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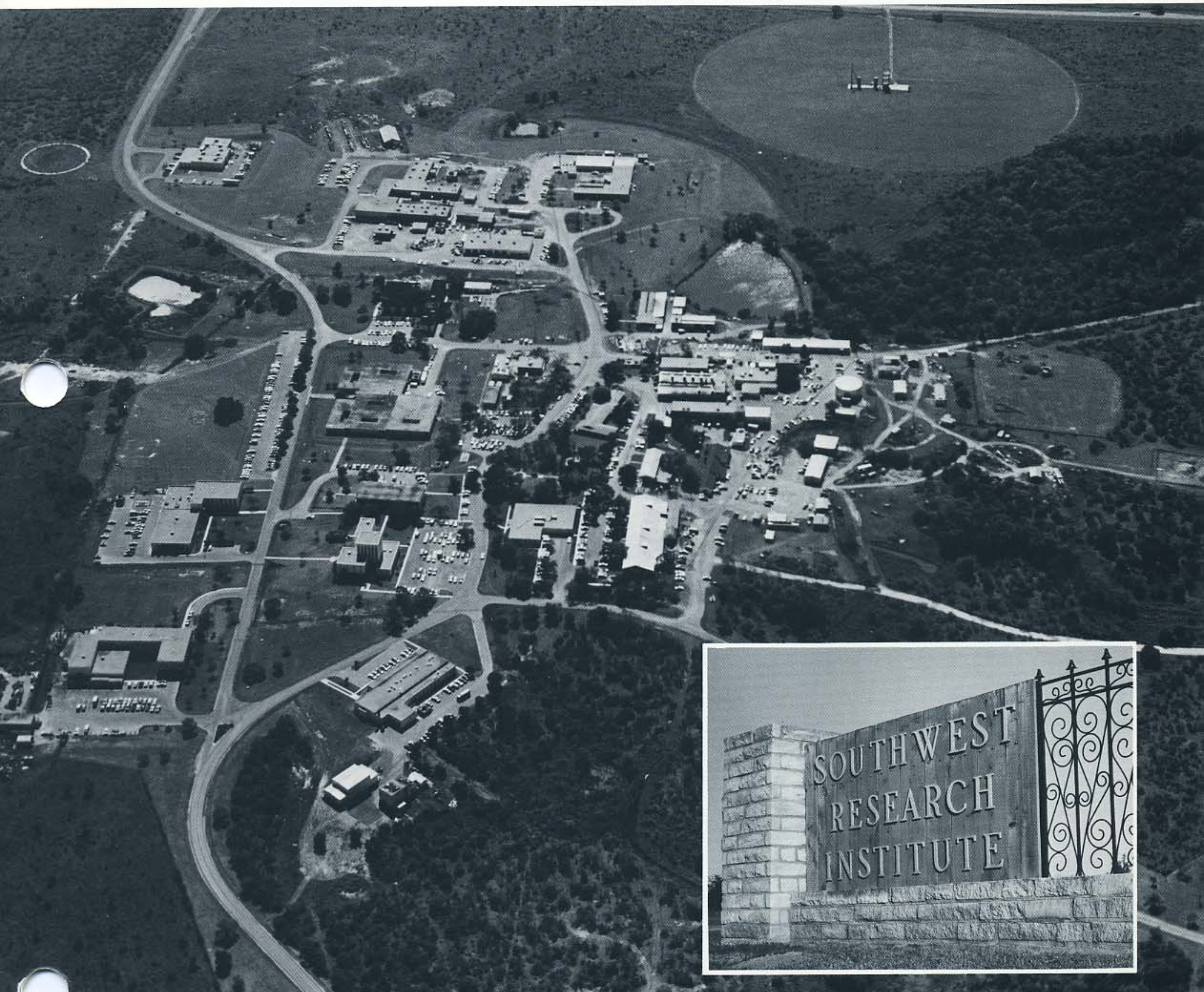
AUTOMATIC MEASUREMENT SYSTEMS
APPLICATIONS SERIES

