximately equal to 15 usec. The signal goes into an inverting buffer in the PDU and then directly into the 469 computer.

Two sections of U4 are used to logically output the emergency stop signal from the PDU and the engine kill signal from Board #1. The output of this circuit, U4-4, goes to the emergency shut-off line on the ignition interrupter, Board #4.

3.2.4. Ignition Circuits

The ignition circuits board #3, is divided into two main categories: ignition coil primary and secondary circuits.

Primary Circuits

With reference to schematic number 11734981, the primary board consists of a gain section (AR8 and AR9), an attenuator (AR7), and various programmable filters and attenuators. The AR8/AR9 combination is used to look for the voltage drop across the points when they are closed. The gain is such that 0 to 0.5V input represents full scale and therefore even the closing of high contract resistance points may be detected. AR7 is a differential attenuator/ buffer which is used in conjunction with various filters and other attenuators in order to provide useful primary waveform analysis. When the R61 and R62 combination is selected, a full scale range of 400 volts is realized; the R63 and R64 divider gives a 50V full scale range. A bandpass filter (VPBP) and a highpass (VPHP) are included for additional waveform analysis. Initially a low pass filter was included for the primary ignition waveform; however, later investigations of the diagnostic techniques showed a need to use this filter also on the secondary ignition waveform (VSLP). The buffer/amplifier AR9 subsequently feeds the final MUX board directly or may be routed to the sampling peak detector (AR4, AR5, and AR6), thus allowing point by point waveform analysis.

Secondary Circuits

The ignitor probe detects the secondary ignition waveform and presents a 0 to -5V signal to the secondary circuits of the SCU, corresponding to a 0 to -30 KV range at the coil high voltage tower. The most negative peak of the waveform corresponding to the spark line is detected by peak detector AR1 and AR2, which is almost identical to that used in the primary circuit. The plug firing zone signal is amplified by AR3 and is examined by the peak detector used in the primary (AR4, 5 and 6). Outputs VSP, VSM/VSC, VPD, and VPC are routed to the final mux board.

Number 1 Firing Detector

To provide an engine cylinder reference, a number 1 spark plug firing detector is used. The number 1 firing probe delivers a pulse waveform to comparator Q1, Q2 during the firing of the number 1 plug. The output of the comparator sets flip-flop U3 to indicate that number 1 has fired. Recognition of the firing under program control resets U3.

3.2.5 Ignition Interrupter

The ignition interrupter, board #4, is circuit proprietary to RCA and was not disclosed under this contract. It is used in conducting engine power tests and is capable of disabling the engine by shorting the ignition.

3.3 Transducers

A total of seven (7) transducers are available and may be used as directed by the diagnostic program. (Transducers are not connected unless there is diagnostic evidence that they are needed.) The seven major transducers are:

- Ignitor probe #11734927 - This device, installed in an existing access hole of the ignitor, provides information on the primary and secondary condition of the ignition system. It is used to identify point, coil and condensor as well as firing cable and plug problems. The ignition probe was completely redesigned during this contract.
- Current probe #S1-930-150 - The current probe is primarily used for sensing battery current during cranking and thus is capable of providing input data on battery current, starter circuit operation, cylinder compression and timing. It may also be used for probing the current flow in individual electrical circuits. Additional probes were procured during the contract.
- Number 1 firing probe #11735005 - This probe sits in-line with the number 1 spark plug and generates a pulse when that plug is fired. The probe output is used as an event marker for timing and cylinder recognition. The circuitry and mechanical design of the probe were completely redesigned for the program.
- Intake manifold pressure probe #ITQV-1-500-15A - Intake manifold pressure levels and waveforms are used in a variety of diagnostic procedures including automatic timing and identification of manifold

leaks and blockages. The original intake manifold transducers were found to be unsatisfactory and new, higher output devices were obtained.

- Crankcase blowby probe #ITOV-1-500-5 - The crankcase blowby transducer is utilized to look for sources of low cylinder compression associated with worn or broken rings and cylinders as well as head gasket and valve cover leaks. As in the case of the intake manifold probe, new transducers were specified and procured.

- Crankcase oil temperature - #11734132 - This probe is used for insuring the engine is at a correct operational level prior to performance testing. The original probes were found to be satisfactory.

- Hydrocarbon sensor #11734900 - A need existed for means of searching for the presence of gasoline in the engine without opening the fuel lines. A hydrocarbon sensor was developed which would generate a signal of the concentration of hydrocarbons in the tail pipe exhaust. This totally new probe required extensive search for a low cost, reliable sensor principle and hardware. Such a device, operating on a principle of resistance change with absorbed hydrocarbons was found and incorporated into a tail pipe probe.

3.3.1 Igniter Probe

The igniter probe, #11734927, was developed using the original design concept as a starting point. The device had to be located in the access hole of the M151A igniter; no modifications to the igniter or its leads were acceptable. The igniter probe functions are: to provide a signal representative of the secondary voltage, to provide a signal representative of the primary voltage, and finally to provide a path for inhibiting the ignition system for interrupter tests. Mechanically, the probe had to be extremely rugged and easy to handle.

The final design incorporates a cylindrical housing which screws into the access hole of the igniter. Primary voltage measurements are made through a spring-loaded contact which touches the binding post on top of the primary side of the coil. The secondary voltage is received by a ring-shaped antenna mounted co-axially on the primary contact plunger. To insure electromagnetic separation of the two channels, separate cavities are provided in the probe housing, and the primary and secondary channels are brought out through separate connectors.

The secondary voltage amplifier provides a non-inverting, negative going pulse scale so that -5VDC equals 30 KVDC at the secondary. The output is DC coupled and is designed for less than 10 mV offset over the normal temperature range of operation.

3.3.2 Number 1 Cylinder Firing Probe

The function of the number 1 cylinder firing probe, #11735005, is to provide an event marker signal to reference the cylinder and thus correlate faults with individual cylinders whenever possible. The original probe had several serious defects. First, the initial probe design was based upon a high turns ratio coil surrounding a spark plug lead current path. The probe was highly susceptable to noise conducted down the lead and could under certain conditions produce spurious signals.

Secondly, the mechanical design of the probe was poor in that:

- o There was no positive connection of the plug lead into the probe
- o The probe was difficult to locate and tighter in the spark plug hole
- o The probe tip was subject to easy breakage

The new probe was designed to operate electrically as a high impedance voltage divider, with active pulse shaping and noise rejection. Mechanically, it was reduced in size and the connections redesigned to insure firm mechanical joints.

3.3.3 Intake Manifold and Blowby Pressure Transducers

The original pressure transducers were manufactured as special items by Dynasciences Corporation. They were strain gage type instruments having a 200 mV output with a 10 VDC input. Calibration of the transducers indicated that some of the sensors were not meeting the original specifications of linearity or temperature drift. There were only a few "good" transducers of each kind and no source of supply.

After a survey of candidate pressure transducer vendors, devices manufactured by Kulite Corporation were selected. These devices use a semiconductor strain gage and have a preamplifier section built into the housing. Each type gives 5 VDC full-scale output at 10 VDC input. The devices were ordered with special connectors to match the ATE cable connections as per the original sensors and with pressure port terminations to screw into the intake manifold port or into the pressure cap fitting adapted for the blowby transducer.

3.3.4 Hydrocarbon Sensor

The diagnostic approach required determination of the presence of hydrocarbons in the exhaust line of the vehicle. It was necessary to sense the flow of gasoline in a no-start vehicle without opening any fuel lines. If a sensor could be found which would detect the presence of fuel at a combustible level, then the ATE could automatically decide whether or not there was a fuel blockage problem attributable to a malfunctioned fuel pump, clogged carburetor or lack of fuel.

Two devices were identified as having low cost and not requiring elaborate gas sample handling systems. The first, Taguchi Gas Sensor, TGS, manufactured by Figaro Engineering Company, Osaka, Japan, is a bulk n-type metal oxide semiconductor whose resistance decreases when it absorbs reducing agent gases.

The second device studied is the Dolan Adsorptive Sensor, DAS, manufactured by the Danforth Co., Portland, Maine. The sensor works on the principle of adsorption of selected gases or liquids in a mono-molecular layer. The adherence forces to the surface can be high, depending on the chemical composition of the adsorbate and the gas or liquid according to Van der Vaal's equation. Hydrocarbons have particularly high Van der Vaal constants and therefore exhibit high surface forces.

The DAS is an "adsorptive/variable" resistance element whose electrical resistance increases with an increase in the adsorptive nature of the atmosphere in which it is placed. It consists of a rigid, base material in the form of a ceramic 1/2 watt resistor body on which is placed a thin resilient surface coating of silicon rubber. Conductive adsorbent particles such as microfine ground carbon or platinum black are lightly imbedded in the coating.

Normally the sensor's resistance in air is about 750 ohms. However, when it is exposed to an atmosphere containing a gas with a higher Van der Vaal's constant, molecules of that gas will force air molecules out of the sensor's surface layer spaces and produce a tension force in the surface increasing its resistance. An explosive mixture of gasoline can change the resistance to over 100,000 ohms.

Both devices were tested on the exhaust stream of the M151A2 vehicle during cranking. The tests were conducted by insuring the vehicle's fuel delivery system was empty (vehicle was run out of gas and the fuel pump outlet sealed). With the choke closed and the ignition off, the engine was cranked with the test device located several inches inside the tail pipe extension. In the case of the TGS, a power supply was necessary to drive the device to measure its conductivity; with the DAS a simple ohm-meter was used. The change in the devices' resistances as a function of cranking time was noted. The tests were rerun with the fuel line reconnected and the change in the resistance with time again noted.

The TGS device did exhibit a decrease in resistance with time as expected. However, the gain of the device is high and it exhibits saturation and therefore the difference between the no-fuel and fuel conditions were not sufficiently different to be a satisfactory diagnostic tool. The resistance decrease was about 5 to 10% of the initial value. Attempts to decrease the gain electically were not successful, and it was decided that the only practical way of making the device work would be to decrease the hydrocarbon concentrations by air addition to get onto the linear portion of the TGS's response curve. This meant an active air pump and mixing system and the TGS was dropped.

The results with the DAS were more successful. In the no-fuel condition, the resistance of the device never rise above 40,000 ohms even after several minutes of cranking. Once the fuel line was reconnected, the sensor's resistance went to about 100,000 ohms in generally less than 15 seconds.

Further tests were performed to investigate the effects of temperature, moisture and extreme exposure to hydrocarbon vapors. The temperature tests were made by first running the engine for several minutes until the engine block and exhaust system were hot and then the no-fuel/fuel tests were performed. While the no-fuel resistance did increase slightly, it did not exceed

100,000 ohms, while the fuel test results were similar to previous runs. Cold tests were made by running lines around the exhaust pipe and forcing liquid nitrogen through them. The indicated exhaust gas temperature was below 25^{o}F and frost was formed on the DAS. Neither the cold nor the presence of condensed water on the sensor affected its performance.

The DAS was left in a closed beaker containing gasoline for over 48 hours. While the DAS was not in direct contact with the liquid, it was saturated by gasoline fumes. After removal, the DAS recovered its original characteristics within 15 minutes and did not show a residual effect.

The final design of the hydrocarbon probe houses the DAS inside a stainless steel cylinder. The housing has gas flow passages designed to ensure a uniform flow of exhaust gases over it while not obstructing the total exhaust mass flow. A stainless steel screen is provided to prevent impact of exhaust system particulates and to serve as a barrier against water drops in the tailpipe. The probe can be attached to the vehicle using either one of two tailpipe adapters.

To prevent possible probe damage, the diagnostic program inhibits the ignition during that portion of the test. Continued exposure to hot exhaust gases will destroy the DAS and care should be taken to insure the device is not inadvertently left in the tailpipe while the engine is running.

4.0 Software System

The PDU has, as part of its equipment complement, a Control Data Corporation 469 computer. The computer is a reprogrammable unit which executes various diagnostic programs input into the computer via a magnetic tape loader. The tapes control all of the program information necessary for conducting vehicle diagnostics. Thus, the programs contain programs which not only hold the diagnostic structure, but also dictate how the ATE hardware should be controlled during diagnostics and how program elements should be handled. This section describes the software system which was assembled for the present contract.

A major portion of the software program was developed by TRW's subcontractor, RCA. To accomplish their task, RCA established a program writing, interface and debugging system at their facility. Operational software was written in Version 3, 469 Computer Assembly Language utilizing a library of ATE/ICE procedures. Programs were processed on KRONOS, a part of Control Data Corporation's Cybernet Services; see Figure 4-1. KRONOS provided remote batch access from the vehicle test facility to a large Control Data 6000-series system. A CDC 200 users terminal was used for remote batch input and program listing. An ASR 35 terminal was used to create and save files consisting of program segments and procedure libraries, and to output punched paper object tapes for loading into the 469 computer for program debugging. Programs and program segments were tested using 469 peripheral equipment connected to the PDU and two vehicle test stands.

Cassette images were transmitted to a CDC service center in the Detroit area where they were picked up by STIS for direct transcription on cassette. Completed cassettes were then air transported to TRW and RCA for checkout.

4.1 Cassette Loader Program

The cassette loader program has the responsibility for loading program overlay segments into specific locations in core. The cassette loader program can be segmented into two functional units, each independent of the other. The first program, referred to as the "Boostrap Loader", Figure 4-2, has the function of loading the first overlay segment containing records which comprise the operating system and to then passing control to the beginning of the operating system (11000_8).

The function of the second program, the "Cassette Loader", Figure 4-3, is to load individual records, groups of records or entire overlay segments depending on the operating system requirements. The cassette loader is to be available for call at anytime during the program execution and must be relocatable. Further description of both programs is contained below.

4.1.1 Bootstrap Loader

The CDC 469 computer has available for program loading 20000_8 (20000 octal) words of core. In addition, 2000_8 words of core are available as Read Only Memory, ROM. The ROM is permanently wired and thereafter not altered other than by replacing the entire ROM region.

As part of this ROM region, there is available a short program capable of reading one page of data from the cassette. (One page is equivalent to 400_8 words of core.) Since the present hardware dictated a starting point of 20400_8, the ROM is activated at each start-up after power-on. The ROM calls for the tape to rewind to beginning of tape, BOT, reverse and load the first program segment, the Bootstrap Loader. Once the Bootstrap is loaded into core, control is transferred to the Bootstrap. The Bootstrap is loaded into the last page of core (17400_8 to 17777_8) and has its first executable statement located at 17400_8.

The purpose or the Bootstrap Loader is to load an entire overlay segment from cassette to specific locations in core. This segment may contain any number of records subject to the constraints that: 1) the overlay segment can be stored on the cassette, 2) the data format conforms to the format described below.

The Bootstrap Loader will cause the tape to rewind automatically to the point called for by the operating system and to load local sequential records until the end of tape, EOT, is found or a cassette loader malfunction is encountered. If the normal termination is found, control is transferred to the operating system program, core location 11000_8. If a loader malfunction is detected by the hardware, a level two interrupt is issued and program execution is stopped at location 17530_8. A corresponding message is generated on the set communicator.

As part of the four-word header (see below for format) a check-sum is available to confirm a valid record load. At the end of each record load a computed checksum is compared with the input checksum. If they do not compare the program rewinds the tape and attempts to re-read the record. This process is repeated three times or until the checksum is confirmed. If, at the end of the third read of a particular record the checksums still differ, a checksum error message is issued to the set communicator.

If at any time during the loading an end of record is found prematurely, a "short record" message is displayed and a 5-second pause is initiated. Then the checksums are compared and a re-read is performed if necessary. This same procedure is performed in the case of a long record; i.e., an end of record is not found at the termination of a record loading. A "long record" message is displayed on the set communicator, there is a 5-second pause and the tape is advanced to the end of record to enable the next read if the checksums compare.

4.1.2 Cassette Loader

The operation of the cassette loader is very similar to the bootstrap loader. The only major difference is the way in which the routine is utilized. The bootstrap loader is activated by the RØM region and continues to read until an end of tape is encountered. The cassette loader is used as a subroutine and is called by the operating system by the following series of instructions:

```
SRJ    Call, LINK
CØN    SEARCH
CØN    Record ID1
CØN    Record ID2
```

One of the requirements for the cassette loader is that it be relocatable; i.e., the program must be capable of being executed from any portion of core. The variable SEARCH contains the starting address for the loader.

As part of the four-word input information for each record is an unique record identifier. Each record must have this unique identifier and the only constraint is that they be numbered sequentially, starting with the first record possessing any octal number from 1 to 777 and each successive record be incremental by one. Since the total number of bits available for this identifying purpose is 9, the last record must be less than 1000_8. Record ID1 identifies the first record to be loaded and ID2 identifies the last record. It is assumed that ID1 $\leq$ ID2 at all times.

As the cassette loader is called from the operating system, its first function is to rewind to the first end of record and to read the next record four-word header. This supplies the physical tape location by inputing the record identification numbers. The loader then determines if the tape must be advanced or rewound to locate the first record to be read. Both forward and reverse modes are executed with a fast tape movement command, fast reverse or fast forward respectively. When the proper record is found the program begins loading as in the bootstrap loader. The inputed checksum is compared to the calculated checksum and a re-read is performed if necessary. Short and long records are handled in the same manner as in the bootstrap loader and program pauses are activated at useful intervals. The cassette loader differs in that: loading is terminated when record number ID2 is found, and if a short or long record is found only the checksum error is displayed. The latter was necessary because of the program size constraint of one page (400_8 words of core). If a long or short record is encountered and the checksums compare, no message will be displayed on the set communicator.

When the last record has been loaded, program control is transferred back to the operating system by the following sequence of instructions:

```
SRJ        Return, LINK
CØN           2
```

4.1.3 Tape Format

All cassette tape inputs to be read by both the bootstrap loader and the cassette loader, are assumed to have been written with the following format:

<u>WORD 1</u>

(1 to r)	Bits 0-6	SEGMENT IDENTIFIER (7 bits) *(for comment purposes only)*
	Bits 7-15	RECØRD IDENTIFIER (9 bits) A sequential record number, enabling random record access.

WORD 2

	Bits 0-15	CHECKSUM (16 bits) A 16 bit logical checksum error. If zero input, checksum is to be ignored.

WORD 3

	Bits 0-15	WØRD CØUNT (16 bits) A word count starting with word 5 as the first input.

WORD 4

	Bits 0-15	LØAD PØINT (16 bits) The absolute load address for the first data word (word 5) of the record. Subsequent words are loaded in ascending locations of memory.

WORD 5 - End of Record

	Bits 0-15	Data to be loaded into memory.

4.1.4 Messages

The following messages may be displayed on the set communicator during the execution of either the bootstrap loader or the cassette loader.

Message	Description
LØADING RCD XXX	The program is currently attempting to LØAD RECØRD XXX.
SHORT RECØRD RCD XXX*	An End of Record (EØR) was encountered prematurely during LØADING OF RECØRD XXX.
LONG RECØRD RCD XXX*	An EOR was not encountered and the end of LØADING RECØRD XXX.
CHECKSUM ERROR RCD XXX	The calculated Checksum did not compare with Checksum value inputed in the four-word header.
LOAD COMPLETE	The last record has been loaded and control has been transferred back to the operating system.
LOADER FAILED -STØP-	A cassette loader hardware malfunction has generated a level two interrupt. Program execution has been terminated.

*Encountered during execution of Bootstrap Loader only.

4.2 Operating System

The operating system incorporated into the diagnostic software of this program was built upon the PDU/BITE system developed under previous TACOM sponsorship contract DAAE07-73-0035. The PDU/BITE operating system facilitates test program debugging, hardware debugging and operational testing in two ways: it allows interactive software simulation of the Built-in Test Equipment (BITE) interface on a teletypewriter, and operational testing of M151A2 vehicle through the set communicator.

A block diagram of the operating system is shown in Figure 4-4. When the POWER ON switch on the PDU control panel is placed in the ON position, control passes to the ROM which loads the bootstrap loader from the cassette into the last computer page of protected high core. This program in turn loads records 1 - 7 containing the operating system into core and then passes control to the START program of the operating system. START will initialize the hardware and software, start executing tasks determined by task control blocks (TCB), display a request for the Confidence test, and place the system into a ready state (a task which calls itself). The system then waits for a request answer to be entered on the set communicator.

The ENTER button on the set communicator, SC, interrupts the wait cycle. The SC enter program sets an SC ENTER flag and then returns to the executing task. The sequencer scans this flag each time control is returned to it by the executing task. If the flag is set and the request is for an operator enterable task, the sequencer resets the SC ENTER flag and takes the next task request from the set communicator. If the flag is not set, the sequencer takes the task from the current task control block. The sequencer then passes control and new task pointers to the stack handler which invokes the task procedure. The task procedure in turn uses the stack handler to invoke sub-procedures and I/O Handler procedures. The task procedure may also use the task handler to allocate and deallocate dynamic storage. The speed program is entered when the points-open interrupt occurs. This interrupt level, however, is enabled under program control, and updates the current engine speed register only when requested.

Task

A task is made up on one or more standard and/or user-originated test procedures. All ATE/ICE test operations are organized as sequences of tasks controlled by a test executive. A task has the following characteristics:

(1) Identification number
(2) Status
(3) Test data
(4) Test messages
(5) Ordered link with other tasks
(6) Associated procedures which may be invoked

Each task consists of a task control block and one or more task procedures. The TCB is used by both the test executive and the task procedure to coordinate all testing operations.

Task Control Block

Each TCB consists of a minimum of 6 contiguous computer words organized as follows:

TCB +0	TCB NUMBER	
+1	TASK PROCEDURE ADDRESS	
+2	NEXT TCB NUMBER IF GO	
+3	NEXT TCB NUMBER IF NO GO	TCB LENGTH
+4	TCB FAULT MESSAGE ADDRESS	
+5	NEXT TCB ADDRESS IN CHAIN	
+6		
+7		
+10		VARIABLE LENGTH APPENDAGE
+11		
+Ng		

The TCM entries have the following meanings and functions:

(1) TCB Number - A unique identifying number is assigned for each task. The sign of the TCB Number indicates whether or not it is permissible for the operator to enter this task via a set-communicator command: if the TCB Number is negative, the task is operator enterable; if positive, it is not operator enterable.

(2) Task Procedure Address - This portion of the TCB contains the address of the procedure to be executed when the task is invoked. The task sequencer will pass control to this address.

(3) Next TCB Number if GO - This number is the identification of the next TCB in the testing sequence if the current status is GO (not run or no fault). If the TCB Number is negative, this indicates the termination of overlay execution, and thus calls for loading another overlay beginning with this record number.

(4) Next TCB Number if NO GO - This refers to the number of the next TCB in the testing sequence if the current status is NO GO. Zero means the end of the TCB sequence. A negative number is the last record of a call for loading test overlays.

(5) TCB FAULT MESSAGE ADDRESS - The address of the first character of a string of characters to be displayed as a diagnostic fault message if the TCB fault message address. If a task does not determine a diagnostic fault which requires a display, this entry equals zero.

(6) Next TCB Address in Chain - This entry contains the address of next TCB in a linked chain of all TCB's. The chain of TCB's is closed loop in which the last TCB address in the chain is the address of the first TCB.

(7) Appendage - The appendage allocates storage area for use by common test procedures and common data base. The appendage area may contain strings of ASCII message characters for fault displays (typically 12 characters followed by a zero byte which will be conditionally displayed on the current status or past status). It may also contain record number arguments to indicate the first

and last records comprising a segment of test procedures needed to complement TCB's which have already been loaded.

During initialization, the current status of each TCB is set to show that the task has never been run, and the past status is set to show that no fault has occurred. These are also the only two words associated with a TCB that are modified during program execution. Use of the Appendage is optional.

Subtask

The subtask is identical in structure to the task. It is used when more than one task uses the same dynamic stack storage area for the storage of intermediate test results. Subtasks are linked together through the TCB in the same way that tasks are linked together. Return to the main task is invoked by placing an 0 in the appropriate next TCB-block of the current subtask.

Procedure

A procedure is a software module. Procedures observe strict software conventions established for the ATE/ICE program. The test executive invokes a task using the procedure call with accumulator AC7 containing the current TCB address. One procedure can call another procedure. Return to the calling routine is made by a procedure return.

Task Sequencing

Task Sequencing is accomplished by the test executive using the next TCB to run words of the current TCB. For example in Figure 4-5, assume the following organization of TCB's and next TCB to run pointers.

After task 0 is entered and executed, the executive examines TCB 1 such as one which would invoke a task requiring operator intervention (e.g., cranking). Finally, TCB's 2 and 3 would be continually examined since they form a closed loop. This is where continuous monitor functions are performed.

If the operator requested task 4 via the set communicator, the test executive would then use TCB 4 instead of the current tasks "next TCB to run". As shown in the figure, TCB 4 would pass control back to the continuous monitor loop starting with TCB 2. Had the operator requested task 5, its TCB would point to TCB 6 which would then point to the continuous monitor loop. TCB 6, however, has subtasks associated with it. TCB's 10 and 11 are detached from the regular control blocks. Task 6 calls the executive to pass control to subtask 10. Task 10 uses the executive to pass control to subtask 11. A zero in the "next TCB to run" pointer in subtask 11 has the effect of terminating the executive which returns control to Task 6 which originally called it.

Task Chaining

Every TCB must be periodically examined to determine its task number or if a message is to be displayed. The next TCB in-chain word points to another TCB in a continuous chain of all TCB's. Chaining has no effect on task sequencing; it will, however, determine the order in which messages are displayed. The address of the first TCB to be examined after power-on is a suitable place to enter the TCB chain. Using the sample example as was given for task sequencing, Figure 4-6 shows one possible chain.

Status Word Chaining

Every TCB has an associated status word assigned to it in low unprotected core to indicate the past and present status of a task. The status word chain has a 1:1 correspondence mapping with the chain of TCB's found in protected core and is assessed dynamically by the operating system and test procedures to monitor the state of diagnostic testing since initialization. A status word in the chain has the 8 most significant bits assigned to the current status of a task while the 8 least significant bits assigned to the past status of the task.

Current Status

0 Task not run (updated by sequencer prior to execution)
1 No fault found last time task was run
2 Lowest level fault found last time task was run
.
.
.
255 Highest level fault found last time task was run

Status Word

Bit 0	Bit 15	
Current Status	Past Status	Least Significant Bit
Bit 7	Bit 8	

Figure 4-6 shows a possible chain of status words associated with the chain of task control blocks.

Overlays

The operating system is specifically designed to use the cassette program loader to load test programs (confidence inspection, no start, idle performance, power performance, and tune-up) as independent modular test domains. This minimizes the need for a complex portion of the operating system to schedule and maintain a core configuration of task software. Scheduling is solely a function of the execution sequence determined by the task control blocks needed to implement a logical unit of diagnostic testing. This memory management scheme utilizes a minimum overhead: i.e., TCB's to interface diagnostic tasks with the operating system, and provides demand segmentation to effectively utilize secondary storage as a virtual core image extending the useful core storage of the CDC 469 computer.

Overlays are also developed consistent with the structured programming environment to maintain system integrity and security with sufficient flexibility to reduce software development and validation costs. The structure is as follows:

- Test overlays - logical group of TCB's and procedure segments
- Segments - logical group of sequential records to be loaded by one call
- Records - physical blocks of data on magnetic tape

A program loading sequence may be initiated by a set communicator entry number, 3 through 7 to select a task which in turn loads the test overlay appropriate to that test program. For example, number 3 calls for the loading of the confidence test program. The test overlay is comprised of a test TCB segment, a common subroutine segment, and initial subset segment of the test's task procedures. Once the execution of the initial tasks is completed, a dedicated TCB in the chain of TCB's will demand that the cassette loader load additional segments of task procedures to enable further diagnostic testing. Test execution will continue until end-of-test segment is loaded and executed and then a return to a system ready state and a wait will be executed.

Memory Organization

The ATE/ICE Operating System, additional supporting software, and diagnostic software fully utilize the resources of the 8192_{10} word 469 computer. Figure 4-7 shows a breakdown of the software's memory organization. Memory 0 to 4000_8 is unprotected, while memory from 4000_8 to 20000_8 is protected plated wire.

5.0 DIAGNOSTIC ENGINEERING

This section presents much of the diagnostic base for the diagnostic structure developed for the M151A2 engine. It describes the experimental programs and data which support the diagnostic decision making processes. The section is divided into two major subsections. The first describes the tests and results of studies examiming the influence of engine parameters on serviceability, characterization of components and specialized tests aimed at new diagnostic approaches. The second section deals with the cause and effect relationship of faults relative to what would be observed during an EDT.

5.1 Data Base Tests

Test programs were conducted at TRW to support the development of vehicle malfunction diagnostics of the Automatic Test Equipment. For the "top down" diagnostic approach to be viable, sensitive and repeatable measurement of serviceability as well as reliable malfunction diagnostics are necessary for characterization of the serviceability criteria and development of the diagnostic logic. Major data base tests took place at TRW. RCA performed tests on specific diagnostic techniques such as automated timing.

Tests were conducted to investigate malfunctions that would cause the vehicle to be unserviceable in each of the categories of non-serviceability; i.e., no start, idle and power. The tests followed a plan which consisted of (1) initial screening experiments to assess the degree of malfunction necessary for non-serviceability, (2) matrix designed tests with factoral variations of malfunctions for determining main effects and two-factor interactions, and (3) tests for specific characterization of independent parameters.

5.1.1 Test Facilities and Instrumentation

Locations of all instrumentation are shown in Figure 5-1 for diagnostic and characterization tests on the dynamometer. The tailpipe hydrocarbon sensor which normally is located at the position of the exhaust pressure, P_E, transducer is not shown. Tests relating to the development of that device were described in Section 3.3.4.

Instrumentation is divided into two categories: those associated with the operation of the dynamometer -- torque, speed and temperature; and those which are used to sense and record engine parameters. The engine power parameters and intake manifold pressure are displayed as well as recorded for "quick look" engine monitoring.

5.1.1.1 Dynamometer Stand

The dynamometer used for this program was an 800 horsepower water turbine type manufactured by Go-Power Systems of Palo Alto, California. Torque loading of the engine is accomplished by varying the flow rate of water through the power absorber with a hand valve. Engine speed signals were produced by a magnetic pickup adjacent to a toothed wheel on the dynamometer power absorber input shaft. A visual speed output on the dynamometer console was used for monitoring engine speed. The signal was also used for recording on a strip chart recorder.

Engine shaft torque was measured from two tangentially positioned hydraulic cylinders on the trunion-mounted power absorber housing. The pressure output from the cylinder was read out on a high resolution Bourdon tube gauge calibrated directly in torque units. A strain gage pressure transducer connected to the hydraulic line was used to provide a permanent recorded torque trace on the same time base as the speed for instantaneous computation of engine power.

Engine coolant temperature in the cylinder head was measured at a location provided on the engine. The standard engine temperature sensor was replaced with one compatible with the visual display gauge on the dynamometer panel.

5.1.1.2 Dynamometer Instrumentation

Exhaust pressure was measured at the end of the vehicle's exhaust system which consists of a muffler and all piping. The transducer was positioned on an adapter as shown in the diagram. The adapter had a one-inch diameter exhaust exit hole on its side to allow the exhaust gases to escape.

The intake manifold pressure, P_I, transducer was threaded into the existing forward port in the intake manifold. The transducer was tied to a line connected to a manifold pressure gauge for display on the dynamometer control console. A mercury column manometer was used for calibration. Valid intake manifold measurements could be obtained only if all lines to the intake system were secured and the ignitor access port was closed.

Crankcase pressure or blowby pressure, P_C, was sensed at the oil fill port in the rocker arm cover. Pressure at this location is considered common with the crankcase due to the interconnecting push rod passages. The standard oil fill cap was modified to accommodate the transducer.

Primary voltage, V_p, was measured through the existing access port into the ignitor assembly via the ignitor probe. The center portion of the spring-loaded probe contacted the primary post on the ignition coil.

Secondary voltage, V_S, information is in the ATE system obtained from the ignitor probe. In that installation, the high voltage secondary is capacitively coupled to a ring-shaped antenna on the probe and the signal is conditioned within the probe. For the dynamometer installation, however, the distributor cap was modified by removing the bakelite material surrounding the lead from the coil to the distributor rotor. The circuit was broken and an unshielded lead brought out. A conventional clamp-on probe (Sun Instruments) was then used for secondary voltage measurements.

Battery voltage, V_B, was measured by direct contact across the battery terminals. Battery current, I_B, was measured by a precision shunt.

Current to the coil primary, I_p, was measured by installation of a Hall-type clamp-on sensor. The probe and its function are not used in the TK system; however, in the dynamometer tests, this current was monitored to investigate the effects of primary circuit impedances, provide point opening event marks and to evaluate coil transients and saturation.

Number 1 cylinder firing events were sensed by utilizing an inductive probe on the #1 cylinder wire at a location where the protective metal sheath had been stripped away leaving only the silicone rubber insulation. This approach was necessary as the GFE probes required redesign before they could be used reliably.

Oil Temperature, T_O, was monitored in three places. A visual readout for the dynamometer panel orginated from a thermistor sensor mounted in the center of the oil sump drain plug. The other probes were located on the dipstick tube and the oil filter fitting. The probe at the bottom, therefore, measures the coolest (stagnant) oil nearest the bottom of the sump. The dipstick probe measures warmer oil slung off of the crankshaft and that which is returning to the sump from various other parts of the engine. Temperature at the filter is essentially the output temperature from the oil pump prior to being distributed to the engine bearings.

In addition to the above-described sensors, a Sun Engine Performance Tester and dual beam Tektronix oscilloscope were used during various tests primarily for visual display of ignition characteristics. For the Sun Instrument, inductive type probes were used to measure voltages, point dwell, and number 1 cylinder firing. The oscilloscope was used for displaying the secondary trace via high voltage step-down probe connected directly to the ignition coil secondary output. A distributor cap had to be modified so the direct electrical contact could be read. A photograph of the scope display provided a calibrated record of the secondary voltage waveform that was recorded simultaneously on a high-speed oscillograph.

"Interrupter RPM" was used as a measure of engine power output at wide open throttle. For the test phase, a specially designed breadboard interrupter circuit was procured. The laboratory device attached to the ignitor primary post and was activated by depressing a button on top of the unit simultaneously with full opening of the throttle. Ignition interruption was started when the engine reached 3000 rpm. Releasing the button concluded the test by complete shorting of the primary. The electronic design of the interrupter causes four out of every five firings to be shorted out. This allows the engine to develop approximately 20% of its nominal WOT power and allows a progressive evaluation of each ignition path. The process is shown diagramatically as follows:

Cylinder firing order $\underline{1}$ 3 4 2 1 $\underline{3}$ 4 2 1 3 $\underline{4}$ 2 - - - -

where an underline signifies an accomplished firing.

Measurements of idle mixture ratio were made by sampling a portion of the exhaust stream and processing through appropriate cold traps and particulate filters. Carbon monoxide concentrations were measured by a Beckman model 312 non-dispersive infrared analyzer, and was used as the parameter describing air-fuel ratio.

5.1.2 Crank-Won't Start Tests

This subsection describes a series of tests which were conducted to understand the interaction of various engine characteristics in terms of the resulting effect on vehicle startability. Further, these tests served as a data base for the identification and description of the diagnostic measurements which would be required for isolation of no-start faults. The tests presumed that the engine was capable of being cranked at some level sufficient to start it under normal circumstances and thus the tests did not relate to conditions such as an open starter circuit or jammed starter.

Representative strip charts are to be found in Figures 5-2 and 5-3. Figure 5-2 shows the intake, manifold pressure, blowby pressure, starter current and voltage, exhaust pressure and primary current for a nominal engine. Figure 5-3 shows the same data channels with exhaust valve maladjustment.

Failure of the vehicle to start is a result of one or more faults; poor compression, faulty ignition, insufficient cranking speed and poor air-fuel delivery to the cylinders. Each of these conditions was thoroughly explored during the tests.

5.1.2.1 Characterization of the Effects of Low Compression

Low compression was imposed on the engine by three different methods. These were: holes in the piston, intake and exhaust valve maladjustment, and holes in the cylinder head. The first was to simulate piston/ring problems, the last the effect of head gasket and other leaks through the cylinder boundary. Cold, dry compression was varied from 70 to 120 psia.

Two parameters were considered potential candidates for correlation with cylinder compression. They were the starter current amplitude and instantaneous engine rpm. The results indicated that both the amplitude and the instantaneous rpm are good indicators of low compression.

If the peak starter current (after the starter spin up transient was over) was less than 50 amperes, it was indicative in all cases of a compression of 90 psi or less. Dropping the cylinder compression from its normal setting by 50 to 70 psi reduced the peak current by 25 to 35%. For similar conditions, the cranking speed would increase by 10 to 13%.

Initial tests were conducted to determine the effects of low compression imposed by placing holes in the piston. Test results for both cold and hot engine cranking characteristics are shown in Figures 5-4 and 5-5, and are tabulated in Table 5-1. While there is considerable scatter, the tests indicated little difference between the peak starter current with the engine in a cold or hot condition. As the battery voltage (starter terminal voltage) is reduced the cranking speed of the engine falls off. The peak value of the starter current, however, does not begin to drop dramatically until the terminal voltage falls below 18 volts. Under all cranking speed conditions, there is a sizeable change in peak starter current with cylinder compression.

Another means for reducing cylinder compression is by maladjustment of intake and exhaust valves. The results of these tests are presented in Figure 5-6 and Table 5-2. As was the case with the hole in the piston, the data shows that a low compression cylinder can be detected by monitoring the peak starter current. A peak starter current of less than 50 amperes was indicative of a low compression cylinder in the majority of the tests.

In an attempt to obtain a parameter which would flag a cylinder having a low compression relative to other nominal cylinders, the ratio of the peak current of the low compression cylinder to the nominal compression cylinder was computed. The results are presented in Figure 5-7. The data showed that this approach could not differentiate absolute low compression between 70 and 90 psi, but would indicate that low compression did exist.

As an alternative to computing the ratios of peak current, a comparison of the difference in nominal and low compression peak values gives the same conclusion as shown in Figure 5-8. Although no significant difference can be detected between 70 and 90 psig compression, a low cylinder or cylinders can be identified by a drop from the nominal peak current of between 15 and 30 amperes.

When variations in the cranking speed were investigated, it was evident that a speed parameter would also be useful in isolating low compression cylinders from nominal cylinders. Figure 5-9 presents the ratio of the speed of lower compression cylinders to nominal compression cylinders. The cranking speed increases by approximately 12% as the cylinder compression is lowered to 90 psi. Below that point the diagnostic sensitivity of that approach disappears.

5.1.2.2 Characterization of Induction System Parameters

The starting characteristics of the M151A2 engine are such that mixture enrighment (choking) is almost always needed for starting a cold engine. Presuming the fuel delivery system and carburetor provide some fuel to the engine, sustained cranking will always provide enough fuel to start the engine if other parameters permit. Thus, rather than explore the go/no-go limits of the air-fuel ratio, tests were conducted with the choke fully closed to determine whether or not crankcase pressure and/or intake manifold pressure during cranking could be used to detect induction system malfunction. The malfunction was presumed to manifest itself as rough idling and/or reduced peak power. The objective was to identify the following potential faults:

- Partially open throttle (poor throttle linkage system, bent throttle plate, etc.)
- Plugged PCV valve
- Leakages in the intake system (gaskets, holes, etc.)
- Carburetor blockage (clogged air cleaner, collapsed air delivery hose, etc.

Malfunctions were imposed in various ways. A clogged PCV valve (clogged in a closed position) was simulated by capping the return side of the valve to the intake manifold and the line to the manifold. A partially block air filter was simulated by attaching a tygon tube to and equal to the diameter of the air filter inlet. The tube was clamped down until a rough rectangular air passage having about a 1/2" minimum dimension was formed. This area is approximately 10% of the unblocked air flow area. Intake manifold leaks were simulated by installation of plugs with holes of known values in the forward access port of the intake manifold.

Steady state measurements of intake manifold pressure and crankcase pressure were measured at different values of battery voltage (cranking speed). Functional relationships of both intake manifold pressure and crankcase pressure were developed as a function of the average engine rpm. The interaction of low cylinder compression was simulated by running some of the tests with cylinders having pistons with holes in their crowns.

The effect of induction system malfunctions on intake manifold pressure is presented in Figure 5-10; the data is summarized in Table 5-3. The intake manifold vacuum increases with increase in cranking speed independent of the type of malfunction.

The PCV valve represents the single most important air bypass around the throttle and choke, and for a normal engine, a large portion of the idle air flow is delivered through that path. It is not surprising, therefore, that a plugged PCV valve had the most pronounced singular effect; an increase in the intake manifold vacuum from approximately 2.5 in. Hg to 4.5 in Hg at an rpm of greater than 130. By comparison, at this speed a partially open throttle (5% of the total throw of the accelerator arm) caused only 1 in. Hg reduction in the intake pressure.

All other combinations of intake manifold leakage (up to .165 in. hole) or blockage (1/2 in. or 7/32 in. sector opening) resulted in the intake manifold pressure of only approximately 1/2 in. Hg. These variations are quite small and are probably within expected variations from vehicle to vehicle and the accuracy of the pressure measuring sensors.

The effect of lowered compression (holes in piston crown to cause 70 psi cold compression) was as expected. The holes have the effect of making the piston less effective air pumps, reduce the inlet air mass flow and in general lead to a reduction in the intake manifold depression.

The results indicate that an excessive malfunction of the PCV valve or manifold leaks due to a partially open throttle, faulty gasket or cracks, can be readily detected. However, combination of component failures could result in opposing effects which would result in nominal intake manifold pressures and thus would be undetected. The following is a summary of the effects observed at an rpm greater than 130.

- o A plugged PCV valve can cause an increase of intake vacuum from approximately 2.7 in. Hg to 4.6 in. Hg.
- o A small opening in the throttle (5% of total throw) will cause an approximate 50% reduction in intake manifold vacuum.
- o Severe leakage in the intake manifold causes small changes in the manifold pressure.

The effects of malfunctions of the induction system on crankcase pressure is illustrated in Figure 5-11; corresponding data are summarized in Table 5-4. As was the case for intake manifold pressure, the crankcase pressure is directly related to the average cranking speed.

In normal operation, the crankcase communicates to the intake manifold through the PCV valve. Any fault which tends to increase the manifold pressure will tend to drop the driving pressure differential which scavenges the crankcase and the crankcase vacuum will decrease. If the PCV valve is clogged, the crankcase is deadheaded (although it is fed by air from the air cleaner), and a slight pressurization results due to the compressional effects of the pistons, crankshaft motion and oil pump. For example, at 140 rpm, the crankcase pressure of a nominal engine is less than -0.3 psig, while the pressure rises to about 0.5 psig with a blocked PCV valve. Leaks in the intake manifold or partial opening of the throttle reduce the vacuum as much as 60%.

5.1.3 Idle Performance Testing

Engine performance in idling is considered to be one measure of its serviceability. Procedures to quickly assess the serviceability during idle operation were a major goal of the diagnostic program. Tests were conducted to evaluate the effects of ignition maladjustments, ignition malfunctions, cylinder compression and air-fuel ratio on selected idle criteria.

The idle criteria established by TACOM originally stipulated a vehicle was to be judged serviceable if: (1) the engine speed was between 500 and 675 rpm, (2) there were less than two misfires on the same cylinder in a total of 50 sets of cylinder firings, (200 consecutive firings) and (3) the normalized variance of exhaust pressure was less than 0.25. The normalized variance (S^2) was defined as:

$$S^2 = \frac{(X-1)^2}{N-1}$$

where,

X = normalized pressure

$$= \frac{X_i - \bar{\bar{X}}}{\bar{X}max - \bar{\bar{X}}}$$

X_i = maximum pressure for each firing, psi

$\bar{\bar{X}}$ = arithmetic average of maximum and minimum pressures over the computational interval, psi

$\bar{X}$ = arithmetic average of maximum pressures over the computational interval, psi

It was desirable to minimize the number of instruments installed on the vehicle during idle inspection and further the use of exhaust pressure measurement required design and qualification of new instruments. Alternative methods for judging serviceability without the use of the tailpipe exhaust measurement were evaluated.

5.1.3.1 Idle Roughness Tests

The objectives of this series of tests were: to verify that the TACOM-established roughness criteria were reasonable in terms of sensitivity, ease of measurement, and independence of failure means; to assess the type of failures that would result in non-serviceability as defined by these criteria; and to identify an alternate measurement parameter which could be used to assess serviceability.

The investigation consisted of a statistically designed series of tests to determine whether or not specific malfunctions were correlated with engine roughness in terms of the TACOM serviceability criteria. Following establishment of the general range of roughness that could be obtained as a result of reasonable levels of component failures, more detailed tests were conducted to characterize the effects of specific malfunctions. The total test program consisted of the following:

1. General characterization of roughness through a factorial matrix series of tests
2. Study of the effect of valve malfunctions on idle roughness

3. Study of the effect of variations in air-fuel ratio and timing

4. Study of the effects of malfunctions in the induction system

5. Alternate idle serviceability criteria

General Characterization of Roughness-Factorial Matrix

A test series was conducted to simultaneously investigate the effects of idle mixture, engine rpm and ignition timing. Full factorial matrix tests were conducted to investigate the effects of these three parameters. The series which consisted of 30 tests is summarized in Table 5-5. The series was run with an engine having nominal compression, and then with the valves maladjusted or holes into the top of each of the four cylinder combustion chambers.

The following off-nominal compression valves were investigated:

- Head leak - 90 psig compression
- Exhaust valve leakage - 90 psig compression
- Intake valve leakage - 90 psig compression

The engine was systematically malfunctioned and idle intake manifold pressure, engine rpm, and exhaust pressure were recorded. Typical strip chart recordings can be found in Figures 5-12 and 5-13.

The results of the tests are summarized in Tables 5-6 through 5-9. In general, engine roughness showed the greatest sensitivity to idle air-fuel ratio and lesser sensitivity to spark advance and reduced idle speed. A mix of these parameters, i.e., 1% CO, 450 rpm idle speed and 22^{o} BTDC timing, resulted in a no-start vehicle. If the individual cylinder compression levels were reduced, the starting and idling characteristics became poorer.

The data was computer-processed in an attempt to establish a regression fit between the major parameters and the dependent idle criteria--exhaust pressure and idle speed. A search was made for the main effects and two factor ineractions. The results indicated that there was statistical significance, but it was low as shown in Table 5-10. For example, only very few of the correlation coefficients had a level of confidence greater than 90%. The high degree of non-repeatability of the test data makes it difficult to establish a meaningful relationship of the measureable parameters of idle mixture, timing and idle speed to either of the suggested idle performance criteria. What is probably more important, however, is that it was shown that the variance in exhaust pressure as well as the idle speed are effective indicators of idle serviceability, but poor indicators of the specific cause of non-serviceability. For example, poor exhaust valve operation leads to pressure pulses in the exhaust pipe which appear to be misfire events. In the experimental work, these pressure pulsations, therefore, could not be strictly attributable to the failure of the mixture to ignite-misfire, but would be grouped together into the "misfire" ratio.

Effects of the Valve Malfunctions on Idle Roughness

The statistically designed tests indicated that malfunctions of engine valves which result in low compression will influence the roughness characteristic during idle. Further tests were conducted to investigate more thoroughly the effects of various types of malfunctions of engine valves. Various simulations of intake and exhaust valve failures which would result in reduction in compression to 70 psi were investigated. Valve malfunctions were simulated by improper valve adjustment.

The data developed from these tests are summarized in Table 5-11. Valve malfunctions resulted in extremely rough idle operation and the data clearly indicates that the normalized variances of the exhaust pressure were sufficiently large to judge the vehicle unserviceable. Also, in many other cases, the exhaust pressure traces suggested misfire.

In general, poor valve operation was a primary cause of failure to pass the idle criteria based on exhaust pressure variation. In many of the cases where the vehicle would have failed on the pressure variation criteria, it also would fail on the misfire criteria because of the problem of distinguishing misfires from faulty valves as mentioned previously.

Exhaust valve operation is more important to smooth idling than that of the intake valves. For example, if only one exhaust valve were maladjusted to give 110 psi compression, the engine would fail both the pressure variance and misfire criteria. A single intake valve could be adjusted to give 70 psi compression and still pass the idle criteria; it is not until two intake valves are maladjusted to that level that the vehicle would fail.

During the course of the testing, the intake manifold pressure and the crankcase pressure were monitored. The values measured during the tests are summarized in Table 5-12. A correlation of the steady state values of intake pressure or crankcase pressure with valve malfunctions is not evident. Further assessment of the use of steady state values for diagnostic was therefore not conducted. A cursory review, however, of the wave shape of the intake pressure suggested the feasibility of wave form analysis for detecting intake valve malfunctions. The characterization of these wave shapes would require a large amount of analysis and therefore was not conducted as a part of this program.

Effect of Variations in Air-Fuel Ratio and Timing

With the idle speed maintained within 500 and 675 rpm, tests were conducted to determine the degrees to which air-fuel ratio, and timing could be varied before non-serviceability could result. Variations in timing from 22 BTDC to 10 ATDC were investigated. The setting of air fuel was qualitative and ranged from deviations of from 1/2 turn to 1-1/2 turns on the adjustment screw.

The result of the tests are presented in Table 5-13. As was the case in previous testing, a lean air-fuel condition tended to cause extreme roughness. The engine idles poorer when the timing is advanced than when it is retarded.

Effects of Malfunctions in the Induction System

A series of tests were conducted to determine the effects of partial throttle opening, intake manifold leakage, and PCV valve operation. The combinations of malfunctions imposed and their results are shown in Table 5-14. Also, some of the malfunction combinations were imposed on the vehicle with low cylinder compression with all four cylinders (70 psig).

Low cylinder compression was simulated by four holes in the cylinder head. These faults were not in themselves sufficient to cause non-serviceability. However, the introduction of an intake leak (0.165" dia.) was sufficient to cause misfire and rough idling, probably due to the effecive leaning of the mixture and the unbalancing of the charge from cylinder to cylinder. Smaller leakage areas such as a 0.060 inch hole in the intake would not affect serviceability.

Alternate Idle Serviceability Criteria

As was indicated in Section 5.1.3, there were several reasons for attempting to establish other idle performance criteria than the one based on exhaust pressure measurements. Not only does that technique require another transducer, but its response is sensitive to the mounting configuration and the condition of the exhaust system. Further, if there is mechanic error, the device could be left in place while the engine was at fast idle and thermal damage to the transducer could result.

A promising technique involved the measure of the variance of engine rpm as established by the period from one firing event (point closings) to another. A comparison of the normalized exhaust pressure variance (TACOM criteria) and the variance of instanteous rpm was developed to assess the feasibility of correlating instantaneous rpm with exhaust pressure fluctuations. A summary of all of the tests in which the vehicle was judged non-serviceable by the TACOM criteria is presented in Table 5-15. Since only analog equipment was used in the data gathering, precise period measurement for each cylinder was difficult; rather the variance of periods for the total engine was calculated from the stripcharts. The ATE has its own digital processor and thus has the capability of tracking the firing period of each cylinder. The tests reported in Table 5-15 are cursory in nature but are sufficiently quantitative to show the validity of the approach. The large variances in rpm are such that both rough idling (pressure variance) and misfire are pinpointed by the procedure.

5.1.4 Wide Open Throttle Performance

Following verification of a vehicle's serviceability in terms of start and idle, the ATE will progress to screen the vehicle's performance during full power conditions. Without a chasis dynamometer, it is usually impossible to exercise all of an engine's systems at these conditions. An approach was suggested which allows the engine's carburetion system to be tested under wide open throttle--near maximum air flow conditions, while the engine's speed would be sufficiently high to disclose high speed problems associated with ignition and valve action. TACOM required that any screening approach be capable of isolating engines whose peak power fell below 75% of the peak power of a nominal engine.

The approach which was selected and experimentally investigated is the so-called "interrupter technique". The concept is based upon a modification of the standard power balancing test in which cylinders are intentionally shorted out and the effect on engine speed is measured. In the present case, the cylinders are shorted out in a sequential manner such that four out of every five firing events is inhibited. The engine can only develop about 20% of its peak power which is readily balanced by the frictional and pumping losses. The latter tend to be speed dependent and thus the balancing speed is indicative of the developed engine power.

This section reports the tests conducted to establish the viability in the approach and to quantify the effects of malfunctions of high probability. These tests consisted of screening tests conducted to evaluate the impact of candidate malfunctions, characterization experiments to quantify the effects of specific malfunctions, and an evaluation of the repeatability in the measurements.

The experimental program conducted to validate the feasibility of using the interrupter rpm as a criteria for judging serviceability and to identify the parameters which were sensitive to wide open throttle performance consisted of the following:

- Screening experiments
- Evaluation of effects of parameter malfunction
- Evaluation of effects of low compression
- Evaluation of malfunctions proposed in the engineering design tests

Experimentation was initiated with screening experiments to quantify the general range of effects. The program was continued with a detailed evaluation of the effects of various malfunctions on horsepower and interrupter rpm.

5.1.4.1 Screening Experiments

As a prelude to characterization of the effects of malfunctions, screening experiments were conducted to evaluate the gross effects of the most obvious malfunctions. The tests ranged from malfunctions of the parameters which are normally tuned by the mechanic to major engine malfunctions such as low compression which require major overhead.

The effect of timing on engine horsepower was evaluated by varying the timing from 28 degrees before top dead center (BTDC) to 16 degrees after top dead center (ATDC), (engine specification calls for the timing of 6 degrees BTDC). The results of these tests as shown in Figure 5-14 illustrate the drop in horsepower from approximately 56 hp to 36.5 with the timing retarded to 16 degrees ATDC. Advancing the engine to as much as 28 degrees BTDC caused small effects on output horsepower.

The influence of air-fuel ratio is illustrated in Figures 5-15 and 5-16. Wide open throttle (WOT) air-fuel ratio was controlled by changing the main fuel jet orifice. As would be expected, the effects of a fuel rich air-fuel ratio caused only a small variation in the output horsepower as long as the smoke limit was not reached. The particular vehicle tested showed a 4 horsepower increase with a slightly richer than nominal main fuel jet; i.e., 0.059 inch main jet instead of 0.053 inch nominal main fuel jet. The effect of leaning the main jet was more drastic. Reduction of the orifice diameter by 4.7% reduced the peak horsepower by approximately 25%.

Air-fuel ratio changes were also made by introducing leakages into the intake manifold, Figure 5-17. While there is only a small pressure differential across the manifold at WOT, these tests were performed to provide a baseline of understanding the magnitude of leakage which could exist before the mixture was leaned to serious proportions. With the nominal main jet, a leak through a 1/4" diameter hole in the manifold caused only minor power loss --within the accuracy of power measurement. Over the range of variables explored, a spread of perhaps 5 hp was seen.

A common malfunction at WOT is spark plug misfire. In order to obtain the gross effect of spark plug misfire, tests were conducted with one or two cylinders misfiring at a rate of 100 percent. The malfunction was imposed by disconnecting the secondary wire of the cylinder for which the misfire was to be imposed. These tests illustrated that total misfire of a single cylinder will result in reduction of approximately 13 hp in peak power output. Misfire of two cylinders gave a reduction of peak horsepower of greater than 35 hp. Tests results are presented in Figure 5-18.

Breaker point gap and spark plug gap are two parameters which are commonly believed to affect peak power. To assess the real influence, the points were closed to 0.002 and 0.006 inches (timing held at 6° BTDC) and the plug gap opened to 0.062 inch. Figure 5-19 shows the relatively slight effect, generally less than 5 hp.

Figure 5-20 presents data similar to Figure 5-19 except that it includes the effect of reducing the battery voltage. Careful inspection shows that for nominal settings of the points and plug gaps, there is no effect on power until the voltage is reduced below 10 volts at which point there is noticeable misfire and loss in power. With small point gaps and open plug gaps, there is little change in the power characteristics until 16 volts, when the data falls into two distinct bands dependent on the pre-history of the plugs. If the plugs were clean and had previously been run at 24 volts, the data fell into the upper curve band. If the plugs had been used for a while or had been run at lower battery voltage, there was apparently enough deposits on one or more plugs to cause misfire and loss of power. However, the deposit buildup was not noticeable under routine inspection.) It appears that 16 volts with the points and plugs gapped as noted is the voltage for insipient misfire.

The effect of low compression was conducted by simulating a worn engine by creating leaks through the cylinder head into the combustion chamber. The variations investigated, consisting of reductions in compression to as low as 70 psi (cold cylinder cranking pressure) are illustrated in Figure 5-21. Reduced compression caused by a head leak resulted in a loss of about 4 hp. With an engine speed of greater than 4,000, the variations were within the repeatability of the measurement system. This type of defect is highly pressure and speed sensitive. The flow through the leakage paths are choked and do not effectively reduce the pressure-volume characteristics of combustion-expansion. The low differential pressure between ambient air and the cylinder during intake at WOT is probably insufficient to cause cylinder mixture dilution and lean limit misfire.

5.1.4.2 Evaluation of Effects of Parameter Malfunctions

The screening experiments indicated that timing, single cylinder misfire, and air-fuel ratio could cause losses in the peak horsepower greater than TACOM's WOT performance criteria. Further tests were conducted to establish, if possible, the functional relationships between power, speed and malfunction.

The tests were run, as in the previous set, on the engine dynamometer. The procedure was to first run a horsepower vs. rpm characteristic for the engine with the matrix fault (faults) installed. Afterwards, the dynamometer load was removed, the throttle quickly moved to WOT, and the ignition interrupter started. The steady speed-interrupter rpm was noted. The engine was then loaded and the power-speed characteristic repeated without the interrupter. Strip chart records were taken of all engine parameters. The time for the engine to accelerate from idle up to interrupter speed was noted as well as the coast-down time at the end of the interrupter test. (Interrupter tests were terminated by shorting out the ignition at WOT.) The results of the tests are summarized in Table 5-16.

A regression analysis of the test data was conducted to determine the magnitude of the main effects (slopes) and the significance of the two factor interactions. The statistics of the regression are summarized in Table 5-17. There is significant correlation of the malfunctioned parameters to peak horsepower and interrupter rpm. The index of determination (R^2) is greater than 0.88 for both regressions. The Standard Error of Estimate (SEE) which is a measure of the combined uncertainties of the instrumentation system and engine performance is 4.9 hp and 205 rpm for the two regressions. The main effects--ignition timing, misfire, main jet diameter, were all statistically significant when correlated with wide open throttle peak horsepower. For the regression developed with interrupter rpm, the only parameter that was significant was misfire. In both cases, none of the two factor interactions were significant. Although the effects are not linear, a gross influence of any of the malfunctions on peak horsepower can be approximated with the main effects; for example, the influence of ignition timing can be approximated as 0.51 hp per degree with a change in the advanced direction causing greater horsepower. The corresponding linear effects of misfire and main jet diameter are -0.69 hp/% misfire and 1.03 hp/10^{-3} inches.

A major consideration was an evaluation of the effectiveness of the interrupter rpm as a measure of peak horsepower. The very high degree of correlation of interrupter rpm with peak horsepower is illustrated in Figure 5-22. The SEE of this regression was 3.1 hp. Further discussion of the effectiveness of interrupter rpm for assessing wide open throttle performance is presented in a latter part of this section.

5.1.4.3 Evaluation of Efffects of Low Compression

The tests described in Section 5.1.4.1 conducted to evaluate the effects of low engine compression showed that compression loss resulting from a leak in the head caused only a slight loss in horsepower. With the consideration that a leak through the engine head might not be a true simulation of all means for loss in compression, further tests were conducted by reducing cylinder compression by maladjusting the valves. The results from these tests together with data from repeat tests with head leaks, are shown graphically in Figure 5-23 and summarized in Table 5-18. These tests showed the major contributor to loss in power which would show up as loss in compression is faulty exhaust valve operation resulting from improper adjustment and/or burnt valves. For all other faults in compression which dropped the cylinder compression to 70 psi, the loss in power was no greater than 5 hp. In contrast, a single exhaust valve adjusted to give 70 psi compression would drop the peak power by about 12 hp. If two or more exhaust valves were faulted, the power loss always exceeds 20 hp.

Other Influences on WOT Performance

The effectiveness of any method which presumes to assess serviceability or isolate malfunctions is dependent upon the repeatability of the symptoms of the fault and the measurement technique. A number of tests were performed to gain some measure of confidence in the interrupter procedure.

Throughout the testing period, the engine was repeatedly returned to nominal conditions and power-speed characteristics measured. The results are shown in Figure 5-24. The data spread is approximately 4 hp, which agrees well with the regression analysis of power vs. speed and power vs. fault. In the latter cases the spread was 3 to 5 hp, suggesting that the major portion of variability had been accounted by the regression analysis.

Another set of correlations of interrupter speed vs. peak power were developed in support of the Engineering Design Test (EDT) verification (see below) and are presented in Figure 5-25. Review of the correlations relating interrupter rpm with peak horsepower indicated two distinctively different slopes in the correlation, as illustrated in Figure 5-26. The difference can be attributed to the condition of the engine in that initial tests were conducted with a new engine and later tests were conducted with two engines which could be considered to be thoroughly broken in. Although the slopes of the regression are different, the two curves intersect at around 45 hp. Since the use of the interrupter is to assess serviceability, i.e., less than 25 percent reduction in horsepower, the interrupter technique is sufficient. The curve representing all of the data is given in Figure 5-27.

All of the tests conducted to assess the effects of malfunctions on wide open throttle performance were initially conducted with a fully warmed-up engine. Cursory tests were performed to evaluate the effect of oil temperature on interrupter speed. The results of these tests are presented in Figure 5-28 and indicate a continual change in rpm with oil temperature. Further, the warmup rate of the engine maintained at a 1000 rpm idle is relatively slow as shown in Figure 5-29. The curves suggest that over twenty minutes would be needed for the engine to reach 90% of its steady state temperature; far too long for the speedy screening of engine performance.

A method for normalizing the interrupter rpm which compensates for this effect was developed for the diagnostic program. The engine is always preconditioned by fast idling between 1500 and 2000 rpm until the oil at the dipstick temperature probe reaches 100°F. At the conclusion of the interrupter test, the rate of slow engine slow-down at WOT and shorted ignition is measured and is translated into an incremental speed which must be added or substracted to the measured interrupter speed.

5.1.5 Characterization of Components

Selected components were isolated and studied to related specific diagnostic parameters to failure/faults in the components. Particular attention was paid to the starting system and the ignition system.

5.1.5.1 Starter System Tests

Battery Characterization

One series of tests was aimed at understanding the voltage-current-charge state relationship of the starter batteries as a function of temperature in order to predict what would be acceptable limits for normal battery operation. In the tests, two type BB 249/V (2HN) 12 volt batteries were placed in series and placed in ambient air or a small refrigerator. Resistors were used to load the batteries after the circuit was made by a M151A2 starter switch. Battery terminal voltage and currents were recorded. The state of charge of the batteries was controlled by discharging the batteries until a known fraction of the ampere-hour rating of the battery had been passed through the resistors. The results of the tests are tabulated in Table 5-19.

The open circuit battery voltage is relatively unaffected by temperature and charge state over the range of conditions tested. Battery resistance increases with decrease in charge state and temperature. In these tests, cutting the charge state in half had the same relative effect as lowering the battery temperature by about 19^{o}C. A battery whose internal resistance is less than 50 milliohms can be considered to be functionally good, i.e., capable of supporting a normal cranking load.

Starter Characterization

The starter current prior to engagement with the flywheel tends to indicate the acceptability of the starter circuit. During this time, the starter current is limited by its impedance and the driving voltage and impedance of the battery-starter-switch-cable system because the inertia of the motor reflects a near-locked rotor load (no emf).

Tests were conducted on a good starter (Mfr. No. MCZ-4005-AUT, Serial No. 6G002-326). The starter was attached and clamped to a bench vise. Two sets of data were taken. The first, allowed the rotor to spin freely, and starter peak currents as a function of terminal voltage were measured. In the second set, the rotor was locked and the steady current after the initial transient died out was recorded. The results are shown in Figure 5-30.

The no-load tests show a consistently lower peak current than the locked rotor tests reflecting the influence of the back emf. From no-load speed vs. voltage tests the back emf relationship of the motor is about .01 volts/rpm. Thus comparison of equal starter currents of 100 amperes shows a difference in terminal voltage of eight (8) volts, meaning the starter was probably at 800 rpm at peak current.

From a diagnostic view, a peak current of over 150 amperes would be clearly representative of a locked or jammed rotor given the battery characteristics previously described.

5.1.5.2 Ignition Diagnostic Parameters

Tests were conducted to investigate the feasibility of diagnosing ignition system malfunctions. The candidate diagnostic parameters were:

Primary Spark Line Voltage
Secondary Firing Line Peak Voltage
Secondary Spark Line Voltage
Secondary Spark Line Duration

The primary spark line voltage is measured on the binding post connecting the battery to the coil. Voltages at that point reflect the voltage at the coil and provide information as to the primary circuit voltage drop (when points are closed), condensor behavior and coil inductance. Secondary voltages are measured using the ignitor probe. Signals from the high voltage tower contain information as to the voltage available for establishing a spark and the quality of the spark once it is ignited. There is additional information on coil inductance and condensor operation. It is important to realize, however, that the secondary voltage signal is unable to distinguish arcing in the rotor gap from those at the spark plugs.

Various ignition malfunctions were imposed on the engine and the magnitude and dispersion of the above diagnostic parameters were computed. Failures were imposed to simulate several malfunctions, such as, large rotor gap, high point contact resistance, inoperative condensor (open circuit), low supply voltage (primary), and shorted or open spark plug or secondary wires. The data were recorded on a high speed oscillograph. Reproductions of the signals are presented in this section to illustrate the analog output signals of the sensors.

The data developed in the tests are summarized graphically in Figures 5-31 to 5-34. These figures present the magnitude and dispersion ($\pm$ one estimate of standard deviation) of each of the candidate diagnostic parameters for the various malfunctions imposed on the vehicles. The diagrams should be read as follows. The top graph of each figure represents nominal conditions, that is all cylinders with same conditions. Reading from left to right, "NOM" represents a nominal ignition system. "Short rotor" refers to the condition where the rotor tab was filed off to the phenolic. "8 ohms" and "12 ohms" refer to series resistances placed in the primary path. "No Cond." means the condensor was left out simulating an open condenser. "18 volts", "16 volts", and "14 volts", refer to differing open circuit battery voltages. The remaining graphs on each figure show what occurs when the specific fault indicated is introduced. The unhatched bar shows the average of the signals from the numbers 1, 2, and 4 cylinders, while the hatched bar shows the data from the number 3 cylinder--the one which is malfunctioned.

A summary of the change in the level of each of the candidate diagnostic parameters corresponding to the malfunctions imposed on the vehicle are listed in Table 5-20. These data show that any one of the four candidate diagnostic parameters would likely be effective in diagnosing ignition malfunctions. Secondary firing line voltage was most sensitive to malfunctions in the primary circuit, with the exception of the malfunctioned rotor. Secondary spark line voltage exhibited the lowest level of sensitivity to the imposed primary circuit malfunctions. It should be emphasized, however, that in the detection of malfunctions in the secondary circuit, the secondary spark line voltage was extremely sensitive.

The short rotor which simulated a burned rotor or rotor cap was developed by cutting 0.125 inch off the top of the rotor. As would be expected, the larger gap resulted in higher voltage levels and corresponding shorter than nominal secondary spark line duration.

The simulation of the poor point contact was made by inserting additional resistance in the point circuit. The secondary spark line duration indicated greatest sensitivity to this type of malfunction. It must be cited that the addition of 12 ohms of resistance to the circuit is a condition of incipient no-start and, therefore, resulted in somewhat erratic results--EDT simulation test and crank no-start test discussed in other sections of the report suggested that a no-start condition will result when there is more than 11 to 13 ohms resistance in the primary circuit.

Gross malfunction of condenser was imposed by removing the condenser.

All the vehicles started in this condition, but performance in idle was extremely rough and wide open throttle performance could not be attained. It is speculated that prolonged operation with a malfunctioned condenser will cause failures in the points or the rotor and therefore result in a problem comparable to the malfunctions simulated by imposing resistance in the primary circuit. Removal of the condenser caused a severe drop in all of the voltage signals together with a large increase in the spark line duration. The reduction in primary voltage, i.e., from 24 volts to 18, 16, 14 volts, resulted in reductions of the firing line voltages as expected. The result of the low voltages are clearly discernable and therefore could be readily diagnosed using any one of the candidate parameters.

Apart from the primary circuit and rotor malfunctions previously discussed, misfire or erratic combustion occurs frequently as a result of malfunction of the secondary circuit. Although secondary circuit failures can occur in many ways, the combination of an open spark plug electrode (largest) gap possible) or shorted electrode (zero gap) and the failures previously discussed was considered sufficient to simulate the types of failures that would be expected in the field. Cursory experimentation was conducted to illustrate that a short or open circuit in the secondary wires would be exaggerated versions of the corresponding failure in the spark plug.

All parameters exhibited highly sensitive response to an open spark plug. All the voltages had increased levels, and the secondary spark line duration was less than with a properly operating cylinder. The response to shorted electrode was less vivid. The differences were, however, clearly discernable and displayed reduced voltage levels and longer secondary spark durations.

As a part of the background tests conducted to support the definition of the Engineering Design Test Program, other tests were conducted in the idle mode. The malfunctions imposed on the vehicle during the course of these tests are summarized in Table 5-21. The tests during which the engine failed the idle performance criteria are underlined. The only conditions which led to non-serviceability were: a leak in the intake system, extreme advanced timing (35 before top dead center), or major malfunction of the ignition system (broken rotor, crossed wires).

In a similar manner, certain tests were performed to evaluate fault effects on WOT performance for the EDT. A summary of the results is presented in Table 5-22 and was previously plotted in Figure 5-25. Several of the malfunctions which were identified as part of the EDT are sufficient to drop the peak power of the engine by 25% or more.

The acceleration rate of the engine was markedly affected by loss of the accelerator pump (Test No. 7). Other faults which lead to greatly reduced peak power tended to have lower acceleration rates, but the difference between them and a nominal engine were small indicating that accelerator pump fault or operator errors could be detected readily and distinguished from peak power loss faults.

5.2 Engineering Design Test (EDT) Plan Verification

The Engineering Design Test (EDT) Plan is a program consisting of series of tests to be conducted to establish the capability of the ATE of assessing vehicle serviceability and detecting malfunctions which would result in a non-serviceable vehicle. A description of the EDT Plan is provided in "Engineering Design Test (EDT) Plan for Automatic Test Equipment/Internal Combustion Engine (ATE/ICE)," TRW Systems Group 73.4300.10-15, 25 October 1973, and the reader is referred to that document for the detailed fault list of conditions proposed to be tested. The list consists of faults of the electrical, fuel and air intake, ignition, engine's mechanical system and combinations of two minor faults.

In support of development of the plan, a large number of candidate faults that were expected to occur at a high frequency and were suspected to result in an unserviceable vehicle were imposed on a test vehicle. The assessment of serviceability and the feasibility of ATE detection of malfunction was made. A discussion of this experimental effort is presented in this section.

The tests are summarized in Table 5-23. The table describes the system or component affected, the means for fault introduction, the serviceability resulting from the fault, the parameter and diagnostic logic which is used to isolate the fault and any remarks on the specific test.

Thirteen of the 49 fault conditions resulted in serviceable vehicle performance. It should be noted, however, that some of these faults cause other effects which could be considered unacceptable to the vehicle's operator or would cause deterioration of components and thus would eventually result in an unserviceable vehicle. For example, EDT Test No. 13, a malfunction of the carburetor accelerator boost circuit, does not affect idle quality or steady state WOT power. However, the engine lags and hesitates when attempting to accelerate during an interrupter test. Although there is currently no failure criteria for describing this transient performance, a measure of the time for the engine to speed up to a certain level was included in the ATE logic for detection of inoperative accelerator pump.

Other faults which allowed serviceability are shown in Tests 21 and 24. In these cases, extremely large breaks in the secondary circuit were introduced. The wide gaps could rapidly deteriorate their respective components from spark erosion and might affect component durability after a number of hours of operation. Also, operating at a substantially higher secondary voltage will make the entire secondary circuit to be more vulnerable to leakage and shorting.

Another condition to be noted is included in Test 22. The very small point gap caused a qualitatively detectable change in performance, but did not cause unserviceability. However, with the point gap substantially reduced to only 2 or 3 mils, the ignition timing is significantly retarded due to the large increase in dwell angle. These conditions will result in increased burden on the engine system; retard causing the exhaust temperature to rise and increased dwell causing a longer coil saturation time and therefore a more severe thermal duty cycle. Extended operation under these conditions, particularly in a high temperature environment, could cause overheating and degradation of the coil.

In test 30, a new distributor cap was randomly cracked. There were no detectable misfires or degradation of idle and power. However, it is highly possible that cracks in some areas coupled with contamination and heat-caused breakdown of the electric material could lead to arc-over inside the cap and misfire.

6.0 DIAGNOSTIC TEST PROGRAMS

The final cassette contains five diagnostic programs in addition to the cassette program loader. They are:

Program	Entry Number
Confidence	3
Auto. Inspection	4
No Start	5
Performance Test	6
Tune Up	7

The entry number refers to the input code number on the set communicator for calling a specific program. The interrelationship of these programs and the user is shown in Figure 6-1 and a detailed description of each is included later in this section.

When the ATE/ICE system is initially started, the Confidence Test should be run to check out the system hardware. After the initial loading of the operating system, the Set Communicator will ask the operator if he wants the Confidence Test. If the response is "yes" as signified by entry "1", the Confidence program will be loaded and the initial portion of the program will start. The operator can also enter "3" after completion of any of the 5 programs and re-run the Confidence Test if he desires to retest the system. During the operation of the confidence program, ATE system will sequencially test; the operation of the set communicator and its links to the PDU, the internal clock, and all the data handling channels from J-Box through the I/O boards. Faults may be displayed identifying major subsystem failures and instructions issued to the operator as to his course of action.

Before proceeding on with the diagnosis, the vehicle should be inspected by the mechanic for problems which cannot be diagnosed by the present test system. These include an inventory of vehicle consummables, accessories and chassis/body parts. The Automated Inspection List program prompts the operator on those items to be inspected in a preoperational vehicle inspection. After a Confidence Test has been run successfully, the ATE/ICE system assumes that this pretest inspection is the next step. The Set Communicator therefore asks the operator if he wants the Automated Inspection List program and automatically loads and starts executing appropriately if the response is "yes". The operator can also enter "4" after completion of any of the 5 test programs and run the Automated Inspection List if at any time he wants a reminder of what was to be checked in the pretest inspection. Upon completion of this inspection, the vehicle is ready for testing. The program will therefore execute a wait in readiness for the next operator's input.

The three remaining diagnostic programs are based upon a performance-oriented test philosophy. It assumes that vehicle performance should be evaluated first before attempting to isolate real or imagined faults. The programs are designed to isolate and indicate faults only if the vehicle is found to be unserviceable, as defined by any of the following:

(1) Engine will not start.

(2) Engine misfire rate at idle exceeds 4% on any cylinder.

(3) Engine power output is less than 75% of rating at some test speed greater than 2000 RPM.

(4) Engine maximum acceleration rate less than 75% of nominal for 1500-2500 RPM range.

(5) Charging system regulating voltage is outside 28 $\pm$ 1.5 volt range.

All of the above criteria with the exception of the first can easily be evaluated by the present ATE/ICE diagnostic programs. However, the evaluation of the ability of the vehicle to start is left to the mechanic. Before entering either the No-Start program or the Performance program, he should try to start the vehicle. If the vehicle starts, he should enter "6" for the Performance program bypassing No-Start. If it fails to start after a reasonable attempt, he should enter "5" for the No-Start program. This initial evaluation is best left to the mechanic since the proper state for the throttle and choke for starting may vary widely depending on engine and atmospheric conditions. For example, it might start best at full choke for cold weather and cold engine but no choke when the engine is warm.

If the engine starts while in the No-Start program, the Set Communicator will tell the operator to keep the engine running and then the system will start loading the Performance Test. Similarly, if the engine does not start within 30 seconds from the instruction to crank and start in the Performance Test, the system will give the mechanic the option of going back to No-Start.

The Tune Up program allows the mechanic to use the PDU and TK for vehicle tune up and individual manual tests. Once the mechanic has entered the Tune Up program, entry number 7, there are 12 individual tests available to him that are accessible by a series of 12 entry numbers. Thus, if the mechanic wishes to use the ATE/ICE system as a tachometer, he can enter "20" and the Set Communicator will display engine speed; if he enters "21" the system will display dwell in degrees. If the operator does not know the entry numbers or wishes to exercise all of the tune up capabilities, he may elect to use the tune up option list which will serially present him with all 12 tests.

6.1 Confidence Program

The purpose of the ATE/ICE Confidence Test is to establish a static confidence in the signal processing components of the ATE/ICE system. This confidence test is capable of testing to a limited degree the essential analog and digital circuits used in the PDU and SCU. It will also test the operator interface functions of the Set Communicator. The essential logic flow diagram is shown in Figure 6-2.

The confidence test, when testing the SCU analog sections, will measure the combined effects of scale factor and amplifier offsets by means of self test voltages. If the voltage at the analog-digital converter (ADCON) is within $\pm 10\%$ of a predetermined value for the channel under test, the analog channel will be given a passed status.

The only digital sections tested are those which contain vehicle information and which are received through analog channels. These include the #1 firing flip-flop, > 70 RPM indicator, cylinder enabled indicator, and points square wave.

The essential functions in the PDU are tested by implication with the exception of the real time clock and the ambient pressure transducer. For example successful completion of Task 2 in the confidence flow chart will imply confidence of the following PDU functions:

(1) The ability of the PDU to completely control the SCU.

(2) The ability of the PDU to successfully make analog to digital conversions through the ADCON.

(3) The operation of the SCU analog channel, CH4.

Confidence in the set communicator is established by testing all button functions except the emergency stop.

6.2. Auto Inspection Program

The Auto Inspection Program prompts the mechanic on items which should be inspected in a pre-operational vehicle inspection. These are items which are not tested by the automated diagnostic programs but should be included in a comprehensive vehicle test and inspection. The inspection starts on the passenger side of the vehicle and works around the front of the vehicle back to the driver's seat to check brakes, etc. Then the items which are spread throughout or around the vehicle such as lights and brake lines are covered. Table 6-1 lists the items included and the expected inspection actions.

6.3 No-Start Diagnostic Program

The No-Start program is entered when the vehicle is assumed or demonstrated to be unable to start. There are four basic probable causes for failure to start: the engine may be cranking too slowly, the spark plug discharges may be incapable of igniting the air/fuel mixture either due to lack of a high intensity spark or improperly timed spark, the engine compression is too low, or there may be a carburation problem such that the proper air/fuel mixture is not delivered to the cylinders. The diagnostic logic tests for these conditions in the above order and branches to isolation procedures appropriately is shown in Figure 6-3.

6.3.1 CI - Test Initialization

The function of this segment of the program is to insure that the vehicle is properly instrumented for cranking and ignition system tests. The operator is instructed to install 4 probes as listed below:

(a) Voltage probe on the terminals of the battery
(b) Igniter Probe
(c) #1 Firing Probe
(d) Current probe on any one of the battery cables

If the ATE system is being powered from the vehicle batteries, the operator will have already attached the battery cables. The program checks for a battery voltage greater than 3 volts and, if it detects such a signal, it asks for the installation of 3 probes only.

Once the probes are connected the system measures the zero current offset on both ranges of the current probe and will not allow the program to continue unless the absolute value of the offsets are within the following usable ranges:

High Range		Low Range	
Offset	10 Amps	Offset	6 Amps

The offset measurements are also stored to be subtracted from all future current measurements made within the no-start program.

6.3.2 C2 - Cranking Performance

The function of this program segment is to check to see if the starter system is cranking the engine fast enough to start. During the cranking period data is also being taken which will aid in diagnosing the problem if the cranking performance is found to be low. Table 6-2 summarizes that data. After the start of engine cranking, the diagnostic procedure allows two seconds for the engine speed to reach and exceed 90 rpm. If the speed is greater than 90 rpm, the program continues on to segment C4. If the engine fails this test condition the program automatically passes on to C3.

6.3.3 C3 - Starter/Battery Fault Isolation

This program segment performs the fault isolation procedures required if and only if the cranking performance is found inadequate during C2. Initially it evaluates data taken during C2 and determines whether the problem is in the battery or starter assembly (starter motor, switch, and cables). If the problem is in the starter assembly, the mechanic is given the option of choosing further automated fault isolation or simply ending the test sequence. Further isolation requires removal of the transmission cover for attaching Set Communicator voltage probes at the starter motor to differentiate between starter motor faults and switch or cable problems. With these clips attached, the data taking tasks of C2 are repeated with one additional parameter, V_{SP}, also recorded (V_{SP} = starter motor probe voltage at time of initial starter current peak).

The purpose of the battery tests is to evaluate its performance capability in terms of being able to start the engine. This cannot be done in terms of a single voltage measurement since the voltage of a battery is a function of its load current and charge state (Table 5-19). Thus, the diagnostic test includes a voltage measurement as a function of the battery load.

The starter assembly diagnostics depend upon comparing the actual measured dynamic operation with its normal performance characteristics. A simplified model of the starter motor is described below:

Symbol

I_A = Armature Current

V = Motor Terminal Voltage

R_A = Total Starter Motor Resistance (Ohms)

E_M = Armature Back E.M.F. (Volts)

$\emptyset$ = Field Flux (Lines)

w = Armature Speed (Radius per second)

K_e = Back E.M.F. Constant (Volts per line per radians per second)

The equations describing the modeled starter motor operation are:

$$V = I_A R_A + E_M$$

and

$$E_B = \phi \omega K_e$$

thus for $\omega = 0; E_B = 0$

and $V = I_A R_A$

or $R_A = V/I_A$

and for $\omega \neq 0; \; E_B \neq 0$

and $$K_e\phi = \frac{V - I_A R_A}{\omega}$$

In terms of this model the starter system fault isolation program first looks at the initial starter current peak (see Figure 5-30), and then if the engine is turning, look at its steady state cranking characteristics. For steady state calculations voltage, current, and speed are measured parameters and a nominal R_A is assumed.

Table 6-3 gives a quantitative summary of the starter system fault isolation tests. These faults are also easily summarized from a qualitative point of view. Low battery voltages will result in battery fault indications. Shorted or partially shorted starters may cause excessive current at either the initial peak or only during steady state cranking. In either case this is easily detected. Open windings or high resistances due to poor connections or worn brushes could be detected during the initial peak resistance calculations or during the steady state flux calculations. In the latter case, note that if high resistance causes the starter motor to rotate below normal speed, a low speed measurement will result, forcing the calculated $K_e\phi$ value high and once again a starter motor or starter system fault is found. A broken starter drive will not turn the engine over which will cause the test system to assume that the starter is not turning. This will result in a very large resistance value calculation due to ignoring the high back EMF term, and a starter or starter drive fault will be indicated. The program will suggest that the operator listen for the spinning sound of the starter motor.

It is possible for the test program to assume a cranking problem when in fact none exists. This condition can occur if there is an ignition problem such that the ATE hardware cannot measure the speed by means of point closings. Problem of this sort should result in the program branching from C3 (starter fault isolation) to C5 (ignition fault isolation) as shown in Figure 6-3.

6.3.4 C4 - Ignition Performance

This program segment checks the ignition system performance and saves data for the fault isolation routines in C5 which are run if the ignition system performance is found unacceptable. Data is taken on five basic ignition parameters given below:

(a) Spark Delay
(b) Spark Duration
(c) Spark Zone Voltage
(d) Closed Points Voltage
(e) Timing

The data relating the first three of these parameters are carried according to cylinder number (based on signal from 1 Firing Transducer) and the last four of these parameters have an average value calculated.

The ignition system performance is evaluated in terms of how many good sparks are generated at the proper time in the engine cycle. A spark must be sustained long enough to ignite the compressed fuel/air mixture. Each spark duration is compared to a lower limit of 0.85 msec and must be above this limit. Similarly, unless there is a partial short in the secondary output system (such as a shorted cable or plug) the spark duration should not exceed 3.5 msec for normal M151A2 ignition systems. Thus, the absolute upper limit for spark duration is set at 3.5 msec.

Absolute limits on the spark zone voltage for each spark have also been established with the allowable range for a good spark being 500 - 1500 volts (see Figure 5-33). Spark zone voltage is measured 0.7 msec after points opening.

A single limit of 0.2 msec has been established for the allowable spark delay. That is, the time from initial points opening to when the spark voltage rises about 3 KV cannot be greater than 0.2 msec for a good spark. A delay greater than this limit is usually from points arching caused by bad points, condenser, or both.

Another set of criteria which must be met in order for a spark to be considered good are limits which are set relative to the average values of spark zone voltage and spark duration and thus give a crude indication of erratic behavior. These average values are calculated only from data that lies within the limits discussed above. Thus for the spark zone voltage, no value should exceed $\pm$ 45% of the average value. Thus, a good spark is a spark delayed less than 0.2 msec with spark zone voltage and spark duration within both absolute and relative limits.

For No Start vehicles with comparatively normal ignition systems (plugs not too bad, coil normal, etc.), experience has shown that the spark characteristics are rather erratic, especially at lower battery voltages and slower cranking speeds. Thus, the No Start ignition performance test is a rather loose one. The test system will take ignition data until it has found either three good sparks for each cylinder or until it has taken data on 14 sparks for each cylinder and not met the above three good spark criteria. In the latter case, the ignition system has not met its performance criterion and the program jumps to C5 to isolate ignition system faults.

6.3.5 C5 - Ignition Fault Isolation

This part of the program isolates ignition system faults. As shown in Figure 6-3, this section can be entered in two ways. Entry from C3 implies that the test system found no ignition points openings. Entry from C4 implies that the point openings were sensed and spark data was taken but that insufficient good sparks were found for at least 1 cylinder, possibly all cylinders. The spark data which is passed from C4 is listed in Table 6-5.

Not sensing any point openings could be caused by any one of several problems. The operator may have simply failed to turn the ignition on as directed in which case he is told to "TRY AGAIN". If the vehicle ignition system is assembled incorrectly with the coil polarity reversed, the vehicle could actually crank and start without the system hardware detecting any points transitions due to the characteristics of the interrupt hardware. This symptom could be due to: points not closing, points not opening, shorted condenser, igniter probe problems, open coil primary, or open ballast resistor.

Table 6-4 lists these faults and all others detected by the test system in this portion of the No Start program and also lists the isolation criteria used to each fault. Note that most of the data used for this portion of C5 was taken during the C2 test period. The remainder of this program segment diagnoses ignition faults from data taken during C4.

Fault diagnosis is broken into 2 major sections. The first section isolates faults which affect most sparks -- the succeeding section isolates individual cylinder ignition faults if compression and timing are found to be good.

Section 1

1. The first data checked is DS and if more than 2 sparks were found to be delayed a points/cap fault is set and the program terminated.

2. SD1 - 8 is analyzed next to determine if most sparks are short ($\leq$850 usec). If all or all but one spark are short, the program isolates for leaky capacitor, high resistance igniter input, opens in the igniter cap, rotor, or a bad coil and ballast resistor.

3. If most sparks were not short, VSL1 - 8 and SD1 - 8 are checked to see if all but one spark are too long, too high or too low. If all but one are long, high, or low, the program isolates for opens or shorts in the ignitor cap, a bad rotor, or a coil secondary fault.

4. Closed point voltage, VPLA is checked next and if greater than 0.2 volts a points fault is set and the program terminated.

Section 2

1. The first data checked is SNC. If SNC is 0, all the cylinder data taken in CYL1 may not be correctly correlated to the right cylinder number. If this is the case, the program isolates to a #1 cylinder plug or cable fault, or to a igniter cap fault.

2. Cylinder compression is tested next and if compression is unbalanced, individual ignition cylinder isolation is skipped over, and the program proceeds to C6. If compression is not unbalanced, individual cylinder fault isolation is done.

3. CYL1-CYL4 are examined to isolate individual cylinder faults. If less than 3 good sparks were found in any cylinder, that cylinder is isolated for a plug, cable or igniter cap fault and the program is terminated.

6.3.6 C6-Test Initialization

The function of this segment of the program is to get the vehicle properly instrumented for engine compression intake, and blowby tests. The operator is instructed to install the intake manifold pressure and blowby pressure transducers.

Once the probes are all connected, the system takes zero offset readings on both transducers and will not allow the program to continue unless the absolute value of the offsets are within a usable range ($<$10% of full scale). The offset measurements made are also stored to be subtracted from all future measurements on the channels to correct for offset errors.

6.3.7 C7 - Engine Data Sampling

This test segment takes the data required for the basic engine compression fault isolation. The operator is asked to crank the engine and after steady state cranking speed is reached, the test system monitors three dynamic vehicle parameters: cranking battery current, intake manifold vacuum, and crankcase blowby pressure. Table 6-6 lists the important waveform and parameter characteristics saved by this segment for use in the fault isolation procedures of C8.

6.3.8 C8 - Engine/Fuel Fault Isolation

This test segment uses the data collected in C7 and more if necessary to isolate faults in the basic engine or fuel system. Table 6-7 summarizes the major test decisions made in this portion of the program. The first test made is to check for a restricted intake. If the fault criteria is exceeded on the first test the operator is instructed to check the throttle and choke. This is because if the idle speed is set extremely low, the throttle plate may be fully closed at the "no throttle" test condition and could falsely indicate a restricted intake. If the throttle is found in such a state, it should be readjusted (slightly open throttle) and a retest can be made as indicated by Set Comm messages.

The next test made is a compression check based on the starter current wave-form. There are two ways in which the engine can fail the compression test. One is from cylinder unbalance where there is about 25% or more

unbalance in compression between cylinders (See Table 6-7 $I_{MP} < L_C$).
The other is when all cylinders are found to have low compression.

If a compression problem is found, the system will next isolate that fault to the block or to the cylinder head assembly by checking the crankcase blowby pressure. The crankcase pressure is a function of the magnitude of and rate of change of crankcase volume and of the mass flow rate of gas that escapes from around (or through) the pistons in the compression stroke. If cylinder bores are scored, or if the piston ring seal is poor, the average pressure in the crankcase rises and is ducted back into the intake system. If the crankcase is sealed and vented through an orifice whose dimensions are such that there is no pressure increase in the crankcase at the allowable blowby rate, the blowby pressure waveform can be used to analyze the block condition. The positive slope of the blowby waveform is proportional to the amount of blowby and therefore a timed pressure reading can be used to determine if blowby is excessive; i.e., measure the crankcase pressure during the Nth cycle of the blowby waveform and if the pressure is above a specified limit, the blowby is excessive. If the blowby is not equal from each cylinder (caused by a broken compression ring on one cylinder or a hole in the piston, etc.) the peak to peak blowby signal amplitude changes from cylinder to cylinder. It is, therefore, possible to compare a percentage of the largest individual cylinder peak-to-peak pressure to the smallest individual cylinder peak-to-peak pressure to determine if the smallest is lower than the percentage limit. This is an indicator of excessive blowby in one or more cylinders such as would be found for an engine with unbalanced compression due to a blowby or "block" problem.

Any compression problem which is not due to the block is assumed to be a cylinder head or head gasket problem. If such a condition is found, the system instructs the mechanic to inspect the value train assembly and value adjustment. Problems of this type found may often be fixed without major engine disassembly (removal of head) and thus are called out as separate faults. If no problems of this type can be found, the system identified the fault as a head or head gasket fault.

The intake manifold leak test is called for if the intake is not found to be restricted or no compression problems are found. This test may be failed because of the throttle or choke is set improperly (i.e., throttle set for high idle speed with throttle plate open excessively). The operator should check for such a condition when such a check is indicated by the Set Command retest after adjustment if necessary.

The last portion of this test segment assumes that the vehicle has a fuel system fault since no other faults could be found. The operator is instructed to install the hydrocarbon probe and checks the exhaust gas stream for hydrocarbons while cranking. As indicated in Table 6-7, the test system then decides whether there is a fuel supply problem or a carburetor mixture problem.

6.3.9 C9 - Fault Display and Test Data Output

This test segment simply lists the faults detected on the SC for the user and checks to see if a printer is attached to the system. If such a system is sensed, many of the important test parameter values are printed out along with a list of executed test tasks.

6.4 Performance Diagnostic Program

The Performance Program evaluates the vehicle according to several performance criteria. Fault isolation procedures are used only if performance criteria are not met. Figure 6-4 illustrates the test program flow for all major performance and isolation test segments. This section describes in greater detail each of the segments of the program starting with the test segments which are run to test for serviceability. The fault isolation paths which follow a detected failure of the charging system or poor idle performaance test are covered. Finally a description of the fault isolation routines associated with acceleration and power tests are given.

6.4.1 Vehicle Serviceability Tests

6.4.1.1 D1 - Test Initialization

The function of this segment of the program is to get the vehicle properly instrumented for a serviceability test. The operator is instructed to install 4 probes:

(a) Battery Cables
(b) Igniter Probe
(c) #1 Firing Probe
(d) Oil Temperature Probe

If the ATE system is powered from the vehicle batteries, the mechanic must have already attached the battery cables. The program checks for a battery voltage greater than 3 volts and if it detects such a signal, it only asks for the installation of 3 probes.

6.4.1.2 D2 - Start Up Procedure

This program segment instructs the operator to crank and start the engine. It does not attempt to tell the mechanic how to start the engine since different engine and weather conditions require different starting procedures. The mechanic is assumed to know how to start the vehicle and is given 30 seconds to get the engine running. If the engine has not started by the end of that time, he is questioned by the Set Communicator to see if he tried to start the engine. Given a response of "NO", the system will once again allow 30 seconds to crank and start the engine. If the mechanic responds "YES", the system instructs him to install the current probe on the battery cable and automatically transfers into the No Start program.

If the engine starts running while the "CRANK AND START" message is displayed, the system changes the message on the Set Communicator to "KEEP RUNNING" and waits several seconds to see that the engine does not just start and stall out immediately. After the engine successfully runs for several seconds, the program advances.

6.4.1.3 D3 - Warm Up Procedure

This program segment assures that the engine is thermally conditioned in a repeatable manner. First, it assures that the engine is sufficiently warmed up (greater than 100^{o}F) for testing and second, it establishes the proper engine running conditions for subsequent tests (or for warming up the engine if necessary). During this test segment the system directs the operator to run the engine between 1500 and 2000 RPM and checks to see that he does. If the engine temperature is less than 100^{o}F, it will display the oil temperature and continue to do so until the 100^{o}F temperature is reached. If the operator allows the engine speed to fall outside of the 1500 to 2000 rpm band, the system displays a command to reset engine speed. When 100^{o}F is reached and the engine speed is within the proper speed range, the program advances to the next segment, D31.

6.4.1.4 D4 - Install Oil Temperature Transducer

This program segment is not used if the program is entered through "Performance". However, if the operator enters the No Start program and the vehicle starts within that program, the system automatically transfers to the Performance Program. Since the oil temperature probe is not required for No Start, the mechanic is instructed to install that probe and then the program branches into the normal Performance Program as indicated in Figure 6-4.

6.4.1.5 D31 - Alternator/Regulator Performance Test

This program segment checks that the engine speed is within the 1500 - 2000 RPM and then tests the charging system regulated voltage. If the average regulated battery voltage is 28 $\pm$ 1.5 volts, then the charging system is considered good. Too high a voltage will result in an alternator/regulator fault being set. Too low a voltage will cause the test system to branch to D32 to check the electrical system load.

6.4.1.6 D7 - Idle Performance Test

This test segment evaluates the engine's idle performance and stores data for later use. Entering this part of the test sequence the engine is still running at 1500-2000 RPM due to prior testing. While still in this speed range, an ignition dwell measurement is made and stored for future reference. Then the operator is instructed to adjust the engine speed such that the minimum speed is 450 - 650 rpm. The program then measures the engine speed over 2 - 3 second time periods and displays the minimum speed noted over that duration. The mechanic is given time to adjust the idling speed to a value within the acceptable test range.

Idle performance is measured by misfire rate and roughness. Misfire rate is limited to 4% on all cylinders and is determined by measuring the time between successive points closings. A misfiring cylinder is declared when the elapsed time of any cylinder dramatically exceeds that of the average time. Engine speed variation is measured, and as was shown in Section 5.1.3.1, the variation of speed correlates well with the TACOM recommended criteria of idle roughness. If the idle performance test is failed, the program branches to D8.

If the test is passed, the program continues on to the acceleration and power tests.

6.4.1.7 D-15 Acceleration to Power Test

The object of this program segment is to evaluate the no-load acceleration characteristics of the engine. The SC displays a "FULL THROTTLE" command, requesting the operator to quickly open the throttle. The ATE system then waits for the engine speed to increase and will allow the speed to reach 3500 rpm at which point the interrupter power test described in the next section begins. If the engine stalls or accelerates too slowly, the acceleration test is failed, and progresses to D22 for fault isolation.

6.4.1.8 D16 - Interrupt Power Test

This test segment evaluates the engine's power output capacity under simulated full load conditions. In addition, ignition data is taken and stored which may be used in isolation procedures - D19 - which follow if the power is found unacceptable. The engine's power is evaluated using the ignition interrupt technique for simulating full load conditions (see sections 3.2.5 and 5.1.4). Under normal conditions the power test lasts for 40 seconds and is terminated automatically with the ignition shorted out.

This test segment also measures and saves spark data for the fault isolation routines of D19 (executed if the acceleration or power test are failed). Data is only taken at times when the ignition is not inhibited. The data saved for D19 is the same as that saved by D10 with the exception of spark zone voltage which appears erratic during interrupt conditions and thus has no diagnostic use. The criteria for a good spark is also slightly different at WOT. The energy required to fire a spark plug under full load operating conditions is higher and therefore average spark duration during the interrupt power test is shorter than at idle. The absolute lower limit on spark duration for a good spark is set at 0.8 msec for this test. The other absolute and relative limits for good spark duration during the power test are the same as in D10. Table 6-8 lists the data saved for D19.

6.4.1.9 D20 - Acceleration Data Check

The acceleration data check tests the acceleration rate measured in D15. A rate of 4010 rpm/sec is considered nominal and an engine giving less than 75% of that rate is failed. If the engine passes, the program proceeds to D33, the end of test. If the engine fails, the program moves to D22 to check for operator error.

6.4.1.10 D33 - Fault Display and Test Data Output

This test segment uses the Set Communicator to list the faults detected for the operator and tests to see if a printer is attached to the system. If such a printer is sensed, many of the important test parameter values are printed out along with a list of executed test tasks.

6.4.2 Charging System and Idle Performance Fault Isolation Tests

6.4.2.1 D32 - Charging System Load Test

The purpose of this program segment is to determine the cause of low charging voltage. Since an alternator/regulator system fault or an excessive electrical load on the system could give this condition the test segment only differentiates between these two conditions. The program instructs the operator to connect the current probe and then the ATE takes a zero offset measurement for each range of the current probe, records the value for future measurement and offset correction, and checks out the current probe by comparing these offsets with maximum allowable limits (as done in C1 of No Start). Once this is completed, the operator is instructed to install the probe on the alternator output cable so that the alternator electrical load can be measured. If the load is found to be in excess of 40 amps, the problem is identified as an electrical loading problem. If there is no excessive electrical load on the system, then an alternator/regulator fault is set which means that there is a problem in the alternator/regulator system (including cables). The program then returns to its normal execution path and continues on to D7.

6.4.2.2 D8 - Idle Mixture Adjustment

This program segment is used after failing the idle performance test the first time. The operator is instructed to adjust the idle mixture to maximum engine speed and is given the Set Communicator to use as a digital tachometer. When he is done system returns to D7 to test the idle performance again. Failure to pass on the retest will not ask for idle mixture adjustment again.

Since some carburetors have no idle mixture adjustment screw on them, the system asks the mechanic if the mixture is adjustable before instructing him to do so. If the operator responds no to this question or the vehicle fails the idle performance test the second time, the test system loads a new set of program segments and continues on to D10 to isolate the cause of rough idling.

6.4.2.3 D10 - Idle Ignition Data Sampling

This program segment checks the ignition system idle performance and saves data for the fault isolation routines in D12. Data is taken on four basic ignition parameters given below:

(a) Spark Delay
(b) Spark Duration
(c) Spark Zone Voltage
(d) Closed Points Voltage

The first three of these parameters have data correlated by cylinder number based on signals from the #1 Firing Transducer; the values of the last three of these parameters are calculated on an average basis. The idle ignition system performance is evaluated in terms of how many bad sparks are generated. A good ignition system must meet several service criteria. First, it must sustain a spark at each cylinder long enough to consistently ignite the compressed fuel/air mixtures. Therefore, each spark duration is compared to an absolute lower limit of 1.0 msec. Similarly, unless there is a partial short in the secondary output system (such as a shorted cable or plug) the spark duration should not exceed 3.5 msec and the absolute upper limit for a good spark is set at 3.5 msec.

Absolute limits on the spark zone voltage for each spark have also been established with the allowable range for a good spark being 500 - 1500 volts.

Another set of criteria which must be met in order for a spark to be considered good are limits which are set relative to the average values of spark zone voltage and spark duration. These average values are, however, only calculated from data that is within the absolute limits discussed briefly above. For the spark zone voltage these limits are set at $\pm$ 35% of the average value. For the spark duration these relative limits are set at $\pm$ 20% of the average value.

A single limit of 0.2 msec has been established for the allowable spark delay. That is, the time from initial points opening to when the spark voltage rises about 3 KV cannot be greater than 0.2 msec for a good spark. A delay greater than this limit is usually from points arching caused by bad points, condenser, or both.

In summary, a good spark is a spark delayed less than 0.2 msec with spark zone voltage and spark duration within both absolute and relative limits and a bad spark is one which is outside any one of these test limits.

The test system will take ignition data until it either has found at least 7 bad sparks for any cylinder or until it has taken data on 40 sparks for each cylinder and not found 7 bad sparks. The data passed which is then passed to segment D2 is similar in format to that passed from C4 to C5 in No Start and is shown in Table 6-9.

An exception to this test procedure occurs when the ignition points are bad enough to give erratic operation such that the system hardware cannot reliably take a full set of spark data. The test system under these conditions will attempt to get the full data set six times and then give up and call out a points fault.

6.4.2.4 D12 - Idle Ignition Fault Isolation

This part of the program isolates ignition system faults mainly from data taken during the D10 segment. Fault diagnosis is broken into two major sections. The first section isolates faults which affect most sparks, the second section isolates individual cylinder ignition faults if timing and compression are found to be acceptable.

Section 1

1. The first data checked is D5 and if more than 2 sparks were found to be delayed a points/cap fault is set and the program terminated.

2. SD1 - 8 are analyzed to determine if most sparks are short (< 1.0 msec). If all or all but 1 spark are short, the program searches for leaky capacitor, high resistance igniter input, open circuits in the igniter cap, rotor, or a bad coil and ballast resistor.

3. If most sparks were not short, VSL1 - 8 and SD1 - 8 are checked to see if all or all but one spark are too high, too low or too long. If all but one are high, low, or long the program identifies open or shorted igniter cap, a bad rotor, or a coil secondary fault.

4. Closed point voltage, VPLA is checked next and if greater than 0.2 volts, a points fault is set and the program terminated.

Section 2

This section of the ignition diagnostics isolates individual cylinder ignition faults. The first data checked is SNC. If SNC is 0, all the cylinder data taken in CYL1 may not be correctly correlated to the right cylinder number. If this is the case, the program identifies a #1 cylinder plug or cable fault, or to a igniter cap fault.

The system then checks the idle performance data saved in D7 to see if it failed the idle performance test due to a non-random misfire. Such behavior could be due to compression unbalance or consistently misfiring cylinders. The compression test eliminates that possibility at this point in the program. The bad spark counter for the bad cylinder is therefore set to 15 to insure that an ignition fault is found. This is necessary to improve the reliability of the individual cylinder ignition diagnostics since it is possible to have fouled plugs with normal sparking characteristics. The bad spark counters, CYL-1 through CYL-4, are next examined to isolate individual cylinder faults. If more than 7 bad sparks are found for any cylinder, that cylinder is isolated for a plug, cable or igniter cap fault by visual inspection techniques. Table 6-10 shows the ignition system faults found in this portion of ignition fault isolation program.

6.4.2.5 D-11- New Transducer Installation

The function of this segment of the program is to get the vehicle properly instrumented for the engine compression, intake, and blowby tests. The operator is instructed to install the intake manifold and blowby pressure probes.

AD-A117 265 TRW SYSTEMS GROUP REDONDO BEACH CA F/G 21/1
ATE/ICEPM DEVELOPMENT REPORT AND FUNCTION DEMONSTRATION TEST.(U)
JAN 75 G H GELB DAAE07-73-C-0268

UNCLASSIFIED TACOM-TR-11977 NL

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When the operator responds that he has installed the probes, the system attempts to sense the transducer signal. If it cannot, it asks the operator if he has installed the transducer(s) and a positive response causes the computer to identify a transducer problem and stop to prevent the operator from continuing on with a bad transducer. If a probe is sensed, the system takes zero offset readings and will not allow the program to continue unless the absolute value of the offsets are less than 10% of full scale.

6.4.2.6 D13 - Cranking Tests and Fault Isolation

This test segment takes the data required for the basic engine compression fault isolation and performs the problem diagnosis. The operator is asked to crank the engine and after steady state cranking speed is reached the system monitors three dynamic vehicle parameters: cranking battery current, intake manifold vacuum, and crankcase blowby pressure. Table 6-11 lists the important waveform and parameter characteristics saved for use in fault isolation.

Table 6-12 summarizes the major test decisions made in this portion of the program. The first test made is to check for a restricted intake. If the fault criteria is exceeded on the first test, the operator is instructed to check the throttle and choke because setting the idle speed abnormally low could falsely indicate a restricted intake. If the throttle plate is found fully closed, it should be readjusted to slightly open condition and a retest can be made as indicated by Set Communicator messages.

The next test made is a compression check based on the starter current waveform. There are two ways in which the engine can fail the compression test. One is from cylinder unbalance where there is 25% or more compression unbalance between cylinders (see Table 6-12 $I_{MP} < L_C$). The other is when all cylinders are found to have low compression.

If a compression problem is found, the system will next isolate that fault to the block (including pistons and rings) or to the cylinder head assembly by checking the crankcase blowby pressure in a manner similar to No Start.

A compression problem which is not due to the block is assumed to be a cylinder head or head gasket problem. The system instructs the mechanic to inspect the value train assembly and value adjustment. Problems of this type may often be fixed without major engine disassembly (removal of head) and thus are called out as separate faults. If no problem of this type can be found, the system identifies the fault as a head or head gasket fault.

6.4.2.7 D14 - Idle Timing and Manifold Tests

This test segment will isolate faults to one of the following areas: idle timing, intake manifold leaks, fuel supply problems, or carburetor. Since the program enters this segment with the engine stopped, the system first instructs the operator to start the engine and adjust it to the proper idle speed. Then it checks the average intake manifold vacuum for gross intake manifold leaks. If there is no manifold vacuum problem, the system checks the timing at idle since a broken advance mechanism could give different results than those taken during cranking.

After this test, the system either branches to D9 intake manifold leak display or displays an idle mixture fault. This latter assumption is based on a process of elimination which has eliminated ignition system (including timing) and compression problems as possible causes of the idle misfire problem. The program informs the operator that there is an idle mixture problem and successively instructs him to inspect for fuel supply and intake manifold leak problems. If neither of these exist, a carburetor fault is displayed and the test program is terminated.

6.4.2.8 D9 - Fault Display and Test Data Output

This test segment uses the Set Communicator to list the faults detected for the operator and tests to see if a printer is attached to the system. If such a printer is sensed, many of the important test parameter values are printed out along with a list of executed test tasks.

6.4.3. Acceleration and Power Fault Isolation Tests

6.4.3.1 D 17- Acceleration Data Check

This program segment checks to see if the cause of acceleration and power test failure was operator error. If the operator accelerates too slowly the power test may start, fail, that is the speed drops below 2000 RPM, and terminates before the engine ever reaches full throttle. The first time this segment is entered it checks the acceleration rate and time at which the power test was failed. If the acceleration rate is less than 75% of nominal and the power test speed dropped below 2000 RPM within 5 seconds of the beginning of test, then the test system will inform the operator that the acceleration was too slow and branch to D22 to force a retest with operator error checks.

6.4.3.2 D19 - Power Ignition Fault Isolation

This part of the program isolates ignition system faults mainly from data taken during the D16 test period. Fault diagnosis is broken into two major sections. The first section isolates faults which affect most sparks, the second section isolates individual cylinder ignition faults if timing and compression are found to be acceptable.

Section 1

1. The first data checked is DS and if more than two sparks are found to be delayed, a points/cap fault is set and the program terminated.
2. SD1 - 8 are analyzed next to determine if most sparks are short - < 0.8. If all or all but one spark are short, the program searches for a leaky capacitor, high resistance igniter input, an open igniter cap, rotor, or a bad coil and ballast resistor.
3. If most sparks are not short SD1 - 8 are checked to see if all or all but one spark are too long. If so, the program searches for shorts in the igniter cap, a bad rotor, or a coil secondary fault.
4. Closed point voltage, VPLA, is checked next and if greater than 0.2 volts, a points fault is set and the program terminated.

Section 2

This section of the ignition diagnostics isolates individual cylinder ignition faults. The first data checked is SNC. If SNC is 0, all the cylinder data taken in CYL1 may not be correctly correlated to the right cylinder number. If this is the case, the program looks for a #1 cylinder plug or cable fault, or to a igniter cap fault. The bad spark counters, CYL1 - CYL4, are then examined to isolate individual cylinder faults. If more than 7 bad sparks are found for any cylinder, that cylinder is identified as having a possible plug, cable or igniter cap fault and the mechanic is required to perform a visual inspection. Table 6-13 shows the ignition system faults found in this ignition fault isolation program.

6.4.3.3 D21 - Install More Transducers

This segment is used to get the vehicle properly instrumented for the engine compression, intake, and blowby tests. The operator is instructed to install the intake manifold and blowby tansducers and the program progresses as in 6.4.2.5.

6.4.3.4 D23 - Cranking Tests and Fault Isolation

This test segment is similar to D15 and requires the same parameters as listed in Table 6-11.

Table 6-14 summarizes the major test decisions made in this portion of the program. These are similar to those of Section 6.2.2.5 and identical commands and procedures are followed.

6.4.3.5 D27 - Acceleration and Power Data Check

The purpose of this segment is to detect accelerator pump problems by checking the acceleration rate and the interrupter power calculation. The program went to this path because of the acceleration was less than 75% of nominal, but the power test was passed. This may be due to an accelerator pump problem which, unless it is extremely bad, will not affect the operational use of the vehicle seriously. An accelerator pump problem/carburetor fault are not identified unless the problem is bad enough to cause the acceleration rate to be less than 50% of nominal - less than 2674 RPM/sec. In that case, the program proceeds to D33 and fault display.

A carburetor fault is displayed if the rate is less than 50% of nominal. In the marginal case of acceleration rates between 50% and 75%, the vehicle is still considered serviceable and no fault is displayed and the programs proceed to D24.

6.4.3.6 D22 - Install Intake Manifold Transducer

This program segment instructs the operator to install the intake manifold vacuum transducer and follow procedures as in 6.4.2.5.

6.4.3.7 D24 - Timing and Advance Tests

This program segment tests both the idle timing and the centrifugal advance mechanism. If either an idle timing or insufficient advance problem is found, the program identifies the fault and proceeds to D33 for fault display. If no timing or advance faults are found, the program continues to search for other causes of low power.

6.4.3.8 Acceleration and Operator Error Check

As in D15, the purposes of this segment are to command the operator to go to WOT and to take acceleration data during that period. Because the intake manifold transducer has been previously installed, means are available for checking on operator error. As the throttle is opened, the manifold pressure increases and the rate of change of pressure is indicative of the rate of throttle opening. If the operator is opening the throttle too slowly he is told to do it faster next time, and allowed to try again. Once the engine has reached 3500 RPM the program either branches back to D16 (if program hasn't executed D27 yet) or continues on to D28 for further fuel and intake system testing.

This segment also includes special procedures to circumvent stalling problems which may occur when the throttle is suddenly opened. If this happens, the operator is instructed to accelerate the engine more slowly. After he reaches the interrupt test speed of 3500 RPM, he is instructed to go WOT and the interrupt test will begin. In this way, even if the engine immediately stalls out, there will be sufficient time to get meaningful ignition data so that the system can decide whether the problem is due to a marginal ignition system that cannot supply the full load ignition requirements or simply due to an accelerator pump. In either case, the appropriate fault is set and displayed.

6.4.3.9 D28 - Wide Open Throttle Data Task

This program segment appears similar to the 40-second power test, D16; however, its purpose is that of a fault isolation data-taking task and not that of a power test. At this point in the program the engine power output has been shown to be low and the cause has been shown not to be in the ignition system, timing, or compression.

The interrupt portion of the test starts at 3500 RPM. The test ends when either the speed drops below 2000 RPM or 40 seconds of elapsed test time have been completed. During this time the carburetor is at wide open throttle so that there is almost no pressure drop across it. Thus, the intake manifold vacuum is effectively a measure of the pressure difference across the air filter under full air flow conditions. This parameter is monitored during this test and the maximum value saved for the fault isolation tasks of D30. A final supply problem can also be identified during this time by the speed/time characteristic of the test. For a vehicle which has a marginal fuel supply system, the vehicle may be able to idle well but not be able to produce near-full power when near maximum fuel flow is required. If the latter is the case, power will be developed initially but will drop off as the carburetor bowl empties - it takes about 15 seconds to lower the fuel bowl enough to cause low power if fuel is totally cut off.