An Automated Engine Laboratory in a Research Environment



A Solution to a Measurement Problem for SOUTHWEST RESEARCH INSTITUTE, San Antonio, Texas

An Automated Engine Laboratory in a Research Environment

In its own words, "Southwest Research Institute is a nonprofit corporation organized to work in the public interest in cooperation with industry, government, and individuals to produce a better way of life through science and technology". As one of the few large, non-governmental research institutes in the country, SwRI is well recognized as a significant contributor in virtually every area of scientific endeavor.

At the main institute facilities in San Antonio, Texas, SwRI concentrates its diverse efforts on applied research and development. Activities at the institute cover all the major scientific disciplines: biomedicine, electronics, mechanics, chemistry, physics, and social sciences. Some of the important fields of research within these disciplines include: applied electromagnetics, automotive research, bioengineering, instrumentation research, materials engineering, and structural research. Greatly aiding in the success of the institute is the fact that a tremendous amount of interdisciplinary cooperation exists among all levels, benefitting the institute by improving its reputation for accuracy and also the sponsors (more than 50 percent are industrial) of the various projects by providing very thorough evaluations upon which to base corporate judgments.

Typical of the reasons why SwRI maintains its excellent reputation and acceptance with industry and government is the methodical care exercised in the institute's engine, fuel, and lubricant projects. Every engine received for service is disassembled, thoroughly inspected, and reassembled to assure that an unspecified engine condition will not present any degradation to lubricant and other types of evaluations conducted. A continuous program of maintenance and rebuild work not only maintains the engines at original factory condition, but has provided engines which are now in fact precision instruments.

Figure 1. In the computer lab, data acquisition, software development, and general engineering calculations are being handled on a simultaneous basis.