The test sytem looks for this speed versus time inflection and saves the slope(ΔS_{MIN} and ΔS_{MAX}) data for the isolation tasks of D30 - Figure 6-5 illustrates four sample tests where cases 1 and 2 represent very low power due to something other than fuel supply, case 3 illustrates this special fuel supply problem characteristic discussed above, and case 4 represents the low power case that can sustain a speed greater than 2000 RPM for 40 seconds. At this time (or when the speed drops below 2000 RPM) the interrupt portion of the test is ended by totally inhibiting the ignition.

6.4.3.10 D30 - Intake and Fuel System Fault Isolation

This program segment checks the data taken in D28 and isolates between restricted intake, fuel supply, and carburetor problems. A restricted intake fault is set if the maximum vacuum measured during D28 is greater than 4.0 In.

Hg. A fuel supply problem is identified if the speed inflection characteristic previously discussed (D28) is found and the mechanic is directed to inspect the pump, lines, and filter in order to isolate the fault to carburetor supply or carburetor problem (such as needle value). If neither of those problems are found, the system assumes a carburetor problem, and sets a carburetor fault. After setting a fault, the isolation path of the program is complete and the program continues on to the operator display of results, D33.

6.5 Tune Up

The purpose of the Tune Up program is to extend the usefulness of the system. It takes many of the measurement program modules used within the larger diagnostic routines and allows the mechanic to individually call and use them. The mechanic can use the ATE/ICE system for adjusting the carburetor or timing or as a meter to read speed, dwell, voltage, current, manifold vacuum, oil temperature, blowby pressure, or ambient pressure. Table 6-15 lists the individual routines included in Tune Up along with their entry number, function, and transducer requirements. The Option List is included to minimize the list of numbers to be remembered and to allow the system to act as a teaching system. This is accomplished by displaying the entry number corresponding to an individual module each time that it is requested from the Optional List. After repeated usage of the same module, its entry number will become familiar to the user.

7.0 Configuration Management and Documentation

During the life of the project, full configuration management was implemented on all hardware items modified and/or newly designed by TRW, RCA, and supporting vendors. The Configuration Management Plan, prepared at the start of contract go-ahead, was the basis for implementation. The end result is a complete technical data package that has been prepared to reflect the latest configuration of all ATE hardware.

The drawing package contains the following:

- All original Dynasciences data not modified but used as is on the final configuration shipped to TACOM.
- All original Dynasciences data modified by TRW and/or RCA. Each change has been documented on each company's standard engineering change orders, using the original drawing number and the next sequential alpha character. Microfilm cards have been prepared and filed with the drawing they affect.
- All newly designed hardware manufactured by TRW and/or RCA. Each new item has been documented on each company's standard engineering drawing format, using the newly assigned eight-digit Army part number. Microfilm cards have been prepared and filed in the master drawing file.
- All vendor related data used to modify or change the PDU and a TK-13. As these are blue line copies of vendors' drawings and will not reproduce as microfilm copies, they have been filed in the master file as is.

All data contains the eight-digit Army part numbering system. All engineering orders prepared under this contract contain the part number of the item affected by the change, the next sequential alpha character, a clear description of the changes made, and the serial numbers affected. None of the engineering orders have been incorporated into the drawings. Therefore the drawing and latest engineering order will always be required together in order to assure that the correct drawing configuration is known.

All data that could be reproduced on microfilm has been prepared.

TRW has established two separate files as described below:

- Original vellums - master file
- Working microfilm - master file

The original vellum file contains all original vellums produced by Dynasciences, TRW, RCA and Vendors. It is structured in numerical sequence by drawing size and contains obsolete as well as current configuration data.

The working microfilm file contains all technical data related to the as-built, as-delivered ATE system. All required specifications, assembly, subassembly detail drawings, and related engineering orders are in the file. The file is structured in numerical sequence and is to be used in conjunction with the configuration control list which is described in detail below.

TRW has prepared a Configuration Control List (CCL) which will enable the rapid retrieval of data required to modify, repair, or redesign the present ATE system configuration.

The user can find the appropriate data required by two methods. The first and best method is to locate the part number of the item in question and refer to the CCL for nomenclature, latest revision level, and all related data. Using the working microfilm file, the drawing and all engineering orders must be reviewed in detail as many of the engineering have not been incorporated into the drawings.

The second method is to locate the nomenclature in the CCL that corresponds to the part in question and obtain the part number and proceed as described in method one above.

The Configuration Control List contains the following format information:

- Drawing number (in numerical sequence)
- Latest revision level
- Drawing title
- Drawing size
- Other related data and their revision level

The list is composed of Dynasciences, RCA, and vendor data. There is also a list of original Dynasciences data that was never received from TACOM upon start of contract go-ahead.

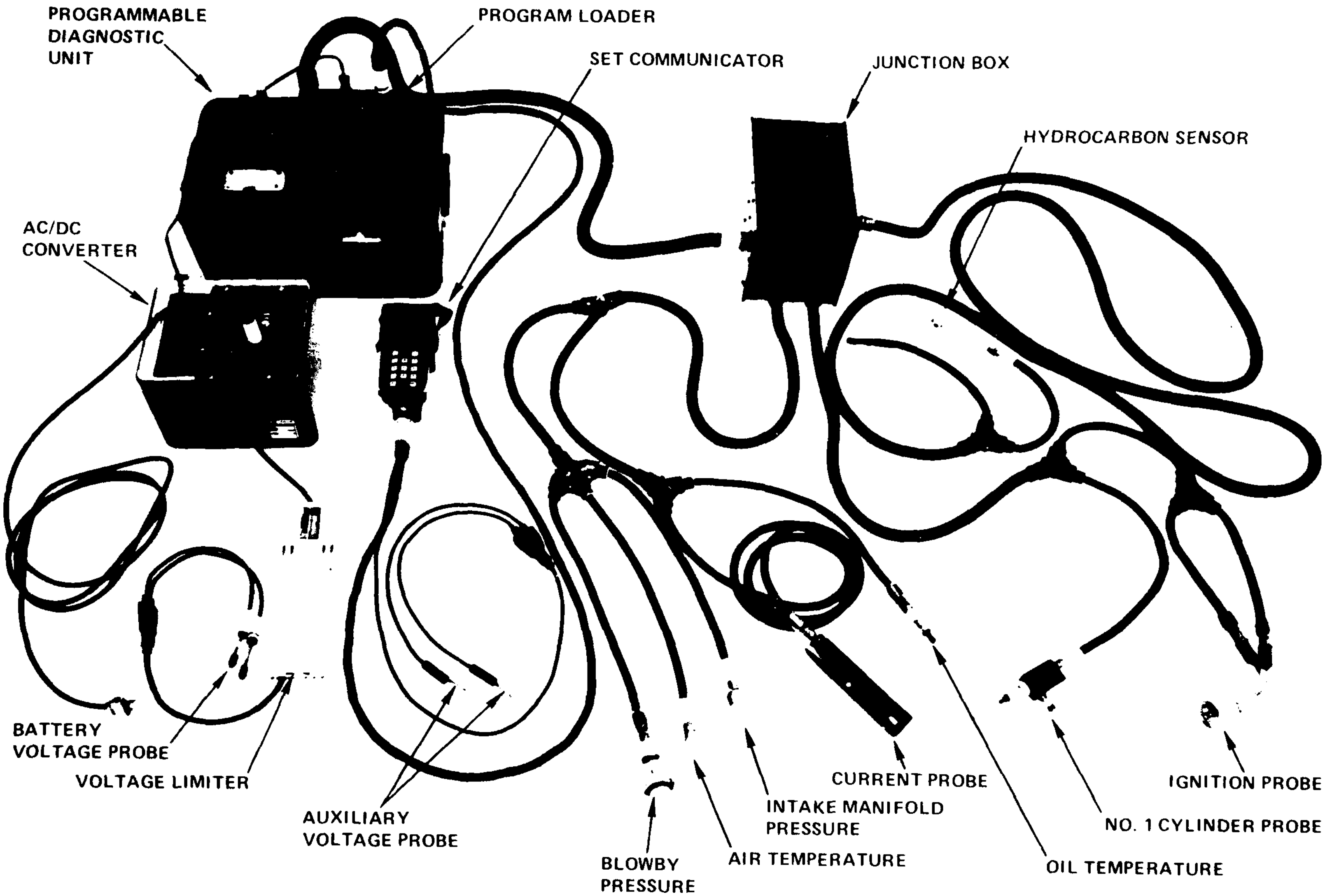
TRW has taken great care to maintain and preserve the correct configuration of all ATE system hardware. However, there are some cases where the configuration of the hardware and technical data will not agree. These few exceptions are the result of the following historical problems.

1) Dynasciences, during the final days of their contract, made hardware changes and did not fully document them.

2) The Army made changes to the six systems prior to the inception of this contract which were not fully documented.

APPENDIX

Figure 2-1



PROGRAMMABLE DIAGNOSTIC UNIT
PROGRAM LOADER
SET COMMUNICATOR
JUNCTION BOX
HYDROCARBON SENSOR
AC/DC CONVERTER
BATTERY VOLTAGE PROBE
VOLTAGE LIMITER
AUXILIARY VOLTAGE PROBE
BLOWBY PRESSURE
AIR TEMPERATURE
INTAKE MANIFOLD PRESSURE
CURRENT PROBE
OIL TEMPERATURE
NO. 1 CYLINDER PROBE
IGNITION PROBE

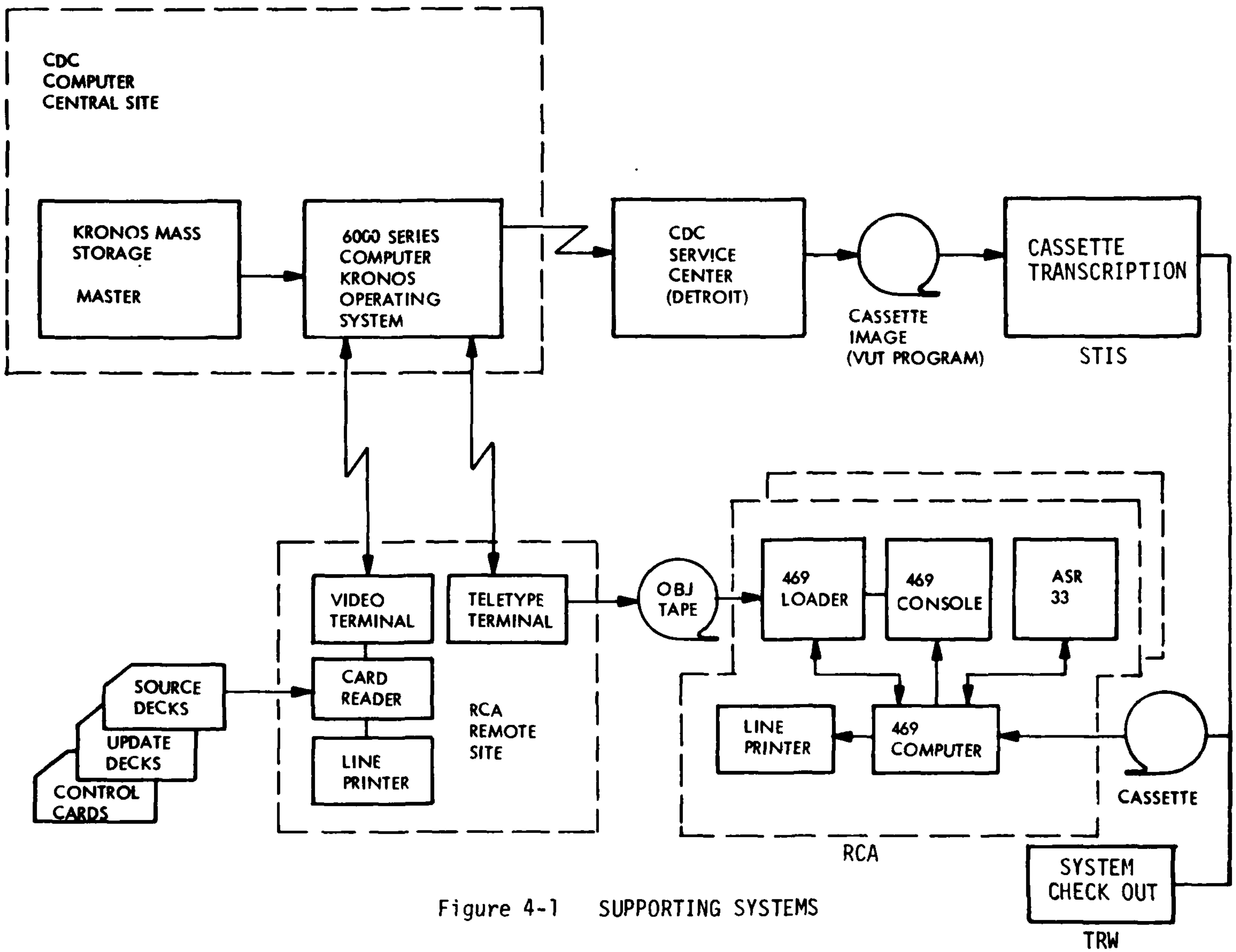


Figure 4-1 SUPPORTING SYSTEMS

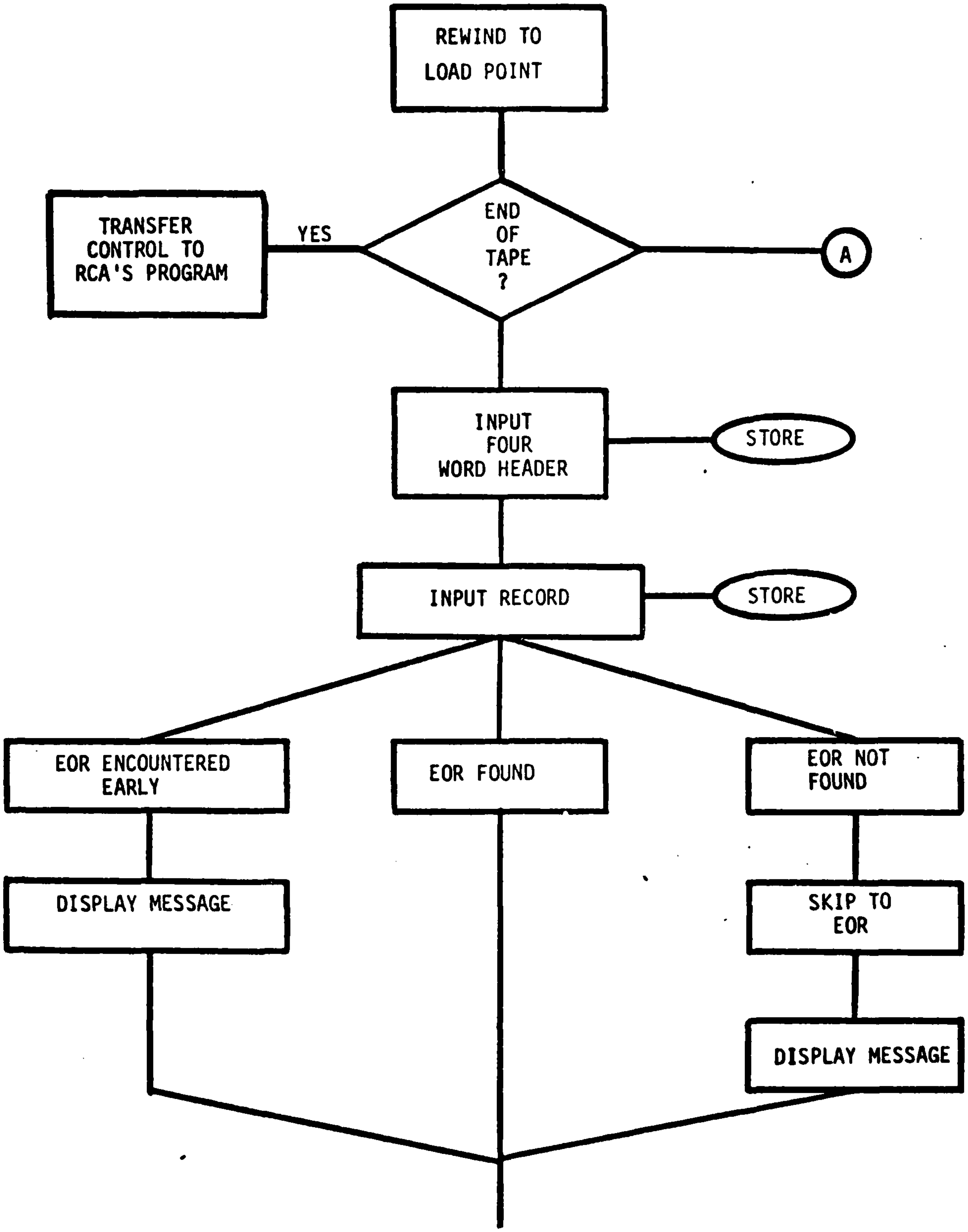


Figure 4-2
BOOTSTRAP LOADER

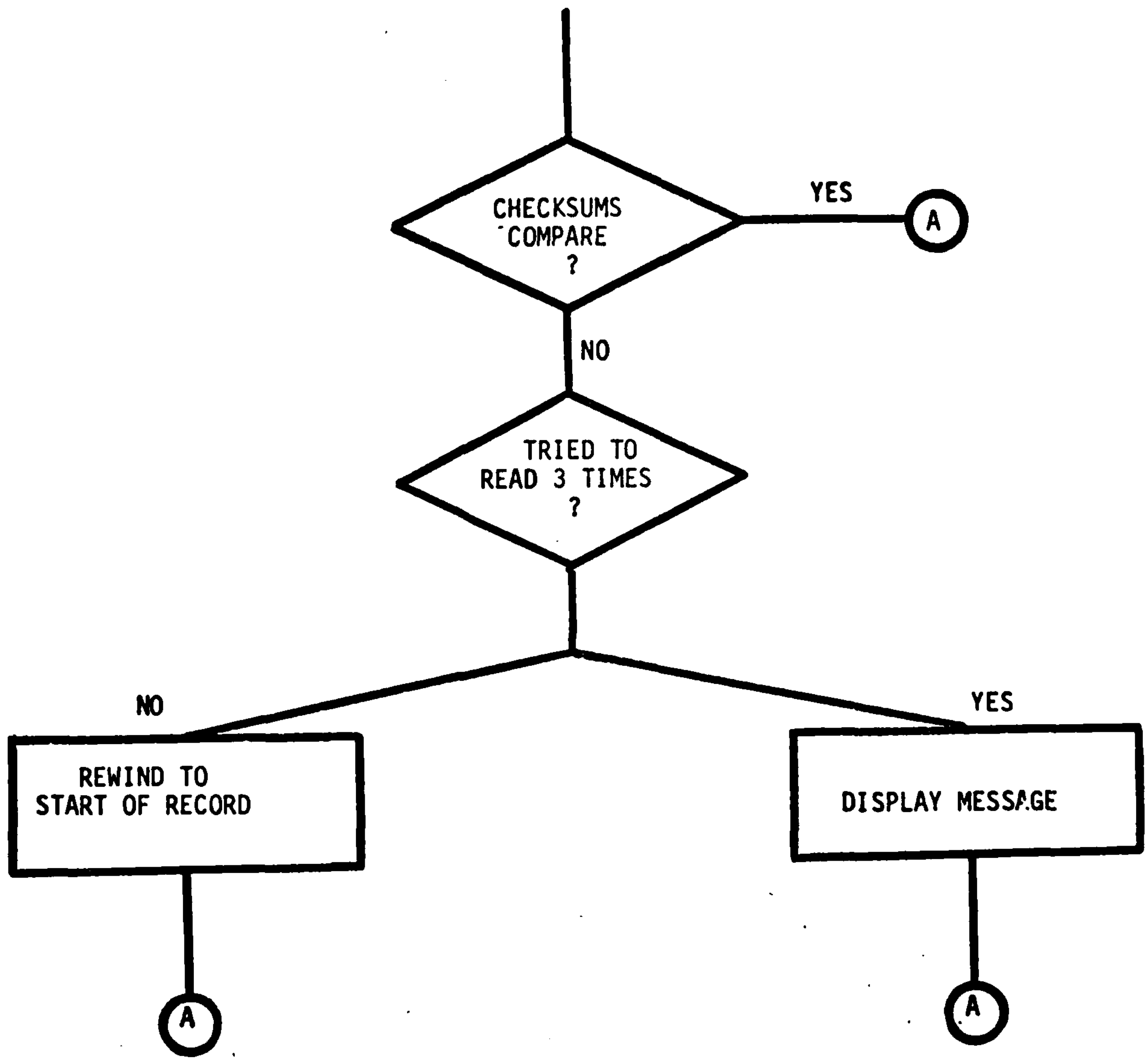
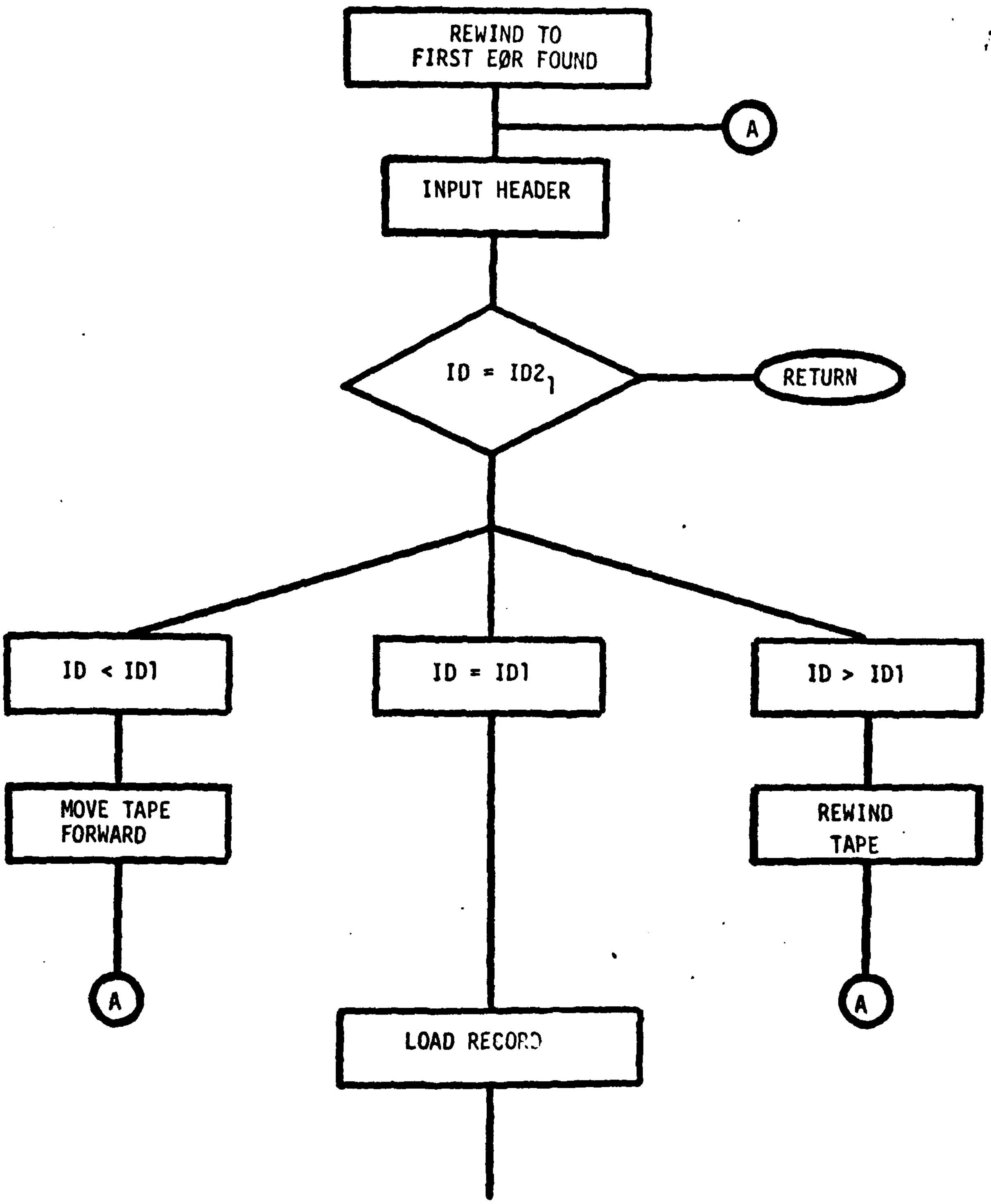


Figure 4-2 (Continued)
BOOTSTRAP LOADER

CASSETTE LOADER



1 . ID is Record Indentifier from tape
ID1, ID2 are first and last RECORDS to be read

Figure 4-3
CASSETTE LOADER

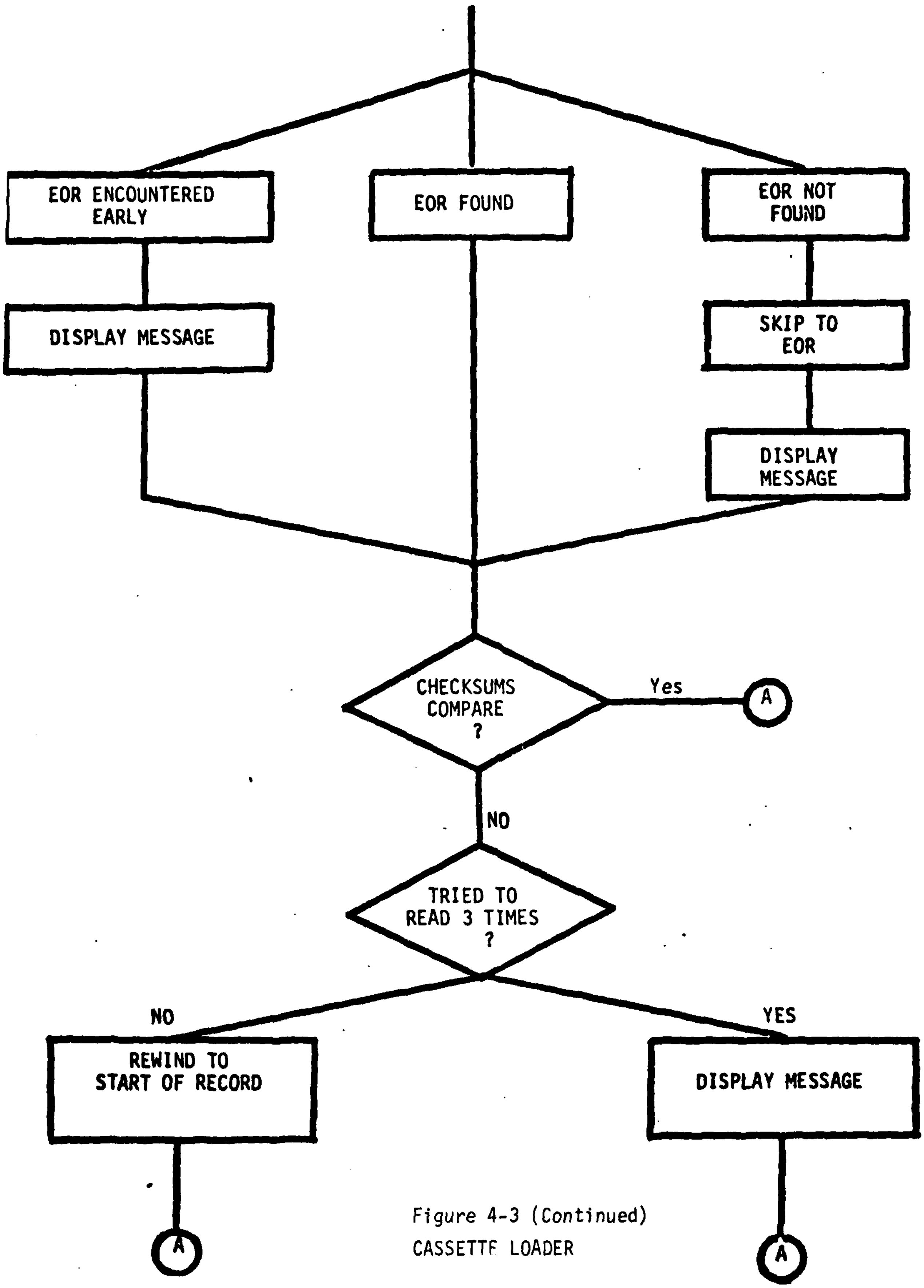


Figure 4-3 (Continued)
CASSETTE LOADER

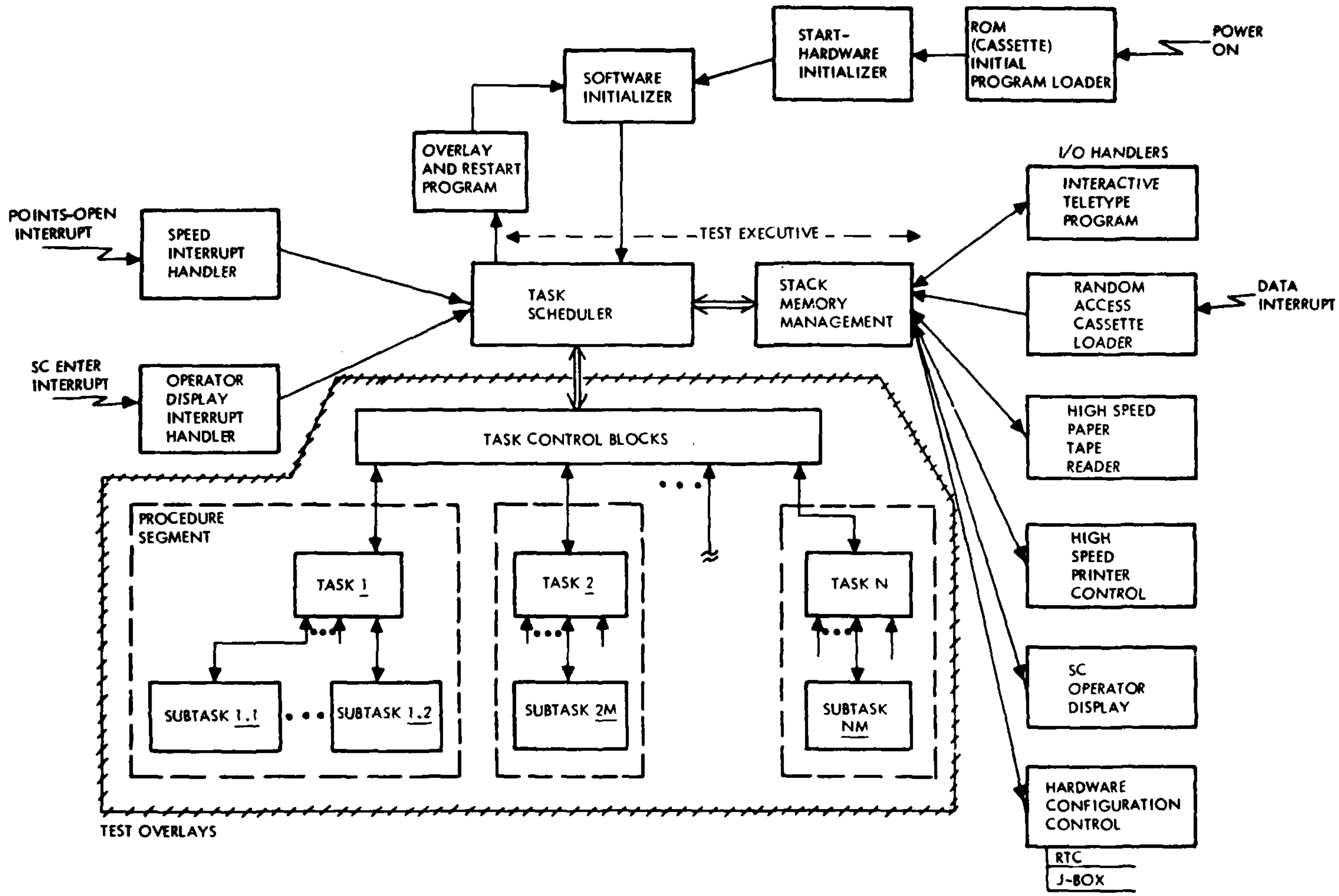


Figure 4-4 Operating System Simplified Block Diagram

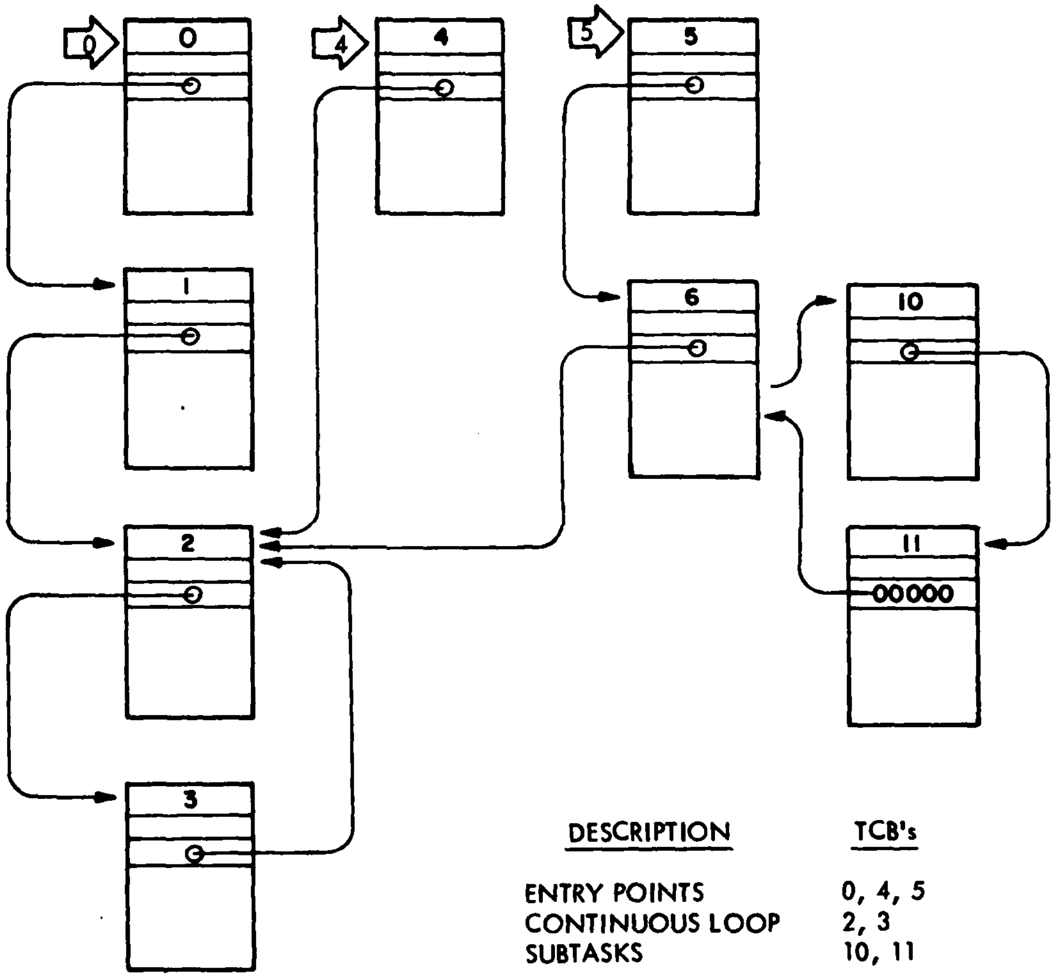


Figure 4-5 **Task Sequencing**

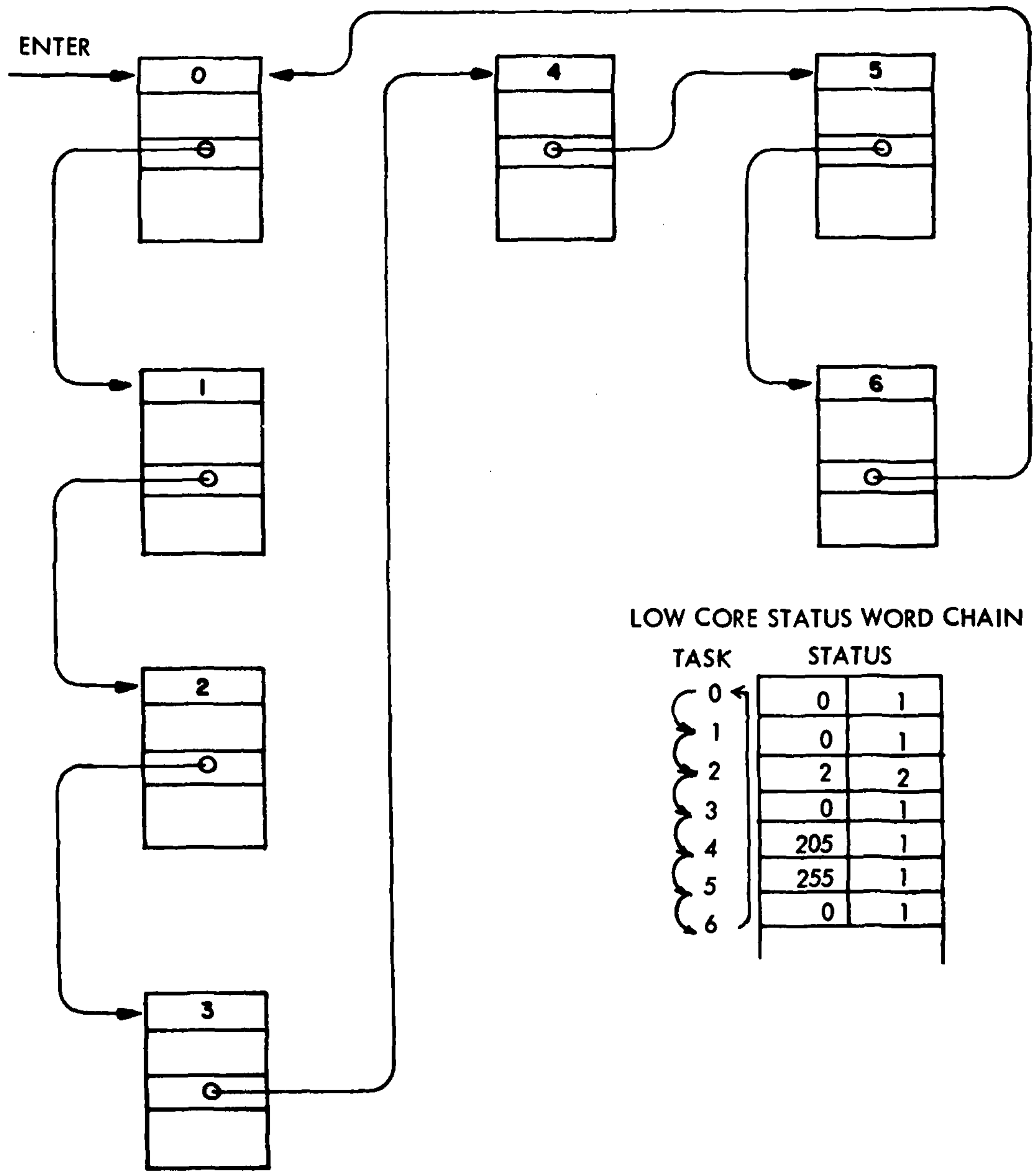


Figure 4-6 **Task Chaining**

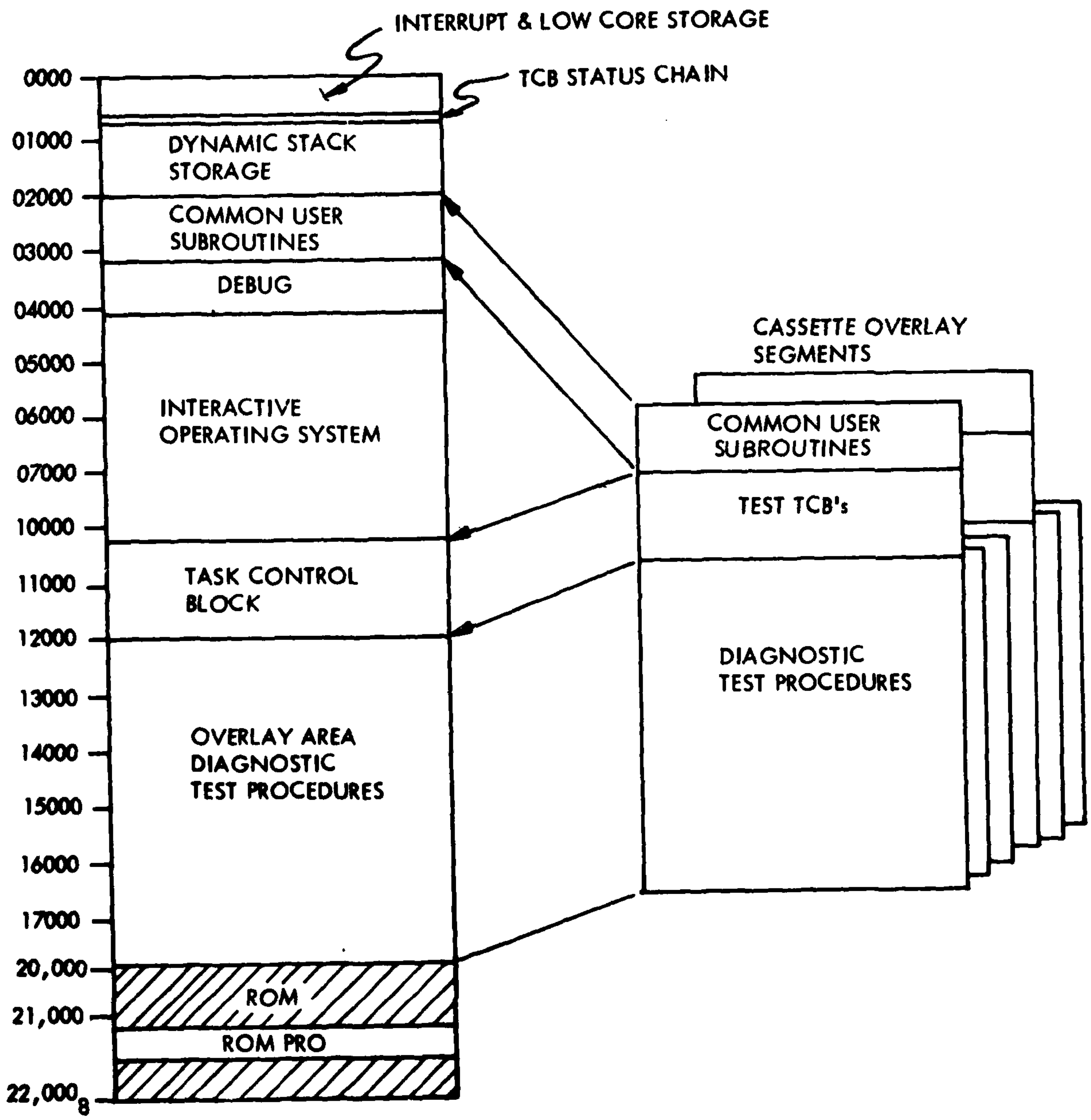


Figure 4-7 **Memory Map**

FIGURE 5-1

INSTRUMENTATION

DYNAMOMETER DIAGNOSTIC TESTS

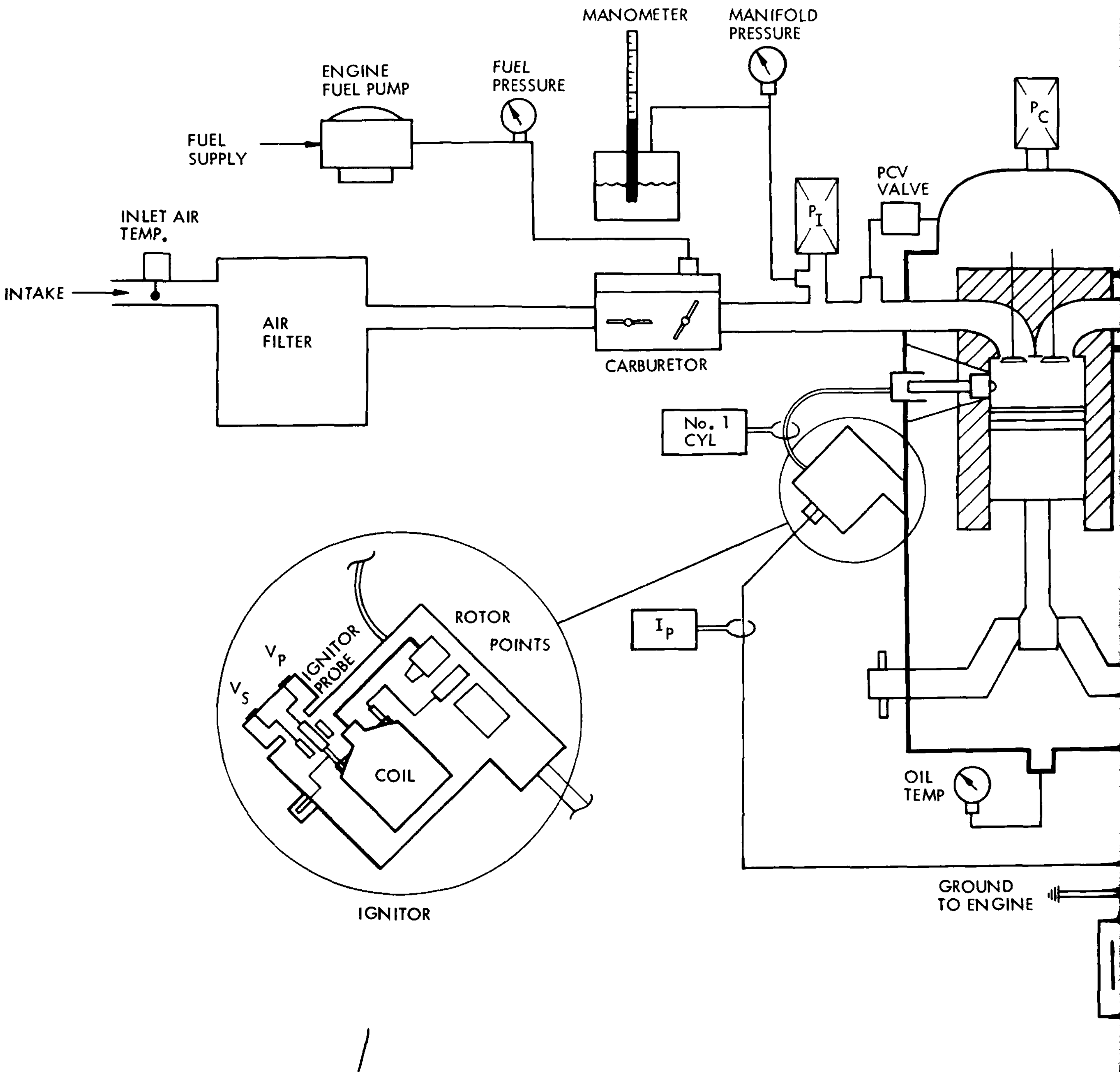
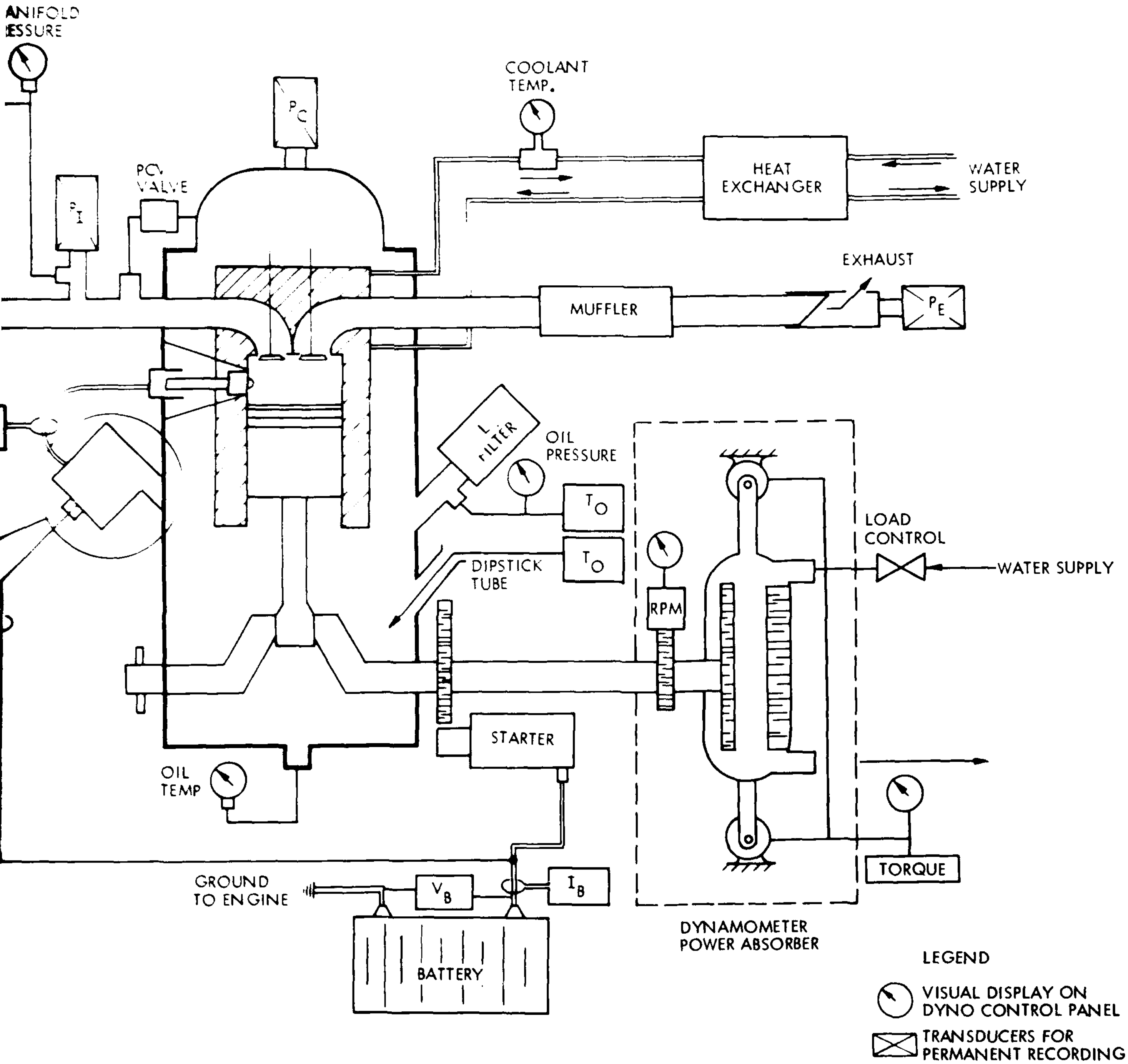


FIGURE 3-1

INSTRUMENTATION

YNAMOMETER DIAGNOSTIC TESTS



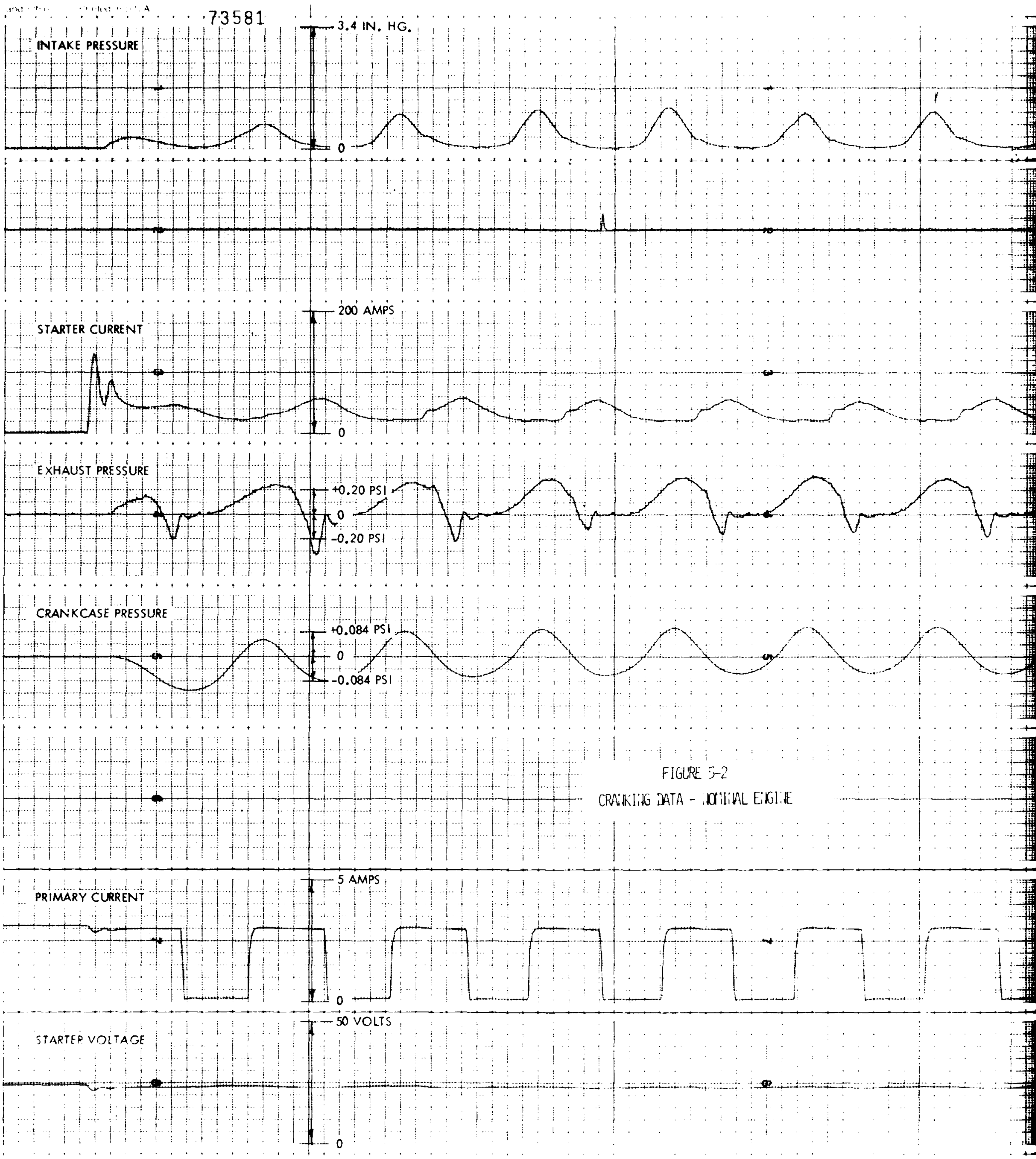
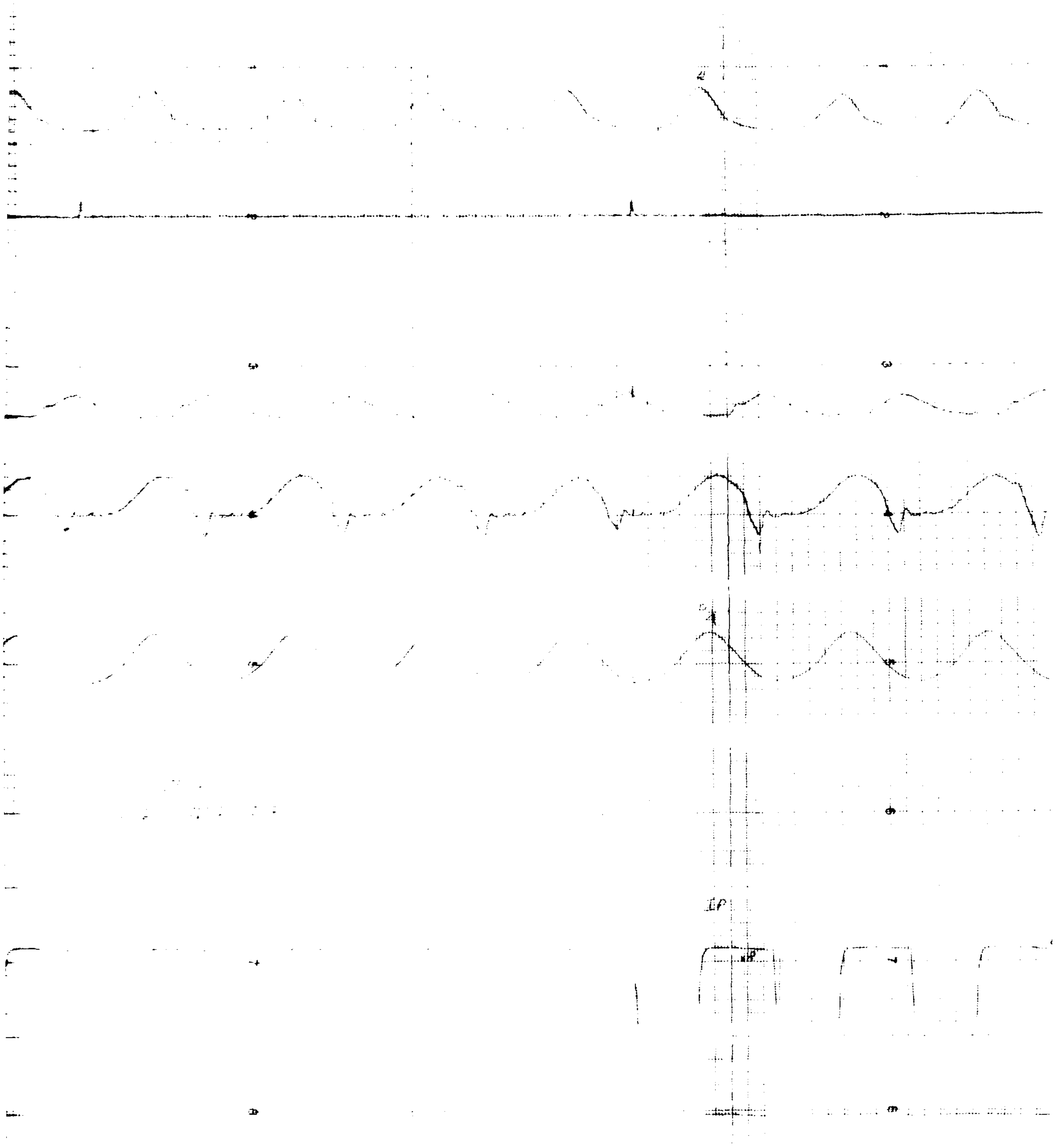
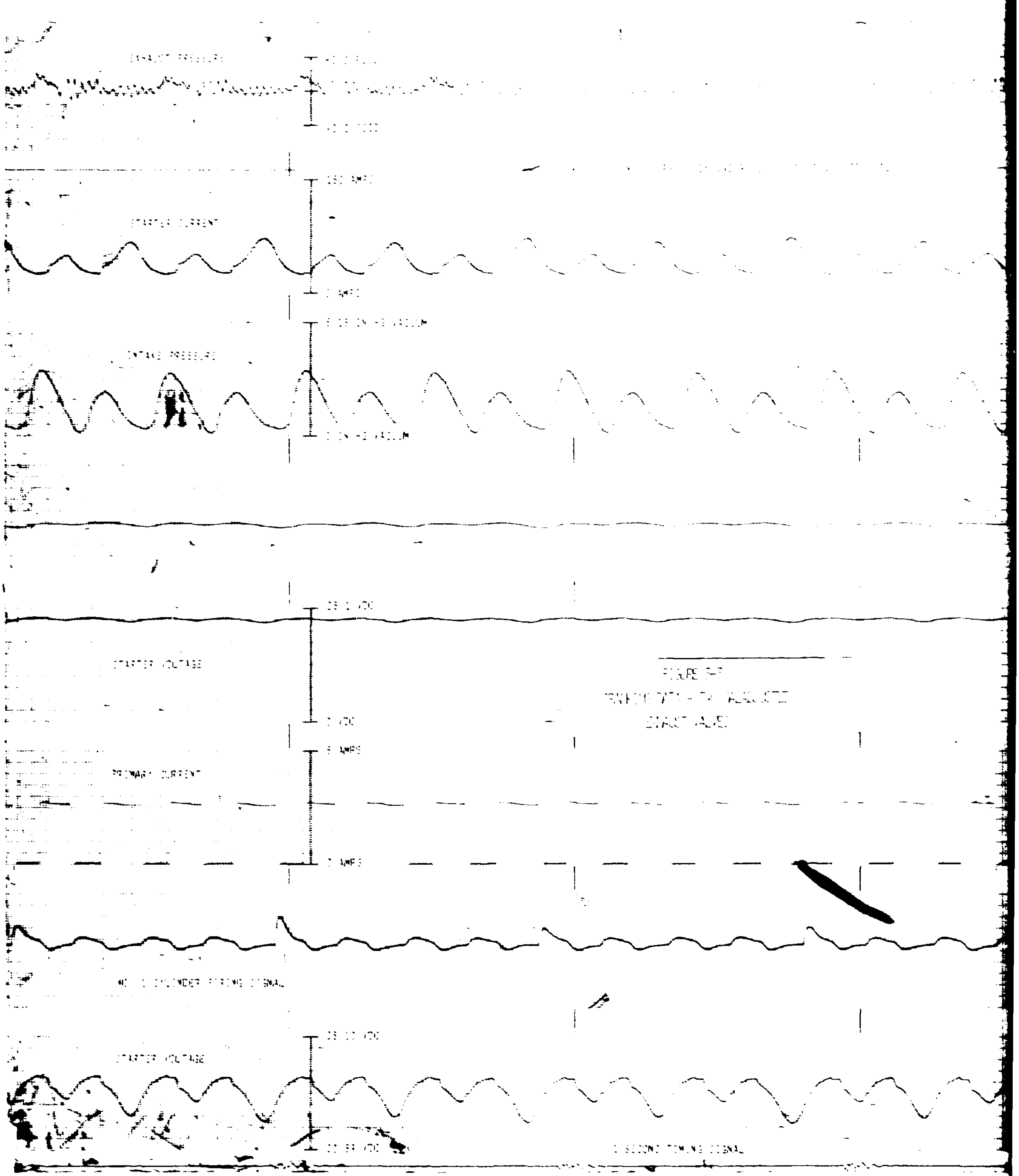


FIGURE 5-2

CRANKING DATA - NOMINAL ENGINE

BRUSH ACCUCHART





EXHAUST PRESSURE
STARTER CURRENT
0 AMPS
INTAKE PRESSURE
STARTER VOLTAGE
0 VDC
PRIMARY CURRENT
5 AMPS
0 AMPS
STARTER VOLTAGE

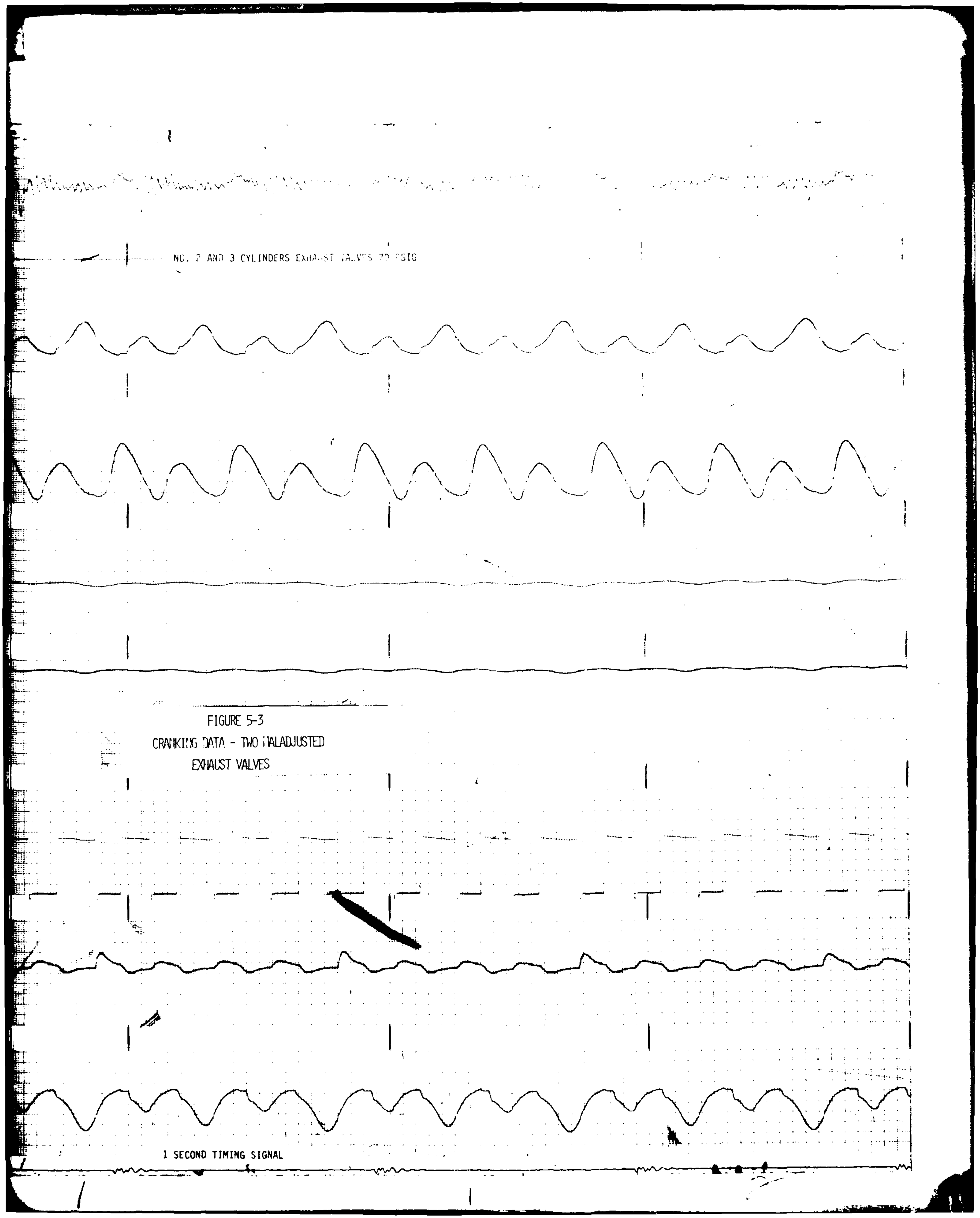


FIGURE 5-3
CRANKING DATA - TWO MALADJUSTED
EXHAUST VALVES

FIGURE 5-4

HOLED-PISTON ENGINE

PEAK STARTER CURRENT

COLD ENGINE CRANKING

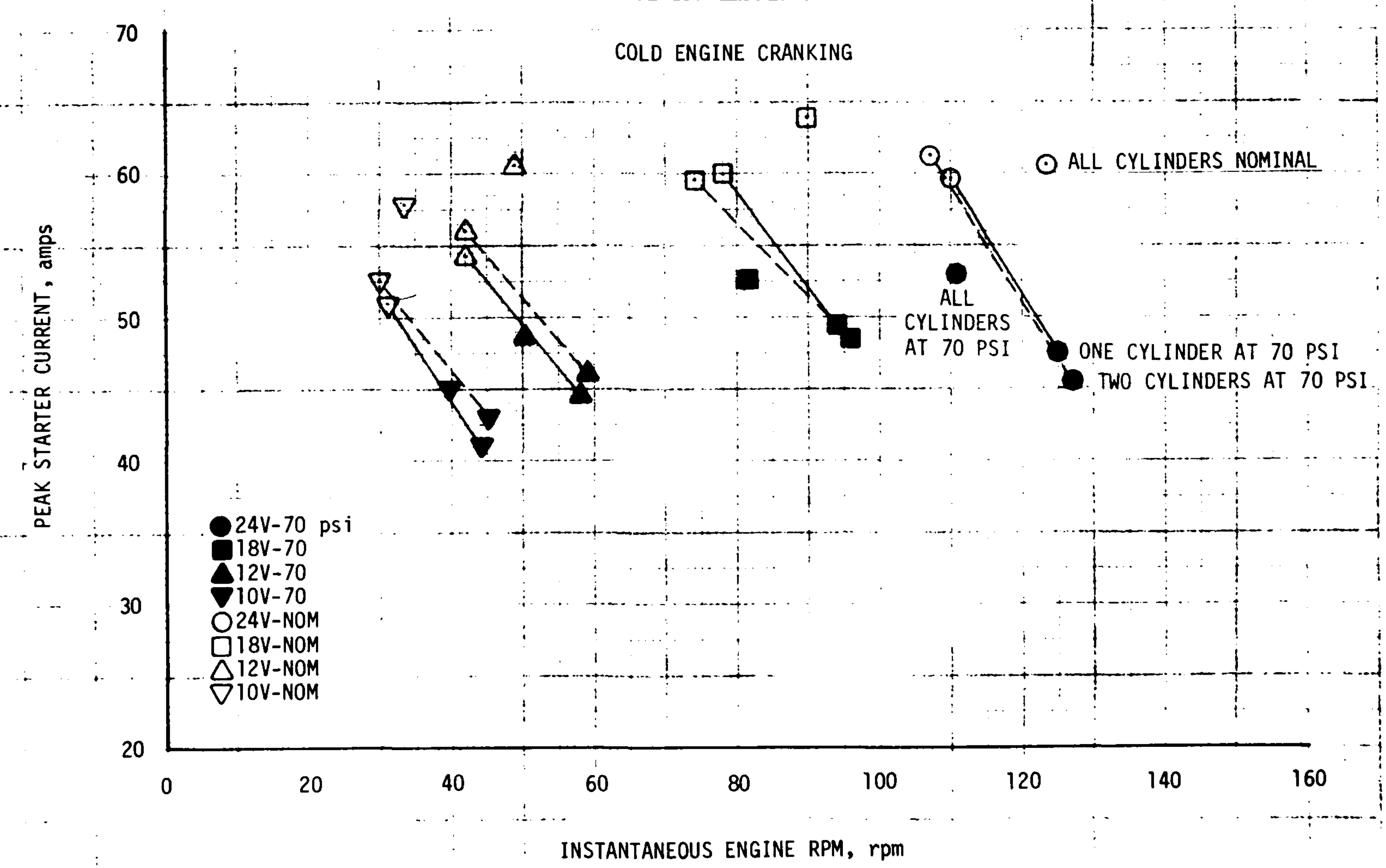


FIGURE 5-5

HOLED-PISTON ENGINE

PEAK STARTER CURRENT

HOT ENGINE CRANKING

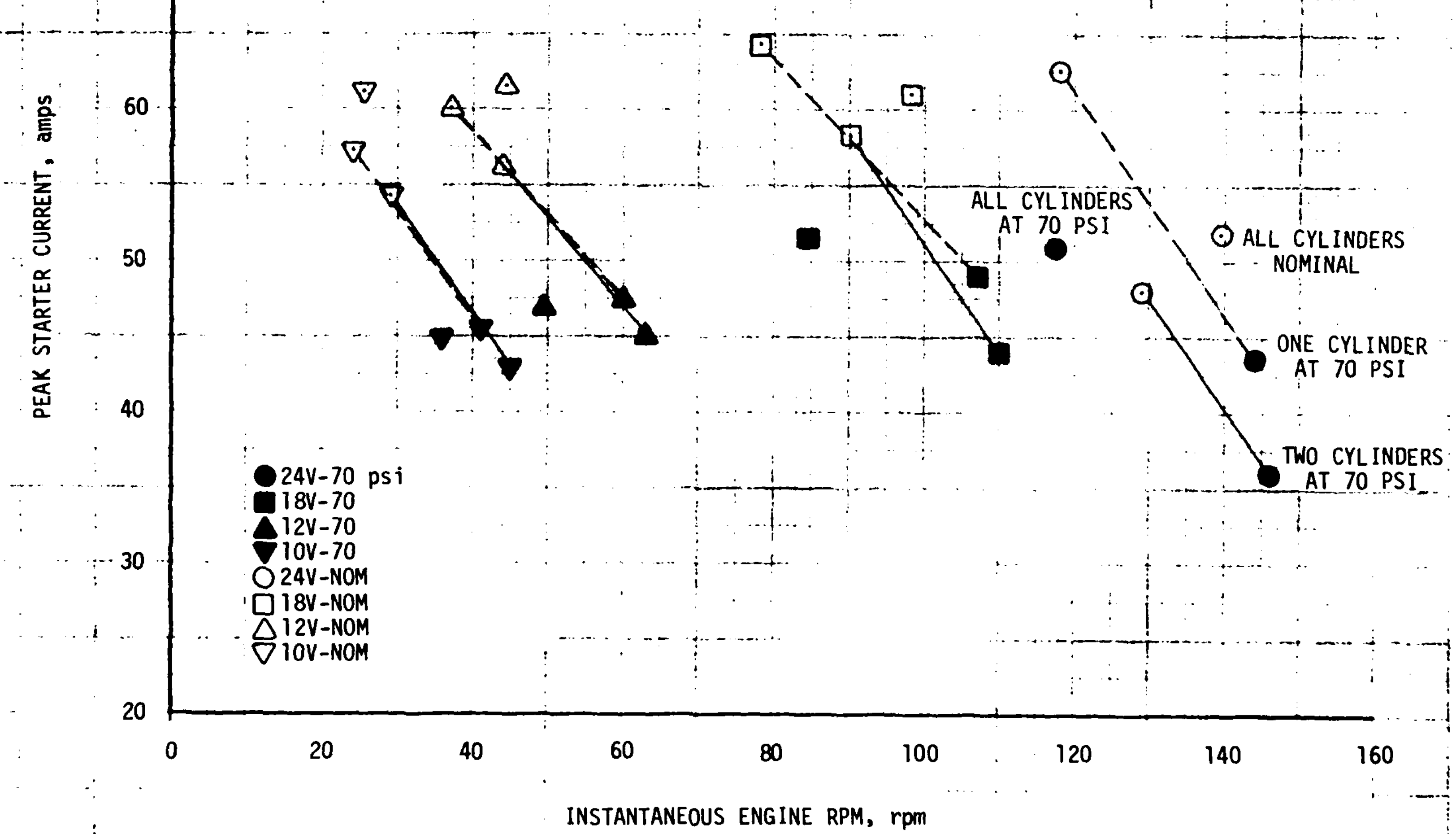
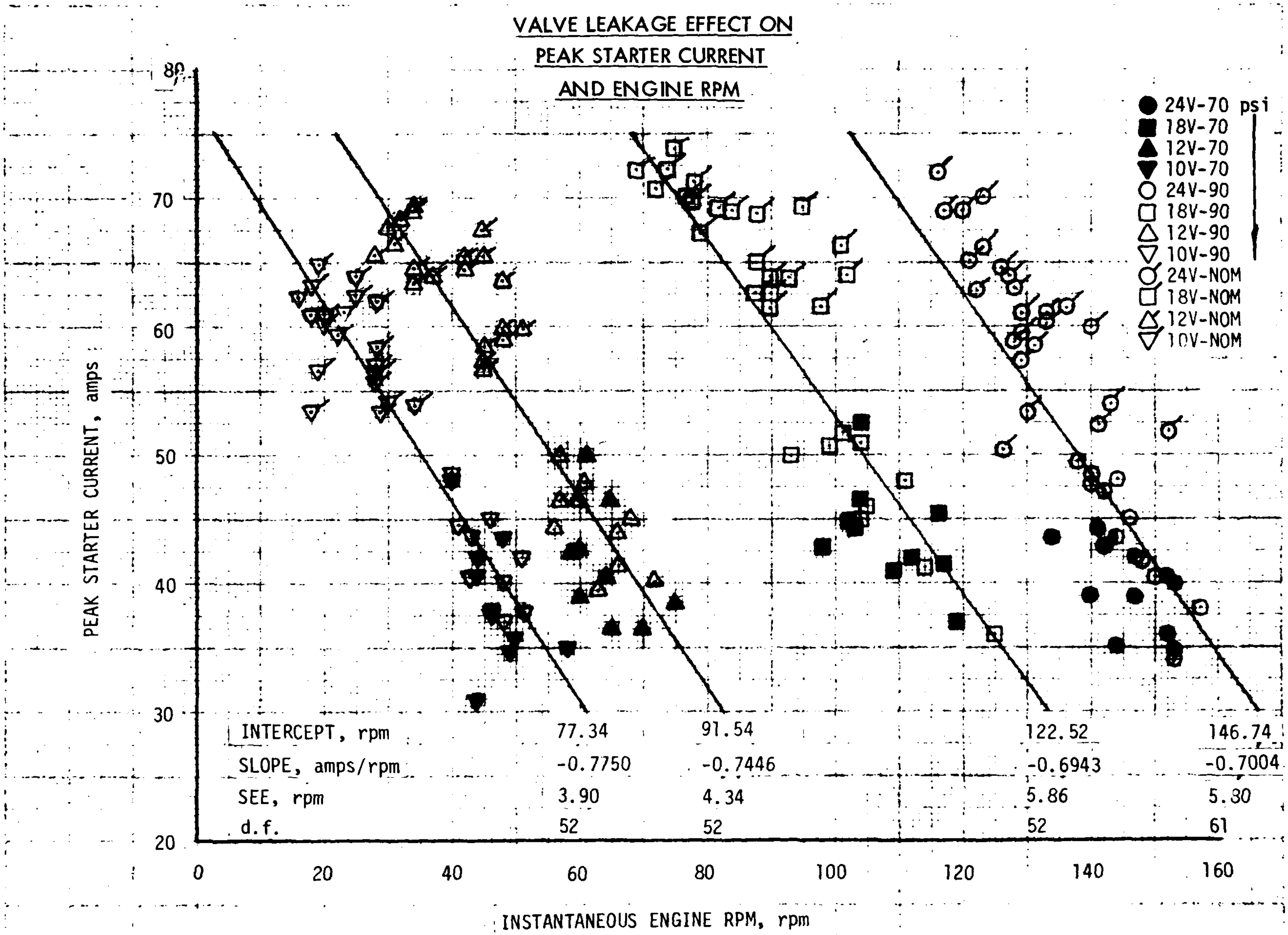


FIGURE 5-6



VALVE LEAKAGE EFFECT ON
PEAK STARTER CURRENT
AND ENGINE RPM
24V-70 psi
18V-70
12V-70
10V-70
24V-90
18V-90
12V-90
10V-90
24V-NOM
18V-NOM
12V-NOM
10V-NOM
PEAK STARTER CURRENT, amps
INSTANTANEOUS ENGINE RPM, rpm
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
INTERCEPT, rpm 77.34 91.54 122.52 146.74
SLOPE, amps/rpm -0.7750 -0.7446 -0.6943 -0.7004
SEE, rpm 3.90 4.34 5.86 5.30
d.f. 52 52 52 61

FIGURE 5-7

STARTER CURRENT RATIO

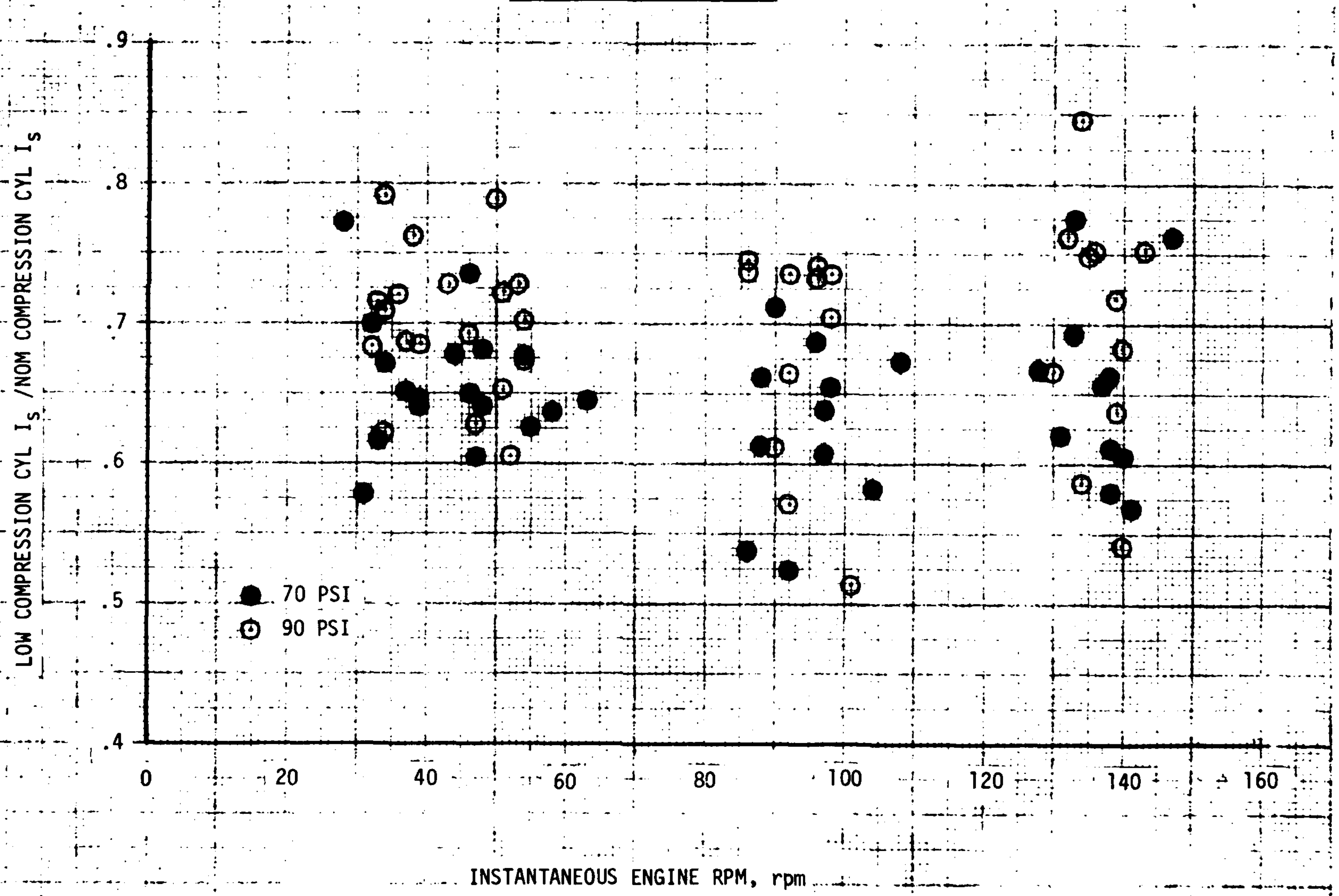


FIGURE 5-8

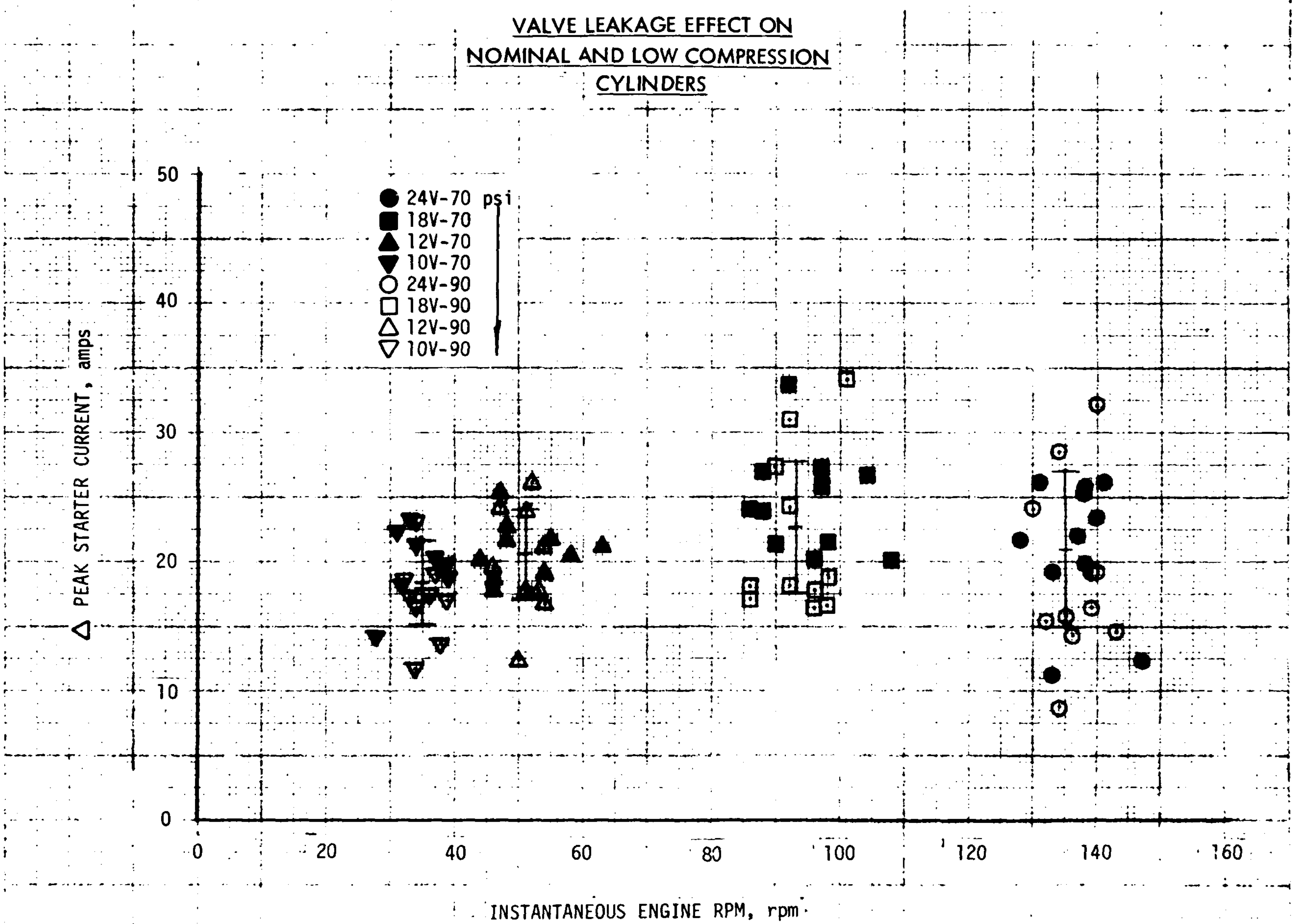

VALVE LEAKAGE EFFECT ON
NOMINAL AND LOW COMPRESSION
CYLINDERS
24V-70 psi
18V-70
12V-70
10V-70
24V-90
18V-90
12V-90
10V-90
Δ PEAK STARTER CURRENT, amps
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
INSTANTANEOUS ENGINE RPM, rpm

FIGURE 5-9

LOW COMPRESSION RPM/HIGH COMPRESSION RPM

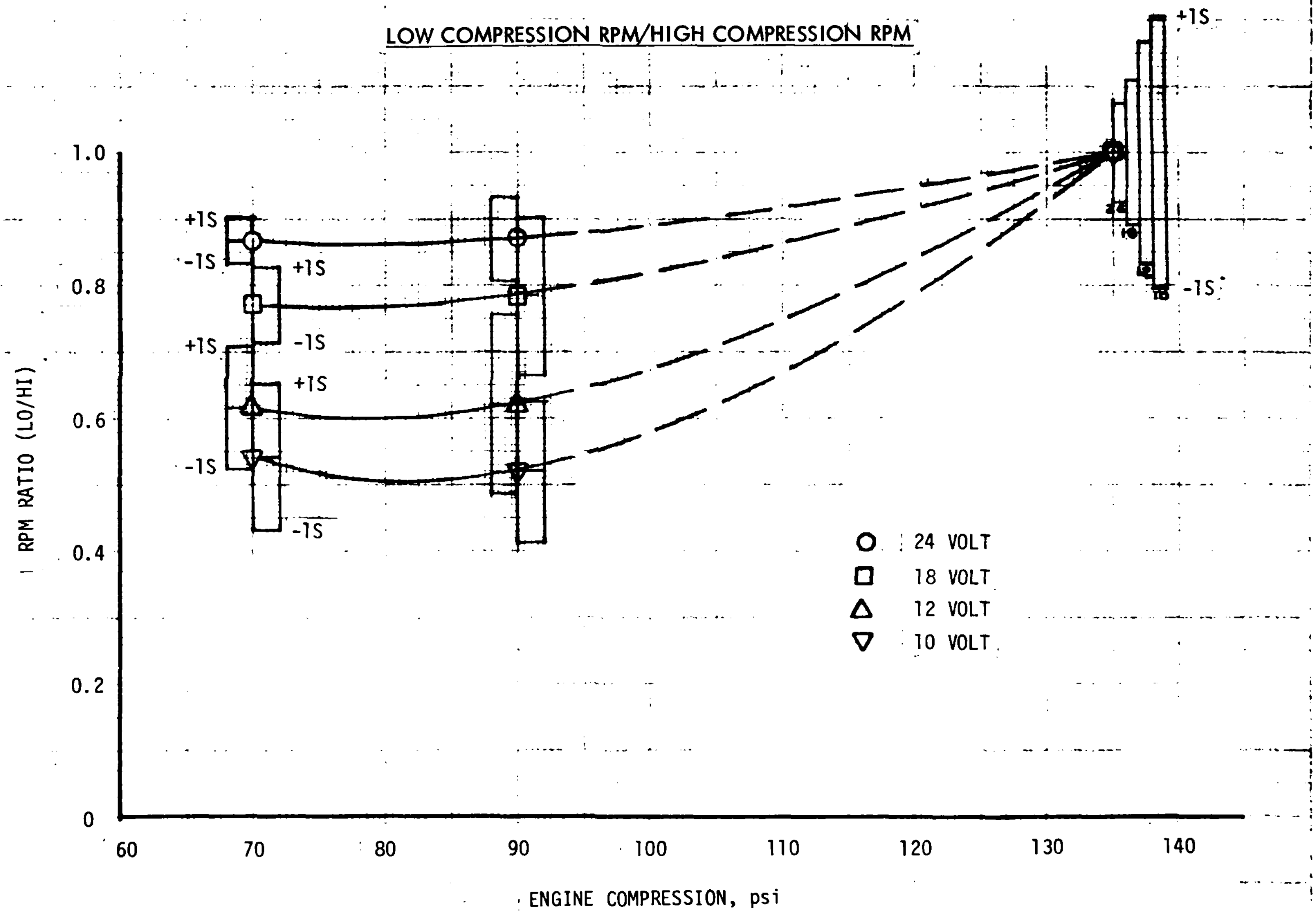


FIGURE 5.10

AVERAGE INTAKE PRESSURE

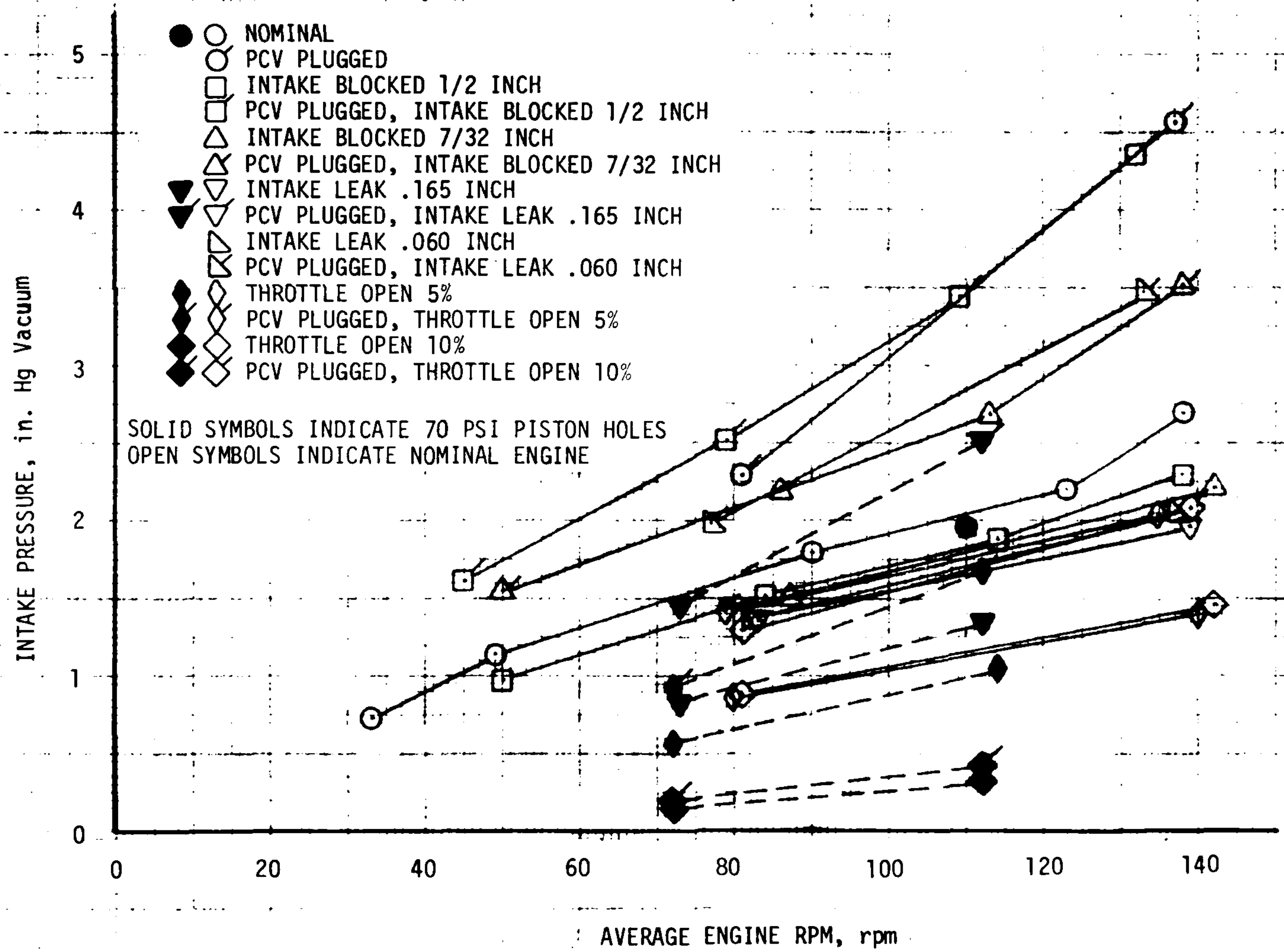
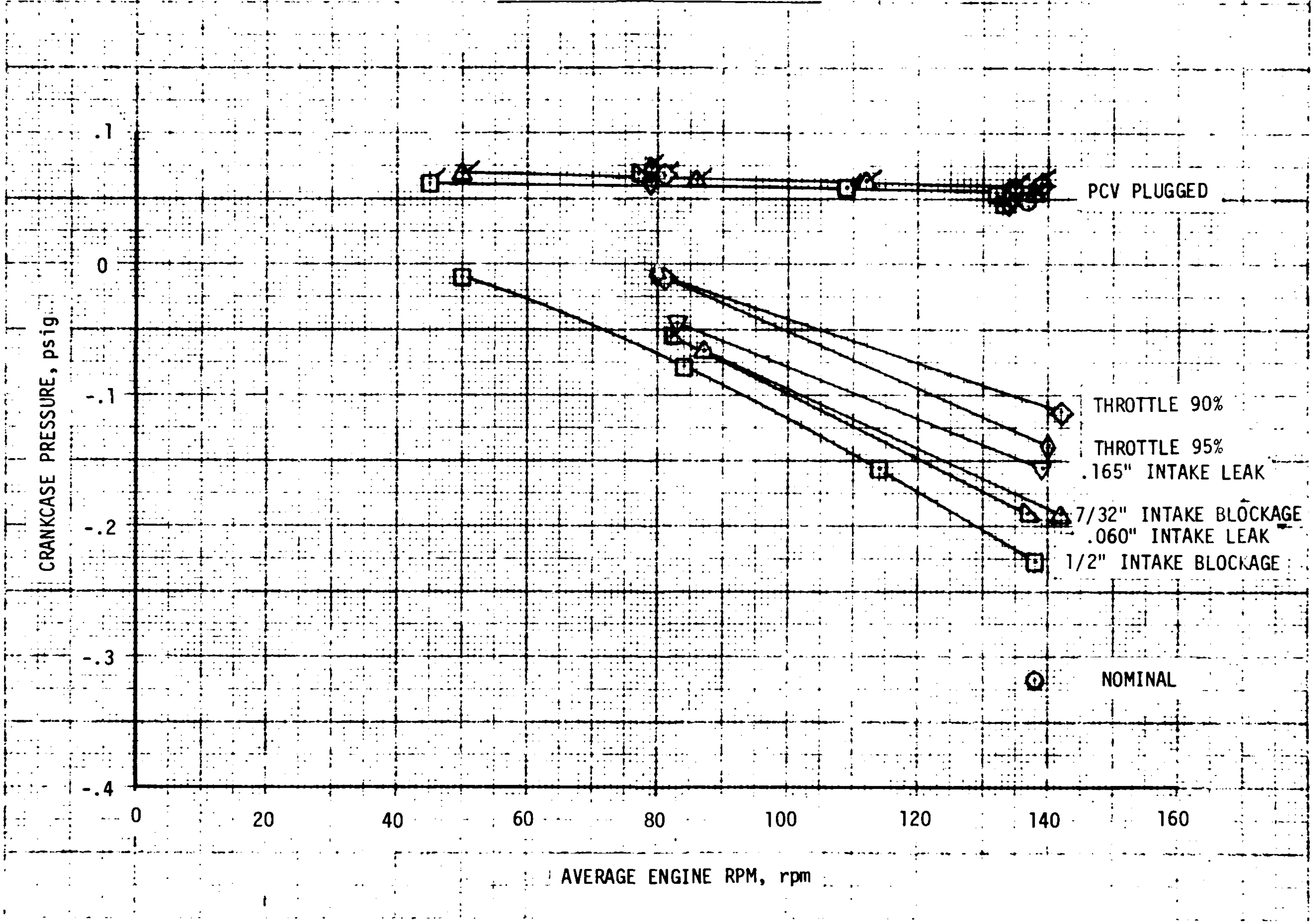


FIGURE 5-11

AVERAGE CRANKCASE PRESSURE



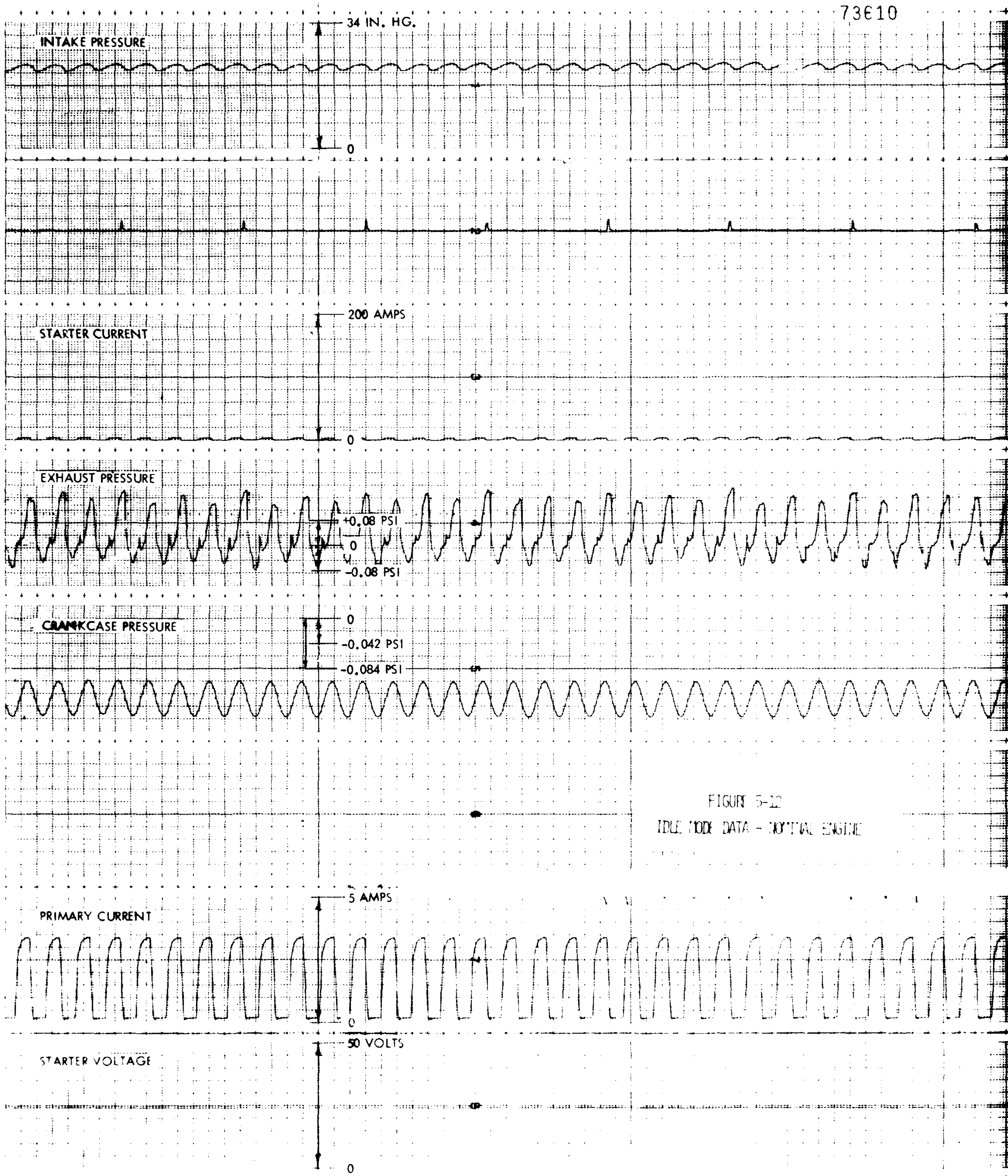
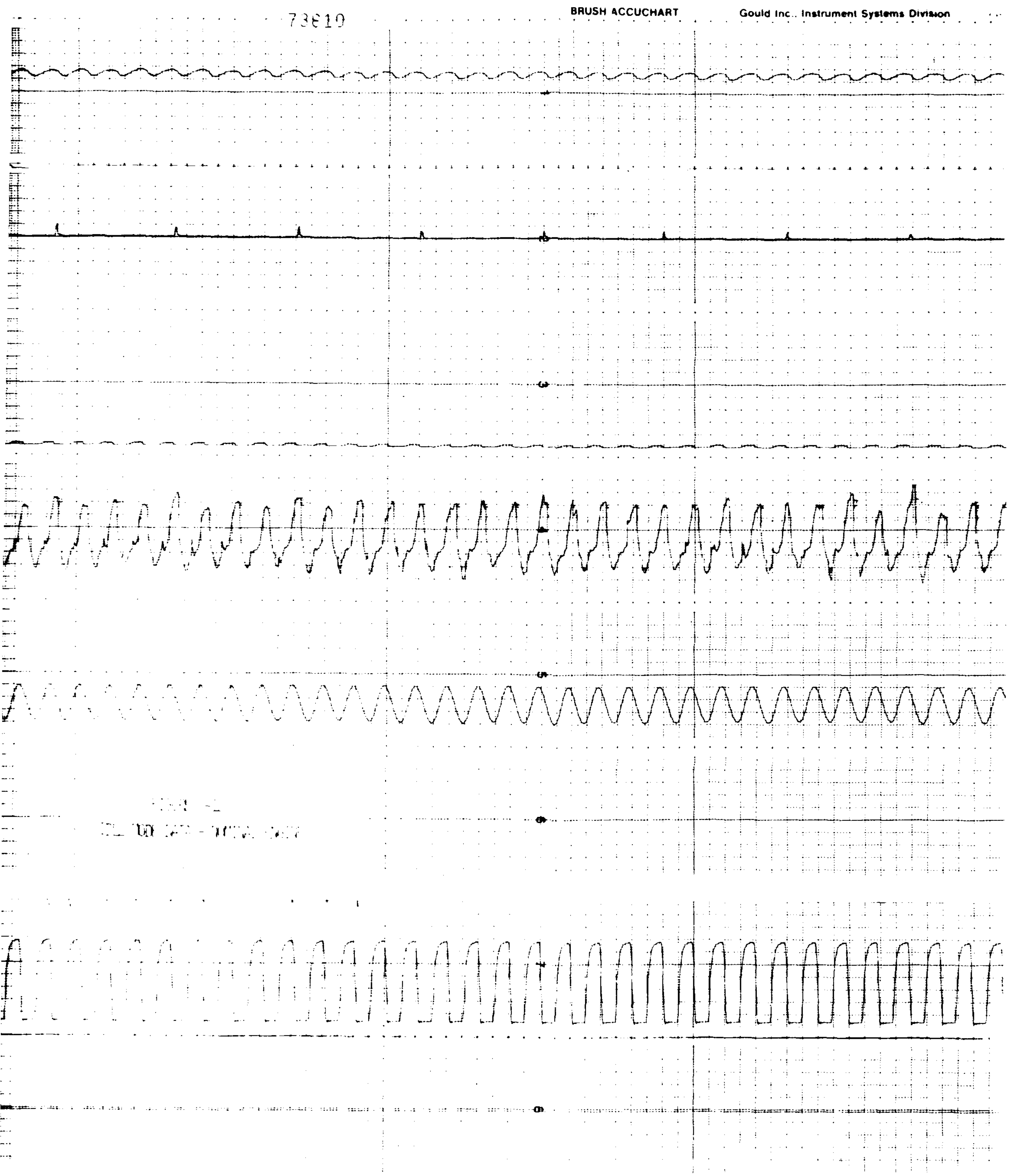