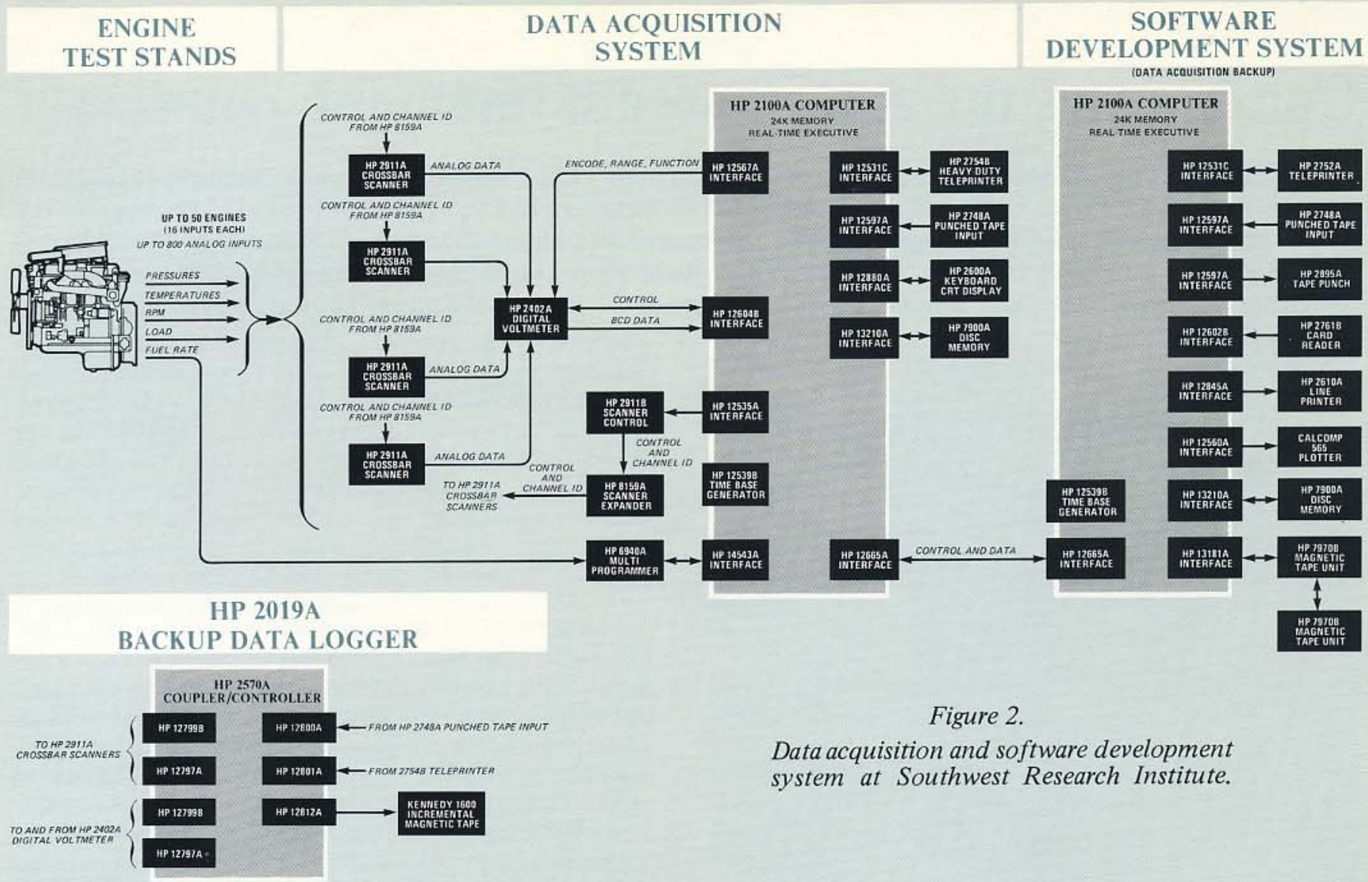


Figure 2.

Data acquisition and software development system at Southwest Research Institute.

Measurements – A Basic Tool

Basic to the nature of the work being conducted, and underlying every research, development and evaluation effort is the need to measure and record numerous variables affecting the desired end product. The fruits of modern technology – new materials, new products, etc. which must be evaluated – have created additional needs for better, faster, and more accurate measurement techniques.

While every department is engaged in varying degrees of measurements, these needs are particularly evident in the Engines, Fuels, and Lubricants Department where evaluations are made of physical and chemical properties of fuels, lubricants, additives, hydraulic oils, automatic transmission fluids, and antifreeze compounds. The department performs a variety of diesel and gasoline engine evaluations, and light and heavy-duty dynamometer evaluations 24 hours/day, 364 days/year. The broad range of activities includes: vehicle road fuel economy, engine and gear lubricant performance, engine octane requirements, tire wear and performance characteristics, hydrocarbon emission studies, and many other performance and endurance qualification programs. Operating such a comprehensive research and evaluation program requires measurement systems that are suitable and adequate to handle large amounts of data.

The Need for Automation

Traditionally, SwRI Department of Engines, Fuels, and Lubricants conducted automotive engine lubricant product analyses by reading analog meters, recording the readings, calculating averages, and plotting the results – all manually. While this was the best available method for acquiring data, it was relatively slow and subject to possible errors from human interpretation.

A few years ago, the department recognized that manual methods would not be able to adequately cope with the projected future workload and would not be capable of providing the accuracy and repeatability demanded by its sponsors. The decision was considerably influenced by present and impending federal statutes regulating such factors as passenger car safety and permissible levels of exhaust pollutants. For example, greater loads placed on engines by certain types of anti-pollution devices have prompted development of suitable lubricant additives to help maintain proper operation. This, in turn, means more in-depth evaluations must be conducted before the products can be recommended by a refiner or vehicle manufacturer.

The need for automation was then well established. Long-range plans were formulated for automating operations wherever specific benefits from automation could be realized. Accordingly, Southwest Research Institute chose its single-cylinder Caterpillar engine laboratory facility for the first-phase upgrading to automation. A Hewlett-Packard sensor-based computerized data acquisition system, shown in Figures 1 and 2, was selected.

Configuring the Automated System

Although this was a different and unique problem for SwRI, previous experience was brought to bear and its own in-house engineering staff was called on to design the physical layout of the automated system. An example of the engineering thoroughness can be seen in the transducer cabling termination panel in Figure 3. Here, the entire 800 lines, from the 50 Caterpillar engines, are brought into the computer lab fully identified and with connector terminals. All cabling is routed from the engine laboratory through ceiling ducts to the termination panel.

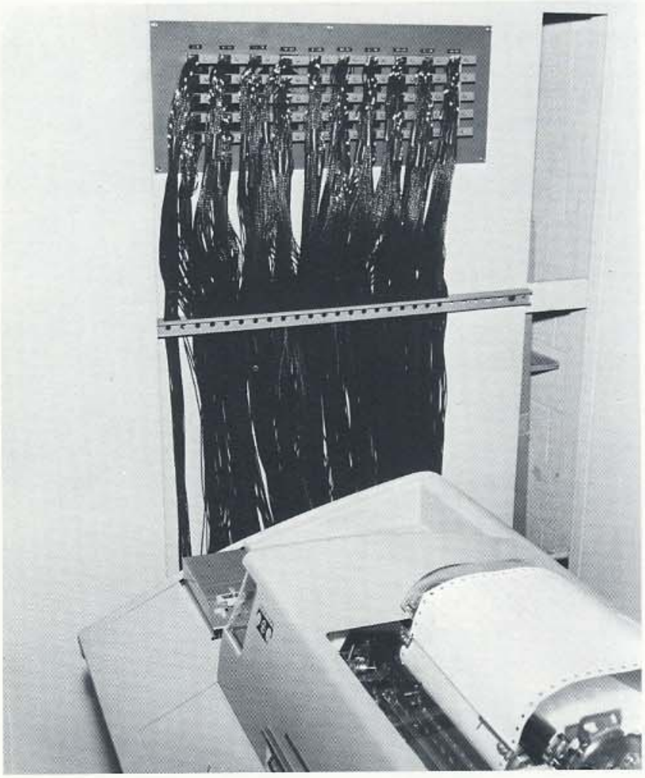


Figure 3. The 800-line input termination panel is indicative of the good engineering practices employed by SwRI in all phases of the computer system installation.

Inside the computer lab are three systems: (1) a computerized data acquisition system which performs the data acquisition and analysis functions, (2) a software development system which is used for software development purposes and also as a general-purpose computer handling a variety of computational needs for personnel from any department in the institute. As a secondary function, this system also acts as backup for the data acquisition system in the event its computer is out of service, and (3) a manually-programmable data logging system which backs up both computer systems. If both computers are out of service, this system will record raw measurement data on magnetic tape for subsequent off-line computer analysis.

At the heart of the data acquisition system is an HP 2100A Computer with 24K 16-bit words of memory. The heavy-duty teleprinter is used for general purposes of communication with the system and also for printing out test measurement data. The punched tape input is used to read programs, data, long edit files, etc. into the system. By means of the keyboard CRT display terminal, an engine operator or supervisor can request the computer to display all operating data for any engine under evaluation to check its status at any time. The disc memory is used for temporary storage of measurement results which are subsequently transferred to magnetic tape for permanent storage. The scanner control unit performs control and input channel selection for the four crossbar scanners. The scanner expander allows the single scanner control unit to handle all four crossbar scanners. The digital voltmeter converts the analog inputs to digital form compatible with the computer.