FIGURE 5-12

IDLE MODE DATA - NORMAL ENGINE


73810
BRUSH ACCUCHART
Gould Inc., Instrument Systems Division

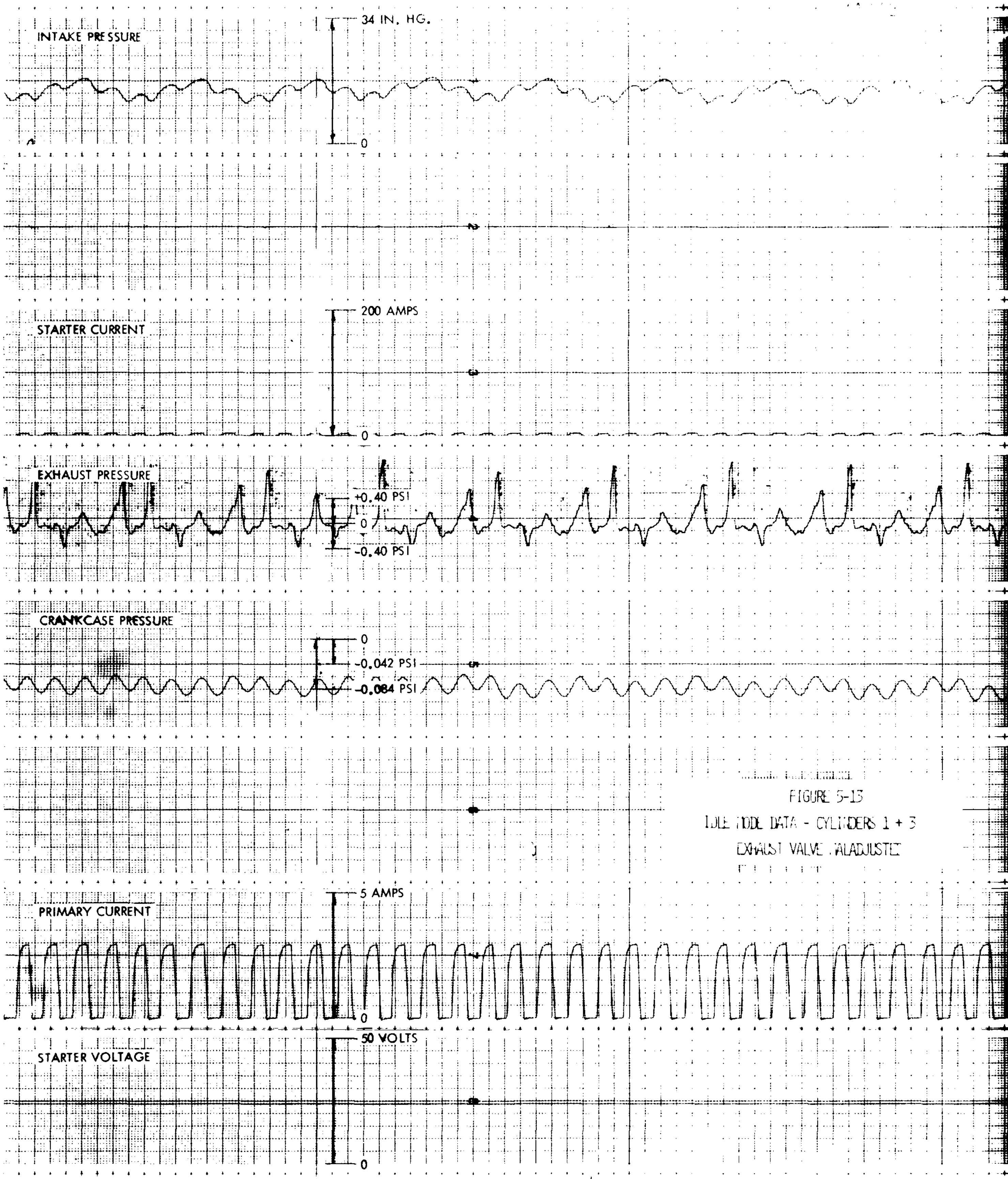


FIGURE 5-13
IDLE MODE DATA - CYLINDERS 1 + 3
EXHAUST VALVE MALADJUSTED

BRUSH ACCUCHART Gould Inc. Instrument Systems Division

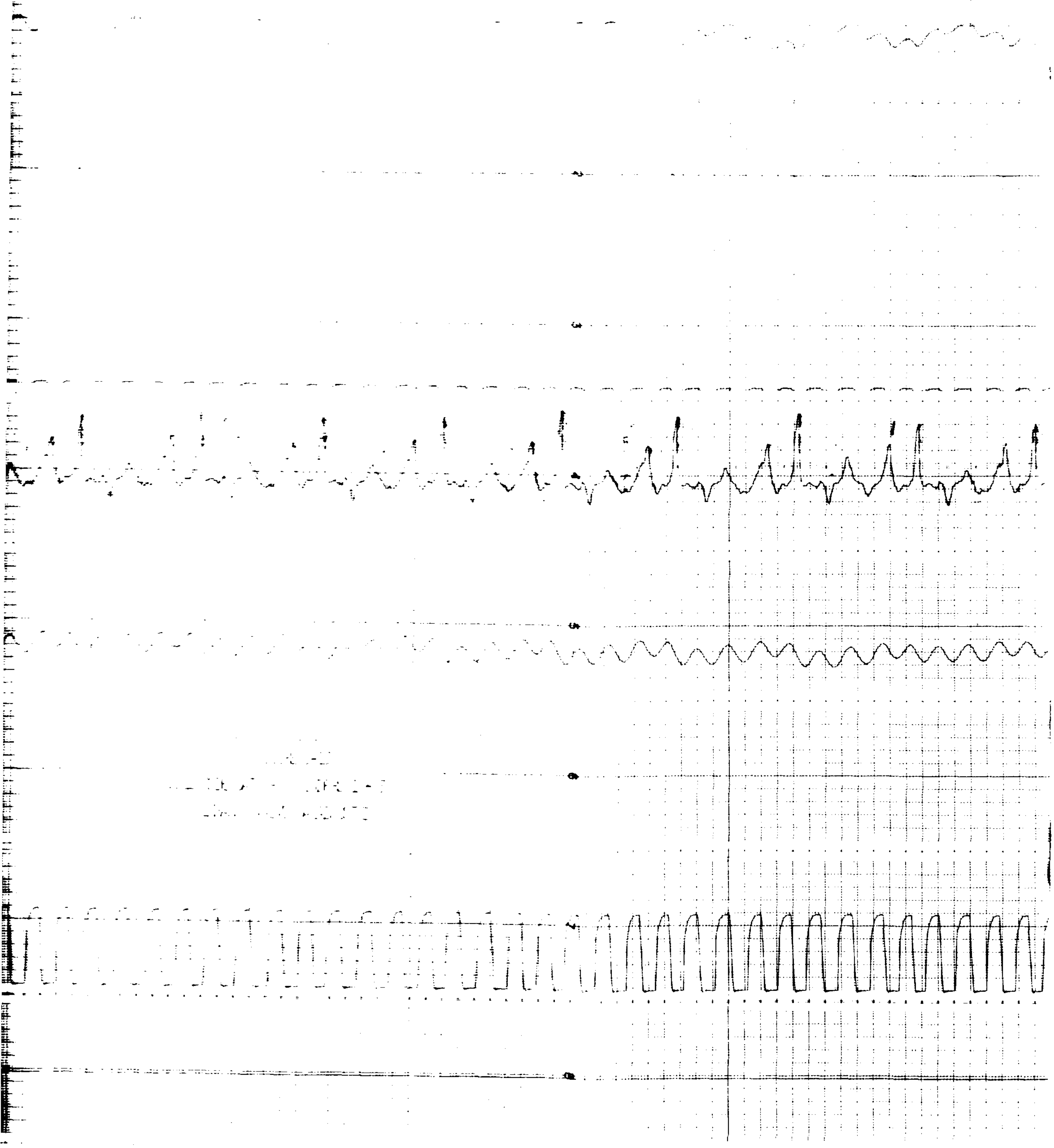


FIGURE 5-14

EFFECT OF VARIATIONS IN TIMING ON HORSEPOWER

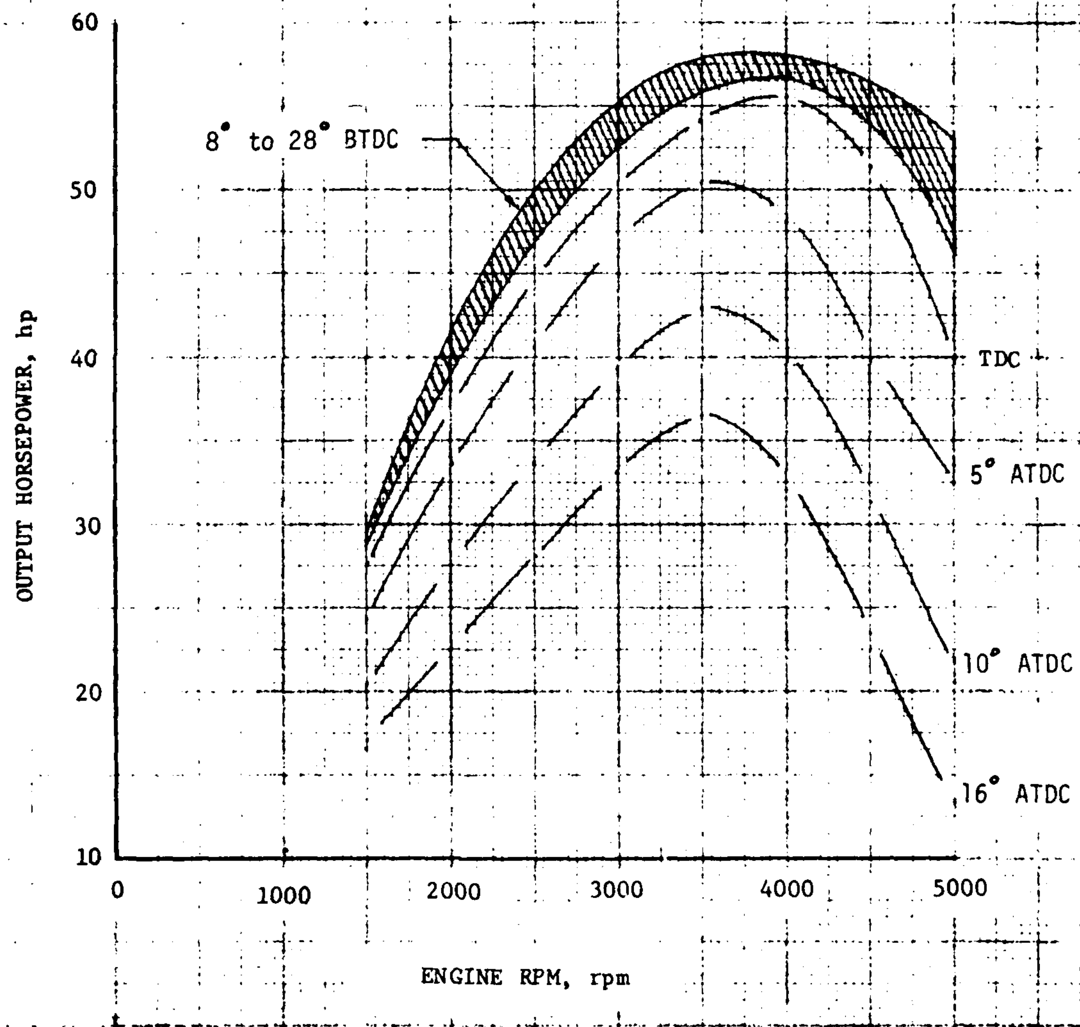


FIGURE 5-15

EFFECT OF RICH MAIN JET ON HORSEPOWER

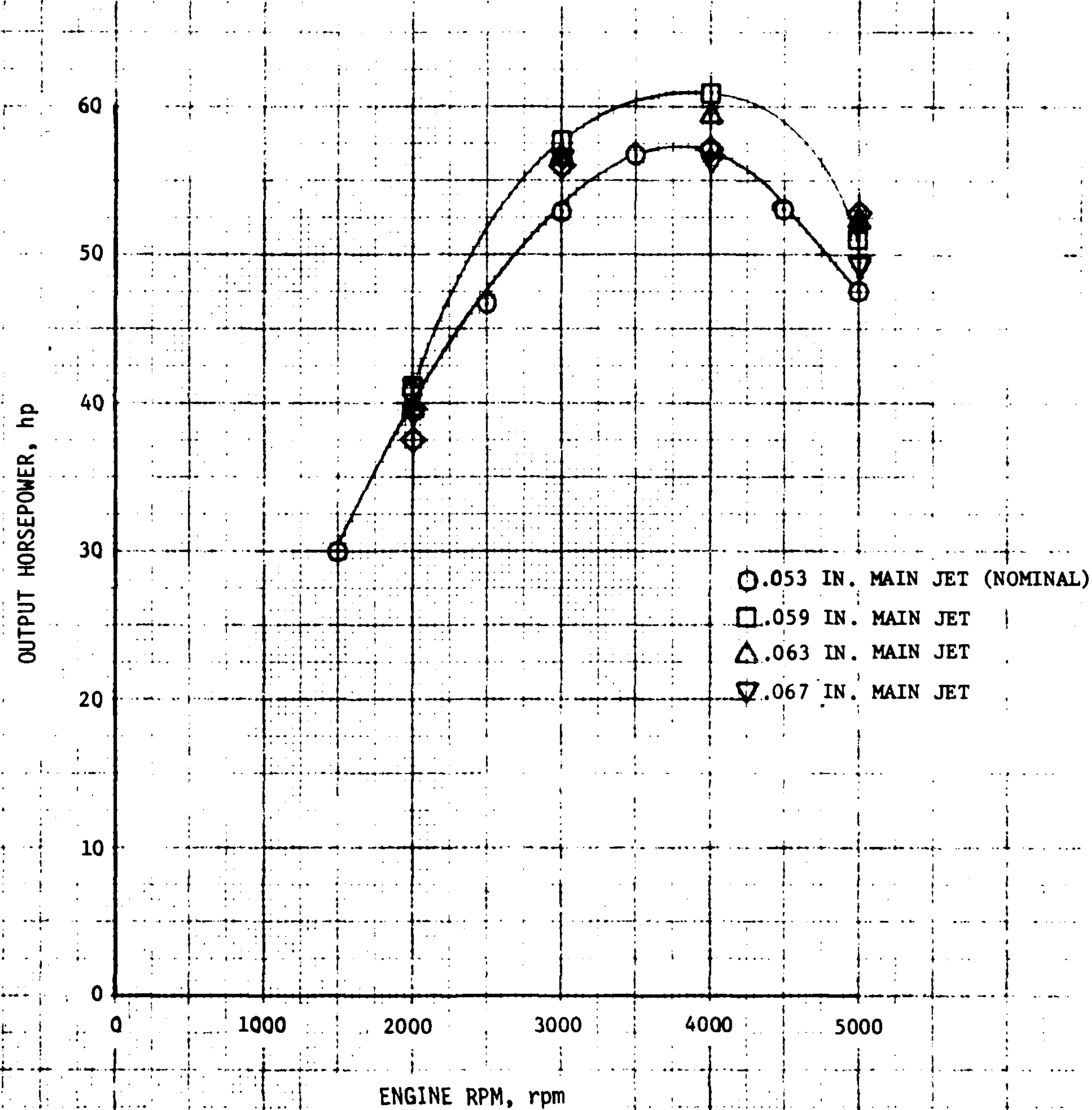


FIGURE 5-16

EFFECT OF LEAN MAIN JET ON HORSEPOWER

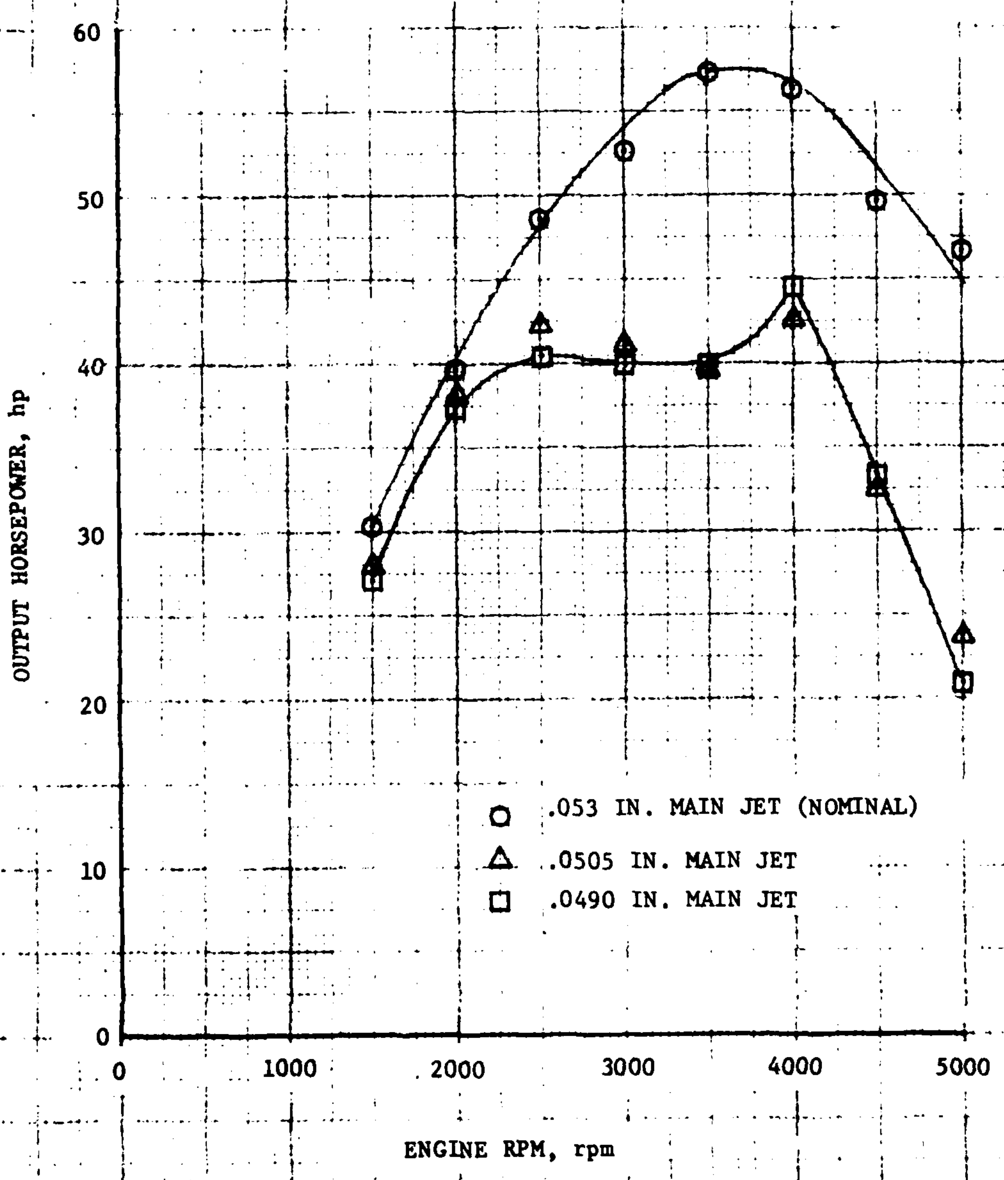


FIGURE 5-17

EFFECT OF VARIATION IN AIR/FUEL RATIO ON HORSEPOWER

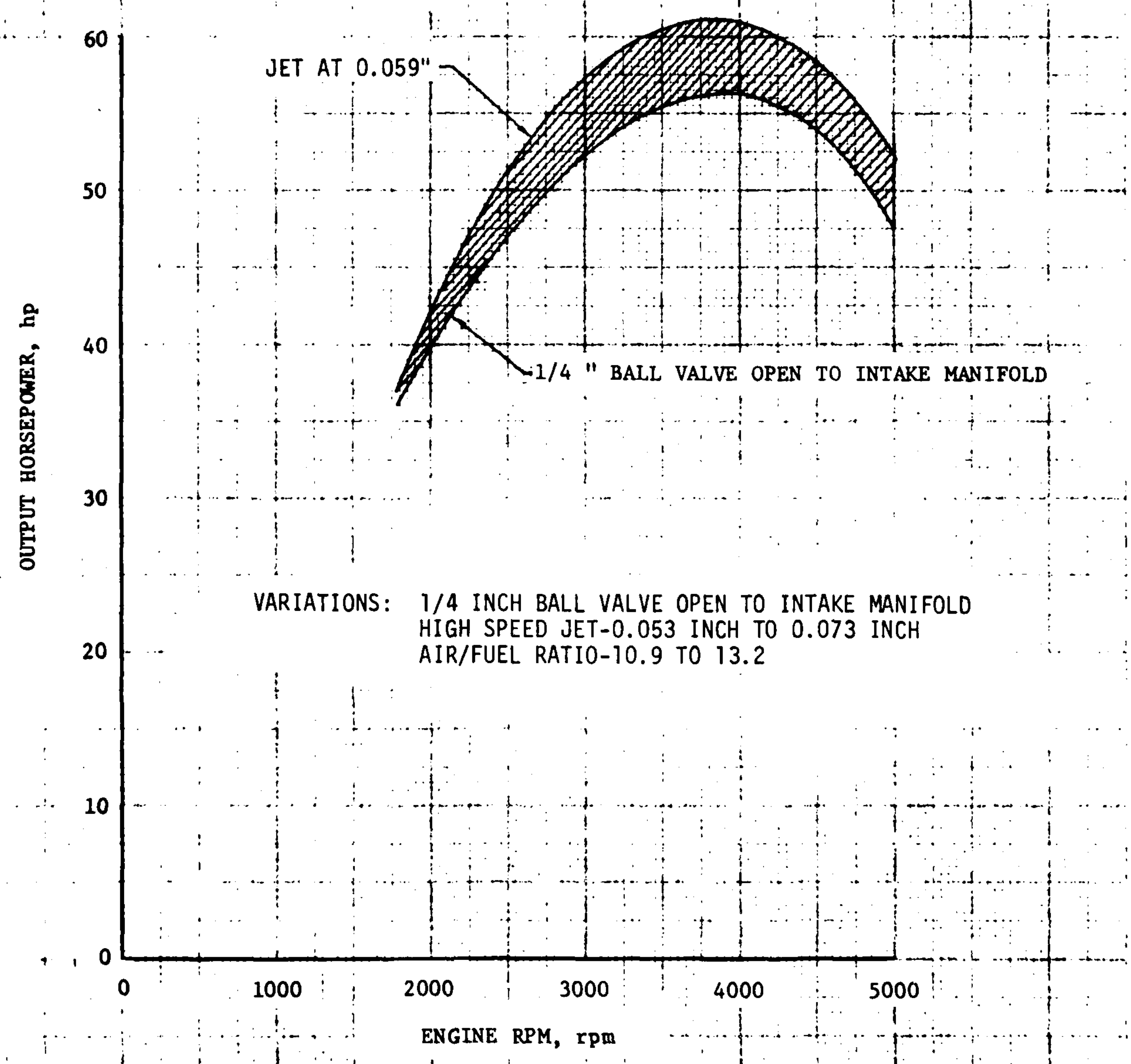


FIGURE 5-18

EFFECT OF MISFIRE ON HORSEPOWER

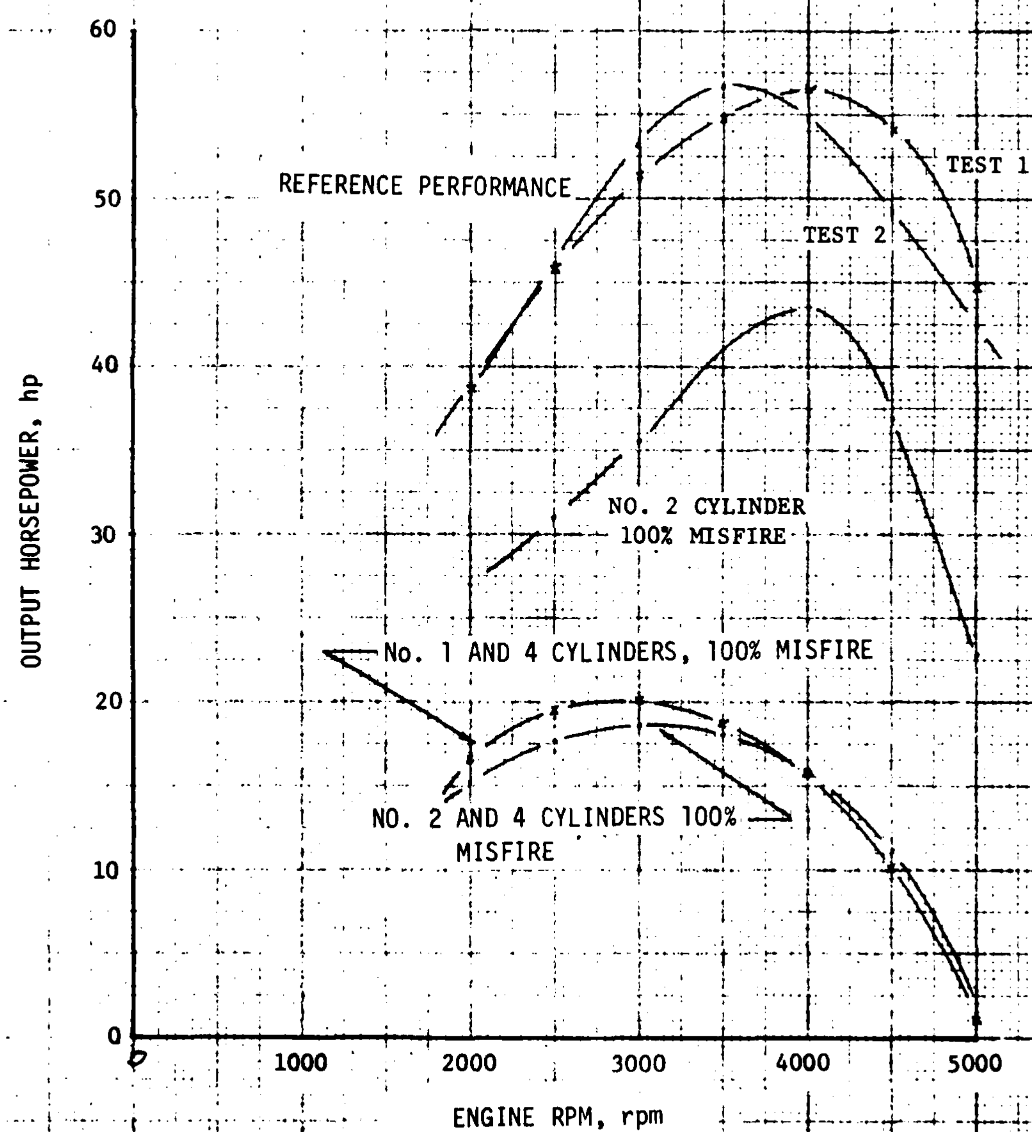


FIGURE 5-19

EFFECT OF PLUG CAP AND POINT GAP ON HORSEPOWER

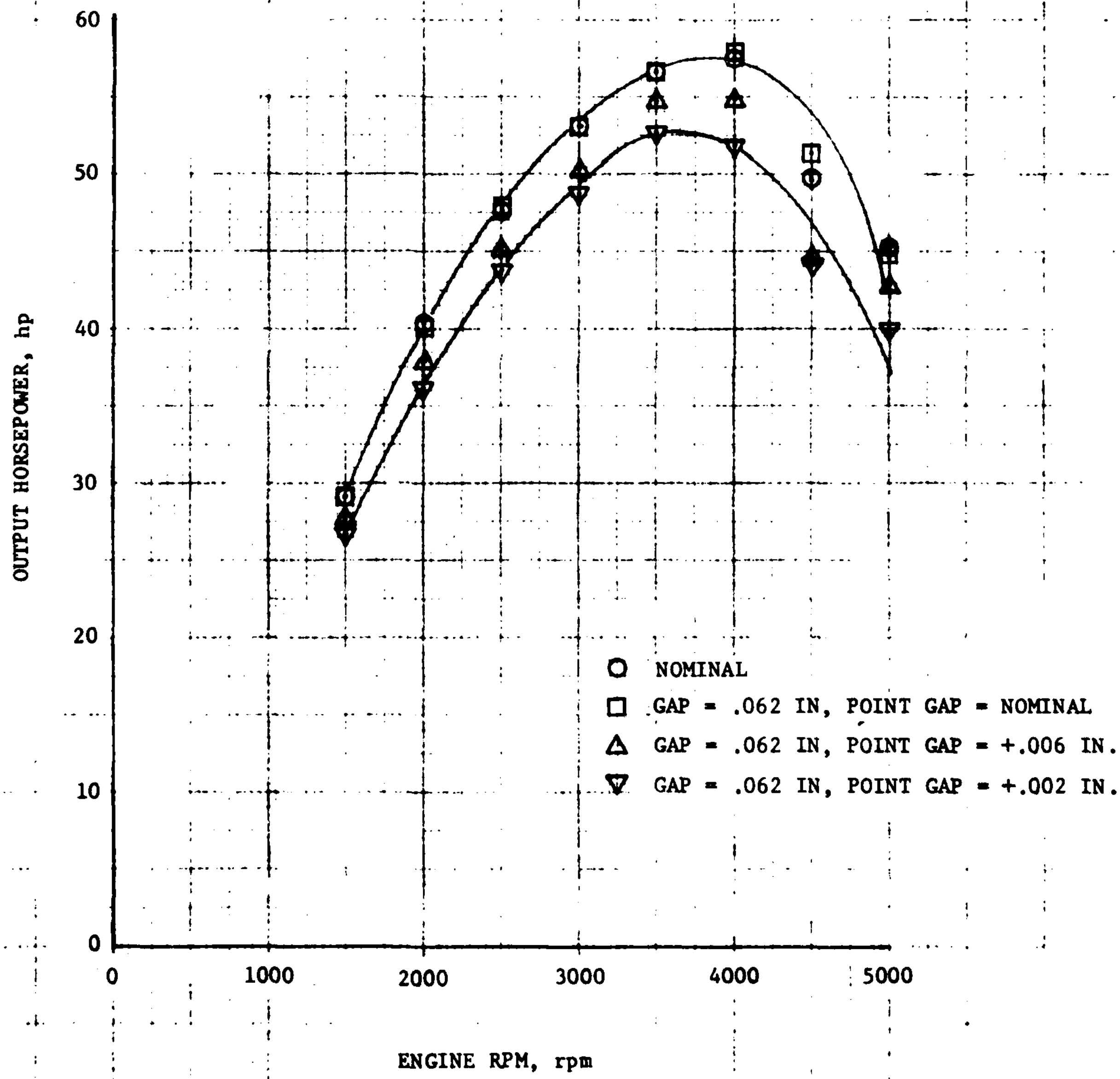


FIGURE 5-20

EFFECT OF VOLTAGE, POINT GAP, AND PLUG GAP ON HORSEPOWER

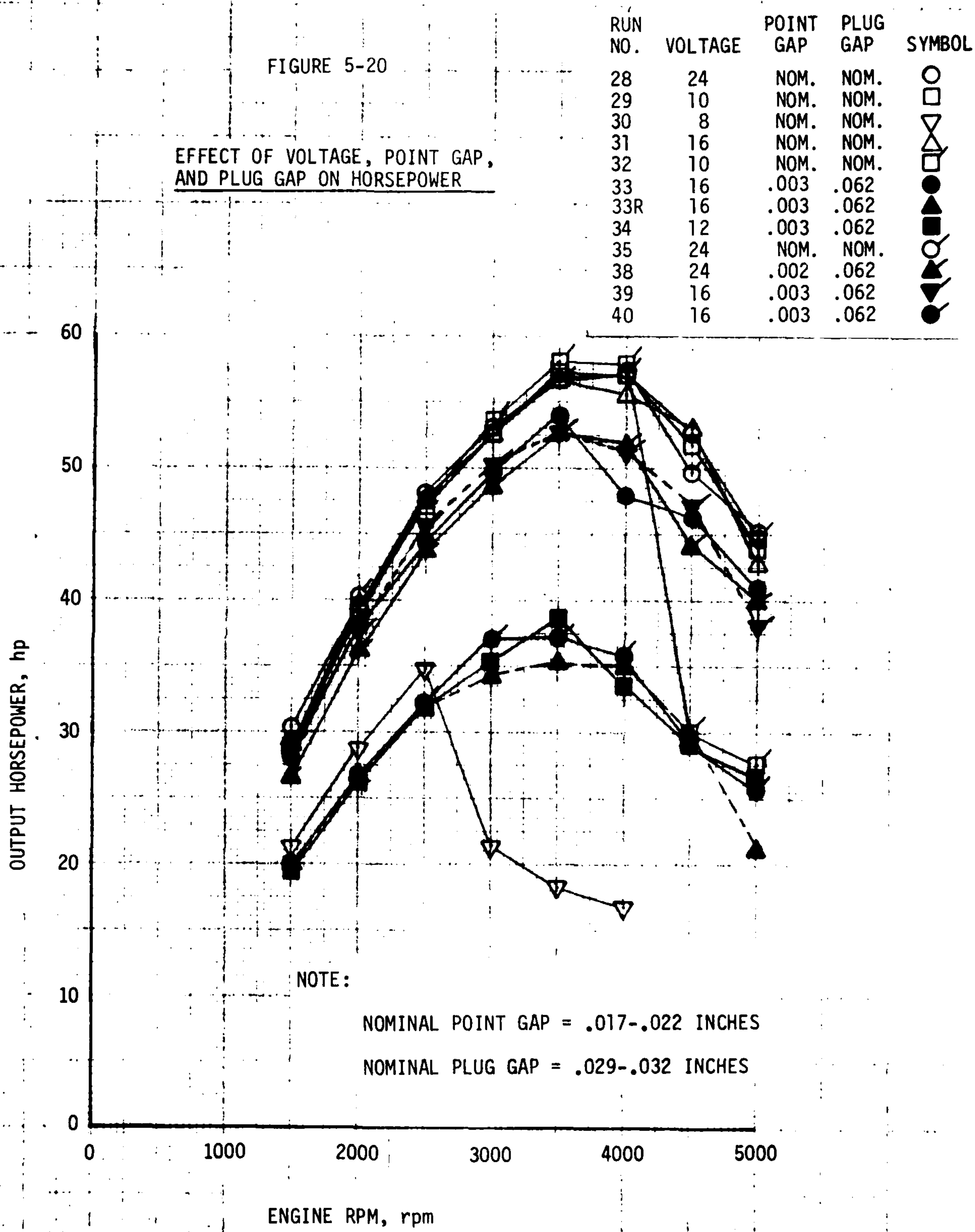
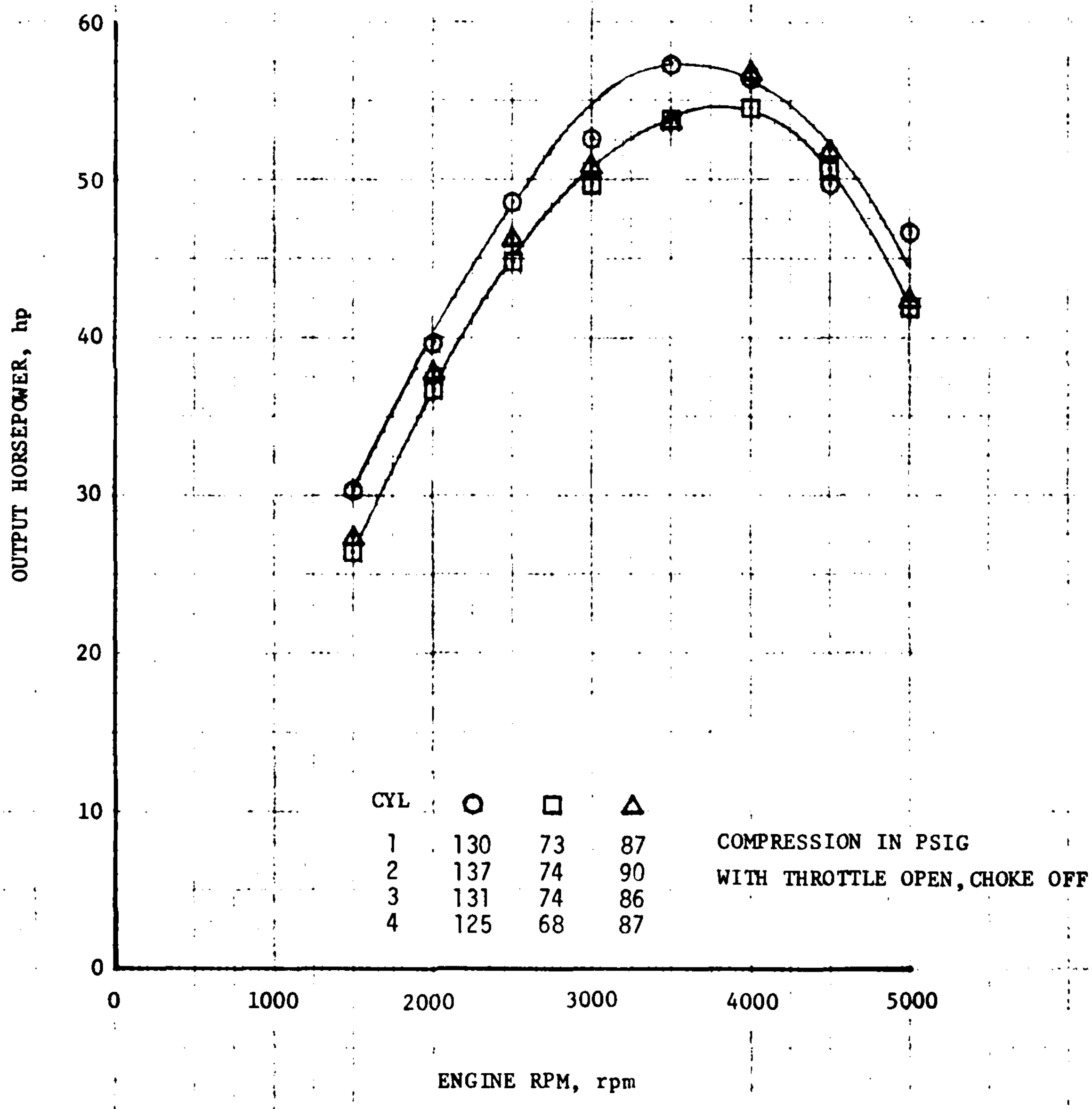


FIGURE 5-21

EFFECT OF LOW COMPRESSION ON HORSEPOWER



IGURE 5-22

TIMING, MISFIRE AND A/F RATIO
PEAK HORSEPOWER
VERSUS
FULL THROTTLE INTERRUPTER RMP

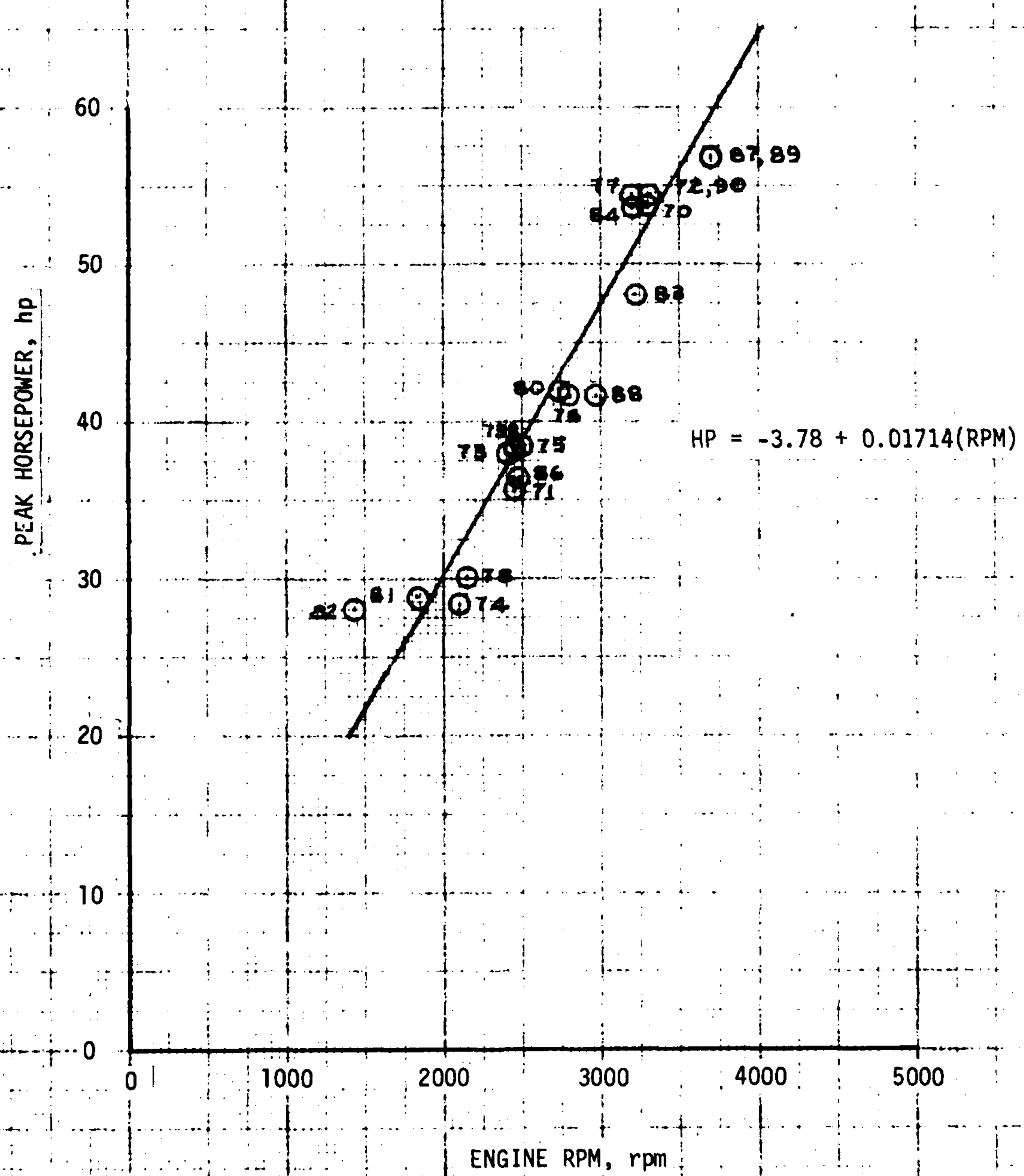


FIGURE 5-23

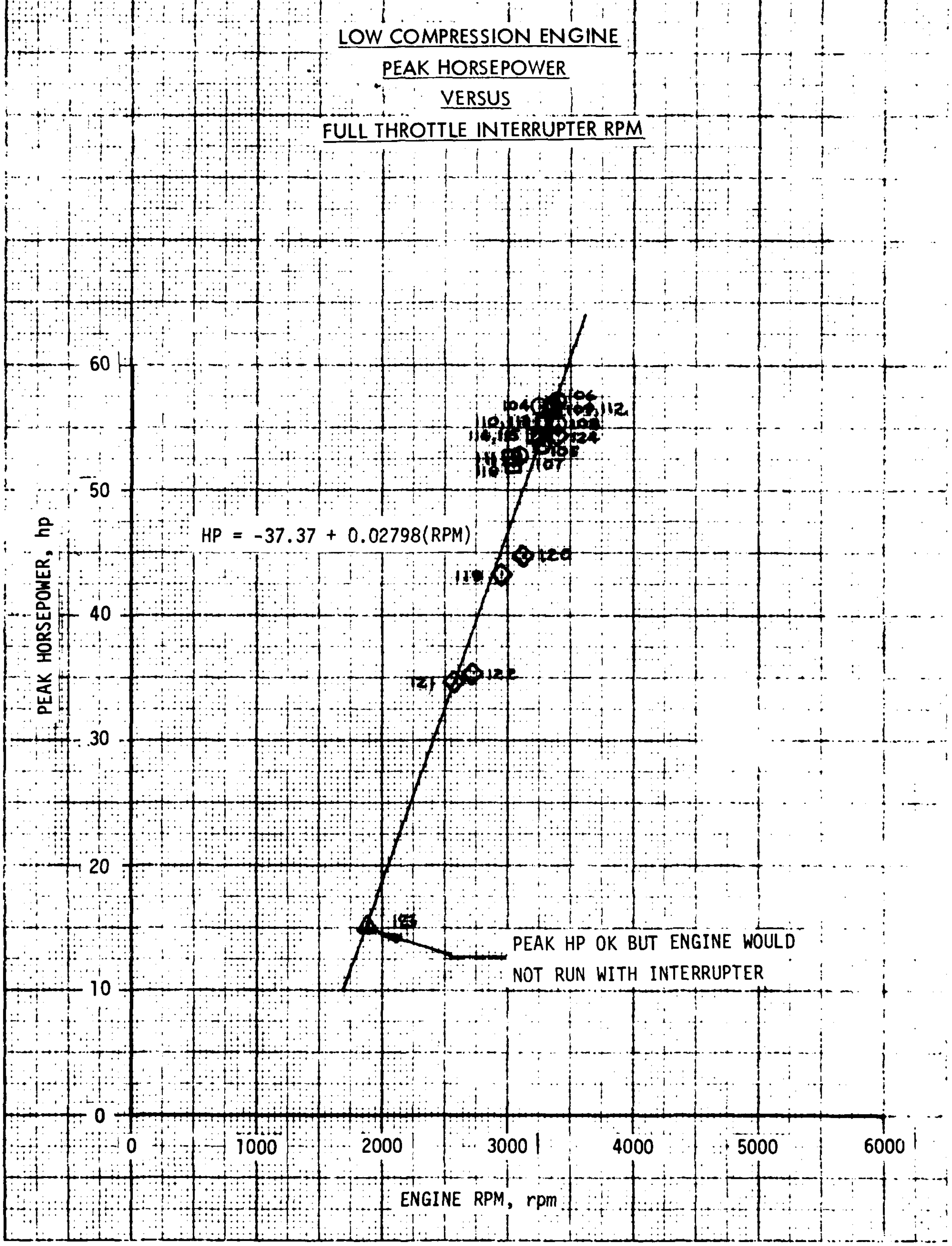

LOW COMPRESSION ENGINE
PEAK HORSEPOWER
VERSUS
FULL THROTTLE INTERRUPTER RPM
HP = -37.37 + 0.02798(RPM)
PEAK HP OK BUT ENGINE WOULD
NOT RUN WITH INTERRUPTER
PEAK HORSEPOWER, hp
ENGINE RPM, rpm
0
10
20
30
40
50
60
1000
2000
3000
4000
5000
6000

FIGURE 5-24

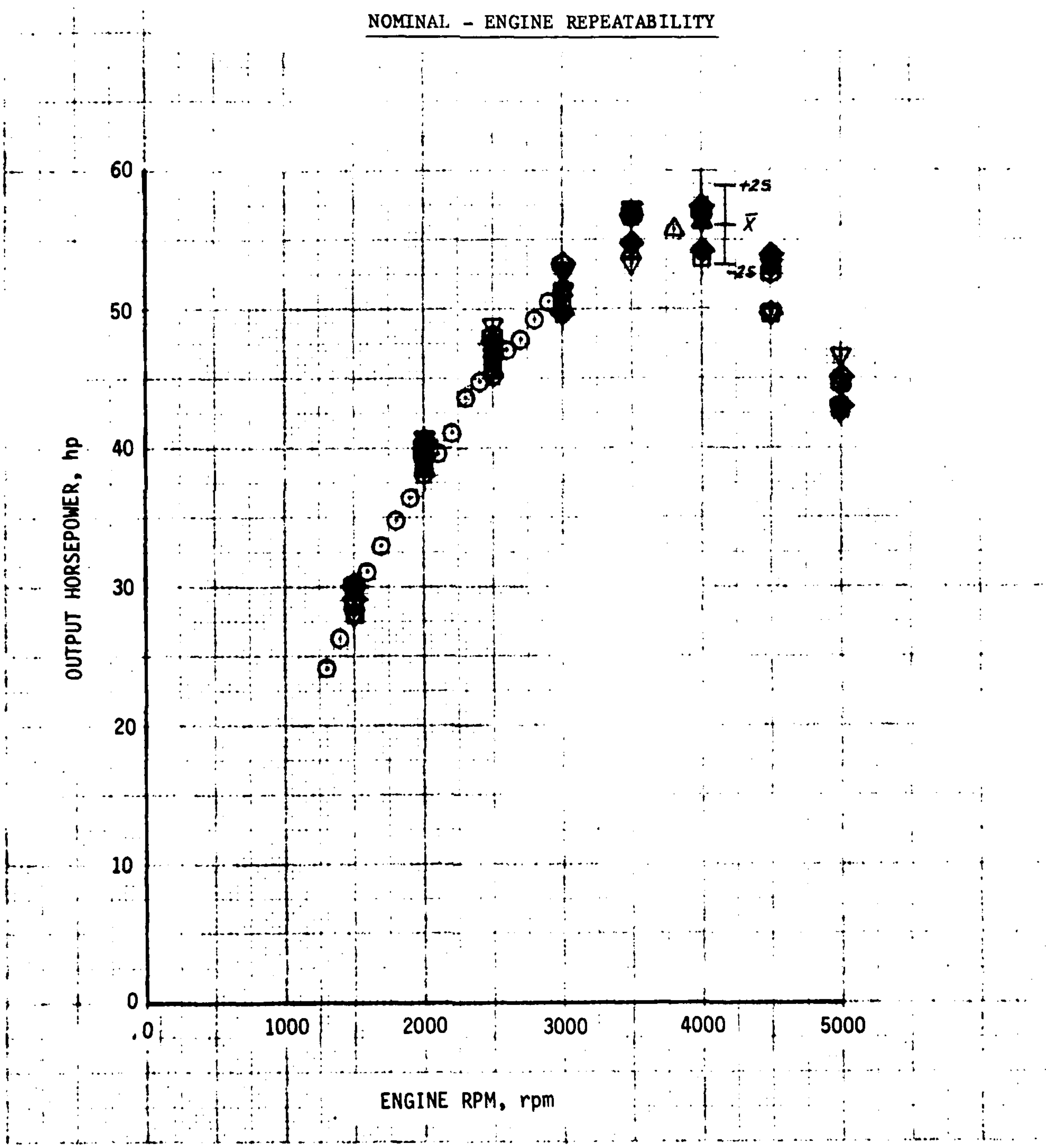

NOMINAL - ENGINE REPEATABILITY
60
50
40
30
20
10
0
OUTPUT HORSEPOWER, hp
0
1000
2000
3000
4000
5000
ENGINE RPM, rpm
+2S
$\bar{X}$
-2S

FIGURE 5-25

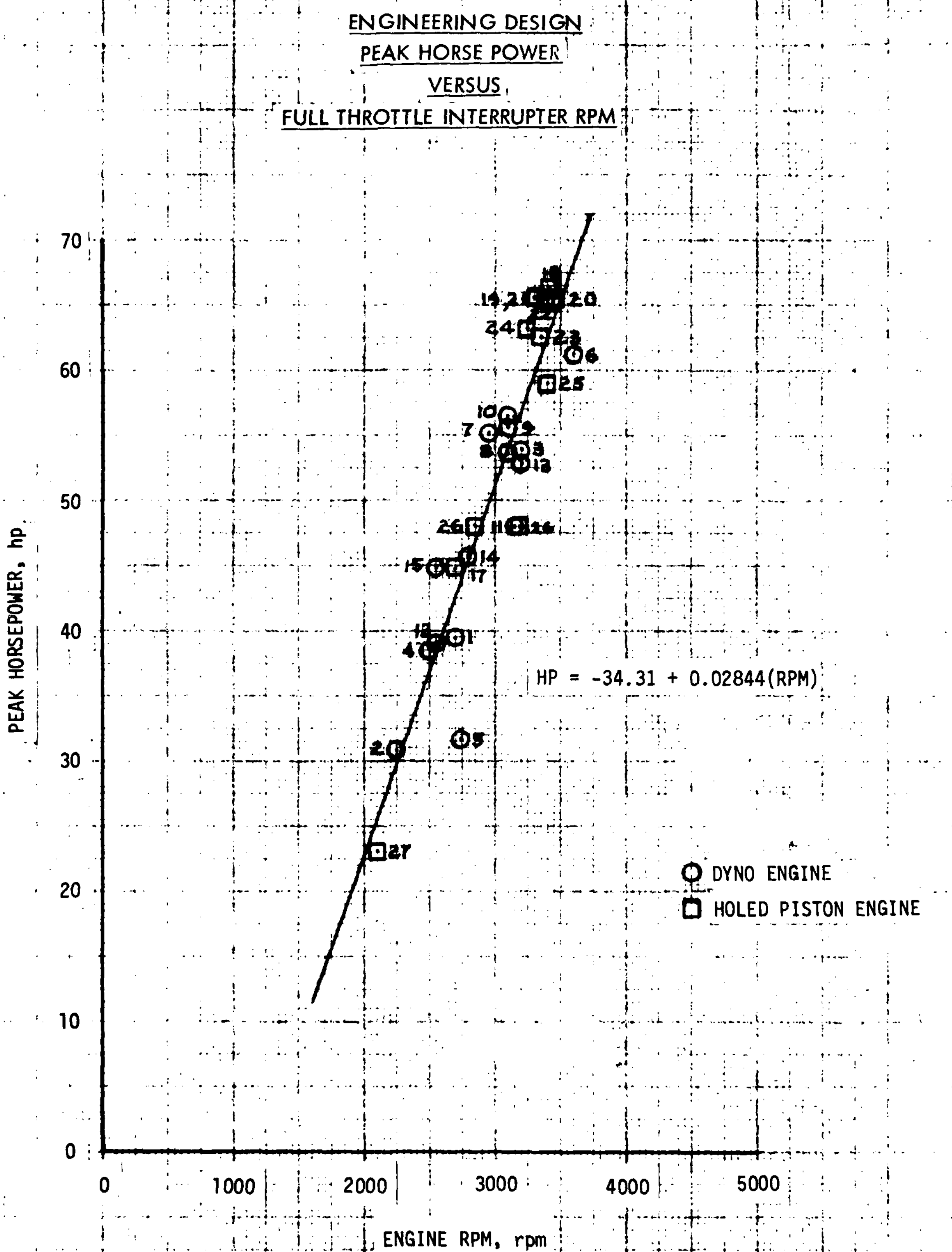

ENGINEERING DESIGN
PEAK HORSE POWER
VERSUS
FULL THROTTLE INTERRUPTER RPM
PEAK HORSEPOWER, hp
ENGINE RPM, rpm
HP = -34.31 + 0.02844(RPM)
DYNO ENGINE
HOLED PISTON ENGINE
0
10
20
30
40
50
60
70
0
1000
2000
3000
4000
5000

FIGURE 5-26

PEAK HORSEPOWER
VERSUS
INTERRUPTER RPM

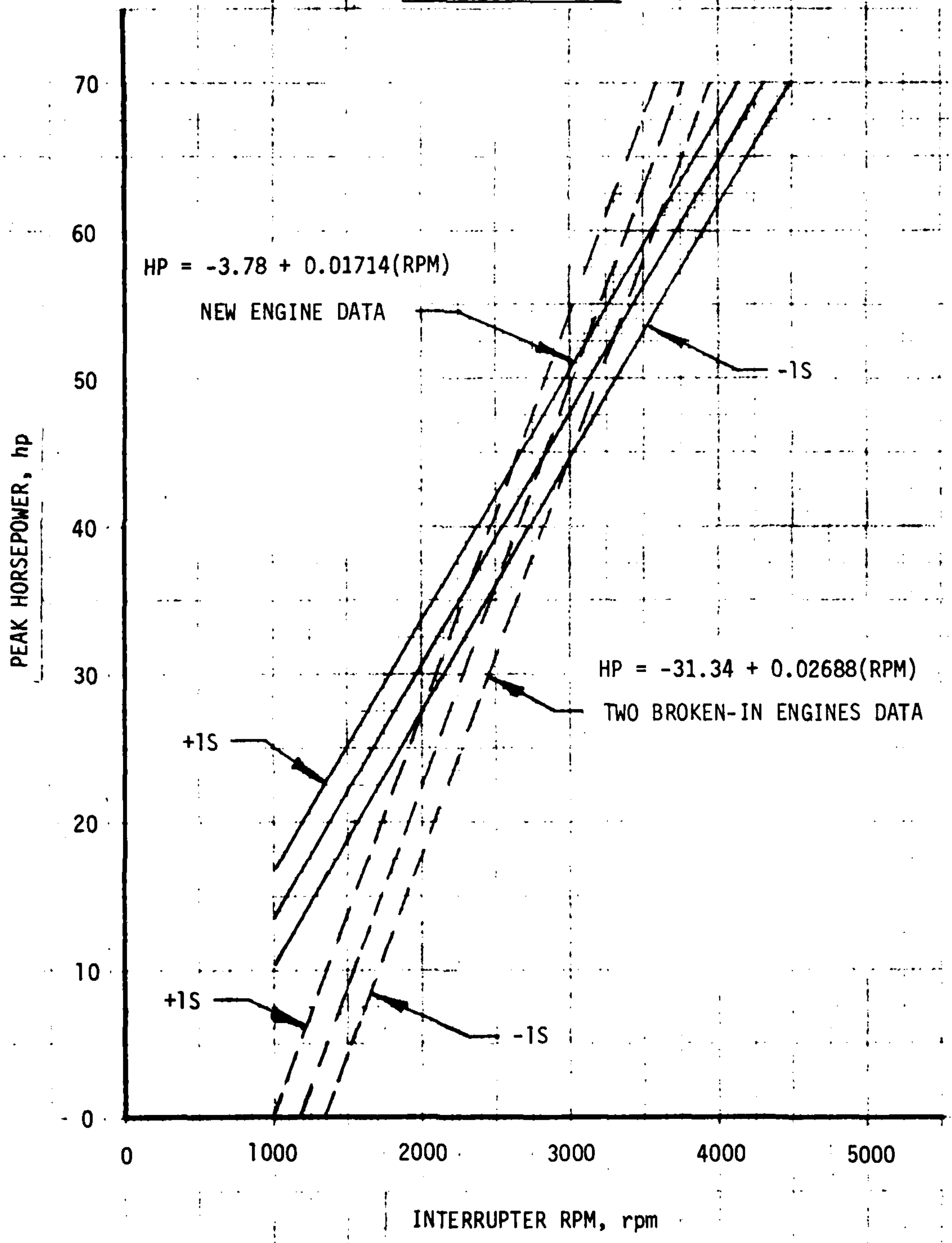


FIGURE 5-27

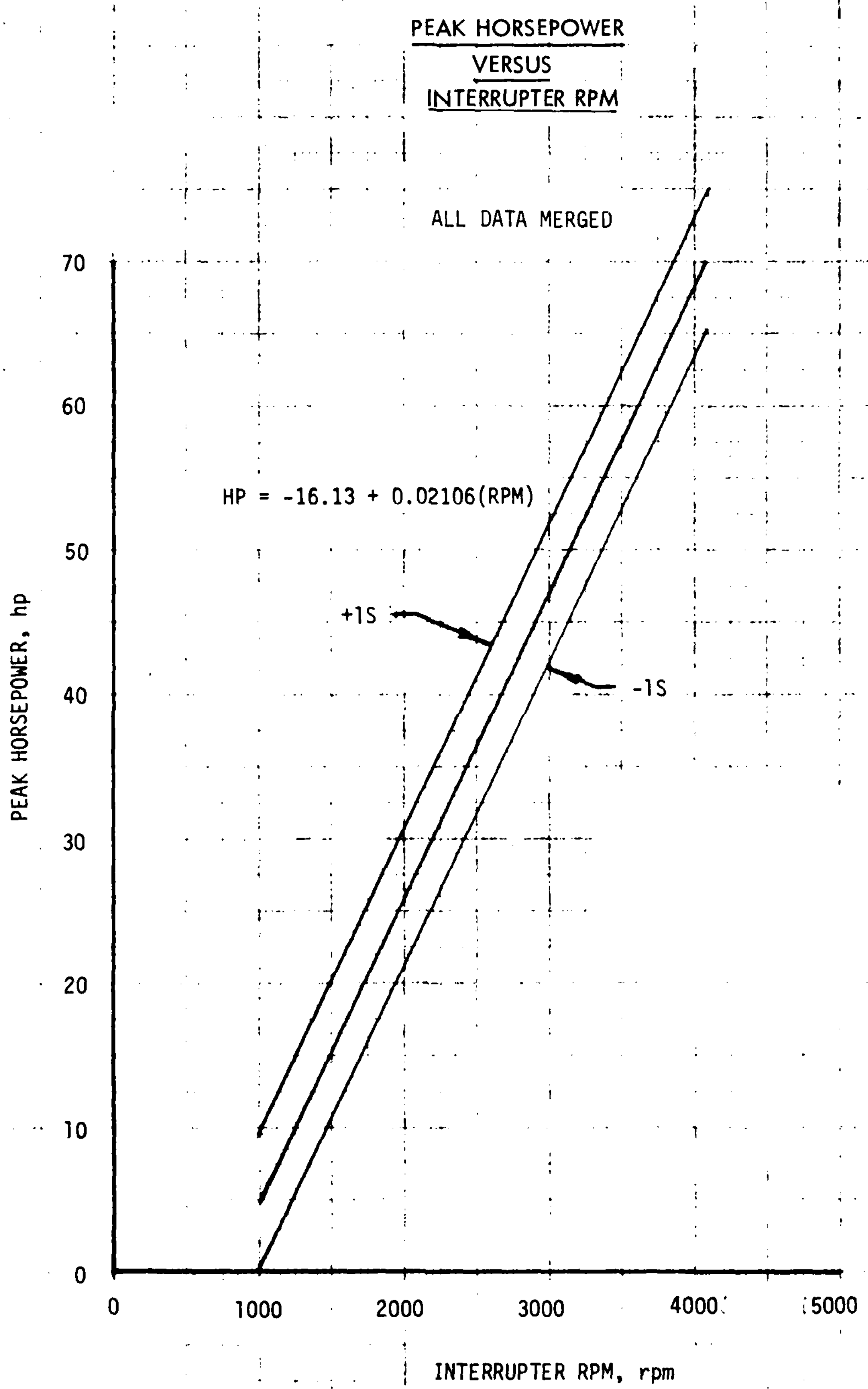

PEAK HORSEPOWER
VERSUS
INTERRUPTER RPM
ALL DATA MERGED
HP = -16.13 + 0.02106(RPM)
+1S
-1S
PEAK HORSEPOWER, hp
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
INTERRUPTER RPM, rpm