The data acquisition system communicates with an identical computer in the software development system over a data communications line with appropriate interfaces. The card reader is used for program preparation purposes. The line printer is the main hard-copy printout device for the system and is used for printing historical data, hourly average reports, etc. from magnetic tape or disc. The plotter provides X-Y plots of data for comparisons, trends, and other engineering purposes. The disc memory is the principal storage medium for most of the recurring programs used by other departments in the institute, and also provides temporary data storage. Programs are swapped from disc into computer core memory for execution and then returned to disc for storage. All measurement data are converted to maximum-minimum-average values for each of the appropriate parameters, and placed in permanent storage on magnetic tape.

The backup data logger consists of an HP coupler/controller and an incremental magnetic tape unit. In the event both computers are out of service, the coupler/controller will assume control of the scanners and digital voltmeter. The raw measurements will then be recorded on magnetic tape for subsequent computer analysis. Header and other pertinent information can be added to the operational data from the teleprinter keyboard or punched tape input. The coupler/controller controls input and output operations through self-contained internal programming or external programming by means of the teleprinter keyboard.

Flexibility for Multiple Use

The data acquisition system is under control of the HP real-time executive (RTE) software operating system with foreground-background and multiprogramming capabilities. The RTE allows SwRI to operate multiple engine stands *on-line* and on a *simultaneous* basis. The multiprogramming capability makes it possible to conduct several different evaluation procedures at the same time.

For example, some engines may be running a 1-D* procedure, some running a 1-G* procedure, and others running a 1-H* procedure. While operational, any program parameter can be modified (in the background area of core) by calling that parameter and typing in the changes on the teleprinter without recompiling or disturbing the data acquisition sequence. The computer performs conversions on-line to convert analog transducer signals to engineering units. Thus, corrected data are available immediately, without waiting for subsequent off-line reduction.

The software development system is also under control of an HP RTE software operating system, which means it too functions in a foreground-background multiprogramming environment. SwRI is very successfully utilizing the power of the real-time executive software to make this a truly flexible system. While its primary mission is for development of new and improved research programs, it is always ready to assume the data acquisition function, on a standby basis in the event of computer failure, and it also performs as a general-purpose computer for scientists, engineers, and non-technical users in the institute. Since all programs are run on a priority basis, and because of the large core memory and disc memory storage, an engineer, for example, can run his program concurrently with a programmer who may be debugging a new routine and concurrently with transfer of data from disc to magnetic tape, without disturbing or even being aware of the other transactions.

The real-time executive can be programmed in FORTRAN, Assembly, or ALGOL language. Most of the programming for data acquisition and software development is done by SwRI programmers in Assembly language for maximum core efficiency. Others usually do their programming in the more familiar FORTRAN language.

** 1-D, 1-G, and 1-H are Federal Test Method Std. 791B, Methods 340.3, 341.3, and 342.3, respectively.*

Engine Operation

A portion of the 50 Caterpillar engines evaluating fuels and lubricants under control of the automated system is shown in Figure 4. Conceivably, all of the engines could be under evaluation simultaneously; however, this is not usually the case, since some would normally be shut down due to maintenance or changeover to another program sequence. The system is designed to account for all operating time, thus an accurate record is maintained which can be analyzed for all periods including shutdowns. At the present time, six different types of evaluations are being run, either all at the same time or only a few, depending upon the current requirements. Specifications for these evaluations are stored in the data acquisition system computer memory.

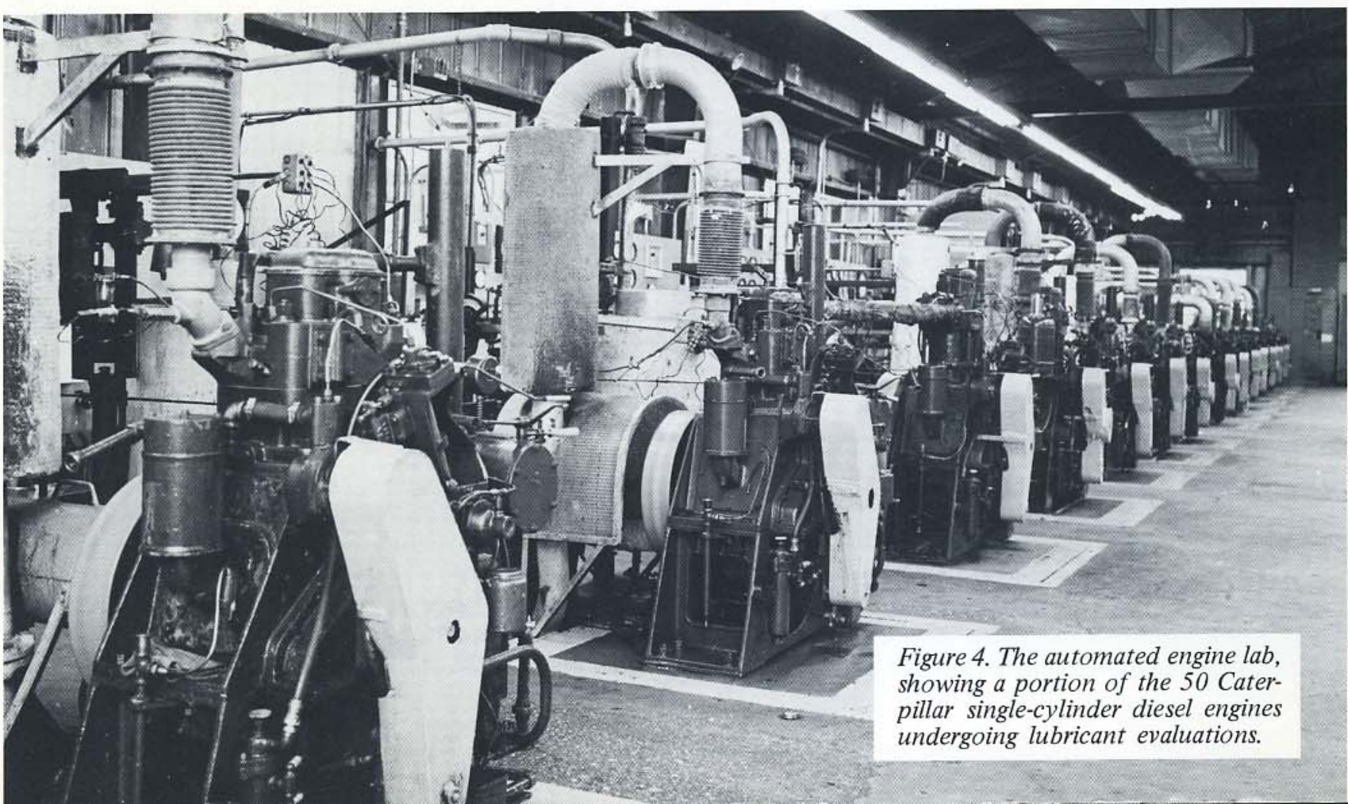


Figure 4. The automated engine lab, showing a portion of the 50 Caterpillar single-cylinder diesel engines undergoing lubricant evaluations.

```
*ON,PSTAT,A
ENGINE NO. A
CHAN. NO.  00  WATER OUT TEMP.         0159
CHAN. NO.  01  WATER IN TEMP.          0147
CHAN. NO.  02  OIL TEMP.               0177
CHAN. NO.  03  INTAKE AIR TEMP.        0169
CHAN. NO.  04  EXHAUST TEMP.           1090
CHAN. NO.  05  RPM                     1808
CHAN. NO.  06  LOAD                    0074
CHAN. NO.  07  OIL PRESSURE            0297
CHAN. NO.  08  FUEL PRESSURE           0019
CHAN. NO.  09  INTAKE AIR PRESSURE     0398
CHAN. NO.  10  EXHAUST PRESSURE        0005
```

Figure 5(a)