FIGURE 5-28

EFFECT OF OIL TEMPERATURE ON INTERRUPTER RPM

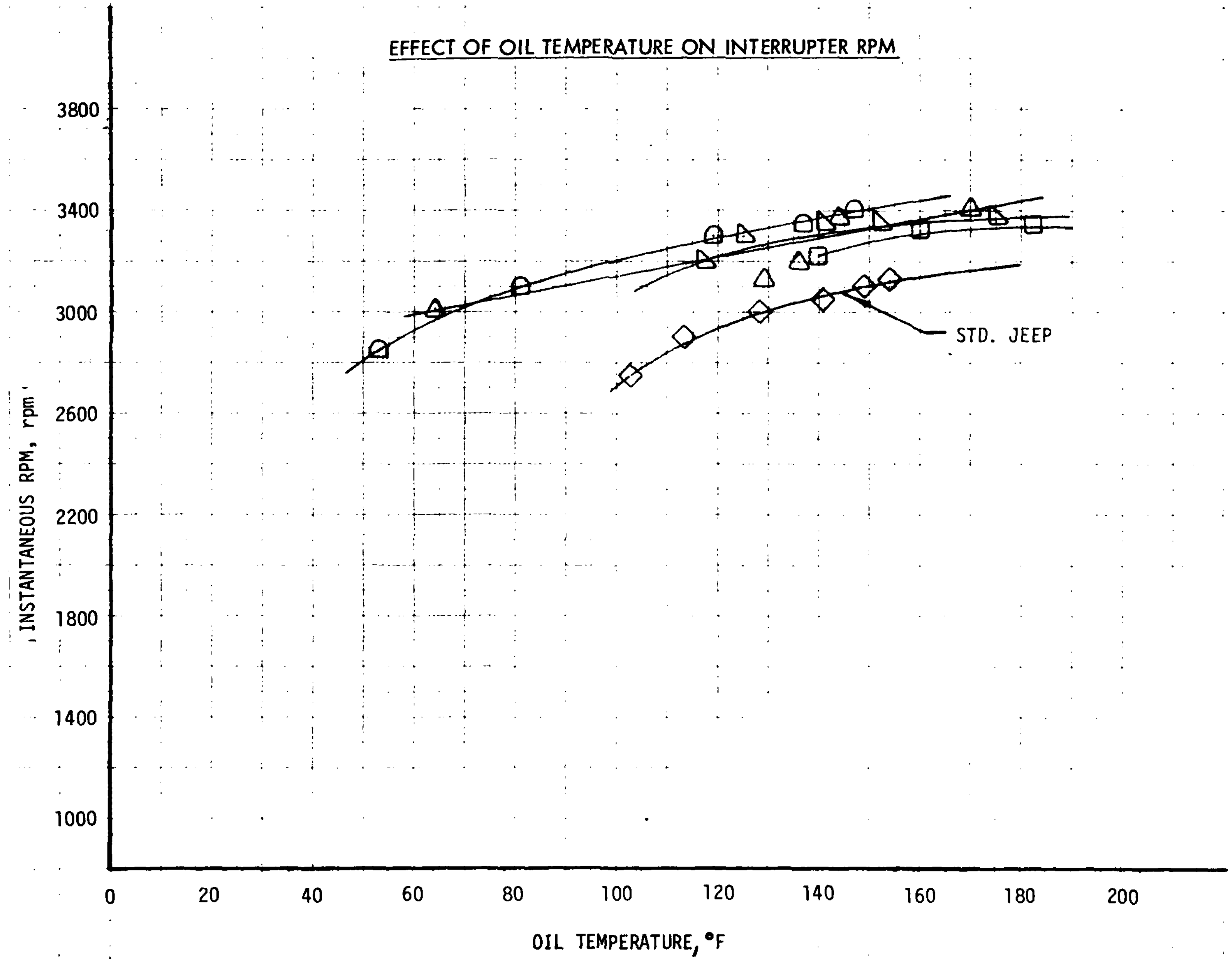


FIGURE 5-29

OIL TEMPERATURE VERSUS TIME

AT 1000 RPM

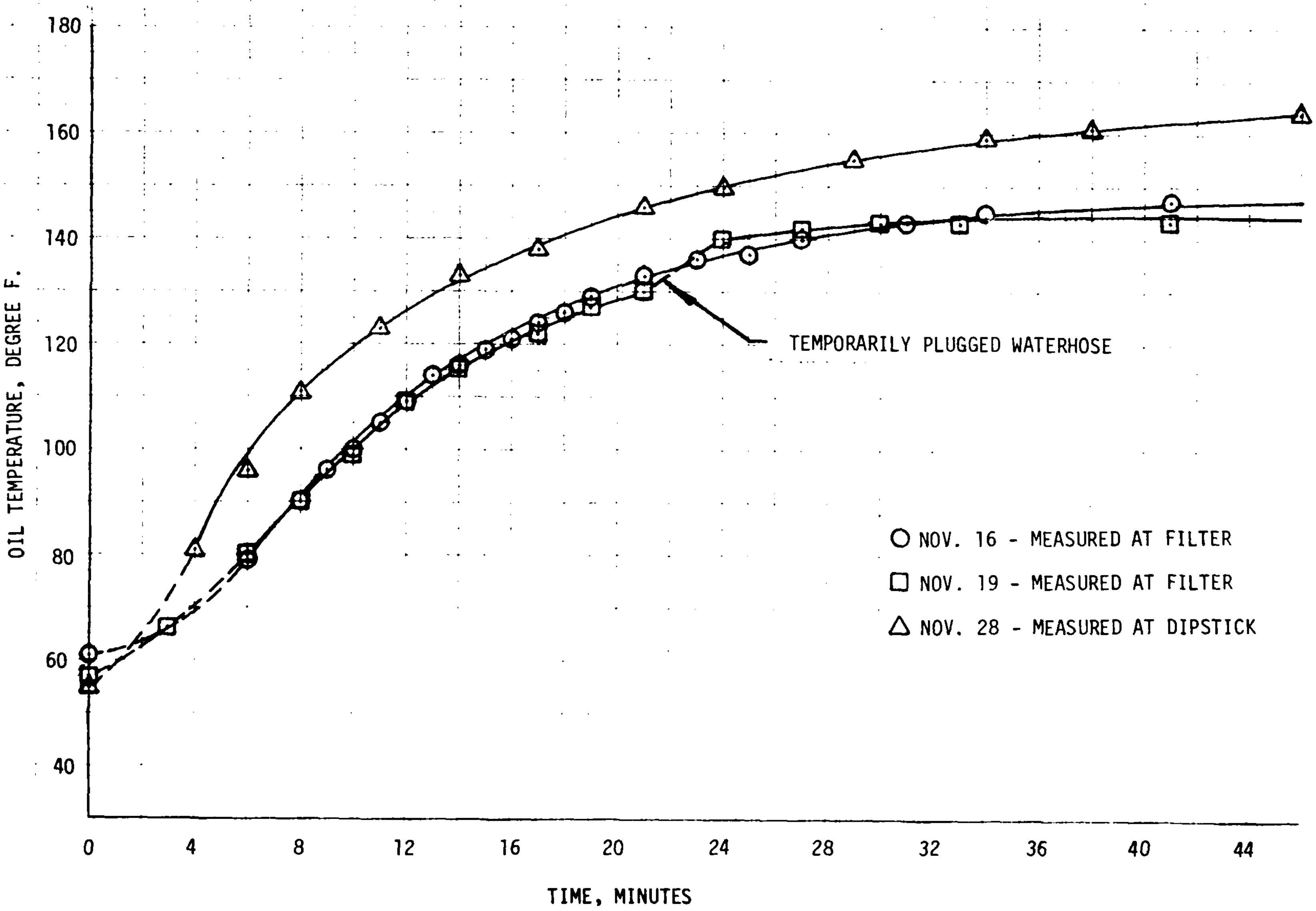
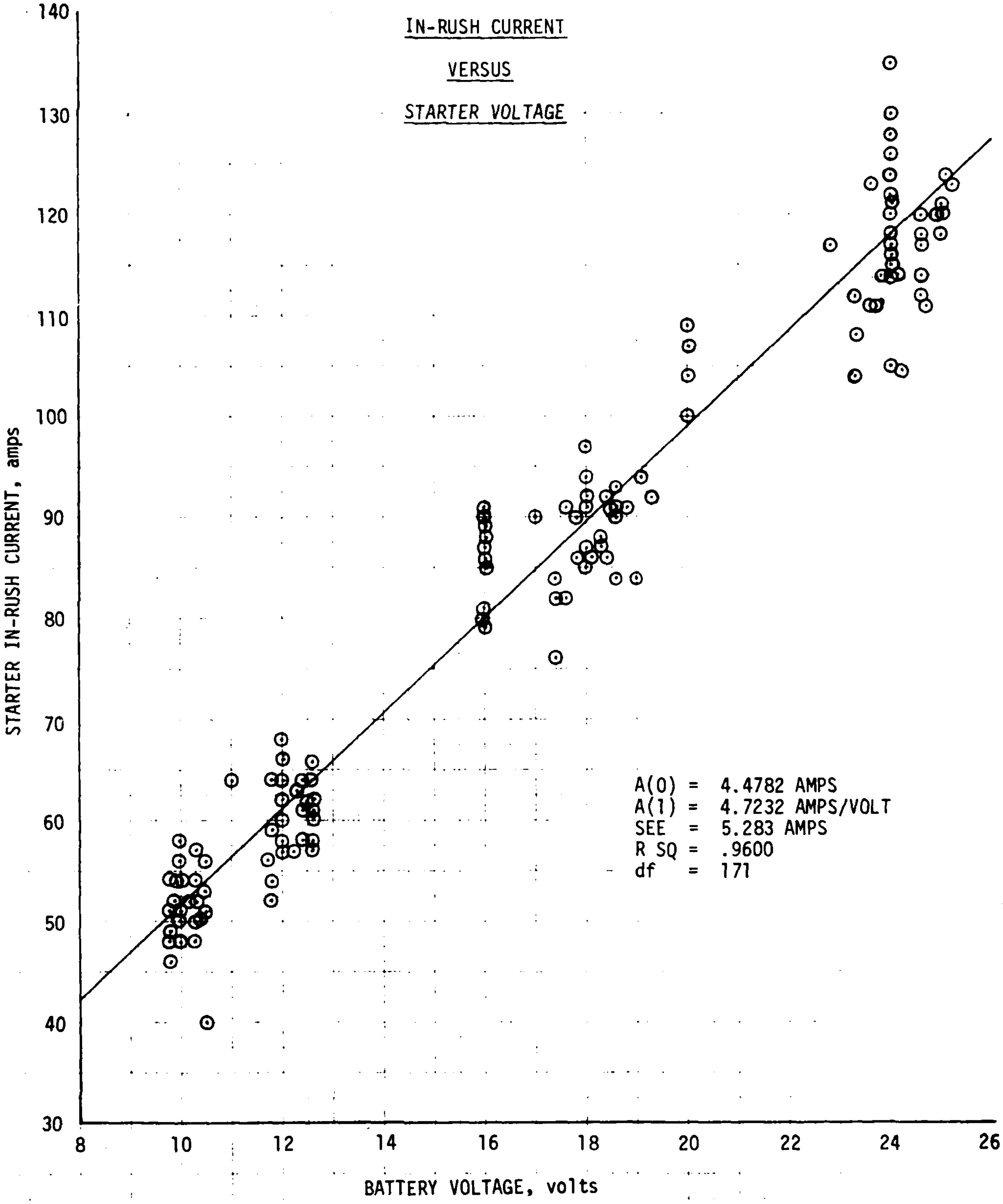


FIGURE 5-30



IN-RUSH CURRENT
VERSUS
STARTER VOLTAGE
STARTER IN-RUSH CURRENT, amps
BATTERY VOLTAGE, volts
30
40
50
60
70
80
90
100
110
120
130
140
8
10
12
14
16
18
20
22
24
26
A(0) = 4.4782 AMPS
A(1) = 4.7232 AMPS/VOLT
SEE = 5.283 AMPS
R SQ = .9600
df = 171

FIGURE 5-31

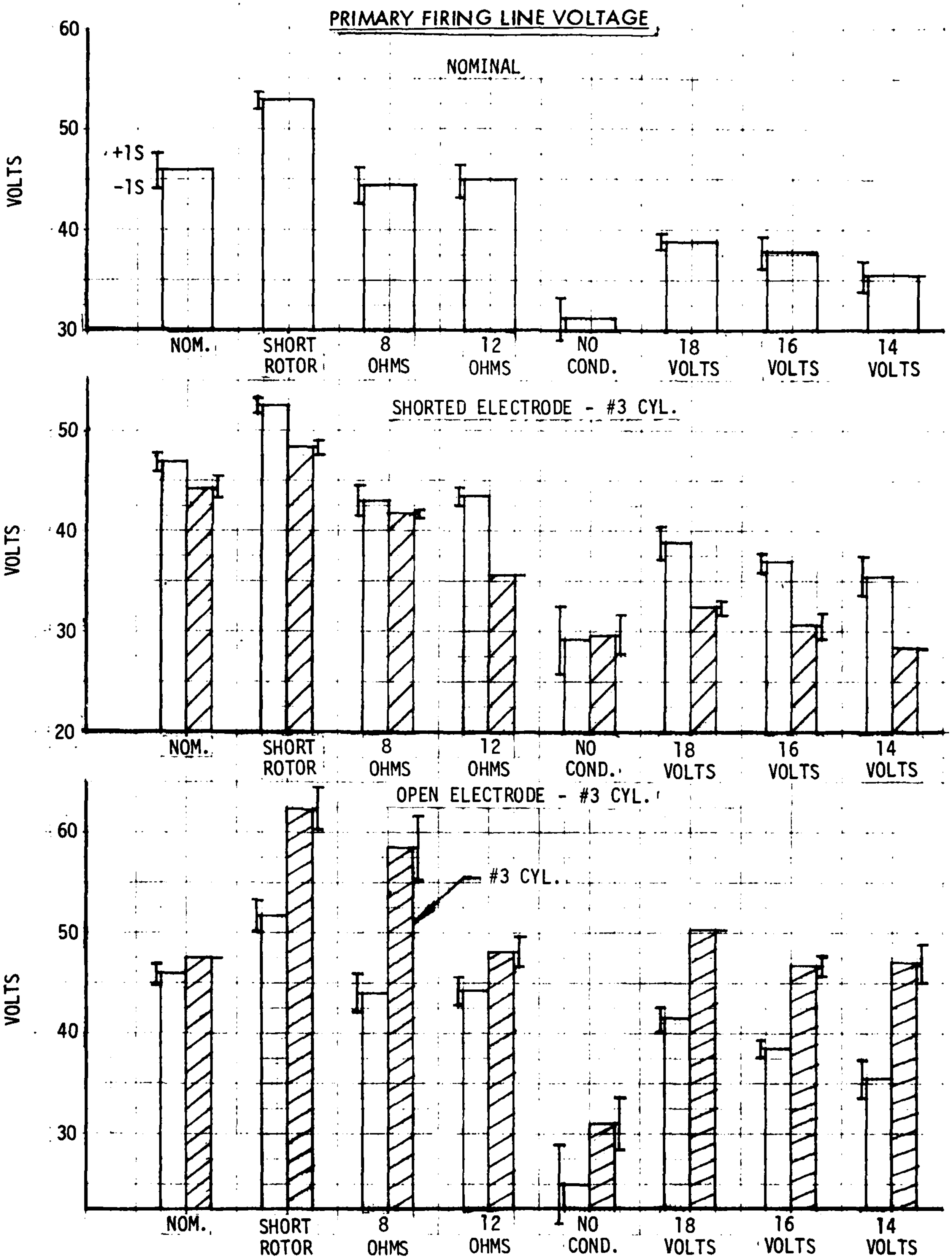

PRIMARY FIRING LINE VOLTAGE
NOMINAL
VOLTS
60
50
40
30
+1S
-1S
NOM.
SHORT ROTOR
8 OHMS
12 OHMS
NO COND.
18 VOLTS
16 VOLTS
14 VOLTS
SHORTED ELECTRODE - #3 CYL.
VOLTS
50
40
30
20
NOM.
SHORT ROTOR
8 OHMS
12 OHMS
NO COND.
18 VOLTS
16 VOLTS
14 VOLTS
OPEN ELECTRODE - #3 CYL.
#3 CYL.
VOLTS
60
50
40
30
NOM.
SHORT ROTOR
8 OHMS
12 OHMS
NO COND.
18 VOLTS
16 VOLTS
14 VOLTS

FIGURE 5-32

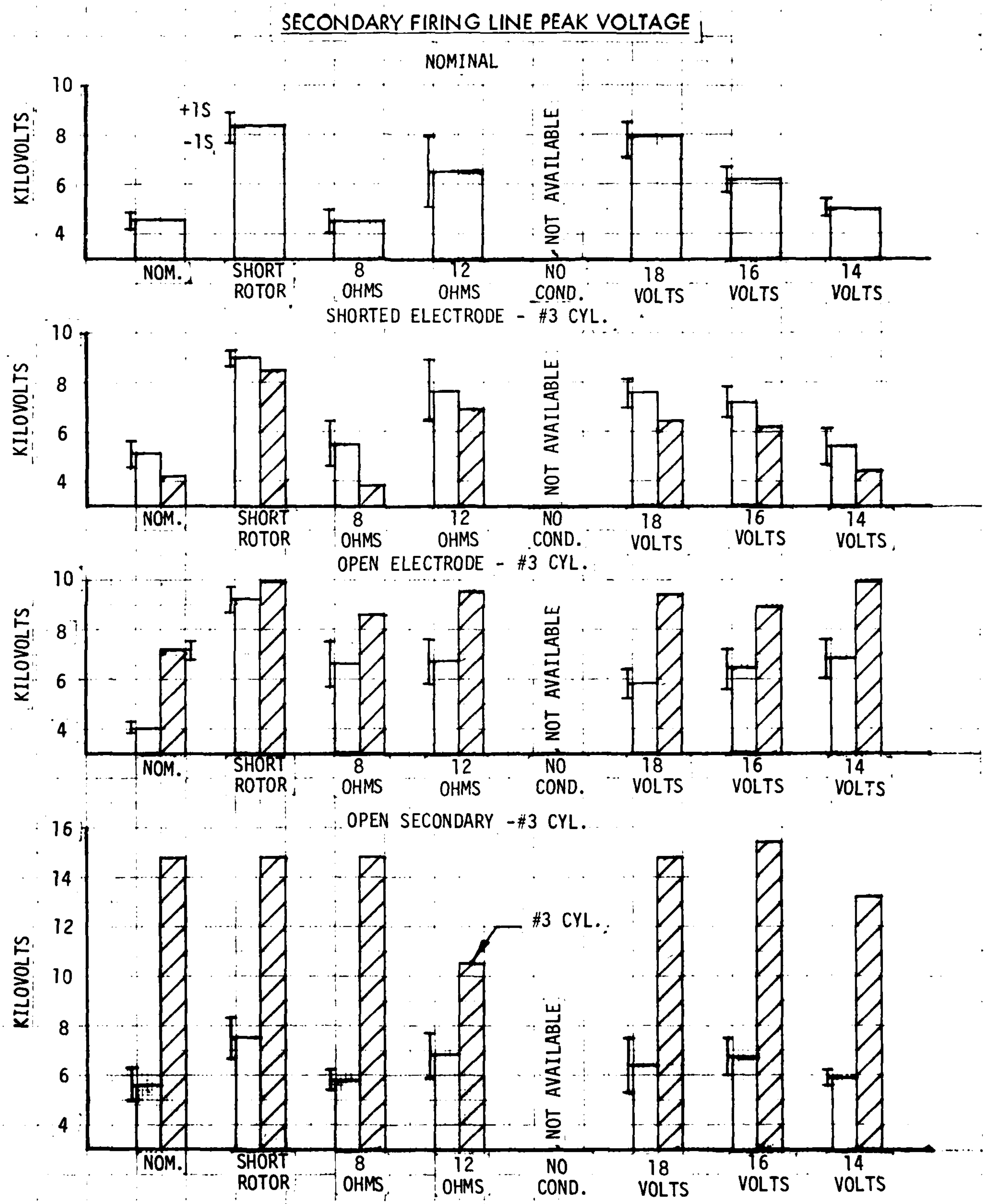
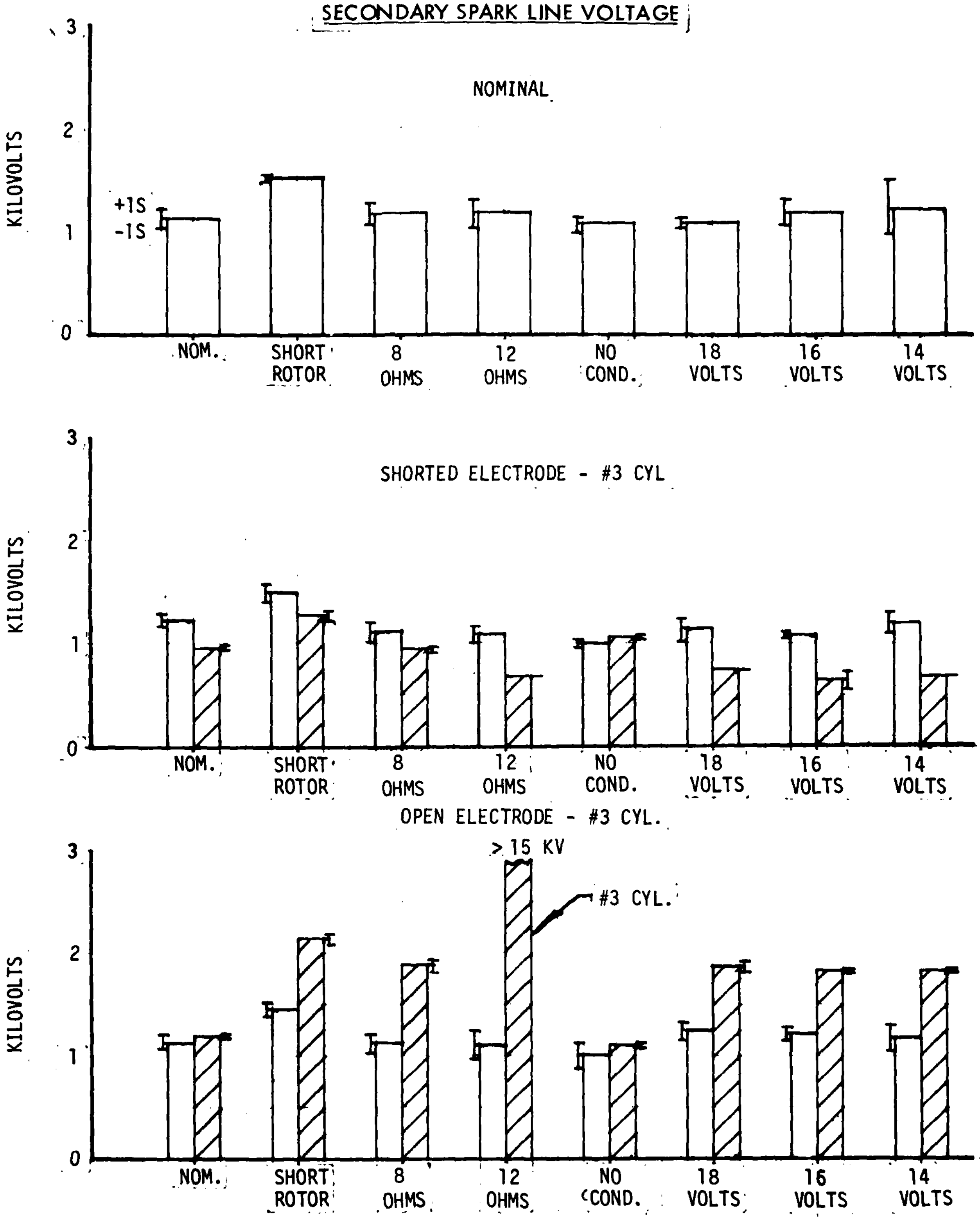

SECONDARY FIRING LINE PEAK VOLTAGE
NOMINAL
KILOVOLTS
+1S
-1S
NOT AVAILABLE
NOM.
SHORT ROTOR
8 OHMS
12 OHMS
NO COND.
18 VOLTS
16 VOLTS
14 VOLTS
SHORTED ELECTRODE - #3 CYL.
OPEN ELECTRODE - #3 CYL.
OPEN SECONDARY -#3 CYL.
#3 CYL.

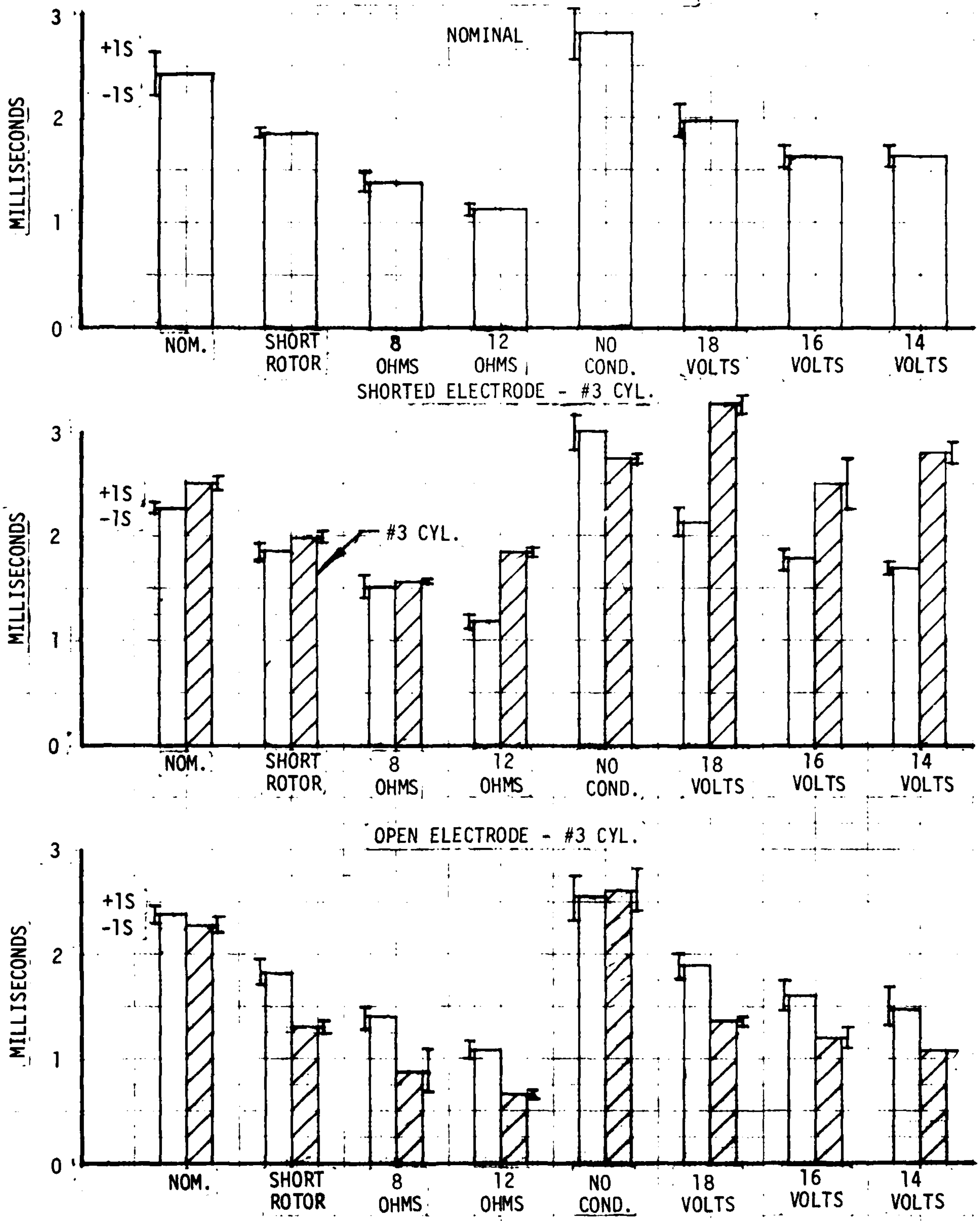
FIGURE 5-33

SECONDARY SPARK LINE VOLTAGE



FIGURF 5-34

SECONDARY SPARK LINE DURATION



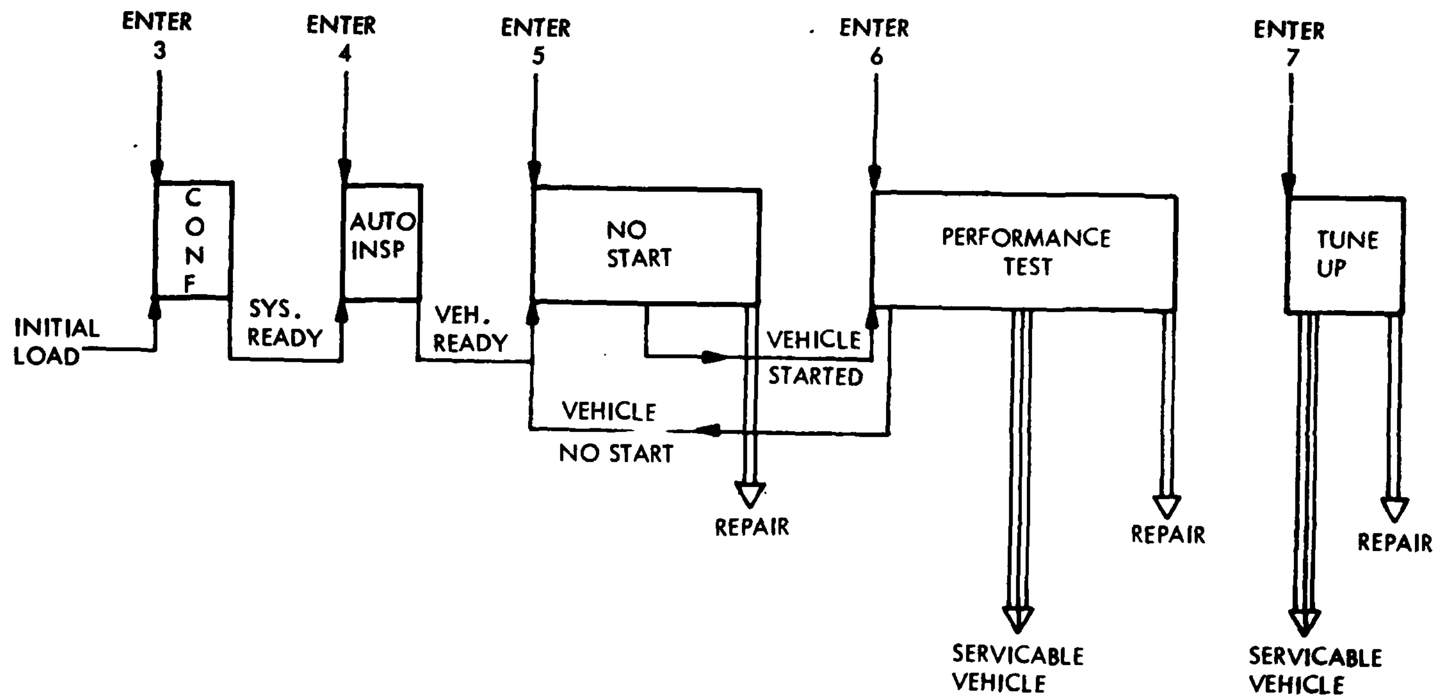


Figure 6-1

ATE/ICE PROGRAM FLOW

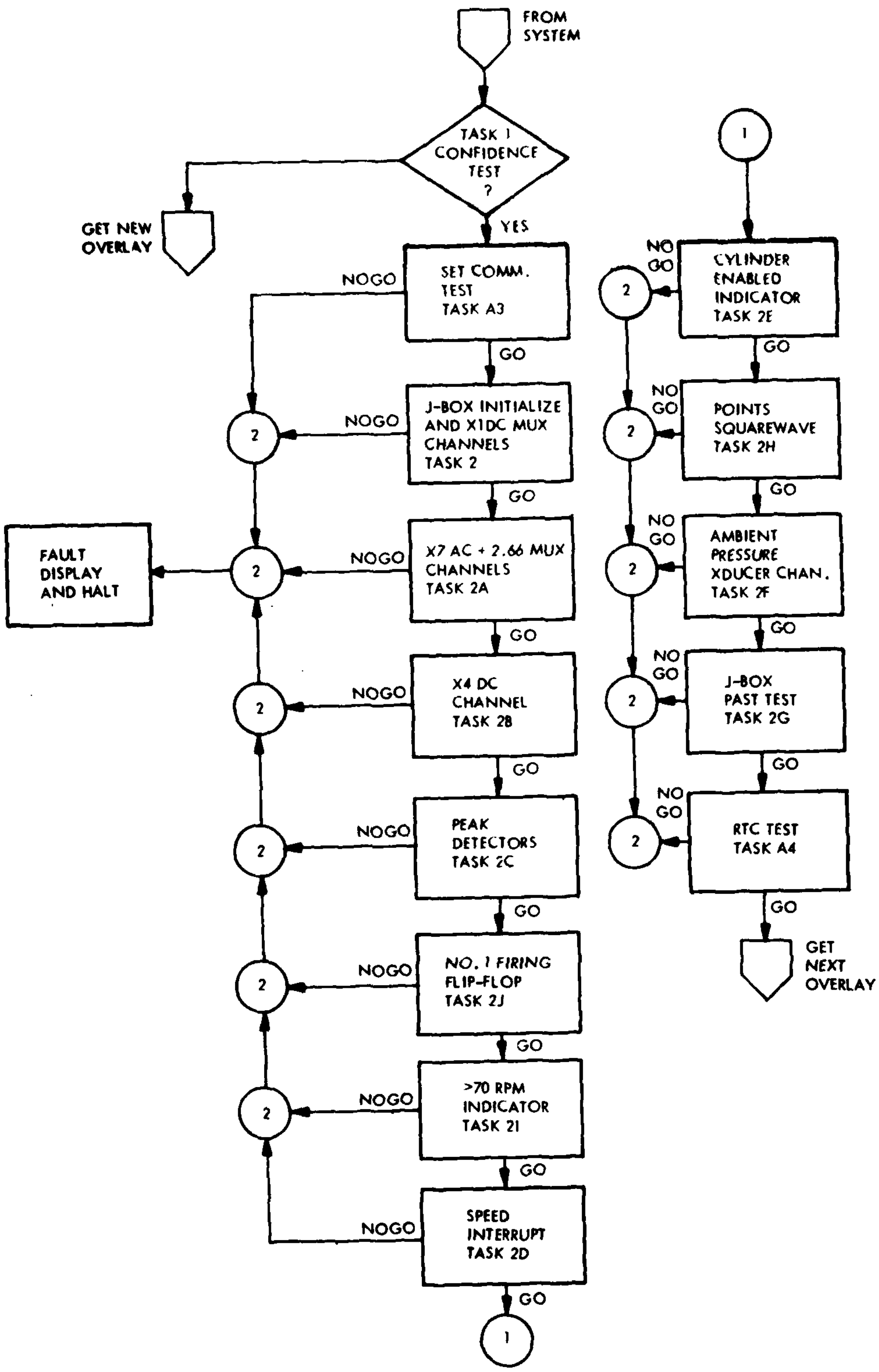


Figure 6-2

CONFIDENCE TEST TASK FLOW

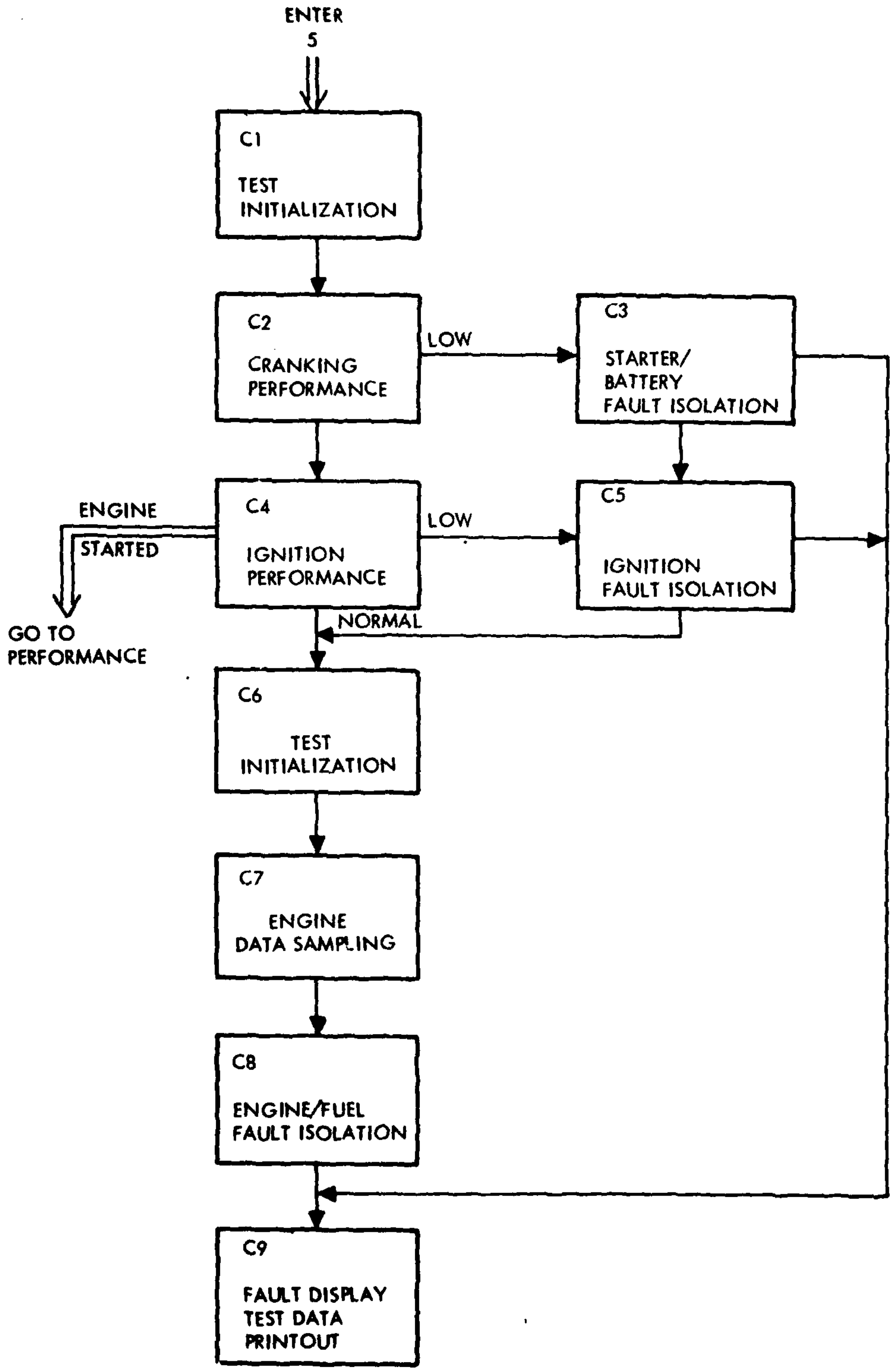


Figure 6-3

ATE/ICE NO START TEST FLOW DIAGRAM - M151A2

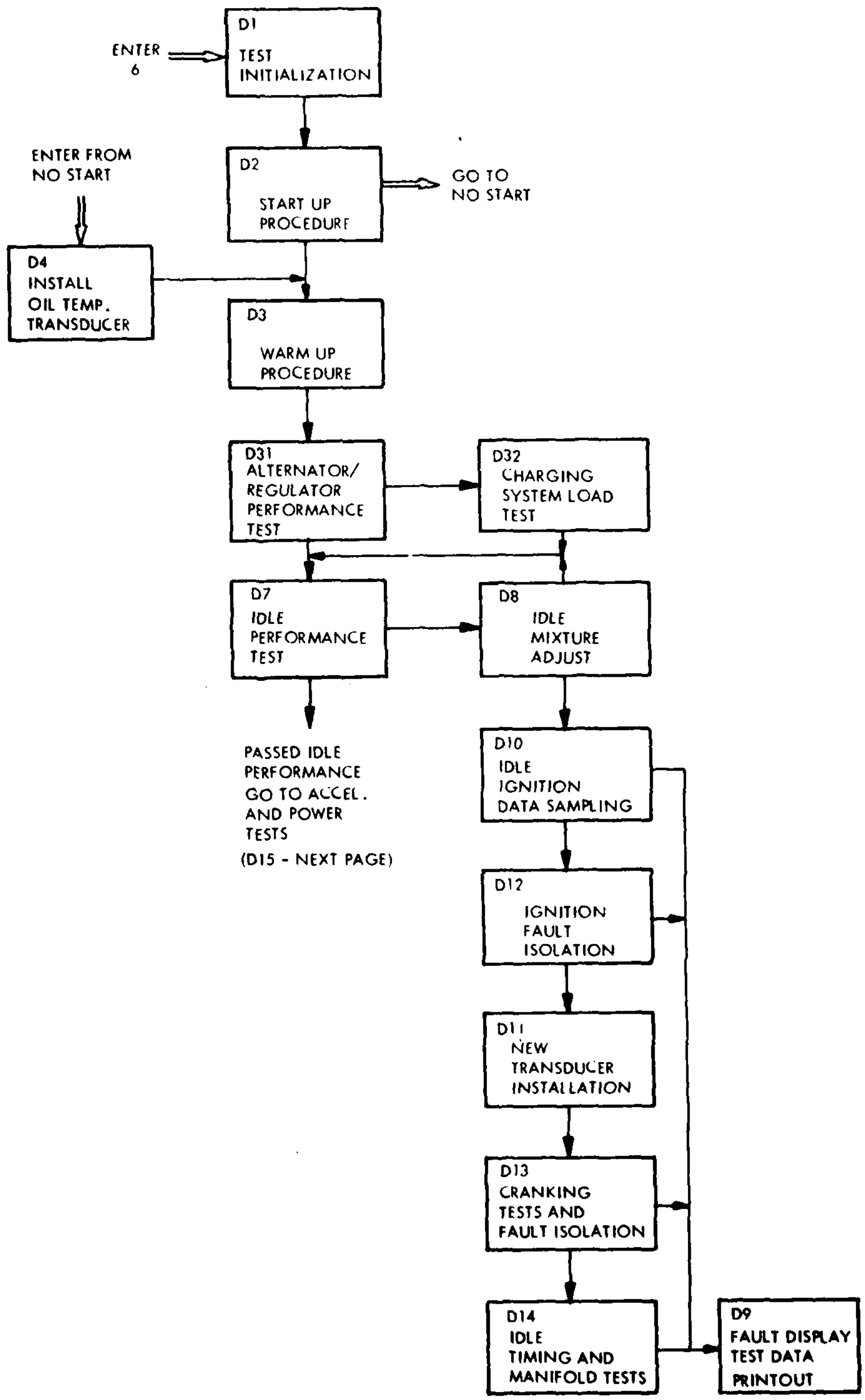


Figure 6-4

ATE/ICE PERFORMANCE TEST FLOW DIAGRAM - M151A2

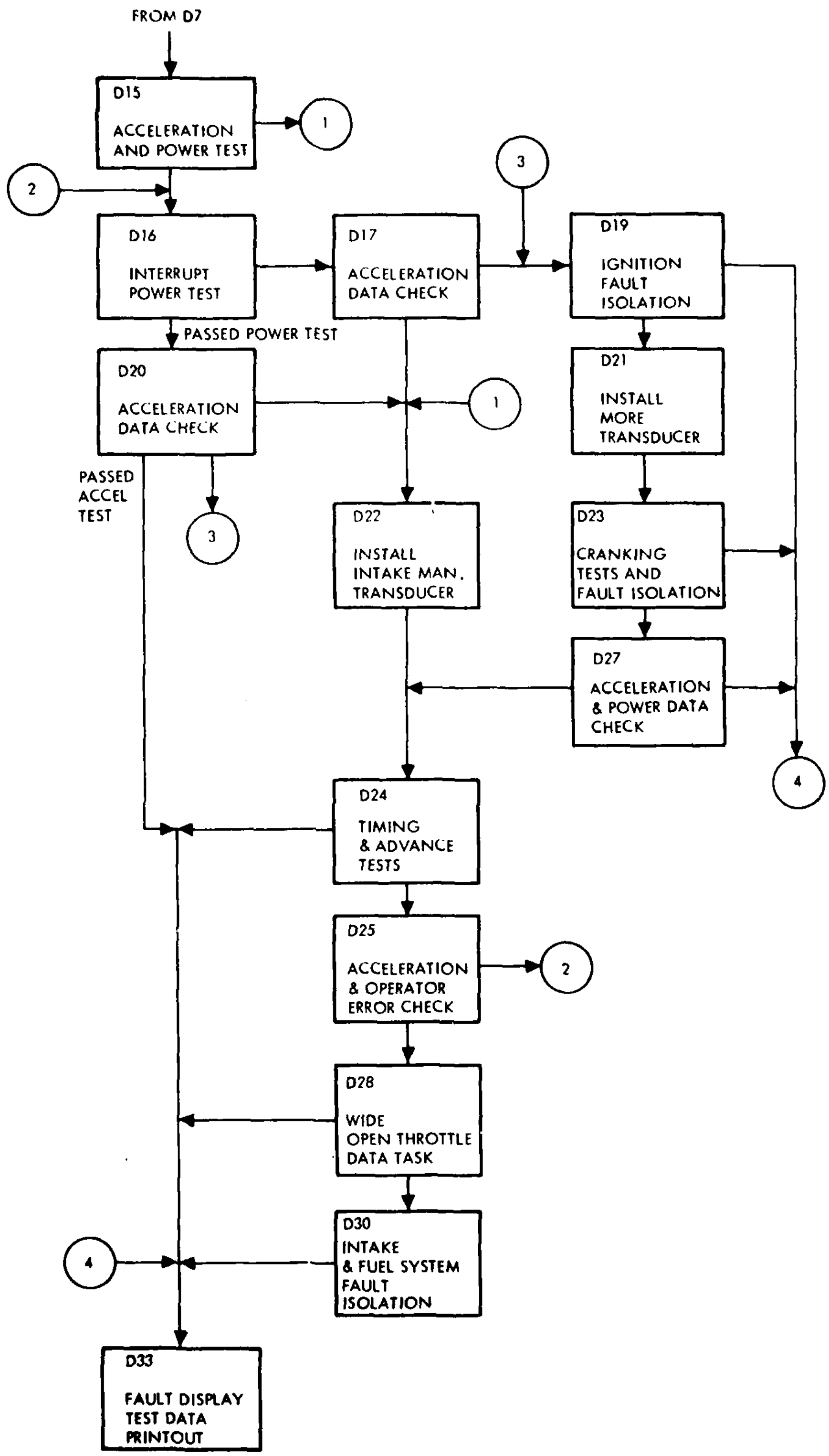


Figure 6-4 (Continued)

ATE/ICE PERFORMANCE TEST FLOW DIAGRAM - M151A2

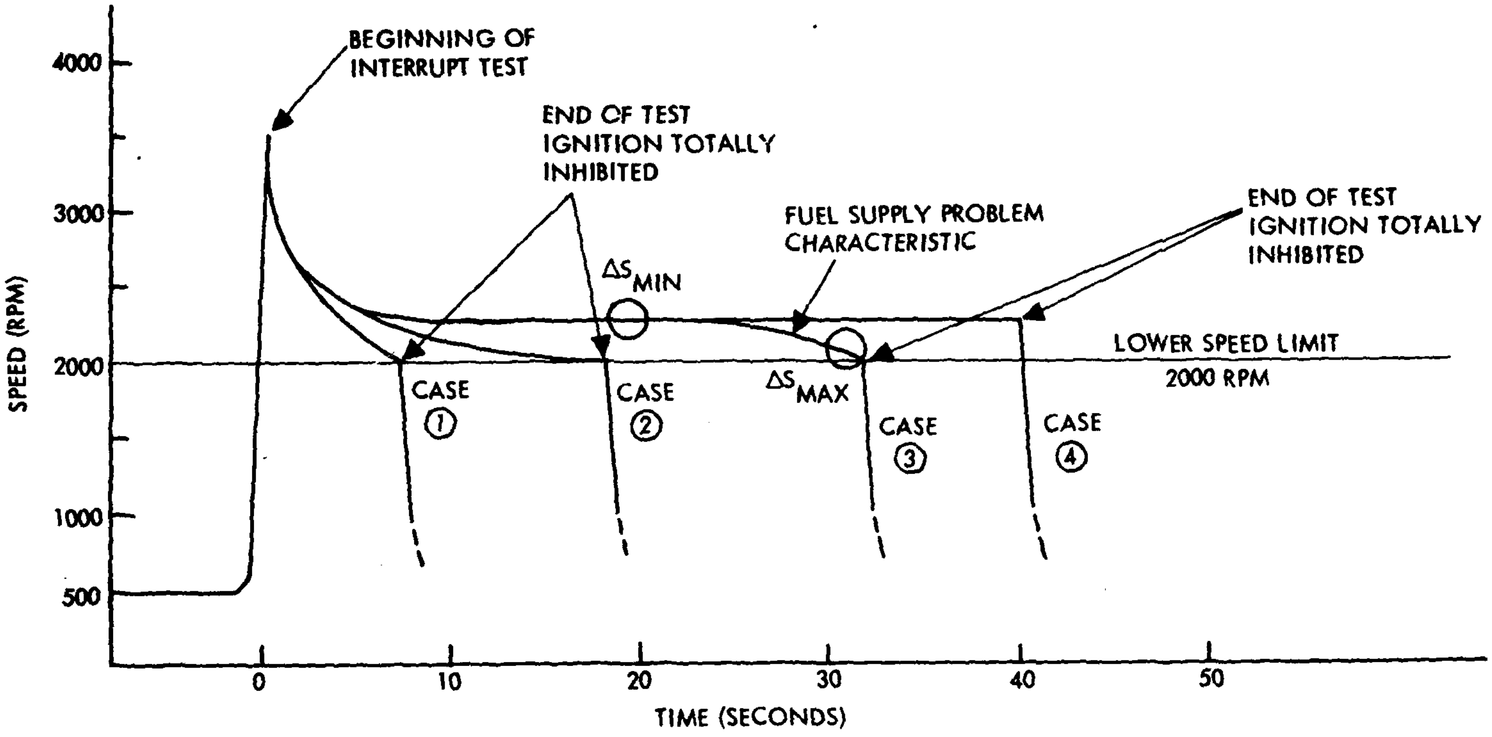


Figure 6-5

INTERRUPT SPEED VERSUS TIME

Table 2-1

MATERIAL DELIVERED TO TACOM UNDER CONTRACT DAAE07-73-C-0268

NAME	PART NUMBER	QTY DELIVERED
Programmable Diagnostic Unit (PDU) w/cassette program loader	11733817 11734941	4
Programmable Diagnostic Unit w/hermetically sealed program loader		1
Hermetically sealed program loader		1
Transducer Kit (TK) w/J-box, transducers, cables and program cassette		6
Transducer Spares		At least 6 of each transducer

Table 2-2 **ATE/ICE Diagnostic Test Capabilities**

Subsystem	Component/Faults Diagnosed	No-Start	Performance	Tune-Up
Engine	Rings or Block	A	A	
	Cylinder Head/Valves	A	A	
	Valve Adjustment	S	S	
	Valve Train	S	S	
	Compression	A	A	
	Power Output		A	
Ignition	Spark Plug/Cable	A	A	
	Points	A	A	S
	Condenser	A	A	
	Coil/Ballast Resistor	A	A	
	Rotor/Distributor Cap	A	A	
	Timing	A	A	A
	Dwell	A	A	A
	Advance Mechanism		A	A
Electrical	Battery	A	A	S
	Starter	A	A	S
	Starter Cables or Switch	A	A	
	Alternator		A	S
Fuel	Carburetor Adjust	S	A	A
	Carburetor Failure	A	A	
	Fuel Pump/Lines/Filter	S	S	
Intake	Restricted Air Intake	A	A	S
	Intake Manifold Leak	A	A	S

Code: A = Automatic
S = Semi-Automatic

Table 3-1 - SCU Storage Register Assignments

Register Number	SCU Register Strobes					IB HI-LO (Strobe)
	Information Bits					
	C7	C8	C9	C10	TAG	
1	X	0	0	0	1	↑
2	X	0	0	1	1	↑
3	X	0	1	0	1	↑
4	X	0	1	1	1	↑
5	X	1	0	0	1	↑

Table 3-2 - SCU Register #1 Assignments

Information Bits				Function (See Reg. #5) Engine Xducers/Ignition
SA0	SA1	SA2	SA3	
	0	0	0	PK/VSP Self-Test
1 = SELF TEST MODE FOR ENGINE XDUCERS CHANNELS	0	0	1	PIM/VSLP
	0	1	0	TO/VPL
	0	1	1	TA/VPBP
X	1	0	0	IB/VPM
X	1	0	1	PEX/VPH
X	1	1	0	HC/---
X	1	1	1	---------------------

Table 3-3 - SCU Register #2 Assignments

Information Bits			
SA0	SA1	SA2	SA3
1 = FAST PEAK DETECTOR SAMPLE	1 = FAST PEAK DETECTOR DUMP	1 = PEX SELF-TEST 0 = IB SELF TEST	CURRENT PROBE RANGE (I_B) 1 = 0 TO $\pm$30 AMPS 0 - 0 TO $\pm$150 AMPS

Table 3-4 - SCU Register #3 Assignments

Information Bits			
SA0	SA1	SA2	SA3
1 = SLOW PEAK DETECTOR SAMPLE	1 = SLOW PEAK DETECTOR DUMP	SECONDARY CHANNEL GAIN 1 = X10 0 = X3	SLOW PEAK DETECTOR INPUT 1 = PRIMARY 0 = SECONDARY

Table 3-5 - SCU Register #4 Assignments

Information Bits			
SA0	SA1	SA2	SA3
NOT USED	1 = ENGINE KILL	1 = FIOR	1 = INTERRUPTER ENABLE

Table 3-6 - SCU Register #5 Assignments

Information Bits				Function
SA0	SA1	SA2	SA3	
X	0	0	0	ENGINE XDUCERS (X1 DC)
X	0	0	1	ENGINE XDUCERS (X7 AC +2.66)
X	0	1	0	ENGINE XDUCERS (X4DC - 1.00)
X	0	1	1	FAST PEAK DETECTOR
X	1	0	0	SECONDARY WAVEFORM
X	1	0	1	SLOW PEAK DETECTOR
X	1	1	0	PRIMARY CIRCUITS
X	1	1	1	FIO OUTPUT

Table 3-7 - SCU Control Register In PDU

Output Channel 8	
BIT	**Function**
(MSB) 0	0 ⟶ 1 SCU STROBE BIT - IB HI-LO
1	EMERGENCY STOP BIT (1 = STOP) (0 = RUN)
2	ADCO-RTC BITS (1 = 8 LSB) (0 = 8 MSB)
3	EMERGENCY STOP RESET (1 = RESET) (0 = $\overline{\text{RESET}}$)
4	SC BEEPER (1 = ON) (0 = OFF)
5	SCU POWER CONTROL - ±19 VDC (1 = ON) (0 = OFF)
6	C7
7	C8
8	C9
9	C10
10	TAG (1 = ENABLE SCU CONTROL REGISTERS) (0 = ENABLE A/D ANALOG MUX)
11	SA0
12	SA1
13	SA2
14	SA3
(LSB) 15	SA4

TABLE 5-1

TEST NO.	TEST DATE	VOLT-AGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	$\overline{\Delta S}$	$\overline{X}$	S	
ISCBL	1-4-73	23.5	-	-	-	-	-	-	-	62.4	1.82	32.9	1.82	110	1.1	ALL = 70 HOT
1	11-28-73	24.0	122	-	-	-	-	-	-	61.0	1.00	29.2	0.84	111	2.4	ALL = 70 COLD
2	↓	18.0	97	-	-	-	-	-	-	58.8	1.09	28.2	0.84	82	1.5	↓
3	↓	12.0	66	-	-	-	-	-	-	52.6	0.89	23.8	0.45	50	1.3	↓
4	↓	10.0	58	-	-	-	-	-	-	49.0	0.71	21.0	0.71	40	0.6	↓
5	↓	24.0	118	-	-	-	-	-	-	58.8	1.09	26.2	0.84	118	2.9	ALL = 70 HOT
6	↓	18.0	91	-	-	-	-	-	-	59.4	0.54	27.8	0.89	84	1.6	↓
7	↓	12.0	64	-	-	-	-	-	-	54.8	0.44	24.0	0	49	0.7	↓
8	↓	10.0	56	-	-	-	-	-	-	52.8	0.82	22.0	0.71	36	0.7	↓
9	11-29-73	22.8	117	65.6	1.52	38.0	2.64	110	8.4	53.5	0.71	28.5	0.71	125	-	NO. 2 = 70 COLD
10	↓	17.0	90	65.0	1.00	39.3	3.78	78	6.5	54.0	0	31.0	0	94	-	↓
11	↓	11.0	64	60.3	0.57	36.3	4.04	42	3.3	50.5	0.71	30.5	0.71	58	-	↓
12	↓	9.8	54	54.0	1.00	34.0	3.00	31	2.8	45.0	1.41	28.0	0	44	-	↓
13	↓	24.0	120	52.0	3.60	31.0	2.00	129	9.3	40.0	0	20.0	0	146	-	NO. 2 = 70 HOT
14	↓	17.8	90	58.3	2.08	38.3	3.51	90	9.7	44.0	0	25.5	0.71	110	-	↓
15	↓	11.8	59	56.3	1.52	39.0	3.46	44	4.7	45.0	0	31.0	0	63	-	↓
16	↓	9.8	49	54.3	0.57	36.0	2.64	29	2.9	43.0	0	28.5	0.71	45	-	↓

TABLE 5-1

TEST NO.	TEST DATE	VOLTAGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	
17	11-30-73	24.0	124	62.3	0.57	37.7	0.58	107	1.4	46.5	0.71	28.0	1.41	127	1.5	NO. 2 AND 3 = 70 COLD
18	↓	18.0	94	58.6	1.15	36.0	1.00	74	0.7	47.5	0.71	32.0	0	96	0.6	↓
19		12.0	62	54.0	0	33.3	0.58	42	0.7	44.0	0	30.5	0.71	59	0.6	
20		10.0	56	49.6	0.57	30.3	1.53	30	0	40.0	0	27.5	0.71	45	1.2	
21		24.0	124	63.6	0.57	37.7	0.58	118	3.5	44.5	0.70	21.0	1.40	144	0.6	NO. 2 AND 3 = 70 HOT
22		18.0	92	64.3	0.57	39.0	1.00	78	2.8	49.0	0.70	29.0	1.41	107	2.5	↓
23		12.0	64	62.0	1.00	38.0	1.00	37	1.4	49.5	0.71	32.5	0.71	60	0.6	
24		10.0	54	59.3	1.15	35.7	1.15	24	2.1	47.5	0.71	29.5	0.71	41	1.0	
25	12-6-73	24.0	124	66.6	3.78	42.6	3.78	123	5.5	-	-	-	-	-	-	NOMINAL COLD
26	↓	18.0	94	68.8	2.59	46.8	2.59	90	4.6	-	-	-	-	-	-	↓
27		12.0	64	65.6	2.60	45.6	2.61	49	3.8	-	-	-	-	-	-	
28		10.0	56	61.8	3.11	42.0	3.00	33	3.9	-	-	-	-	-	-	
29		24.0	117	55.8	4.02	32.8	4.02	139	4.4	-	-	-	-	-	-	NOMINAL HOT
30		18.0	87	65.0	3.74	44.6	3.78	98	5.0	-	-	-	-	-	-	↓
31		12.0	60	65.6	3.67	47.0	3.39	44	4.3	-	-	-	-	-	-	
32		10.0	51	63.2	4.43	44.0	4.69	25	3.9	-	-	-	-	-	-	

TABLE 5-2

TEST NO.	TEST DATE	VOLT-AGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	
2	1-7-74	24.0	126	61.00	4.2	38.00	2.83	129	5.4	34.67	2.1	14.00	3.0	153	1.4	NO. 1 AND 3I = 70
		16.0	90	69.50	0.7	48.50	3.54	72	8.1	37.33	4.0	17.34	2.3	101	9.1	NO. 1 AND 3I = 70
2A	1-7-74	24.0	128	61.00	2.8	37.50	3.54	133	3.8	41.67	1.2	18.34	1.6	148	0.3	NO. 1 AND 3I = 90
		16.0	87	69.50	0.7	48.50	2.12	76	4.5	51.33	3.2	31.00	2.6	95	0.4	NO. 1 AND 3I = 90
1	1-7-74	24.0	130	60.34	5.1	35.33	5.1	133	2.7	35.00	0	11.00	1.4	144	0.3	NO. 1I = 70
		16.0	87	70.66	1.5	49.67	1.2	76	6.5	37.00	0	16.00	0	108	0.8	NO. 1I = 70
1A	1-7-74	24.0	130	53.34	1.5	33.33	3.2	125	3.4	34.00	1.4	14.50	0.7	153	0	NO. 1I = 90
		16.0	89	70.34	1.8	49.00	0	77	6.2	43.00	0	22.00	0	104	0.5	NO. 1I = 90
1	10-29-73	24.6	120	53.88	3.1	33.88	3.1	143	3.3	-	-	-	-	-	-	NOMINAL
	↓	18.6	93	64.00	2.4	45.32	2.4	102	3.3	-	-	-	-	-	-	↓
		12.4	64	63.44	1.3	47.44	1.3	48	2.8	-	-	-	-	-	-	
		10.2	52	61.88	1.7	43.76	1.8	28	2.4	-	-	-	-	-	-	
3	10-29-73	25.0	120	59.75	2.6	35.75	2.5	140	6.9	45.00	-	23.00	-	146	-	NO. 1E = 90
	↓	19.0	84	67.27	1.6	46.53	2.8	79	4.5	50.10	1.0	30.60	0.3	93	-	↓
		12.5	62	65.25	0.5	38.56	7.2	42	2.9	44.00	-	25.00	-	66	-	
		10.5	56	62.40	1.1	39.00	5.1	25	1.2	45.00	-	25.00	-	46	-	
4B	10-30-73	25.1	124	52.34	2.9	31.73	2.6	141	4.2	39.90	0.1	19.90	0.1	153	-	NO. 1E = 70
	↓	19.1	94	61.66	3.1	41.73	5.1	98	6.5	41.50	0.7	23.00	0	117	-	↓
		12.6	64	59.66	2.5	41.73	6.7	51	3.3	38.50	0.7	23.00	0	75	0.4	
		10.3	52	53.66	3.1	39.67	6.8	34	2.4	34.90	1.3	21.90	1.3	58	-	

TABLE 5-2

TEST NO.	TEST DATE	VOLT-AGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	
6	10-30-73	25.2	123	57.34	2.1	34.33	0.6	129	3.9	48.50	0.7	25.50	2.1	140	3.3	NO. 1 AND 2E = 90
	↓	18.6	93	61.50	0.7	42.00	2.8	90	6.4	45.00	1.0	26.33	4.6	103	6.9	↓
		12.6	64	56.50	0.7	37.00	7.1	45	3.1	39.66	4.0	22.33	9.0	63	3.9	
		10.5	53	54.00	0	34.50	5.0	30	0.6	37.00	3.6	19.67	7.6	48	1.5	
7	10-30-73	25.0	121	50.33	8.4	25.67	9.0	126	3.8	39.00	5.6	19.00	5.6	140	5.5	NO. 1 AND 2E = 70
	↓	19.3	92	65.00	1.4	39.50	5.0	88	7.6	44.67	1.2	18.00	6.1	103	9.7	↓
		12.6	58	58.33	0.6	39.67	4.9	45	2.3	36.50	3.5	17.00	9.9	65	5.2	
		10.5	40	53.33	1.5	33.67	4.7	29	0.5	34.50	5.0	16.00	9.9	49	1.1	
13	10-31-73	24.9	120	58.5	3.2	37.4	2.9	131	4.6	42.0	0	21.0	0	147	0.5	NO. 1I = 90
	↓	18.8	91	63.8	3.3	44.8	3.0	93	6.5	45.0	0	27.0	0	104	7.1	↓
		12.6	66	65.5	7.1	48.0	7.4	45	2.3	47.7	0.5	30.0	0	61	-	
		10.5	51	57.0	1.2	40.1	1.0	28	0.9	43.5	-	25.8	0	48	-	
14	10-31-73	25.0	118	59.5	3.5	38.5	2.8	129	5.6	36.0	0	15.4	0.5	152	1.1	NO. 1I = 70
	↓	18.5	91	63.8	2.7	44.5	0.4	90	4.7	37.1	1.6	18.8	1.1	119	1.3	↓
		12.6	64	57.0	2.2	42.0	3.3	45	3.0	36.4	0.5	22.9	0.5	70	0.9	
		10.3	52	55.55	1.5	39.2	2.4	28	1.5	35.6	0.5	20.6	0.5	50	0.8	
16	10-31-73	24.6	117	57.8	3.2	36.4	2.7	129	5.2	43.5	2.6	22.0	2.2	144	5.4	NO. 1 AND 2 = 90
	↓	18.3	88	62.6	2.6	43.9	1.6	90	7.2	46.0	3.5	26.0	1.7	105	8.4	↓
		12.3	63	58.9	1.6	41.2	1.1	44	2.0	46.5	1.3	28.5	0	57	4.3	
		10.3	52	56.2	-	37.2	0.5	28	1.3	44.5	0.9	26.0	0.5	41	3.0	

TABLE 5-2

TEST NO.	TEST DATE	VOLT-AGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	
17	10-31-73	24.6	118	58.9	4.8	37.6	3.2	128	8.6	39.0	2.6	17.3	1.3	147	4.7	NO. 1 AND 2I = 70
	↓	18.6	91	62.6	2.6	42.8	0	88	7.0	41.0	2.4	21.0	0.8	109	6.4	↓
		12.6	62	59.8	1.1	40.2	0.5	44	4.0	40.5	0	21.3	1.9	64	5.5	
		10.3	54	58.1	2.6	39.0	1.1	28	1.8	37.8	0.4	18.5	1.6	46	3.8	
22	10-31-73	24.6	117	-	-	-	-	-	-	47.7	1.1	22.2	1.2	140	2.0	ALL = 90
	↓	18.6	90	-	-	-	-	-	-	51.8	1.3	28.2	1.2	101	1.9	↓
		12.6	60	-	-	-	-	-	-	50.0	1.3	28.8	1.5	57	1.4	
		10.3	57	-	-	-	-	-	-	48.3	1.1	27.0	1.4	40	0.9	
23	10-31-73	24.6	117	-	-	-	-	-	-	44.2	0.5	17.4	0.4	141	2.4	ALL = 70
	↓	18.4	92	-	-	-	-	-	-	44.7	0.4	19.5	0	102	0.8	↓
		12.4	61	-	-	-	-	-	-	42.6	0.3	18.6	0.6	60	1.7	
		10.5	53	-	-	-	-	-	-	40.6	1.0	17.7	1.2	44	1.5	
25	10-31-73	24.6	114	63.0	0	39.4	0.4	128	2.8	47.2	0	24.2	0.4	142	1.5	NO. 1I/E = 90
	↓	18.4	86	68.8	0.4	47.2	1.4	88	2.4	51.0	0	30.0	0	104	0.2	↓
		12.6	61	64.2	1.1	42.9	3.4	42	11.5	46.4	0.5	25.8	0.4	60	1.1	
		10.4	50	61.0	1.7	38.0	4.6	23	1.4	43.7	0.7	22.0	0.6	43	0.4	
26	10-31-73	24.7	111	64.0	0.9	39.5	0.9	127	3.8	42.0	0	18.0	0	147	1.6	NO. 1I/E = 70
	↓	18.6	84	69.2	1.6	46.3	3.7	82	4.3	42.0	0	20.6	0.5	112	-	↓
		12.6	57	63.2	1.1	41.0	5.1	34	0.3	40.5	0	19.5	0	63	-	
		10.3	48	60.0	3.0	36.0	3.0	20	2.1	42.0	0	19.5	2.0	44	-	

TABLE 5-2

TEST NO.	TEST DATE	VOLT-AGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	
28	10-31-73	24.6	112	64.9	0.5	40.2	0.5	126	2.6	49.5	1.3	24.5	0.5	138	3.3	NO. 1 AND 2I/E = 90
	↓	18.3	87	69.0	0	47.2	1.1	84	2.8	50.8	0.4	27.8	2.0	99	5.4	↓
		12.4	58	63.8	1.1	41.2	3.2	37	1.6	44.2	2.7	19.3	6.8	56	3.5	
		10.3	50	59.2	1.1	34.9	4.8	22	2.7	40.5	2.6	15.5	3.0	43	1.1	
29	10-31-73	24.6	114	65.2	1.1	39.0	2.1	121	9.2	43.5	0.8	15.8	3.0	134	5.6	NO. 1 AND 2I/E = 70
	↓	18.3	88	69.8	2.1	44.0	7.8	78	7.8	42.8	1.3	15.5	6.7	98	8.0	↓
		12.4	58	64.5	2.1	40.2	6.8	34	0.7	39.0	3.9	14.0	7.4	60	1.4	
		10.3	52	60.8	4.2	36.4	7.9	20	3.0	37.5	4.0	12.5	6.7	46	1.2	
33	11-1-73	23.8	114	72.0	3.2	44.0	2.4	116	4.2	48.0	0	22.5	0	144	0.9	NO. 2 AND 3E = 90
	↓	17.8	86	72.2	2.4	42.0	2.0	74	4.9	48.0	0	25.5	0	111	2.7	↓
		12.0	57	69.0	2.6	41.0	2.4	34	3.3	45.0	0	24.8	0	68	1.8	
		9.8	51	61.0	1.7	35.5	1.7	23	3.4	42.0	0	22.2	0.5	51	0.3	
34	11-1-73	23.7	111	69.0	4.2	43.2	3.7	120	4.4	42.8	10.6	17.2	9.5	142	3.3	NO. 2 AND 3E = 70
	↓	18.0	85	73.8	2.3	47.5	1.2	75	5.5	52.5	1.1	30.8	1.1	104	2.5	↓
		12.2	57	68.2	3.3	40.0	3.5	32	3.4	46.5	0	26.3	0	65	2.4	
		10.0	48	64.8	3.8	38.5	3.8	19	3.5	43.5	0	22.9	0.6	48	1.3	
35	11-1-73	23.6	111	70.1	2.6	45.0	2.1	123	4.3	38.0	0.4	14.0	0.4	157	0.9	NO. 2 AND 3I = 90
	↓	17.4	82	70.1	1.6	48.4	1.6	77	3.7	36.0	1.3	16.5	1.3	125	4.4	↓
		11.7	56	66.4	2.6	45.0	3.2	31	4.0	40.2	1.6	22.8	1.1	72	3.4	
		9.8	51	60.8	5.3	40.0	5.3	18	4.3	37.8	1.1	19.8	0.4	51	2.0	

TABLE 5-2

TEST NO.	TEST DATE	VOLT-AGE	STARTER IN-RUSH	HI COMPRESSION CYLINDER						LO COMPRESSION CYLINDER						TEST DESCRIPTION
				I_S		ΔI_S		RPM		I_S		ΔI_S		RPM		
				$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	$\overline{X}$	S	$\overline{\Delta X}$	ΔS	$\overline{X}$	S	
36	11-1-73	23.3	112	66.3	2.8	43.8	2.8	123	4.6	40.5	2.1	18.8	2.1	152	3.2	NO. 2 AND 3I = 70
		17.4	84	71.2	2.0	50.5	1.6	78	3.5	45.4	2.6	25.9	2.7	116	6.3	
		11.7	56	67.8	4.5	48.5	4.1	30	3.2	49.9	2.6	31.9	2.7	61	5.0	
		9.8	48	62.2	3.8	42.5	4.1	16	3.0	48.0	1.1	30.0	0.5	40	2.8	
37	11-1-73	23.3	108	69.0	3.3	43.8	2.8	117	5.6	40.5	2.1	17.6	2.6	150	6.4	NO. 2 AND 3I/E = 90
		17.6	82	72.2	2.8	45.0	2.0	69	3.9	41.2	1.1	20.2	1.1	114	4.3	
		11.8	54	65.5	2.3	38.8	1.9	28	3.7	41.2	1.1	22.5	0	66	3.2	
		9.9	52	56.5	1.7	32.3	1.3	19	3.1	40.1	1.6	20.2	1.1	48	2.7	
38	11-1-73	23.3	104	62.8	3.4	42.5	2.8	122	6.1	43.5	1.1	24.0	1.1	144	1.9	NO. 2 AND 3I/E = 70
		17.4	76	70.8	2.3	50.0	0.9	72	5.6	46.9	2.6	29.6	2.6	104	0.3	
		11.8	52	62.5	4.3	40.0	4.3	28	4.2	42.4	0.5	26.2	1.1	59	0.3	
		9.8	46	53.2	2.6	32.6	2.4	18	2.8	30.8	10.6	14.6	10.1	44	0.4	
39 COLD	11-1-73	23.6	123	61.5	3.5	38.4	3.7	136	4.2	-	-	-	-	-	-	NOMINAL
		17.6	91	69.4	2.5	49.1	2.7	95	3.9	-	-	-	-	-	-	
		11.8	64	67.4	1.9	48.8	1.8	45	3.9	-	-	-	-	-	-	
		9.9	54	63.8	2.8	44.9	2.4	25	3.9	-	-	-	-	-	-	
39 HOT	11-1-73	24.1	114	51.8	1.8	29.3	1.8	152	3.4	-	-	-	-	-	-	
		18.1	86	66.3	2.7	46.5	3.0	101	3.3	-	-	-	-	-	-	
		12.0	58	69.2	2.1	50.4	1.9	34	2.9	-	-	-	-	-	-	
		10.0	50	63.0	2.1	42.8	2.4	18	1.7	-	-	-	-	-	-	

TABLE 5-3

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	INTAKE PRESSURE, IN. HG VACUUM MAXIMUM Mean	MAXIMUM Variance	AMPLITUDE Mean	AMPLITUDE Variance	AVERAGE in. Hg	ENGINE RPM Mean	ENGINE RPM Variance
		HOLE ENGINE								
		ALL CYLINDERS AT 70 PSI								
1/4/74	BL	BASELINE	24	3.56	.193	3.21	.211	1.953	110.2	2.22
1/4/74	7	PCV OK								
		.165 IN. INTAKE LEAK	24	2.65	.182	2.61	.184	1.348	112.4	2.27
			16	1.59	.148	1.51	.151	0.842	72.7	1.26
1/4/74	8	PCV PLUGGED								
		.165 IN. INTAKE LEAK	24	4.24	.248	3.95	.285	2.515	111.7	1.64
			16	2.73	.233	2.56	.227	1.450	72.6	1.33
1/4/74	12A	PCV OK								
		THROTTLE = 95% CLOSED	24	2.10	.145	2.10	.146	1.050	114.5	5.36
			16	1.13	.149	1.13	.149	0.565	72.2	1.24
1/4/74	12B	PCV PLUGGED								
		THROTTLE = 95% CLOSED	24	3.20	.228	3.07	.219	1.665	112.4	2.24
			16	1.86	.209	1.86	.209	0.930	72.5	1.55
1/4/74	13A	PCV OK	24	0.644	.048	0.644	.048	0.322	112.0	1.35
		THROTTLE = 85% CLOSED	16	0.292	.032	0.292	.033	0.146	72.1	1.55
1/4/74	13B	PCV PLUGGED	24	0.834	.058	0.834	.058	0.417	112.4	1.55
		THROTTLE = 85% CLOSED	16	0.369	.006	0.369	.037	0.184	71.8	3.75
		NOMINAL ENGINE								
1/11/74	NOM.	NOMINAL	24	1.06	.069	1.01	.064	0.555	136.3	3.01
			20	0.856	.068	0.856	.068	0.428	113.5	2.81
			16	0.649	.067	0.649	.067	0.324	85.5	2.02
			12	0.357	.075	0.340	.075	0.187	52.9	1.60
1/11/74	1	PCV OK	24	4.029	.160	3.466	.139	2.296	137.6	2.96
		INTAKE BLOCKAGE 1/2 IN.	20	3.519	.202	3.256	.210	1.891	114.2	3.20
			16	2.839	.202	2.666	.202	1.506	84.4	2.95
			12	1.862	.228	1.774	.227	0.975	50.3	2.23

TABLE 5-3 (continued)

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	INTAKE PRESSURE, IN. HG VACUUM					ENGINE RPM	
				MAXIMUM		AMPLITUDE		AVERAGE		
				Mean	Variance	Mean	Variance	in. Hg	Mean	Variance
1/11/74	2	PCV PLUGGED	24	6.503	.197	4.294	.171	4.356	132.0	2.73
		INTAKE BLOCKAGE 1/2 IN.	20	5.661	.189	4.448	.206	3.437	109.1	3.70
			16	4.675	.167	4.326	.191	2.512	78.9	3.63
			12	3.230	.159	3.248	.142	1.606	45.2	2.40
1/11/74	3R	PCV OK	24	3.902	.168	3.396	.172	2.204	141.8	2.97
		INTAKE BLOCKAGE 7/32 IN.	16	2.822	.172	2.650	.173	1.497	86.7	3.59
1/11/74	4	PCV PLUGGED	24	5.551	.184	4.092	.175	3.505	137.8	3.11
		INTAKE BLOCKAGE 7/32 IN.	20	4.777	.182	4.198	.195	2.678	112.6	3.82
			16	4.284	.200	4.180	.195	2.144	86.3	4.08
			12	3.103	.242	3.100	.242	1.553	50.1	5.19
1/11/74	7	PCV OK	24	3.613	.144	3.280	.192	1.973	138.6	2.44
		.165 IN. INTAKE LEAK	16	2.584	.160	2.426	.156	1.371	82.7	2.77
1/11/74	8	PCV PLUGGED	24	—	.242	4.324	.156	—	133.5	2.14
		.165 IN. INTAKE LEAK	16	—	.253	4.724	.227	—	78.9	3.18
1/11/74	9	PCV OK	24	3.723	.172	3.354	.161	2.046	137.1	11.38
		.060 IN. INTAKE LEAK	16	2.635	.121	2.532	.122	1.369	81.5	3.26
1/14/74	10	PCV PLUGGED	24	5.585	.247	4.212	.193	3.479	133.4	2.01
		.060 IN. INTAKE LEAK	16	3.961	.230	3.934	.227	1.994	77.4	2.18
1/14/74	NOM	NOMINAL ENGINE	24	4.539	.157	3.704	.151	2.687	138.1	1.87
1/14/74	12	PCV PLUGGED	24	6.664	.257	4.198	.177	4.565	137.2	1.43
			16	4.471	.157	4.358	.143	2.292	80.7	2.20
1/14/74	13	PCV OK	24	2.737	.122	2.660	.105	1.407	190.2	1.50
		THROTTLE = 95%	16	1.726	.126	1.724	.125	.864	79.9	1.92
1/14/74	14	PCV PLUGGED	24	3.868	.156	3.652	.155	2.042	135.4	2.20
		THROTTLE = 95%	16	2.754	.202	2.652	.191	1.428	78.8	2.03
1/14/74	15	PCV OK	24	2.831	.115	2.744	.114	1.459	141.5	1.24
		THROTTLE = 90%	16	1.785	.150	1.784	.150	.893	81.3	1.80

TABLE 5-3 (continued)

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	INTAKE PRESSURE, IN. HG VACUUM					ENGINE RPM	
				MAXIMUM		AMPLITUDE		AVERAGE		
				Mean	Variance	Mean	Variance	in. Hg	Mean	Variance
1/14/74	16	PCV PLUGGED	24	3.961	.129	3.762	.130	2.080	139.3	1.72
		THROTTLE = 90%	16	2.678	.199	2.760	.199	1.298	80.6	1.89
12/6/73	NOM	HOLE ENGINE - NOMINAL	24	4.358	.1473	4.316	.1372	2.200	123.3	5.46
		ENGINE COLD	18	5.596	.1544	3.592	.1546	1.800	89.9	4.59
		CRANKCASE NOT SEALED	12	2.272	.2724	2.268	.2701	1.138	48.6	3.80
			10	1.453	.1644	1.450	.1667	.728	33.4	3.94
12/6/73	NOM	HOLE ENGINE - NOMINAL	24	5.805	.1527	5.244	.0926	3.183	139.96	4.46
		ENGINE HOT	18	5.037	.1609	4.750	.1615	2.662	97.06	5.01
		CRANKCASE NOT SEALED	12	2.810	.3580	2.604	.3507	1.508	44.26	4.31
			10	1.683	.3252	1.450	.3221	.958	25.28	3.92

TABLE 5-3 (continued)

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	INTAKE PRESSURE, IN. HG VACUUM					ENGINE RPM	
				MAXIMUM		AMPLITUDE		AVERAGE		
				Mean	Variance	Mean	Variance	in. Hg	Mean	Variance
1/14/74	16	PCV PLUGGED	24	3.961	.129	3.762	.130	2.080	139.3	1.72
		THROTTLE = 90%	16	2.678	.199	2.760	.199	1.298	80.6	1.89
12/6/73	NOM	HOLE ENGINE - NOMINAL	24	4.358	.1473	4.316	.1372	2.200	123.3	5.46
		ENGINE COLD	18	5.596	.1544	3.592	.1546	1.800	89.9	4.59
		CRANKCASE NOT SEALED	12	2.272	.2724	2.268	.2701	1.138	48.6	3.80
			10	1.453	.1644	1.450	.1667	.728	33.4	3.94
12/6/73	NOM	HOLE ENGINE - NOMINAL	24	5.805	.1527	5.244	.0926	3.183	139.96	4.46
		ENGINE HOT	18	5.037	.1609	4.750	.1615	2.662	97.06	5.01
		CRANKCASE NOT SEALED	12	2.810	.3580	2.604	.3507	1.508	44.26	4.31
			10	1.683	.3252	1.450	.3221	.958	25.28	3.92

TABLE 5-4

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	CRANKCASE PRESSURE, PSIG						ENGINE RPM	
				MINIMUM		AMPLITUDE		MAXIMUM	AVERAGE		
				Mean	Variance	Mean	Variance	psig	psig	Mean	Variance
		HOLE ENGINE ALL CYLINDERS AT 70 PSI									
1/4/74	BL	BASELINE	24	.0079	.0008	.0216	.0008	-.0139	-.0031	110.2	2.22
1/4/74	7	PCV PLUGGED									
		.165 IN. INTAKE LEAK	24	.0096	.0006	.0220	.0007	-.0120	-.0011	112.4	2.27
			16	.0160	.0007	.0102	.0008	-.0044	.0007	72.7	1.26
1/4/74	8	PCV PLUGGED									
		.165 IN. INTAKE LEAK	24	.0108	.0008	.0182	.0008	-.0042	.0049	111.7	1.64
			16	.0195	.0005	.0101	.0004	-.0013	.0037	72.6	1.33
1/4/74	12A	PCV OK									
		THROTTLE = 95% CLOSED	24	.0149	.0010	.0226	.0015	-.0081	.0032	114.5	5.36
			16	.0192	.0007	.0102	.0004	-.0036	.0015	72.2	1.24
1/4/74	12B	PCV PLUGGED									
		THROTTLE = 95% CLOSED	24	.0188	.0007	.0195	.0006	-.0042	.0055	112.4	2.24
			16	.0215	.0004	.0096	.0002	-.0009	.0039	72.5	1.55
1/4/74	13A	PCV OK									
		THROTTLE = 85% CLOSED	24	.0132	.0005	.0194	.0008	-.0066	.0031	112.0	1.35
			16	.0173	.0003	.0092	.0004	-.0015	.0031	72.1	1.55
1/4/74	13B	PCV PLUGGED									
		THROTTLE = 85% CLOSED	24	.0160	.0005	.0198	.0004	-.0034	.0065	112.4	1.55
			16	.0177	.0006	.0096	.0005	-.0007	.0041	71.8	3.75
		NOMINAL ENGINE									
1/11/74		NOMINAL	24	.1516	.0023	.1592	.0017	-.0584	.0212	136.3	3.01
			20	.1667	.0031	.1588	.0033	-.0433	.0361	113.5	2.81
			16	.1852	.0037	.1522	.0030	-.0248	.0513	85.5	2.02
			12	.1957	.0034	.1398	.0016	-.0143	.0556	52.9	1.60
1/11/74	1	PCV OK									
		INTAKE BLOCKAGE 1/2 IN.	24	.0197	.0051	.1866	.0036	-.3205	-.2272	137.6	2.96
			20	.0823	.0038	.1964	.0034	-.2537	-.1555	114.2	3.20
			16	.1580	.0019	.2008	.0046	-.1780	-.0776	84.4	2.95
			12	.2350	.0023	.1822	.0066	-.1010	-.0099	50.3	2.23

Legend: Hole Engine - Hole in Cylinder Head

TABLE 5-4 (continued)

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	CRANKCASE PRESSURE, PSIG MINIMUM Mean	MINIMUM Variance	AMPLITUDE Mean	AMPLITUDE Variance	MAXIMUM psig	AVERAGE psig	ENGINE RPM Mean	ENGINE RPM Variance
1/11/74	2	PCV PLUGGED INTAKE BLOCKAGE 1/2 IN.	24	.1880	.0018	.1530	.0028	-.0220	.0545	132.0	2.73
			20	.1910	.0030	.1550	.0020	-.0190	.0585	109.1	2.70
			16	.1600	.0217	.1618	.0081	-.0500	.0309	78.9	3.63
			12	.1970	.0030	.1490	.0040	-.0130	.0615	45.2	2.40
1/11/74	3R	PCV OK INTAKE BLOCKAGE 7/32 IN.	24	.0460	.0076	.1820	.0026	-.2816	-.2816	141.8	2.97
			16	.1730	.0031	.1950	.0042	-.1630	-.0655	86.7	3.59
1/11/74	4	PCV PLUGGED INTAKE BLOCKAGE 7/32 IN.	24	.1900	.0024	.1498	.0022	-.0200	.0549	137.7	3.11
			20	.1890	.0023	.1514	.0016	-.0126	.0631	112.4	3.82
			16	.1910	.0021	.1510	.0031	-.0106	.0649	86.3	4.08
			12	.1980	.0035	.1482	.0038	-.0036	.0705	50.1	5.19
1/11/74	7	PCV OK .165 IN. INTAKE LEAK	24	.0890	.0055	.1834	.0026	-.2470	-.1553	138.6	2.44
			16	.1950	.0015	.1918	.0036	-.1410	-.0451	82.7	2.77
1/11/74	8	PCV PLUGGED .165 IN. INTAKE LEAK	24	.1820	.0028	.1498	.0022	-.0280	.0469	133.5	2.14
			16	.1940	.0031	.1498	.0038	-.0118	.0631	78.9	3.18
1/11/74	9	PCV OK .060 IN. INTAKE LEAK	24	.0890	.0024	.1898	.0182	-.2848	-.1899	137.1	11.38
			16	.1370	.0018	.1966	.0045	-.1528	-.0545	81.5	3.26
1/14/74	10	PCV PLUGGED .060 IN. INTAKE LEAK	24	.2411	.0023	.1482	.0197	-.0285	.0456	133.4	2.01
			16	.2608	.0031	.1546	.0035	-.0080	.0693	77.4	2.18
1/14/74	NOM.	NOMINAL ENGINE	24	.4294	.0058	.1880	.0022	-.4106	-.3166	138.1	1.87
1/14/74	12	PCV PLUGGED	24	.1822	.0023	.1554	.0016	-.0278	.0499	137.2	1.43
			16	.2012	.0023	.1538	.0036	-.0088	.0681	80.7	2.20
1/14/74	13	PCV OK THROTTLE = 95%	24	.0281	.0028	.1822	.0017	-.1987	-.1376	140.2	1.50
			16	.1189	.0028	.1854	.0027	-.0995	-.0068	79.9	1.92

TABLE 5-4 (continued)

INDUCTION SYSTEM CHARACTERIZATION

DATE	TEST NO.	DESCRIPTION	VOLTS	CRANKCASE PRESSURE, PSIG						ENGINE RPM	
				MINIMUM		AMPLITUDE		MAXIMUM	AVERAGE		
				Mean	Variance	Mean	Variance	psig	psig	Mean	Variance
1/14/74	14	PCV PLUGGED									
		THROTTLE = 95%	24	.2339	.0024	.1546	.0021	-.0181	.0592	135.4	2.20
			16	.2327	.0035	.1538	.0022	-.0025	.0744	78.8	2.03
1/14/74	15	PCV OK									
		THROTTLE = 90%	24	-.0042	.0015	.1802	.0028	-.2016	-.1115	141.5	1.24
			16	.1491	.0021	.1850	.0040	-.1029	-.0104	81.3	1.80
1/14/74	16	PCV PLUGGED									
		THROTTLE = 90%	24	.2742	.0028	.1554	.0045	-.0156	.0621	139.3	1.72
			16	.2037	.0045	.1500	.0050	-.0063	.0687	80.6	1.89
12/6/73	NOM.	HOLE ENGINE - NOMINAL	24	.1350	.0043	.1432	.0050	-.1002	-.0286	123.3	5.46
		ENGINE COLD	18	.1820	.0048	.1044	.0065	-.0658	-.0136	89.9	4.59
		CRANKCASE NOT SEALED	12	.2400	.0035	.0528	.0054	-.0204	.0060	48.6	3.80
			10	.2400	.0032	.0320	.0046	-.0120	.0040	33.4	3.94
12/6/73	NOM.	HOLE ENGINE - NOMINAL	24	.0950	.0028	.1252	.0033	-.0940	-.0314	135.9	4.46
		ENGINE HOT	18	.2230	.0024	.0912	.0041	-.0711	-.0255	98.1	5.01
		CRANKCASE NOT SEALED	12	.2200	.0040	.0380	.0056	-.0194	-.0004	44.3	4.32
			10	.2740	.0018	.0172	.0017	-.0116	-.0030	25.3	3.92

TABLE 5-5

IDLE PERFORMANCE CHARACTERIZATION

FACTORIAL TEST MATRIX

NUMBER	TIMING	IDLE SPEED	AIR/FUEL RATIO (IDLE CO)
1	0	0	0
2	-	+	-
3	0	-	+
4	0	+	0
5	0	-	0
6	0	-	-
7	+	-	0
8	+	-	-
9	+	0	+
10	0	0	+
11	0	0	0
12	0	+	+
13	-	-	-
14	-	-	+
15	-	0	0
16	-	0	-
17	-	0	+
18	-	-	0
19	-	+	+
20	+	0	-
21	0	0	0
22	-	+	0
23	+	+	-
24	+	0	0
25	+	-	+
26	0	+	-
27	+	+	0
28	0	0	-
29	+	+	+
30	0	0	0
	+ = 22° BTDC	+ = 700 rpm	+ = 6.0%
	0 = 6° BTDC	0 = 550 rpm	0 = 3.5%
	- = 10° ATDC	- = 450 rpm	- = 1.0%

TABLE 5-6

IDLE PERFORMANCE MATRIX

NOMINAL ENGINE

MATRIX TEST NO	CO %	RPM	IGNITION TIMING degrees	MAN VAC in Hg	VARIANCE RPM $\sqrt{rpm^2}$	VARIANCE PEX (NORM) $\sqrt{psi^2}$	VARIANCE PEX (AMP) $\sqrt{psi^2}$	MISFIRE PER 200 FIRINGS
1	3.5	542	6	17.70	464.1	.0500	.0523	2
2	1.0	688	-10	12.76	665.6	.0113	.0039	0
2	1.0	699	-10	12.79	739.0	.0157	.0056	0
3	6.0	456	6	17.57	825.7	.0102	.0112	0
4	3.5	683	6	18.03	507.2	.0447	.0174	0
5	3.5	450	6	17.72	467.9	.0049	.0037	1
6	1.0	455	6	16.81	1204.8	.0664	.1458	16
7	3.5	462	22	20.11	2850.3	.0270	.2185	21
8	1.0	450	22	ENGINE WOULD NOT RUN				
9	6.0	538	22	20.45	874.3	.0116	.0138	1
10	6.0	524	6	19.04	236.8	.0615	.0618	0
11	3.5	547	6	19.38	233.9	.0387	.0249	1
12	6.0	684	6	19.61	736.2	.0734	.0401	0
13	1.0	442	-10	15.64	803.0	.3606	.0965	7
14	6.0	434	22	14.30	6271.1	.2972	.0827	0
15	3.5	535	-10	16.90	434.5	.0250	.0085	0
16	1.0	532	-10	15.13	1772.8	.5053	.1282	2
17	6.0	536	-10	15.92	597.6	.0583	.0160	0
18	3.5	444	-10	16.50	324.8	.0236	.0039	1
19	6.0	677	-10	16.47	477.4	.0271	.0076	0
20	1.0	564	22	19.99	1372.7	.1017	.1833	25
21	3.5	549	6	19.42	245.0	.0245	.0112	0
22	3.5	670	-10	16.23	276.9	.0158	.0058	0
23	1.0	675	22	19.87	1274.5	.3705	.7486	29
24	3.5	565	22	20.56	455.3	.0379	.1163	10
25	6.0	462	22	20.84	336.5	.0124	.0031	0
26	1.0	668	6	19.01	561.3	.1398	.0389	0
27	3.5	665	22	20.56	524.4	.2339	.0710	2
28	1.0	559	6	18.73	498.2	.1102	.0347	0
29	6.0	671	22	20.38	1176.6	.0284	.0084	2
30	3.5	555	6	19.43	811.4	.0413	.0106	0

TABLE 5-7

IDLE PERFORMANCE MATRIX

90 PSI HEAD LEAK

(All Cylinders)

MATRIX TEST NO	CO %	RPM	IGNITION TIMING degrees	MAN VAC in Hg	VARIANCE			MISFIRE PER 200 FIRINGS
					RPM $\sqrt{rpm}^2$	PEX (NORM) $\sqrt{psi}^2$	PEX (AMP) $\sqrt{psi}^2$	
1	3.5	505	6	17.82	205.6	.0222	.0137	0
2	1.0	664	-10	13.99	344.5	.0173	.0045	0
3	6.0	498	6	17.50	328.3	.0621	.0165	0
4	3.5	660	6	18.87	416.3	.0789	.0251	0
5	3.5	452	6	17.51	526.2	.0079	.0043	1
6	1.0	441	6	15.54	2900.6	.4276	.2014	4
7	3.5	469	22	18.38	650.4	.0159	.0046	5
8	1.0	450	22	ENGINE WOULD NOT RUN				
9	6.0	570	22	18.37	403.7	.0263	.0277	0
10	6.0	529	6	16.83	439.6	.0310	.0087	0
11	3.5	568	6	17.25	770.8	.0229	.0141	0
12	6.0	663	6	17.15	242.0	.0753	.0282	0
13	1.0	450	-10	ENGINE WOULD NOT RUN				
14	6.0	450	-10	ENGINE WOULD NOT RUN				
15	3.5	558	-10	14.60	406.0	.0193	.0064	0
1	3.5	544	6	17.63	252.2	.0147	.0068	0
16	1.0	536	-10	12.60	350.8	.0532	.0196	0
17	6.0	539	-10	14.17	607.9	.0768	.0210	0
18	3.5	464	-10	14.11	409.0	.0370	.0119	0
18	3.5	464	-10	13.98	641.2	.0511	.0061	0
19	6.0	684	-10	14.81	464.0	.0356	.0133	0
20	1.0	582	22	18.49	2743.6	.1871	.3854	12
21	3.5	553	6	17.65	246.4	.0620	.0330	0
22	3.5	690	-10	14.27	257.1	.0215	.0064	0
23	1.0	704	22	18.83	954.2	.3413	.3121	7
24	3.5	588	22	19.27	466.5	.0156	.0169	5
25	6.0	426	22	17.67	306.7	.0127	.0083	0
26	1.0	664	6	16.76	541.8	.0764	.0259	3
27	3.5	723	22	19.77	1513.4	.0385	.0207	6
28	1.0	573	6	17.16	326.4	.0532	.0253	0
29	6.0	686	22	19.62	611.3	.0281	.0131	0
30	3.5	550	6	18.01	605.6	.0339	.0216	0

TABLF 5-8

IDLE PERFORMANCE MATRIX

EXHAUST VALVE LEAK ON 1 CYLINDER

COMPRESSION = 90 PSI

MATRIX TEST NO	CO %	RPM (PRED) rpm	IGNITION TIMING degrees	MAN VAC in Hg	VARIANCE RPM $\sqrt{rpm^2}$	VARIANCE PEX (NORM) $\sqrt{psi^2}$	VARIANCE PEX (AMP) $\sqrt{psi^2}$	MISFIRE PER 200 FIRINGS
1	3.5	521	6	12.00	809.0	.8408	.1118	0
2	1.0	671	-10	10.56	1010.9	2.4110	.8379	0
3	6.0	450	6	ENGINE WOULD NOT RUN				
4	3.5	700	6	DATA NOT AVAILABLE				
5	3.5	450	6	DATA NOT AVAILABLE				
6	1.0	464	6	12.80	819.8	.5280	.0756	0
7	3.5	465	22	13.12	513.7	.3896	.2726	0
8	1.0	450	22	ENGINE WOULD NOT RUN				
9	6.0	513	22	16.96	612.4	.5893	.0845	0
10	6.0	555	6	11.68	898.2	.7369	.2054	0
11	3.5	565	6	17.92	1155.6	.4540	.0422	0
12	6.0	676	6	13.12	1064.7	.9969	.1481	0
13	1.0	450	-10	ENGINE WOULD NOT RUN				
14	6.0	450	-10	ENGINE WOULD NOT RUN				
15	3.5	587	-10	11.04	602.8	1.4500	1.0400	0
16	1.0	574	-10	8.48	1416.2	1.2100	.8060	0
17	6.0	550	-10	ENGINE WOULD NOT RUN				
18	3.5	450	-10	ENGINE WOULD NOT RUN				
19	6.0	700	-10	ENGINE WOULD NOT RUN				
20	1.0	538	22	12.16	1723.4	.3425	.2174	0
21	3.5	540	6	11.68	948.7	2.2960	1.1250	0
22	3.5	701	-10	10.56	1081.3	.6325	.2305	0
23	1.0	699	22	13.28	1640.1	.7413	.2348	0
24	3.5	558	22	12.80	789.7	.3373	.2906	0
25	6.0	474	22	12.16	1403.9	.1926	.1565	0
26	1.0	684	6	12.64	1386.6	.5848	.2086	0
27	3.5	671	22	13.60	760.6	.6658	.4591	0
28	1.0	535	6	12.16	768.1	.3081	.2116	0
29	6.0	682	22	13.28	1165.4	.5475	.4038	0
30	3.5	543	6	12.48	865.0	.2471	.2029	0

TABLE 5-9

IDLE PERFORMANCE MATRIX

INTAKE VALVE LEAK ON 1 CYLINDER

COMPRESSION = 90 PSI

MATRIX TEST NO	CO %	RPM	IGNITION TIMING degrees	MAN VAC in Hg	VARIANCE RPM rpm^2	VARIANCE PEX (NORM) psi^2	VARIANCE PEX (AMP) psi^2	MISFIRE PER 200 FIRINGS
1	3.5	544	6	16.32	246.3	.2191	.1692	30
2	1.0	684	-10	13.60	629.8	.5190	.3483	35
3	6.0	483	6	14.72	1077.2	.1510	.3458	33
4	3.5	680	6	16.64	552.8	.3120	.4178	21
5	3.5	452	6	17.28	597.1	.1499	.2339	27
6	1.0	459	6	15.36	1364.6	.9493	.6337	38
7	3.5	462	22	16.32	557.3	.1426	.6902	35
8	1.0	450	22	ENGINE WOULD NOT RUN				
9	6.0	541	22	16.64	682.9	.2062	.8152	32
10	6.0	540	6	16.00	623.6	.1953	.5510	28
11	3.5	550	6	16.64	460.1	.2364	.3883	30
12	6.0	716	6	16.32	737.2	.3356	.8500	23
13	1.0	450	-10	ENGINE WOULD NOT RUN				
14	6.0	450	-10	ENGINE WOULD NOT RUN				
15	3.5	531	-10	12.80	400.4	.3568	.1256	18
16	1.0	525	-10	12.16	1377.8	.3831	.1526	42
17	6.0	541	-10	12.16	469.5	.5183	.1880	9
18	3.5	478	-10	12.80	729.1	.4085	.1458	35
19	6.0	689	-10	13.44	840.6	.5334	.1822	3
20	1.0	541	22	16.32	1965.8	.2925	.5757	52
21	3.5	558	6	16.00	716.5	.2345	.6657	44
22	3.5	688	-10	13.44	615.9	.6460	.1846	10
23	1.0	660	22	16.64	1520.8	.3410	.5161	50
24	3.5	540	22	17.60	833.9	.1907	.3484	38
25	6.0	468	22	15.36	888.1	.1407	.5993	40
26	1.0	681	6	16.00	771.4	.3878	.7954	36
27	3.5	673	22	17.44	850.2	.2754	1.1480	31
28	1.0	544	6	16.00	1452.7	.1664	.4692	33
29	6.0	692	22	17.28	1117.6	.2880	1.2360	28
30	3.5	542	6	16.00	383.5	.2168	.5894	33

TABLE 5-10

IDLE PERFORMANCE

ENGINE CONDITION	INTERCEPT	COEFFICIENTS						R^2	SEE
		A	B	C	D	E	F	$(psi)^4$	$(psi)^2$
NORMALIZED P_{EXH} S^2 = INTERCEPT + A(ICO) + B(ERPM) + C(TIMING) + D(ICO)(ERPM) + E(ICO)(TIMING) + F(ERPM)(TIMING)									
NOMINAL	0.28046	-7.1352E-3	-1.6470E-4	-2.4355E-2	-3.6839E-5	9.3098E-4	3.8643E-5	0.2896	0.1231
90 PSI HEAD LEAK	0.43487	-7.6468E-2	-5.6398E-4	2.4272E-3	1.0802E-4	-1.5212E-3	8.6220E-6	0.4308	0.0828
90 PSI EXHAUST	-.010960	.39798	1.9845E-3	-.10400	-7.1450E-4	3.2936E-3	1.0756E-4	0.4049	0.5687
90 PSI INTAKE	0.85180	-.20624	-6.8330E-4	6.0742E-3	3.1752E-4	-5.7658E-4	-1.8566E-5	0.4472	0.1582

ICO = IDLE CO (A/F RATIO), %

ERPM = ENGINE RPM, rpm

TIMING = IGNITION TIMING, degrees

TABLE 5-10 (continued)

IDLE PERFORMANCE

ENGINE CONDITION	INTERCEPT	COEFFICIENTS						R^2	SEE
		A	B	C	D	E	F	$(rpm)^4$	$(rpm)^2$
$RPM\ S^2$ = INTERCEPT + A(ICO) + B(ERPM) + C(TIMING) + D(ICO)(ERPM) + E(ICO)(TIMING) + F(ERPM)(TIMING)									
NOMINAL	1591.2	36.779	-1.1606	172.79	-.019517	6.5513	-.029104	0.3300	1075.9
90 PSI HEAD LEAK	4900.3	-970.35	-6.9275	44.333	1.5085	-9.8499	0.022945	0.5352	515.9
90 PSI EXHAUST	-330.34	135.50	2.5151	8.0356	-.32100	-.65206	0.001074	0.2716	354.8
90 PSI INTAKE	2528.3	-429.96	-2.4946	3.3679	0.59376	-2.0348	0.027545	0.4189	352.5

ICO = IDLE CO (A/F RATIO), %

EPRM = ENGINE RPM, rpm

TIMING = IGNITION TIMING, degrees

TABLE 5-11

IDLE COMPRESSION SURVEY

ICS TEST NO.	REMARKS & TYPE OF TEST	ENGINE RPM			EXHAUST PRESSURE VARIANCE, $(PSI)^2$		MISFIRE	TEST DATE
		MEAN, RPM	VARIANCE, $(RPM)^2$	VARIANCE/ $(RPM\ MEAN)^2$	NORMALIZED	AMPLITUDE		
N1	NOMINAL	571	554	.0017	.0605	.0330	0	1-7-74
1	#1 INT = 70 PSI	579	518	.0015	.4168	.2326	30	1-7-74
1A	#1 INT = 90 PSI	587	386	.0011	.2574	.2120	20	1-7-74
2	#1 & 3 INT = 70 PSI	588	818	.0024	1.0171	.3358	23	1-7-74
2A	#1 & 3 INT = 90 PSI	605	351	.0010	.6957	.1648	6	1-7-74
6R2	#1 & 3 EXH = 70 PSI	601	1515	.0042	1.4852	.4632	0	1-15-74
1R	#1 INT = 70 PSI	596	225	.0006	.0013	.0026	48	1-16-74
1AR	#1 INT = 90 PSI	585	241	.0007	.2276	.7293	21	1-16-74
2R	#1 & 3 INT = 70 PSI	602	601	.0017	.6338	.7460	39	1-16-74
4R	#1,2 & 3 INT = 70 PSI	591	706	.0020	.9187	.5134	10	1-16-74
5R	#1 EXH = 70 PSI	601	441	.0012	.7899	.3716	50	1-16-74
5A	#1 EXH = 90 PSI	578	490	.0015	.7858	.3061	48	1-16-74
5B	#1 EXH = 110 PSI	612	423	.0011	.8371	.4675	48	1-16-74
6R	#1 & 3 EXH = 70 PSI	646	805	.0019	1.3398	.3467	0	1-16-74
6B	#1 & 3 EXH = 110 PSI	633	774	.0019	1.0439	.3429	0	1-16-74
8B	#1,2 & 3 EXH = 110 PSI	591	1504	.0043	2.0225	.6861	6	1-16-74

LEGEND:
INT = INTAKE VALVE
EXT = EXHAUST VALVE

TABLE 5-12

IDLE COMPRESSION SURVEY

TEST NO.	DESCRIPTION OF TEST	INTAKE PRESSURE, IN. HG VACUUM						CRANKCASE PRESSURE, PSIG					
		AMPLITUDE		MINIMUM		MAXIMUM		AMPLITUDE		MINIMUM		MAXIMUM	
		Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
N1	NOMINAL	2.01	.0021	17.94	.0052	19.96	.0062	—	—	—	—	—	—
1	#1 INTAKE = 70 PSI	2.10	.0659	17.78	.0414	19.87	.0632	—	—	—	—	—	—
1A	#1 INTAKE = 90 PSI	1.93	.0449	19.17	.0548	21.11	.0365	—	—	—	—	—	—
2	#1 & 3 INTAKE = 70 PSI	2.04	.1275	15.94	.0543	17.97	.1169	—	—	—	—	—	—
2A	#1 & 3 INTAKE = 90 PSI	2.58	.0260	17.67	.0100	20.25	.0105	—	—	—	—	—	—
6R2	#1 & 3 EXHAUST = 70 PSI	2.47	.1804	11.52	.3628	13.99	.3749	.021	.123000	.092	.195805	.113	.377805
1R	#1 INTAKE = 70 PSI	1.72	.1355	18.42	.0903	20.14	.0535	.121	.002639	.045	.003439	.165	.000311
1AR	#1 INTAKE = 90 PSI	1.63	.0503	19.42	.0449	21.05	.0245	.019	.031627	.073	.031627	.092	0
2R	#1 & 3 INTAKE = 70 PSI	1.92	.0593	15.42	.0542	17.33	.0974	.058	.004249	.072	.006108	.130	.005663
4R	#1,2&3 INTAKE = 70 PSI	2.10	.1048	12.85	.1203	14.95	.1011	.057	.009224	.071	.015692	.128	.008836
5R	#1 EXHAUST = 70 PSI	2.06	.1806	16.64	.2533	18.71	.3131	.058	.005847	.084	.006210	.142	.002298
5A	#1 EXHAUST = 90 PSI	2.10	.1682	16.45	.2556	18.55	.3097	.061	.005963	.091	.006082	.152	.000736
5B	#1 EXHAUST = 110 PSI	1.95	.1618	16.54	.2273	18.49	.2766	.057	.003004	.086	.002269	.143	.000677
6R	#1 & 3 EXHAUST = 70 PSI	2.42	.2387	12.19	.3237	14.61	.3628	.054	.023905	.101	.052274	.155	.039421
6B	#1 & 3 EXHAUST =110 PSI	2.30	.1494	14.02	.3010	16.32	.3407	.030	.193034	.180	.303473	.211	.327016
8B	#1,2&3 EXHAUST =110 PSI	2.71	.1537	8.31	.2172	11.03	.2262	—	—	—	—	—	—

TABLE 5-13

IDLE ROUGHNESS TESTS

TEST NO.	REMARKS & TYPE OF TEST	ENGINE RPM			EXHAUST PRESSURE VARIANCE, $(PSI)^2$		MISFIRE	TEST DATE
		MEAN, RPM	VARIANCE, $(RPM)^2$	VARIANCE/ $(RPM\ MEAN)^2$	NORMALIZED	AMPLITUDE		
	NOMINAL							
2	A/F NOM., 6 BTDC	606.07	96.95	.000263	.0098	.0083	0	11-19-73
3	A/F LEAN, 6 BTDC	621.46	3455.20	.000052	.4851	.3823	10	11-19-73
5	A/F RICH, 6 BTDC	615.16	294.62	.000778	.1168	.0515	0	11-19-73
	#2 PLUG OUT							
7	A/F NOM., 6 BTDC	583.52	251.82	.000739	.1566	.6187	50	11-19-73
9	A/F LEAN, 6 BTDC	659.98	9512.85	.000007	.7444	.5953	54	11-19-73
11	A/F RICH, 6 BTDC	589.97	505.12	.001451	.5393	.4025	50	11-19-73
	NOMINAL							
13	A/F NOM., 22 BTDC	586.42	235.88	.000685	.0332	.0306	0	11-19-73
14	A/F LEAN, 22 BTDC	555.20	5609.17	.018196	.4222	.2181	50	11-19-73
15	A/F RICH, 22 BTDC	581.38	356.92	.001055	.2604	.2722	0	11-19-73
17	A/F NOM., 10 ATDC	585.88	88.70	.000258	.0157	.0061	0	11-19-73
18	A/F LEAN, 10 ATDC	630.21	236.30	.000594	.0295	.0104	0	11-19-73
19	A/F RICH, 10 ATDC	617.21	422.72	.001109	.0481	.0152	0	11-19-73
20	A/F NOM., 6 BTDC	575.80	113.12	.000341	.0388	.0277	0	11-19-73

TABLE 5-13 (continued)

IDLE ROUGHNESS TESTS

TEST NO.	REMARKS & TYPE OF TEST	ENGINE RPM			EXHAUST PRESSURE VARIANCE, $(PSI)^2$		MISFIRE	TEST DATE
		MEAN, RPM	VARIANCE, $(RPM)^2$	VARIANCE/ $(RPM\ MEAN)^2$	NORMALIZED	AMPLITUDE		
	NOMINAL							
1	A/F NOM., 6 BTDC	629.02	119.12	.000301	.0797	.0231	0	11-27-73
2A	A/F LEAN, 6 BTDC	652.29	3059.07	.007189	.4179	.1818	5	11-27-73
2B	A/F LEAN, 6 BTDC	612.26	782.39	.002087	.3156	.1228	5	11-27-73
2C	A/F LEAN, 6 BTDC	632.92	1366.70	.003411	.2034	.0857	5	11-27-73
4	A/F RICH, 6 BTDC	611.54	227.15	.000607	.1094	.0359	0	11-27-73
5	A/F RICH, 10 ATDC	540.75	769.89	.002632	.0565	.0146	0	11-27-73
6	A/F LEAN, 10 ATDC	606.10	6570.56	.017886	.2954	.0919	5	11-27-73
7B	A/F NOM., 22 BTDC	544.11	963.34	.003253	.0327	.1149	5	11-27-73
8	A/F RICH, 22 BTDC	526.29	272.86	.000985	.1428	.0706	5	11-27-73
9	A/F RICH, 22 BTDC	570.61	908.42	.002790	.3876	.3379	5	11-27-73
10	A/F LEAN, 22 BTDC	549.49	4970.59	.016462	.1272	.5513	5	11-27-73
11	A/F LEAN, 22 BTDC	523.46	741.47	.002705	.0469	.2776	5	11-27-73

AD-A117 265 TRW SYSTEMS GROUP REDONDO BEACH CA F/G 21/1
ATE/ICEPM DEVELOPMENT REPORT AND FUNCTION DEMONSTRATION TEST.(U)
JAN 75 G H GELB DAAE07-73-C-0268
UNCLASSIFIED TACOM-TR-11977 NL

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TABLE 5-13 (continued)

IDLE ROUGHNESS TESTS

TEST NO.	REMARKS & TYPE OF TEST	ENGINE RPM			EXHAUST PRESSURE		MISFIRE	TEST DATE
		PREDICTED		RPM VARIANCE/ $(RPM\ MEAN)^2$	VARIANCE, $(PSI)^2$			
		MEAN, RPM	VARIANCE, $(RPM)^2$		NORMALIZED	AMPLITUDE		
9N	NOMINAL	515	272	.0010	.0108	.0098	0	12-26-73
9	22 BTDC A/F RICH	567	461	.0014	.0958	.0567	5	12-26-73
10	22 BTDC A/F LEAN	496	2783	.0113	8.1626	2.3227	56	12-26-73
11	6 BTDC A/F RICH	552	422	.0014	.0029	.0018	30	12-26-73
12	6 BTDC A/F LEAN	509	1357	.0052	8.1769	2.0961	52	12-26-73
13	10 ATDC A/F RICH	586	143	.0004	.0203	.0061	0	12-26-73
14	10 ATDC A/F LEAN	562	9733	.0308	1.6806	.5072	18	12-26-73

TABLE 5-14

INDUCTION SYSTEM CHARACTERIZATION

TEST NO.	REMARKS & TYPE OF TEST	ENGINE, RPM			EXHAUST PRESSURE VARIANCE, $(PSI)^2$		MISFIRE	TEST DATE
		MEAN, RPM	VARIANCE, $(RPM)^2$	VARIANCE/ $(RPM\ MEAN)^2$	NORMALIZED	AMPLITUDE		
	ALL HOLES = 70 PSI							
BL	BASELINE	590	392	.0011	.0611	.0328	0	1-4-74
7A	PCV OK .165 IN. INTAKE LEAK	610	2280	.0061	.4378	.1765	35	1-4-74
8A	PCV PLUGGED .165 IN. INTAKE LEAK	594	1330	.0038	.3521	.2719	57	1-4-74
12B	PCV PLUGGED THROTTLE = 95% CLOSED	567	530	.0016	.0065	.0221	0	1-4-74
N1	NOMINAL	609	335	.0009	.0208	.0119	0	1-11-74
1	PCV OK INTAKE BLOCKAGE 1/2 IN.	611	338	.0009	.0721	.0308	0	1-11-74
2	PCV PLUGGED INTAKE BLOCKAGE 1/2 IN.	636	439	.0011	.0341	.0172	0	1-11-74
3R	PCV OK INTAKE BLOCKAGE 7/32 IN.	596	175	.0005	.0487	.0336	4	1-11-74
4	PCV PLUGGED INTAKE BLOCKAGE 7/32 IN.	656	887	.0021	.0684	.0302	1	1-11-74
7	PCV OK .165 IN. INTAKE LEAK	593	1099	.0031	.3211	.2156	67	1-11-74
8	PCV PLUGGED .165 IN. INTAKE LEAK	603	717	.0020	.5173	.2099	35	1-11-74
9	PCV OK .060 IN. INTAKE LEAK	589	276	.0008	.0319	.0320	0	1-11-74
N2	NOMINAL	599	285	.0008	.0228	.0092	0	1-14-74
10	PCV PLUGGED .060 IN. INTAKE LEAK	578	359	.0011	.0058	.0097	1	1-14-74
12	PCV PLUGGED	580	356	.0011	.0544	.0370	0	1-14-74

TABLE 5-14 (continued)

INDUCTION SYSTEM CHARACTERIZATION

TEST NO.	DESCRIPTION OF TEST	INTAKE PRESSURE, IN. HG VACUUM						CRANKCASE PRESSURE, PSIG					
		AMPLITUDE		MINIMUM		MAXIMUM		AMPLITUDE		MINIMUM		MAXIMUM	
		Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
	ALL HOLES=70 PSI												
BL	BASELINE	1.94	.0090	17.89	.0249	19.83	.0175	—	—	—	—	—	—
7A	PCV OK .165 IN. INTAKE LEAK	1.99	.0169	16.05	.4998	18.04	.4617	—	—	—	—	—	—
8A	PCV CLOSED .165 IN. INTAKE LEAK	2.19	.0885	15.64	.1534	17.83	.0681	—	—	—	—	—	—
12B	PCV CLOSED THROTTLE=95% CLOSED	2.13	.0333	18.31	.0034	20.44	.0242	—	—	—	—	—	—
N1	NOMINAL	1.70	0	21.08	0	22.78	0	.112	0	.047	.000237	.159	.000237
1	PCV OK INTAKE BLOCKAGE 1/2 IN.	1.91	.0200	20.40	0	22.31	.0200	.111	.000526	.041	.000526	.152	0
2	PCV PLUGGED INTAKE BLOCKAGE 1/2 IN.	2.04	0	20.40	0	22.44	0	.084	0	.072	0	.156	0
3R	PCV OK INTAKE BLOCKAGE 7/32 IN.	1.36	0	21.76	0	23.12	0	.056	0	.120	0	.176	0
4	PCV PLUGGED INTAKE BLOCKAGE 7/32 IN.	1.99	.0034	17.09	.0137	19.08	.0034	.066	0	.160	0	.226	0
7	PCV OK .165 IN. INTAKE LEAK	2.04	0	18.87	.0127	20.91	.0127	.054	.048488	.142	.066456	.196	.024958
8	PCV PLUGGED .165 IN. INTAKE LEAK	2.04	0	18.36	0	20.40	0	.112	.003544	.185	.004060	.297	.000892
9	PCV OK .060 IN. INTAKE LEAK	1.71	.0010	20.74	0	22.45	.0010	.060	0	.064	0	.124	0
N2	NOMINAL	1.74	.0041	21.17	.0154	22.90	.0129	.058	.001538	.094	.001569	.152	.000029
10	PCV PLUGGED .060 IN. INTAKE LEAK	1.93	.0038	19.36	.0351	21.29	.0324	.061	.001640	.235	.001492	.297	.000658
12	PCV PLUGGED	5.44	0	17.00	0	22.44	0	.024	0	.232	0	.256	0

TABLE 5-15

IDLE ROUGHNESS VARIANCES

(Unservicable Tests Only)

TEST DATE	TEST NO	TEST DESCRIPTION	VARIANCES: PREDICTED RPM (RPM)^2	VARIANCES: NORMALIZED EXHAUST PRESSURE (PSI)^2	MISFIRE
9-25-73	6	NOMINAL ENG. IDLE TEST MATRIX	1205	.07	16
	7		2850	.03	21
	13		1790	.36	7
	14		6271	.30	0
	16		1773	.51	2
	20		2288	.10	25
	23		1274	.37	29
9-26-73	27		1583	.23	2
	29		1176	.03	2
9-27-73	36	90 PSI HEAD LEAK IDLE TEST MATRIX	2885	.43	4
	37		650	.02	5
9-28-73	51		4769	.22	12
	54		954	.34	7
	55		467	.02	5
10-1-73	58		1513	.04	6
11-19-73	3Z	TIMING AND A/F RATIO VERIFICATION	3455	.48	10
	7Z		252	.16	50
	9Z		9513	.74	54
	11Z		505	.54	50
	14Z		5609	.42	50
	15Z		357	.26	0
11-27-73	2AY		3059	.42	75
	2BY		782	.32	75
	2CY		1367	.20	75
	6Y		6570	.30	75
	7BY		963	.03	75
	8Y		273	.14	75
	9Y		908	.39	75
	10Y		4970	.13	75
	11Y		742	.05	75

TABLE 5-15 (continued)

IDLE ROUGHNESS VARIANCES

TEST DATE	TEST NO	TEST DESCRIPTION	VARIANCES RPM $(RPM)^2$	VARIANCES NORMALIZED EXHAUST PRESSURE $(PSI)^2$	MISFIRE
1-4-74	7A	INDUCTION SYSTEM CHARACTERIZATION	2280	.44	35
	8A		1330	.35	57
1-11-74	7		1099	.32	67
	8		717	.52	35
1-7-74	1	IDLE COMPRESSION SURVEY TEST	518	.42	30
	1A		386	.26	20
	2		818	1.02	23
	2A		351	.70	6
1-15-74	6R2		1515	1.48	0
1-16-74	1R		225	.01	48
	1AR		241	.23	21
	2R		601	.63	39
	4R		706	.92	10
	5R		441	.79	50
	5A		490	.78	48
	5B		423	.84	48
	6R		805	1.34	0
	6B		774	1.04	0
	8B		1504	2.02	6
12-26-73	9	IGNITION CHARACTERIZATION TESTS	461	.10	5
	10		2783	8.16	56
	11		422	.03	30
	12		1357	8.18	52
	14		9733	1.68	18
12-13-73	8	ENGINEERING DESIGN TESTS	3040	.15	30
	13		814	.60	47
	24B		883	.77	60
	24G		2345	.75	59

TABLE 5-16

TIMING, MISFIRE AND AIR FUEL RATIO PERFORMANCE MATRIX

TEST NO	MATRIX TEST NO	MAX HP	INTERRUPTER RPM	TIMING degrees	MISFIRE %	A/F RATIO
70	1	53.6	3300	6B	0	NOM
71	2	35.6	2450	6B	25	NOM
72	3	54.4	3300	6B	0	RICH
73	4	38.0	2400	22B	25	RICH
74	5	28.4	2100	6B	25	LEAN
75	6	38.4	2500	22B	25	NOM
76	7	41.6	2800	10A	0	RICH
77	8	54.4	3200	6B	0	NOM
78	9	30.2	2150	22B	25	LEAN
79	10	15.5	—	10A	25	LEAN
80	11	42.0	2730	10A	0	NOM
81	12	28.8	1830	10A	25	RICH
82	13	28.0	1430	10A	25	NOM
83	14	48.0	3220	22B	0	LEAN
84	15	53.6	3200	6B	0	NOM
85	16	30.0	—	10A	0	LEAN
86	17	36.4	2470	6B	25	RICH
87	18	56.8	3370	22B	0	RICH
88	19	41.6	2970	6B	0	LEAN
89	20	56.7	3370	22B	0	NOM
90	21	54.4	3320	6B	0	NOM
73R	4R	38.4	2450	22B	25	RICH

LEGEND:

TIMING - B = BTDC
- A = ATDC

MISFIRE - 0 = NONE
25 = ONE PLUG SHORTED

A/F RATIO
RICH = 0.059 MAIN JET
NOM = 0.053 MAIN JET
LEAN = 0.049 MAIN JET

TABLE 5-17

WIDE OPEN THROTTLE PERFORMANCE MATRIX - NOMINAL ENGINE

DEPENDENT VARIABLE	INTERCEPT	COEFFICIENTS						R^2	SEE
		A	B	C	D	E	F		
WIDE OPEN THROTTLE PEAK HP	45.4	0.508*	-0.688*	1.03*	-0.006	-0.014	-0.004	0.8793	4.8
INTERRUPTER, RPM	3024.0	16.9*	-42.6*	13.1	0.16	0.05	0.34	0.9118	205

DEPENDENT VARIABLE = INTERCEPT + A(TIMING) + B(MISFIRE) + C(MAIN) + D(TIMING)(MISFIRE) + E(TIMING)(MAIN) + F(MISFIRE)(MAIN)

* Statistically significant at the 95% confidence level

TIMING = IGNITION TIMING, degrees

MISFIRE = MISFIRE PER 200 FIRINGS

MAIN = MAIN JET DIAMETER, inches**

** .049" = -4
.053" = 0
.059" = 6

TABLE 5-18

LOW COMPRESSION ENGINE

PEAK HP & INTERRUPTER RPM

TYPE OF COMPRESSION LEAK	TEST NO.	PEAK HP	INTERRUPTER RPM	REMARKS
HEAD	104	56.7	3260	ALL CYL. NOM
	105R	53.6	3270	CYL 2 = 70 PSI
	106R	57.1	3400	CYL 1 & 3 = 70 PSI
	107	52.8	3100	CYL 1,2,3 = 70 PSI
	108	55.2	3400	ALL CYL NOM
HEAD	109	56.7	3350	ALL CYL NOM
VALVE	110	55.2	3300	ALL CYL NOM
	111	52.8	3050	INTAKE 1,2,3,4 = 90 PSI
	112	56.4	3350	ALL CYL NOM
	113	55.2	3300	INTAKE 1 = 70 PSI
	114	54.4	3250	INTAKE 1 & 4 = 70 PSI
	115	54.4	3200	INTAKE 1 & 3 = 70 PSI
	116	52.0	3050	INTAKE 1,2,3,4 = 70 PSI
	119	43.2	2950	EXHAUST 1 = 70 PSI
	120	43.9	3130	INTAKE & EXHAUST 1 = 70 PSI
	121	34.7	2580	EXHAUST 1 & 3 = 70 PSI
	122	35.2	2720	EXHAUST 1 & 4 = 70 PSI
	123	15.2	—	EXHAUST 1,2,3,4 = 70 PSI
VALVE	124	54.4	3400	ALL CYL.NOM

TABLE 5-19

BATTERY TESTS

Initial State of Battery	Open Circuit Voltage	After 0.01 Minutes			After 10 Minutes		
		Voltage	Current	Battery Resistance	Voltage	Current	Battery Resistance
Fully charged, 20.5°C	25.7	21.8	132	0.0295	21.75	128	0.0308
1/2 charged, 19°C	24.0	20.0	122.5	0.0326	18.9	112.5	0.0453
Fully charged, 1.5° C	25.0	20.4	123.5	0.0372	20.3	121.5	0.0386
1/2 charged, 2.0°C	24.1	19.3	116.3	0.0412	18.6	111.45	0.0493

TABLE 5-20

COMPARISON OF POTENTIAL DIAGNOSTIC PARAMETERS
FOR DETECTION OF IGNITION MALFUNCTIONS

MALFUNCTION	PRIMARY SPARK LINE VOLTAGE		SECONDARY FIRING LINE VOLTAGE		SECONDARY SPARK LINE VOLTAGE		SECONDARY SPARK LINE DURATION	
	volts	percent	kv	percent	kv	percent	msec	percent
SHORT ROTOR	7	15	3.8	83	.4	36	- .6	24
POINT RESISTANCE-8 ohms	0	0	0	0	0.05	4	-1.05	42
POINT RESISTANCE-12 ohms	0	0	1.9	41	-0.05	4	-1.3	53
NO CONDENSOR	-15	-32			0	0	0.35	14
REDUCED VOLTAGE-18v	- 7	-15	3.4	73	0	0	0.45	18
REDUCED VOLTAGE-16v	- 8	-17	1.6	35	0.1	9	-0.8	33
REDUCED VOLTAGE-14v	-10	-22	0.4	8	0.1	9	-0.8	33
NOMINAL	46		4.6		1.1		2.45	

TABLE 5-21

ENGINEERING DESIGN TESTS

EDT TEST NO.	REMARKS & TYPE OF TEST	ENGINE RPM PREDICTED MEAN, RPM	ENGINE RPM PREDICTED VARIANCE, $(RPM)^2$	ENGINE RPM VARIANCE/ $(RPM\ MEAN)^2$	EXHAUST PRESSURE VARIANCE, $(PSI)^2$ NORMALIZED	EXHAUST PRESSURE VARIANCE, $(PSI)^2$ AMPLITUDE	MISFIRE	TEST DATE
--	NOMINAL	563	511	.0016	.0193	.0137	0	12-13-73
--	NOMINAL	556	136	.0004	.0354	.0191	0	12-13-73
20	NO CONDENSER	507	3040	.0118	.1524	.0659	30	12-13-73
21	CUT ROTOR	562	301	.0010	.0325	.0136	0	12-13-73
22A	PT GAP=.0025, -5°	858	96	.0001	.0179	.0063	0	12-13-73
22B	PT GAP=.0025, 6°	530	492	.0017	.0155	.0093	0	12-13-73
24	#4 ELECT. BROKEN OFF	568	344	.0011	.0122	.0123	0	12-13-73
24	#3 & 4 WIRES CROSSED	822	814	.0012	.6046	.0680	47	12-13-73
30	WET CRACKED DIS. CAP	536	314	.0011	.0110	.0070	0	12-13-73
36	GASKET LEAK #2 & 3	587	125	.0004	.0867	.0319	0	1-2-74
36	GASKET LEAK #2 & 3	564	181	.0006	.1115	.0776	0	1-3-74
43	ALL HOLE=85, NOM	553	203	.0007	.0325	.0150	0	1-4-74
43	ALL HOLE=85, 35° BT	703	2392	.0048	NA	NA	0	1-4-74
43	ALL HOLE=85, 10° AT	537	625	.0022	.0694	.0382	2	1-4-74
45	PTS=.003, PLG=.050	535	137	.0005	.0357	.0184	0	12-26-73
48	BAD ROTOR PLG=.050 #2 EX=35	723	883	.0017	.7741	.0615	60	12-26-73
48	GOOD ROTOR .160 INT. HOLE	715	2345	.0046	.7547	.0467	59	12-26-73

TABLE 5-22

ENGINEERING DESIGN TESTS

TEST DATE	TEST NO	PEAK HP	RPM of HP	FULL THROTTLE INTERRUPTER RPM: INTERRUPTER RPM	START-UP SLOPE msec/rpm	SHUT-DN SLOPE msec/rpm	
12-5-73	1	39.4	2500	2700	———	———	HOLE IN CARB DIAPHRAGM
	2	30.8	2500	2250	———	———	HOLE IN DIAPHRAGM - DIFFERENT ASSEMBLY
	3	53.9	4000	3200	———	———	CUT ROTOR .060 IN. ~ 12 VOLTS
12-10-73	4	38.5	3500	2500	———	———	CYL.1 INTAKE PUSHROD REMOVED
	5	31.6	3500	2740	———	———	ALL CYL. EXHAUST = 90 PSI
12-11-73	6	61.2	3500	3600	———	———	HOT RUN WITH NEW 10 WT OIL
12-12-73	7	55.2	3500	2950	.3000	———	ACCEL. PUMP PLUGGED. SLOW THROTTLE FEED.
12-13-73	8	53.6	3500	3100	.0172	.109	CAPACITOR OUT
	9	55.6	3500	3100	.0225	.110	ROTOR CUT OFF FLUSH
	10	56.4	3500	3100	.0185	.113	CRACKED DISTRIBUTOR CAP
	11	48.0	3500	3150	.0239	.095	POINTS = .0025, TIMING = 5° ATDC
	12	39.1	3000	2550	.0215	.112	WET CRACKED CAP, PLUGS = .050, HVY. MISFIRE
12-19-73	13	52.8	3500	3200	.0193	.110	PLUGS=.030, POINTS=.003, CUT ROTOR, RES= 4
12-20-73	14	45.7	4000	2800	.0167	.113	CYL.2 PLUG ELECTRODE CLOSED
	15	44.8	3500	2550	.0247	.105	SECONDARY WIRE FIRING IN AIR
1-4-74	17	44.8	3500	2700	.0290	.094	HOLED PIST., ALL CYL.=70 PSI, TIMING=24° ATDC
1-7-74	18	66.4	3500	3410	.0187	.112	NOMINAL HOLED PISTON ENGINE
	19	65.6	3500	3320	.0227	.091	INTAKE #1 = 70 PSI
	20	65.6	3500	3460	.0200	.115	INTAKE #1 = 90 PSI
	21	65.6	3500	3310	.0210	.110	INTAKE #1 & 3 = 70 PSI
	22	65.6	3500	3370	.0195	.113	INTAKE #1 & 3 = 90 PSI

TABLE 5-22 (continued)

ENGINEERING DESIGN TESTS

TEST DATE	TEST NO	PEAK HP	RPM of HP	FULL THROTTLE INTERRUPTER RPM: INTERRUPTER RPM	START-UP SLOPE msec/rpm	SHUT-DN SLOPE msec/rpm	
1-8-74	23	62.6	4000	3350	.0193	.108	INTAKE #1 & 4 = 70 PSI
	24	63.2	3500	3250	.0200	.107	INTAKE #1,2 & 3 = 70 PSI
	25	59.0	4000	3400	.0197	.108	EXHAUST #1 = 70 PSI
	26	48.0	3500	3190	.0225	.086	EXHAUST #1 & 3 = 70 PSI
1-11-74	27	23.1	2000	2100	.0240	.099	INTAKE BLOCKED TO 7/32 IN.

NOTE: INTERRUPTER START-UP SLOPE
$\overline{.0212} \pm .0060$ (28) msec/rpm

Table 5-23

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
1.	ELECTRICAL/BATTERIES	Batteries discharged to specific gravity less than 1.130; otherwise healthy.	U (Will not crank)	—	—	—	—	I_B Battery Current	Battery current less than 10 amps with starter button depressed.	Pre-test vehicle checkout should include hydrometer test of battery, to check for this common fault.
2.	ELECTRICAL/ BATTERY CABLES	Deteriorated cables and/or poor connections causing resistance of at least 2 ohms in circuit (series).	U (Will not crank)	—	—	—	—	I_B Battery Current	Battery current less than 10 amps with starter button depressed.	Assumes that pre-test vehicle checkout indicated normal specific gravity of battery electrolite.
3.	ELECTRICAL/STARTER	Grounded armature.	U (Will not crank)	—	—	—	—	I_B Battery Current	Battery current greater than 140 amps with starter button depressed.	Detection of this fault and quick release of starter button is necessary to avoid possible electrical fire hazard.
4.	ELECTRICAL/STARTER	Starter motor activates, but drive mechanism malfunction prevents engagement with flywheel gear.	U (Will not crank)	—	—	—	—	I_B Battery Current	Battery current will be non-oscillatory and very low level (less than 5 amps).	Fault can be simulated by removing starter drive pinion gear.
5.	ELECTRICAL/ STARTER SWITCH	Starter won't activate - open circuit.	U (Will not crank)	—	—	—	—	I_B Battery Current	No detectable battery current.	No current indicates open condition at switch or any point in circuit.
6.	ELECTRICAL/ ALTERNATOR	Not charging.	U	—	—	—	—	V_B Battery Voltage	Sees battery voltage ($\leq$25V) rather than 28V ± 1 with engine running.	Fault can be simulated by disconnecting regulator section (6 pin connector). See TM9-2320-218-20, Figure 2-23.
7.	ELECTRICAL/ ALTERNATOR	Excessive charging.	U	—	—	—	—	V_B Battery Voltage	Sees >30V with engine running.	Fault can be simulated by disconnecting ignition sensing lead No. 568. See TM9-2320-218-20, Figure 2-23.

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
8.	FUEL/SUPPLY	Reduction of fuel pressure from 5.0 – 5.5 psig (normal) to ~ 0.5 psig simulating partially clogged fuel supply system.	S	S	S	S	S	—	—	No measurable change in engine performance.
9.	FUEL/CARBURETOR	Lowered carburetor float level to lowest position without shutting off flow to simulate maladjusted or stuck float.	S	S	S	S	S	—	—	Performance was unaffected at any float level in laboratory with engine horizontal. No tests conducted with engine tilted.
10.	FUEL/CARBURETOR	Reduced main carburetor metering jet from 0.053 in. dia. (nom.) to 0.049 in. dia. to simulate partially clogged (lean) condition.	S	S	S	S	U	—	Traceable to the fuel system by process of elimination only.	>25% HP reduction. No interruption RPM recorded.
11A.	FUEL/CARBURETOR	Turned idle mixture screw clockwise until seated (i.e., idle fuel metering circuit closed) to simulate clogged idle circuit.	S	U	U	U	S	—	Traceable to the fuel system by process of elimination only.	Engine will not idle
11B.	FUEL/AIR INTAKE	Partially blocked air intake passage to air cleaner (filter) to simulate partially clogged and/or dirty filter.	S	S	S	S	U	—	Traceable to the fuel system by process of elimination only.	> 25% HP reduction results with >95% blockage of air inlet. PCV valve operable and connected.
12.	FUEL/CARBURETOR	Removed float and needle valve to simulate float sunk or stuck in the open position.	U (CWS)	—	—	—	—	—	Traceable to the fuel system by process of elimination only.	Engine tries to start initially but quickly floods. Hazardous test.
13.	FUEL/CARBURETOR	Plugged accelerator pump jet to simulate clogged condition.	S	S	S	S	S	—	(See Remarks)	Engine will stall or hesitate during acceleration on interrupter test.
14A.	FUEL/CARBURETOR	Turned idle mixture screw clockwise until rough idle occurred simulating maladjusted condition (lean).	S	S	U	U	S	—	(See Remarks)	52 engine misfires out of 200 (< 5 required for serviceability).
14B.	FUEL/CARBURETOR	Turned idle mixture screw counter-clockwise until rough idle occurred simulating maladjusted condition (rich).	S	S	U	S	S	—	(See Remarks)	30 engine misfires out of 200 (< 5 required for serviceability).

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAM-ETER	LOGIC	
				RPM	MISFIRE	ROUGH				
15.	FUEL/CARBURETOR	Choke in full on (closed) position to simulate stuck ON condition.	U (CWS)	—	—	—	—	P_I Intake manifold pressure.	Can be detected as a blockage upstream of the throttle butterfly.	Engine tries to start initially (cold) but quickly floods, then fails to start.
16.	FUEL/INTAKE MANIFOLD	0.165" dia. hole in intake manifold simulating leaking gaskets.	S	S	U	U	S	P_I Intake manifold pressure.	Reduction of manifold vacuum with throttle closed during cranking. (40%)	Has negligible affect on WOT HP.
17.	IGNITION/COIL	Disconnected primary ignition wire simulating open coil winding or open connection in circuit.	U (CWS)	—	—	—	—	V_P Primary voltage.	No voltage output indicates possible: o Disconnected or dead battery o Open or faulty ignition switch o Points closed, no crank. Steady voltage indicates possible: o Open coil primary winding o Open points, no crank o Points shorted to ground	Operator can observe if engine cranks when starter button is depressed. This will simplify fault detection logic. Also, secondary voltage (V_S) should be observed for no output condition to verify output condition of primary.
18.	IGNITION/COIL	Removed distributor rotor to simulate open secondary circuit.	U (CWS)	—	—	—	—	V_S Secondary voltage V_P Primary voltage	Verification of normal "make and break" cycling of primary with no secondary output indicates open coil winding. Response in secondary with high firing line peaks indicates no rotor, coil o.k.	Peak detector or suitable spark line magnitude and duration assessment device required to isolate this fault. V_S peaks 17 to 21 KV.

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
19.	IGNITION/CONDENSER	Shorted positive side of breaker points to simulate condenser shorted to ground.	U (CWS)	—	—	—	—	V_P Primary voltage. V_S Secondary voltage.	No voltage output from primary indicates possible: o Disconnected or dead battery o Open or faulty ignition switch o Points closed, no crank o Points shorted o Condenser shorted	See REMARKS for EDT Test No. 17 above.
20.	IGNITION/CONDENSER	Removed condenser to simulate open condenser condition.	S	U	U	U	U	—	Detection of this fault with igniter probe will be very difficult because waveform changes are very subtle.	Test engine would start repeatedly, but continued operation with this fault may cause severe point burning with resulting resistance increase and possibly a CWS condition.
21.	IGNITION/ROTOR	Cut off approximately .125 inch of rotor tip (flush with insulation) to simulate eroded (burned) condition.	S	S	S	S	S	V_P, V_S Primary and secondary voltage.	Both primary and secondary voltage traces increase by 50 to 80% for both spark line and firing line magnitudes.	Increase in voltage levels resulting from increased motor gap is comparable to voltages resulting from large spark plug gaps. Excessive arcing in cap may cause eventual shorting.
22A.	IGNITION/ BREAKER POINTS	Reduced point gap to approx. 2 - 3 mils to simulate excessively worn cam rubbing block. (Timing retards to approx. 5° ATC due to dwell increase).	S	S	S	S	S	—	—	Retarded condition causes ~ 14% decrease in HP from 56 to 48. Interrupter RPM from 3450 to 3150 although serviceable, overheating may cause problems.
22B.	IGNITION/ BREAKER POINTS	Reduced point gap to approx. 2 - 3 mils to simulate maladjusted points. (Timing at nominal spec. value of 6° BTC).	S	S	S	S	S	—	—	No detectable change in power output but excessive dwell may cause coil overheating during extreme conditions.

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
23.	IGNITION/ BREAKER POINTS	Inserted 12 ohms resistance in primary circuit (in series) to simulate worn out points (burned).	U (CWS)	—	—	—	—	I_P Primary current.	100% reduction in primary current.	Reduction in spark line duration results due to low energy input to coil, but firing and spark line magnitudes do not change measurably. Current is most significant change.
24.	IGNITION/SPARK PLUGS	Broke off one or more ground electrodes on spark plug(s) to simulate excessive gap condition.	S	S	S	S	S	—	—	Firing and spark line magnitudes increase with excessive plug gap but engine performance is unaffected.
25.	IGNITION/SPARK PLUGS	Bent spark plug gap closed on one cylinder, simulating defective plug or shorted plug wire.	S	S	U	U	U	P_E Exhaust pressure.	Cyclic misfire (as opposed to random) is best indication of shorted cylinder.	Shorted cylinder results in 38% decrease in HP. No significant change in secondary voltage trace due to rotor gap. Interrupter = 2600 - 2800.
26A.	IGNITION/ DISTRIBUTOR	Removed one, and both return springs on centrifugal advance mechanism to simulate failure.	S	S	S	S	S	—	—	Engine operates at full advanced position with both springs removed (including Idle). No measurable change in performance.
26B.	IGNITION/ DISTRIBUTOR	Repeated above test, both advance springs removed, but reset timing to Spec. 6° BTC at idle.	S	S	S	S	U	V_P or V_S Primary or secondary voltage.	Breaker point "make" and "break" events on either primary or secondary can be compared to P_I to detect no timing change at any RPM.	Engine timing is set at 6° BTC at Idle (dist. in full advanced position). Therefore, engine remains at 6° BTC at all RPM. At full throttle, torque reduces from 78 to 38 ft-lbs at 4000 RPM (51%) and interrupter drops from 3350 to 2850 RPM. Excessive backfire compared to above test.

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAM-ETER	LOGIC	
				RPM	MISFIRE	ROUGH				
27.	IGNITION/ DISTRIBUTOR	Retard timing from spec. of 6° BTC at 550 RPM to 10° ATC at 550 RPM to simulate maladjustment.	S	S	S	S	U	V_P or V_S Primary or secondary voltage.	Breaker point "make" or "break" events can be compared to P_I (manifold pressure) waveform to detect retard.	WOT performance (HP) drops ~ 27% for 10° ATC and ~ 47% for 16° ATC.
28.	IGNITION/ SECONDARY WIRES	Shorted one spark plug wire to ground to simulate worn or defective part.	S	S	U	U	U	Same as Test No. 25 above.	Same as Test No. 25 above.	Same as Test No. 25 above.
29.	IGNITION/ SECONDARY WIRES	Reversed secondary wires for cylinders 2 and 3 to simulate improper connections.	S	U	U	U	U	P_E Exhaust pressure.	Cyclic misfire (as opposed to random) is best indication of shorted or improperly connected wires.	Approximately 76% reduction in peak HP.
30.	IGNITION/ DISTRIBUTOR	Cracked distributor cap to simulate defective part.	S	S	S	S	S	—	———	Multiple random crack pattern throughout entire distributor cap had no measurable affect on engine performance.
31.	ENGINE/ INTAKE VALVE	Removed rocker arm and pushrod for intake valve of one cylinder simulating inoperative valve (closed).	S	S	U	U	U	P_I and P_E intake manifold and exhaust pressure.	Cyclic omission of every fourth vacuum depression on P_I trace indicates inoperative intake valve.	Approximately same HP reduction as shorted cylinder case on Test No. 25 above. (>25%) 50 ft-lbs at 4000 RPM. Interrupter = 2300 RPM.
32.	ENGINE/ INTAKE VALVE	Tightened valve lash adjustment on one cylinder until intake valve failed to seat, resulting in 70 psig compression at cranking RPM to simulate maladjusted or burned intake valve.	S	S	U	U	S	P_I intake manifold pressure.	Comparison of vacuum peaks during cranking indicates a reduction of about 50% for leaking cylinder.	Intake valve leak had no affect on HP: 82-83 ft-lbs at 4000 RPM interrupter 3350-3450. However, some apparent idle misfire and roughness occurs. $\frac{20\text{-}30}{200}$

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	FAULT/LIMITS	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
33.	ENGINE/ EXHAUST VALVES	Tightened valve lash adjustment on all cylinders until exhaust valves failed to seat, resulting in 90–100 psig per cylinder at cranking RPM to simulate all valves maladjusted or burned.	S (See Remarks)	U	U	U	U	I_S, RPM'S Starter current and RPM	Low compression on all cylinders results in reduced current and RPM increase for starter.	Engine would not idle below ~ 1000 RPM. HP reduced up to 50%. Interrupter RPM reduced from 3325 to 2400. Engine would not start after power tests (CWS).
34.	ENGINE/ EXHAUST VALVE	Tightened valve lash adjustment on one cylinder until exhaust valve failed to seat, resulting in >20 psig at cranking RPM.	S	S	U	U	U	P_E, P_I I_S, RPM'S	Very low compression on one cylinder shows up vividly on all parameters indicated, but not on P_C. (Crankcase pressure).	WOT of 75% of peak was interpolated from the following tests: Torque % Inter. Base-line 0 74 - 3350-3400 cyls. 1 60 -19 2950-3000 at 70 2 48 -35 2500-2600 psig 2 47 -36 2550-2750 (Exhausts open) 4 18 -76 No Data
35.	ENGINE/HEAD GASKET	Bled compression from one cylinder to atmosphere, resulting in 20–40 psig at cranking to simulate head gasket leak to outside of engine.	S			S	S	Same as above Test No. 34	Same as above Test No. 34	
36.	ENGINE/HEAD GASKET	Cut head gasket between two cylinders to simulate head gasket leak. Comp. leak between cylinders only, no coolant leaks permitted.	S	S	S	S	S	—	—	No measurable affect on engine performance.
37.	ENGINE/ PISTON RINGS	Installed orifices in piston domes to allow blowby into crankcase resulting in 70–75 psig in each cylinder at cranking RPM to simulate worn rings.	S	S	S	S	S	—	—	Engine performed satisfactorily but high blowby condition ruptured valve cover gasket and could eventually fail other seals and possibly clog PCV valve.
38.	ENGINE/CYLINDER	Fill cylinder with oil to simulate hydrostatic lockup condition. Blown head gasket to coolant passage.	NO TESTS CONDUCTED FOR THIS FAULT DUE TO RISK OF DAMAGING TEST ENGINE.							
39.	ALL	NONE	S	S	S	S	S	BASELINE AND NOMINAL SPECIFICATION TESTS OF NO-FAULT ENGINES CONDUCTED FOR EACH SERIES. SEE DATA.		

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	COMBINED FAULTS/LIMITS (TWO)	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
40.	ELECTRICAL/ BATTERY AND CABLES	Batteries discharged to specific gravity less than 1.130 and cable resistance greater than 2 ohms.	U (Will not crank)	—	—	—	—	I_B Battery current.	See Tests No. 1 and 2.	See Tests No. 1 and 2.
41.	ELECTRICAL/ BATTERY AND STARTER	Batteries discharged to specific gravity less than 1.130 and one starter brush removed.	U (Will not crank)	—	—	—	—	I_B Battery current.	See Tests No. 1 and 2.	See Test No. 1.
42.	ENGINE/ COMPRESSION IGNITION/ DISTRIBUTOR	Tightened exhaust valve lash on all cylinders to unseat valves and cause leakage down to 90 - 100 psig at cranking RPM. Timing retarted 16° to 10° ATC at idle RPM.	U (CWS)	—	—	—	—	I_S, RPM V_P, V_S	Low compression shows up as low starter current and increased RPM. Retarded timing is detected by comparing V_P or V_S events to P_I, intake pressure pulses.	Crank will not start (CWS) is caused primarily by valve leakage resulting in contamination of the A/F mixture as opposed to low compression or retarded timing. <u>See next test.</u>
43.	ENGINE/ COMPRESSION IGNITION/ DISTRIBUTOR	Installed orifices in piston domes to reduce cranking compression to 80 - 90 psig. Timing retarded 16° to 10° ATC at 500-600 (idle) RPM.	S	S	S	S	U	I_S, RPM V_P, V_S	Low compression shows up as low starter current and increased RPM. Retarded timing is detected by comparing V_P or V_S events to P_I, intake pressure pulses.	Slight idle misfire. HP (torque) and interrupter RPM data shows < 25% reduction but questionable. Refer to earlier test data for EDT Test No. 27 above.
44.	ENGINE/ COMPRESSION IGNITION/ DISTRIBUTOR	Same as above test but timing was advanced to 35° BTC.	S	U	S	S	U	I_S, RPM V_P, V_S	Low compression shows up as low starter current and increased RPM. Retarded timing is detected by comparing V_P or V_S events to P_I, intake pressure pulses.	RPM increased to 703. HP dropped from 60 to 45 (peak). Heavy pinging was experienced during WOT test.
45.	IGNITION/ PLUGS, POINTS	Excessive spark plug gaps of 0.050 and reduced breaker point gap of 0.003 inch, simulating worn ignition system in need of servicing.	S	S	S	S	S	—	—	Idle smooth, HP decrease of about 9% from baseline. Timing was ~ 3-4° ATC at 450 RPM.

Table 5-23 (Continued)

EDT TEST NO.	SYSTEM/COMPONENT	COMBINED FAULTS/LIMITS (THREE)	SERVICEABILITY					FAULT DETECTION		REMARKS
			START	IDLE			WOT	PARAMETER	LOGIC	
				RPM	MISFIRE	ROUGH				
46.	ELECTRICAL/ BATTERY CABLES STARTER	Tests 40 and 41 combined.	U (Will not crank)	—	—	—	—	I_B Battery current.	See Tests No. 1 and 2.	See Tests No. 1 and 2.
47.	IGNITION/ PLUGS POINTS ROTOR	Excess plug gaps of 0.050 inch simulating worn (eroded) condition. Added 8 Ω in series in primary circuit, simulating burned points. Cut off ~0.125 inch from rotor tip, simulating eroded condition.	U (CWS)	—	—	—	—	I_P Primary current.	8 Ω in primary reduces the primary current about 50% (from ~3.0 amps to 1.5 amps).	CWS is caused by low primary current which significantly affects spark plug behavior. Plugs fowl very easily.
48A.	IGNITION/PLUGS ENGINE/ VALVES AND MANIFOLD	Excess plug gaps of 0.050 inch simulating worn (eroded) condition. Tightened exhaust valve lash on all cylinders to unseat valves and cause leakage down to 90 - 100 psig at cranking RPM simulating burned valves. *Added 0.165 inch dia. hole to intake manifold simulating leak.*	U (CWS)	—	—	—	—	P_E, P_I, I_S, RPM	Low starter current and high cranking RPM plus low vacuum depressions on manifold pressure.	CWS caused primarily by exhaust valve leakage. See Test No. 33. See Alternate Test Below.
48B.	IGNITION/PLUGS ENGINE/ VALVE MANIFOLD	Same as above except one cylinder with leaking exhaust valve, other three with nominal compression and valve lash.	S	U	U	U	S	P_E, P_I, I_S, RPM	Cranking pressure and starter current and RPM waveforms will readily indicate weak cylinder.	Idle RPM increased to 715 RPM due to air leak. Rough idle. WOT HP reduced ~16% interrupter reduced from ~3300 to 3100 RPM.
49.	ENGINE/CYL. HEAD FUEL/CARBURETOR IGNITION/COIL	Leaking head gasket simulated by bleeding all cylinders to 70 psi using special-head orifices.	U (CWS)	—	—	—	—	I_S, RPM, I_P, P_I	Low compression detectable from starter RPM (Hi) and current (LO). Weak ignition detected from low primary current input.	Both excessively low compression coupled with weak ignition caused plug fouling, CWS.

Table 6-1 AUTO INSPECTION PROCEDURES

Display Message	Inspection Action
BATTRY LEVEL	Visually check electrolyte level in batteries
OIL LEVEL	Check engine oil level with dipstick.
OIL SYSTEM	Visually inspect for excessive oil leaks.
COOLNT LEVEL	Remove radiator cap and visually check coolant level.
COOLNT SYSTEM	Visually inspect radiator and water pump for leaks.
HOSES	Visually inspect coolant, vacuum, air intake, and fuel hoses for leaks or breaks.
DRIVE BELTS	Manually and visually check tension and general condition of accessory drive belts.
WIPER BLADES	Visually inspect blades.
GAUGES	Start engine and visually check for proper gauge response.
HORN	Press and listen.
PARKING BRAKE	Put vehicle in gear and test against slight vehicle power.
BRAKE TRAVEL	Press and check for excessive travel.
FUEL LEVEL	Check gauge for sufficient fuel for testing.
LIGHTS	Visually check all lights.
TIRES	Visually check for obvious damage or low pressure.
BRAKE LINES	Visually check for signs of leakage.
EXHST SYSTEM	Check for leaks.

Table 6-2 C2 - Cranking Data Stored

Parameter Name	Parameter Description
V_{BS}	Battery voltage before cranking.
V_P	Battery voltage at time of initial transients.
V_B	Average battery voltage during cranking (after initial transients).
I_P	Initial transient starter current peak.
I_A	Average battery current during cranking (after initial transients).
I_{MX}	Maximum battery current during cranking (after initial transients).
I_{MN}	Minimum battery current during cranking (after initial transients).
F	Number of points openings detected during C2.
S	Average steady state cranking speed.
V_{PL}	Primary voltage--low range (points closed).
V_X	Average open points voltage during cranking.
V_N	Minimum closed points voltage during cranking.

Table 6-3 C3 - Battery/Starter System Fault Isolation Tests

Fault Display	Fault Criteria	Calculations	Comments
BATTRY DISCH-ARGED!	$V_B < 16$ volts and $I_A < 110$ amps. or $V_{BS} < 16$ volts or $V_B < L_A$ volts and $I_A < 100$ amps	$L_A = 23 - 0.065 \lvert I_H \rvert$	L_A is voltage limit which has an internal battery resistance adjustment included.
BATTRY MARGI-NAL!	$V_B < 16$ volts and $110 < I_A < 140$ amps.		
STARTR SYSTEM FAULT!	$K_e \phi > 0.150$ or $R_p > 0.232\Omega$ and $K_e \phi < 0.150$ or $R_S > 0.8$ and $R_p < 0.232$ and $K_e \phi < 0.150$	$K_e \phi = \frac{0.752\left(V_B - I_A R_A\right)}{S}$ $R_p = \frac{U_p}{I_p}$ $R_S = \frac{V_{BS}}{I_A}$	Flux calculation assumes nominal armature resistance ($R_A = 0.122\Omega$). R_p is starter system resistance as calculated at initial cranking transient when back EMF is small since speed ≈ 0.

Table 6-3 (Continued) - Battery/Starter System Fault Isolation Tests (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
STARTR SYSTEM FAULT! (Cont.)	and $F = 0$ and Battery O.K.		
STARTR MOTOR FAULT!	$I_p > 140$ amps. or $I_A > 100$ amps and $R_p < 0.232\Omega$ and $I_p < 140$ amps and $F < 2$ and $I_{MX} > 140$ amps and $I_{MN} < 120$ amps or $K_e\phi > 0.150$ and $R_C < 0.02$ or $R_p > 0.232\Omega$ and $K_e\phi < 0.150$ and $R_C < 0.02$	$R_C = \frac{\left(V_p - V_{SP}\right)}{I_p}$	Fault isolation retest V_{SP} = Starter motor voltage at initial current peak. Fault isolation retest.

Table 6-3 (Cont'd) C3 - Battery/Starter System Fault Isolation Tests (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
STARTR DRIVE FAULT!	$R_S > 0.8$ and $R_p < 0.232$ and $K_e \phi < 0.150$ and $F = 0$ and Battery O.K. and $R_C < 0.02$		Fault isolation retest. Probably starter drive problem. R_S appears high, large back EMF term when starter spinning fast.
STARTR CABLS/ SWTCH!	Starter System Fault and $R_C > 0.02$		- Fault isolation retest.
TIGHT ENG/ST FAULT!	$I_A > 100$ amps and $R_p < 0.232$ and $I_{MX} < 140$ amps. or $I_{MN} > 120$ amps.		Partially grounded armatures and tight engines can look similar to system so they are combined in this fault.
STARTR CIRCIT OPEN!	$V_{BS} > 16$ volts and $I < 20$ amps. for 30 seconds.		Current never exceeded 20 amps within 30 seconds, so cranking was not sensed. Operator is questioned to see if he tried to crank engine.

*For parameter definitions see Table 6-2 in C2 section.

Table 6-4 C5 - Ignition Fault Isolation

Fault Display	Fault Criteria	Calculations	Comments
REVERS COIL POLAR!	$F = 0$ and $V_x > 15$ volts and $V_N > 0.3\ V_x$ and $V_N < 0.8\ V_x$		When the coil wires are reversed the signal sensed by the primary pickup in the ignitor probe is no longer the points voltage.
POINTS NEVER CLOSE!	$F = 0$ and $V_x > 15$ volts and no reversed coil fault		
COND/ POINTS SHORT!	$F = 0$ and $V_{PL} > 0.010$ volts and $V_x < 5$ volts and $(V_x - V_N) < 1$ volt		Points may be opening but this would not be detectable if the condenser was sufficiently shorted.
IGNITR INPUT PROBM!	$F = 0$ and ignitor input voltage found low by operator		The Set Communicator is used as a digital voltage meter by the mechanic to check this voltage
COIL/ BA RES FAULT!	$F = 0$ and no other faults found for $F = 0$ case		

Table 6-4 (Continued) C5 - Ignition Fault Isolation

Fault Display	Fault Criteria	Calculations	Comments
REVERS COIL POLAR!	$F = 0$ and $V_x > 15$ volts and $V_N > 0.3\ V_x$ and $V_N < 0.8\ V_x$		When the coil wires are reversed the signal sensed by the primary pickup in the ignitor probe is no longer the points voltage.
POINTS NEVER CLOSE!	$F = 0$ and $V_x > 15$ volts and no reversed coil fault		
COND/ POINTS SHORT!	$F = 0$ and $V_{PL} > 0.010$ volts and $V_x < 5$ volts and $(V_x - V_N) < 1$ volt		Points may be opening but this would not be detectable if the condenser was sufficiently shorted.
IGNITR INPUT PROBM!	$F = 0$ and ignitor input voltage found low by operator		The Set Communicator is used as a digital voltage meter by the mechanic to check this voltage
COIL/ BA RES FAULT!	$F = 0$ and no other faults found for $F = 0$ case		

Table 6-4 (Cont'd) C5 - Ignition Fault Isolation (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
POINTS /CAP FAULT!	> 2 Delayed Sparks		Data transferred directly from C4T1 as "DS"
POINTS FAULT!	Closed Point Voltage VPLA > 200 MVDC	$VPLA = \frac{VPC(1) + VPC(2) + \ldots + VPC(N)}{N}$ Average point voltage is a cumulative average of all measurements taken	Data transferred directly from C4T1 as "VPLA"
CACA-CITOR FAULT!	Points Open Voltage (VPO) $\neq$ Battery Voltage	$(V_B - V_{po}) > 2$ VDC = leaky or shorted cap	VPO is measured dynamically. 8 measurements are averaged to determine capacitor leakage voltage.
IG SW/ WIRE FAULT!	Ignitor Input Voltage $\neq$ Battery voltage with points closed	$\left(V_B - V_{IGIN}\right) > 2$ VDC = High Resistance to ignitor input	Engine kill is turned on to simulate closed point to insure current is flowing for this test
ROTOR FAULT!	Directed Visual Inspection		
IGNITR CAP FAULT!	Directed Visual Inspection or elimination of all other faults in individual cyl fault diagnosis		
COIL/ BALLST FAULT!	Elimination of all other faults in the all or most sparks short fault diagnosis		

Table 6-4 (Cont'd) C5 - Ignition Fault Isolation (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
COIL/ SCNDRY FAULT!	All or most sparks bad either high or low or long		Fall through from no other fault found with visual inspection of the ignitor assy.
#X (X = 1→4) PLUG FAULT!	Visual Inspection based on not getting 3 good sparks from "X" plug		Data transferred directly from C4T1 as "CYL"
#X CABLE FAULT!	SAME AS ABOVE		SAME AS ABOVE

Table 6-5 Spark Data

Parameter Name	Parameter Description
DS	Number of sparks delayed more than 200 usec in set of 8 sparks
VPLA	Cumulative average of closed point voltage from all sparks measured
SNC	Number of data set in which #1 Firing was detected (0 if none detected).
CYL1-CYL4	Number of good sparks detected for each cylinder
SD1-SD8	Spark duration for each of 8 sparks
VSL1-VSL8	Spark zone voltage for each of 8 sparks (measured 700 usec after point opening).

Table 6-6 Waveform and Parameter Characteristics

I_{MN}	Minimum Battery Current
I_{MX}	Maximum Battery Current
I_{MP}	Battery Current at Low Compression Peak
V_{AV}	Average Intake Manifold Vacuum
P_K	Maximum Blowby Pressure
P_{PK}	Largest Peak-to-Peak Blowby Pressure Variation
P_{PN}	Smallest Peak-to-Peak Blowby Pressure Variation
P_A	Ambient Pressure

Table 6-7 C8 - Engine/Fuel System Fault Isolation Tests

Fault Display	Fault Criteria	Calculations	Comments
RESTRD INTAKE PRBLM!	$V_{AV} > 10$ In. Hg.		High vacuum may be caused by completely closed throttle plate so throttle check, adjustment, and retest allowed.
INTAKE MANIFD LEAK!	$V_{AV} < 2$ In. Hg.		Low vacuum may be caused by excessively open throttle place (adjusted for high idle) so throttle check, adjustment, and retest allowed.
BLOCK FAULT!	$I_{MP} < L_C$ and $P_{PN} < 0.75\ (P_{PK})$	$I_{PP} = I_{MX} - I_{MN}$ $L_C = 0.75\left(I_{PP}\right) + I_{MN}$	I_{PP} = Maximum current variation during steady state cranking. L_C = Limit for detecting compression unbalance.
VALVE TRAIN FAULT!	$I_{MP} < L_C$ and No Block Fault Found and Valve Train Fault Found in Directed Inspection Test		

Table 6-7 (Continued) C8 - Engine/Fuel System Fault Isolation Tests (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
VALVE ADJUST FAULT!	$I_{MP} < L_C$ and No Block Fault Found and Valve Adjustment Fault Found in Directed Inspection Test.		
HEAD HD/GAS FAULT!	$I_{MP} < L_C$ and No Block Fault Found and No Faults Found in Directed Inspections.		
FUEL SUPPLY PROBM!	$H_C = 0$ and Fuel Supply Problem Found in Directed Inspection		$H_C =$ 0 for insufficient hydrocarbons sensed in exhaust after 20 seconds of cranking.
CARB-URETOR PROBM!	$H_C = 1$ or $H_C = 0$ and No Fuel Supply Problems Found in Pump Lines, or Filter in Directed Inspection.		$H_C =$ 1 for sufficient hydrocarbons sensed in exhaust after 20 seconds of cranking.

Table 6-8 Power Test Ignition Data

Parameter Name	Parameter Description
DS	Number of sparks delayed more than 200 usec in set of 8 sparks
VPLA	Cumulative average of closed point voltage from all sparks measured
SNC	Number of data set in which #1 Firing was detected (0 if none detected).
CYL1-CYL4	Number of bad sparks detected for each cylinder
SD1-SD8	Spark duration for each of 8 sparks

Table 6-9 Idle Ignition Data

Parameter Name	Parameter Description
DS	Number of sparks delayed more than 200 usec in set of 8 sparks
VPLA	Cumulative average of closed point voltage from all sparks measured
SNC	Number of data set in which #1 Firing was detected (0 if none detected).
CYL1-CYL4	Number of bad sparks detected for each cylinder
SD1-SD8	Spark duration for each of 8 sparks
VSL1-VSL8	Spark zone voltage for each of 8 sparks measured 700 usec after point opening.

Table 6-10 D12 - Idle Ignition Fault Isolation (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
COIL/ BALLST FAULT!	Elimination of all other faults in the all or most sparks short fault diagnosis		
COIL/ SCNDRY FAULT!	All 0 or most sparks bad, either high or low or long		Fall through from no other fault found with visual inspection of the ignitor assembly.
#X (X = 1 4) PLUG FAULT!	Visual Inspection based on getting > 7 bad sparks from "X" plug		Data transferred directly from D10 at "CYL"
#X CABLE FAULT!	SAME AS ABOVE		SAME AS ABOVE

Table 6-10 (Continued) D12 - Idle Ignition Fault Isolation

Fault Display	Fault Criteria	Calculations	Comments
POINTS FAULT!	Irractic points operation		Unable to take full set of spark data
POINTS /CAP FAULT!	> 2 Delayed Sparks		Data transferred directly from D10 as "DS".
POINTS FAULT!	Closed Point Voltage > 200 MVDC	$VPLA = \frac{VPC(1) + VPC(2) + \ldots + VPC(N)}{N}$ Average point voltage is a cumulative average of all measurements taken	Data transferred directly from D10 as "VPLA"
CAPA-CITOR FAULT!	Points Open Voltage (VPO) ≠ Battery Voltage	$V_B - V_{PO} > 2$ VDC = leaky or shorted capacitor	VPO is measured dynamically. 8 measurements are averaged to determine capacitor leakage voltage
IG SW/ WIRE FAULT!	Ignitor Input Voltage ≠ Battery voltage with points closed	$\left[V_B - V_{IGIN} > 2 \text{ VDC} \right]$ = High Resistance to ignitor input	Engine kill is turned on to simulate closed points to insure current is flowing for this test
ROTOR FAULT!	Directed Visual Inspection		
IGNITR CAP FAULT!	Directed Visual Inspection or elimination of all other faults in individual cyl fault diagnosis		

Table 6-11

CRANKING WAVEFORM AND PARAMETER CHARACTERISTICS

I_{MN}	**Minimum Battery Current**
I_{MX}	**Maximum Battery Current**
I_{MP}	**Battery Current at Low Compression Peak**
V_{AV}	**Average Intake Manifold Vacuum**
P_K	**Maximum Blowby Pressure**
P_{PK}	**Largest Peak-to-Peak Blowby Pressure Variation**
P_{PN}	**Smallest Peak-to-Peak Blowby Pressure Variation**
P_A	**Ambient Pressure**

Table 6-12 D13 - Engine/Fuel System Fault Isolation Tests

Fault Display	Fault Criteria	Calculations	Comments
RESTRD INTAKE PRBLM!	$V_{AV} > 10$ In. Hg.		High vacuum may be caused by completely closed throttle plate so throttle check, adjustment, and retest allowed.
BLOCK FAULT!	$I_M < L_C$ and $P_{PN} < 0.75\ (P_{PK})$	$I_{PP} = I_{MX} - I_{MN}$ $L_C = 0.75\ (I_{PP}) + I_{MN}$	I_{PP} = Maximum current variation during steady state L_C = Limit for detecting compression unbalance
VALVE TRAIN FAULT!	$I_{MP} < L_C$ and No Block Fault Found and Valve Train Fault Found in Directed Inspection Test		
VALVE ADJUST VAULT!	$I_{MP} < L_C$ and No Block Fault Found and Valve Adjustment Fault Found in Directed Inspection Test.		

Table 6-12 (Continued) D13 - Engine Fuel System Fault Isolation Tests (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
HEAD HD/GAS FAULT!	$I_{MP} < L_C$ and No Block Fault Found and No Faults Found in Directed Inspections		

Table 6-13 D19 - Power Ignition Fault Isolation

Fault Display	Fault Criteria	Calculations	Comments
POINTS /CAP FAULT!	>2 Delayed Sparks		Data transferred directly from D16 as "DS".
POINTS FAULT!	Closed Point Voltage >200 MVDC	$VPLA = \frac{VPC(1) + VPC(2) + \ldots + VPC(N)}{N}$ Average point voltage is a cumulative average of all measurements taken	Data transferred directly from D16 as "VPLA"
CAPA-CITOR FAULT!	Points Open Voltage (VPO) $\neq$ Battery Voltage	$V_B - V_{PO} > 2$ VDC = leaky or shorted capacitor	VPO is measured dynamically. 8 measurements are averaged to determine capacitor leakage voltage
IG SW/WIRE FAULT!	Ignitor Input Voltage $\neq$ Battery Voltage with points closed	$\left[V_B - V_{IGIN} > 2 \text{ VDC}\right]$ = High Resistance to ignitor input	Engine kill is turned on to simulate closed points to insure current is flowing for this test
ROTOR FAULT!	Directed Visual Inspection		
IGNITR CAP FAULT!	Directed Visual Inspection or elimination of all other faults in individual cyl fault diagnosis		

Table 6-13 (Continued) D19 - Power Ignition Fault Isolation (Cont.)

Fault Display	Fault Criteria	Calculations	Comments
COIL/ BALLST FAULT!	Elimination of all other faults or most sparks; short fault diagnosis		
COIL/ SCNDRY FAULT!	All or most sparks long		Fall through from no other fault found with visual inspection of the ignitor assembly.
#X (X = 1→4) PLUG FAULT!	Visual Inspection based on getting > 7 bad sparks from "X" plug		Data transferred directly from D16 "CYL"
#X CABLE FAULT!	SAME AS ABOVE		SAME AS ABOVE

Table 6-14 D23 - Engine/Fuel System Fault Isolation Tests

Fault Display	Fault Criteria	Calculations	Comments
RESTRD INTAKE PRBLM!	$V_{AV} > 10$ In. Hg.		High vacuum may be caused by completely closed throttle plate so throttle check, adjustment, and retest allowed.
BLOCK FAULT!	$I_{MP} < L_C$ and $P_{PN} < 0.75\ (P_{PK})$	$I_{PP} = I_{MX} - I_{MN}$ $L_C = 0.75\ (I_{PP}) + I_{MN}$	I_{PP} = Maximum current variation during steady state L_C = Limit for detecting compression unbalance
VALVE TRAIN FAULT!	$I_{MP} < L_C$ and No Block Fault Found and Valve Train Fault Found in Directed Inspection Test.		
VALVE ADJUST VAULT!	$I_{MP} < I_C$ $_{MP} < L_C$ and No Block Fault Found and Valve Adjustment Fault Found in Directed Inspection Test.		
HEAD HD/GAS FAULT!	$I_{MP} < L_C$ and No Block Fault Found and No Faults Found in Directed Inspections.		

Table 6-15

TUNE UP ROUTINE

Entry Number	Routine Name	Function	Transducers Required
10	OPTION LIST	To list all other routines available within Tune Up program and link to them if required.	
11	CARB. ADJST	To adjust carburetor idle mixture for maximum speed	Ignitor Probe
12	TIMING TEST & ADJST	To read out idle timing and aid in adjustment if required and to check advance mechanism	Ignitor Probe Intake Manifold Vacuum
20	SPEED DIS-PLAY	Tachometer	Ignitor Probe
21	DWELL DIS-PLAY	Dwell meter	Ignitor Probe
22	VOLTGE PROBE DSPLY	Voltmeter	Set Comm. Voltage Probes
23	CURRNT DIS-PLAY	Current Meter	Clamp-On Current
24	BATTRY VOLTGE DSPLY	Battery voltage meter	Battery Voltage Clips
25	POINTS VOLTGE DSPLY	Points voltage meter	Ignitor Probe
26	MANFLD VACUUM DSPLY	Vacuum gauge	Intake Manifold Vacuum
27	OIL TEMP. DSPLY	Oil Temperature gauge	Dipstick Oil Temperature Probe
28	BLOWBY PRESS. DSPLY	Crankcase blowby pressure gauge	Blowby Pressure
29	AMBNT PRESS. DSPLY	Ambient pressure gauge	(Internal)

REPORT DOCUMENTATION PAGE

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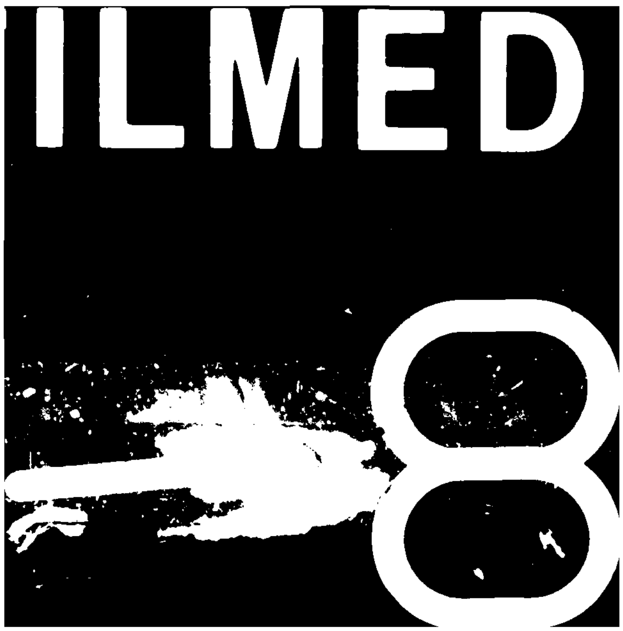
The Automatic Test Equipment for Internal Combustion Engines (ATE/ICE) system was brought to a functional demonstration state. Hardware improvements were made to allow diagnostic development. Diagnostic logic structures were developed for the M151A2 vehicle which utilized an experimental data base on the vehicle's engine. A diagnostic program was written and transcribed to magnetic cassettes. The ability of the system to isolate and identify over 20 engine malfunctions automatically was shown.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