Engine measurement parameters from a typical engine printed out on-line. Readings on far right are actual measured values.

```
1044 ENG. B  00  0184  MIN.  0185
1050 ENG. B  00  0182  MIN.  0185
1056 ENG. B  02  0174  MIN.  0175
1056 ENG. B  00  0183  MIN.  0185
1056 ENG. B  01  0174  MIN.  0175
```

Figure 5(b)

On-line printout examples showing out-of-limits conditions on two engines. The top line shows parameter 00 (Water out temperature is 1° below minimum value of 185°F.

```
                         HOURLY AVERAGE REPORT
              ENGINE NUMBER C  TEST NUMBER XYZ  TEST TYPE 1-D
         RUN  WATER WATER OIL   AIR   EXH                   OIL   FUEL  AIR   EXH
DAY TIME TIM   OUT   IN   TEMP  TEMP  TEMP  RPM   LOAD  PRES  PRES  PRES  PRES
044 1057 163  0200  0184  0177  0202  1006  1194  0142  0298  0021  0443  0004
          HI  0202  0186  0181  0204  1015  1196  0143  0301  0022  0446  0004
          LO  0198  0183  0175  0201  1000  1194  0142  0295  0020  0440  0004
044 1157 164  0201  0185  0176  0202  1010  1195  0143  0299  0022  0444  0004
          HI  0202  0187  0179  0204  1015  1198  0144  0301  0022  0446  0004
          LO  0200  0184  0173  0200  1005  1194  0143  0298  0022  0442  0004
044 1257 165  0200  0185  0174  0202  1006  1194  0143  0299  0021  0444  0004
          HI  0202  0187  0178  0204  1013  1196  0144  0302  0022  0445  0005
          LO  0199  0184  0172  0201  1000  1194  0143  0297  0019  0443  0004
044 1357 166  0200  0184  0177  0200  1003  1194  0143  0297  0021  0443  0004
          HI  0202  0186  0180  0204  1008  1195  0144  0299  0022  0445  0005
          LO  0199  0183  0173  0195  1001  1193  0142  0294  0019  0442  0004
044 1457 167  0200  0184  0176  0198  1016  1194  0145  0297  0022  0442  0004
          HI  0201  0186  0180  0201  1033  1196  0147  0301  0022  0443  0005
          LO  0199  0182  0172  0196  1008  1193  0144  0293  0022  0441  0004
044 1557 168  0200  0184  0174  0198  1020  1193  0145  0299  0022  0442  0004
          HI  0201  0185  0178  0201  1042  1195  0146  0303  0022  0443  0004
          LO  0199  0183  0170  0197  1015  1193  0145  0295  0022  0442  0004
044 1657 169  0200  0183  0175  0197  1015  1193  0144  0300  0022  0442  0004
          HI  0202  0186  0180  0200  1022  1195  0145  0308  0022  0443  0004
          LO  0199  0182  0168  0196  0984  1193  0144  0293  0022  0441  0004
         RUN  WATER WATER OIL   AIR   EXH                   OIL   FUEL  AIR   EXH
DAY TIME TIM   OUT   IN   TEMP  TEMP  TEMP  RPM   LOAD  OIL   PRES  PRES  PRES

**AVG.**      0200  0184  0176  0200  1011  1194  0144  0298  0022  0443  0004
```

Figure 5(c)

Hourly maximum-minimum-average report arbitrarily covering a six-hour period. Large quantities of this type data are stored on magnetic tape, forming a historical data base for off-line, in-depth analyses as needed.

Figure 5. Typical printouts from the automated engine system.

Each engine stand is assigned 16 sequential channels. For each engine, the parameters required for optimum evaluation occupy 13 channels, leaving three for future use if the need arises. The engine stands are permanently wired to the analog input scanners. Thermocouple inputs are routed through 150°F thermocouple reference junctions located in the engine lab.

Measurement scans are made every six minutes of every engine on-line. In comparison, previous manual methods recorded engine parameters only once each hour by reading analog meters. *Now, the data base is increased by a factor of ten, resulting in a comparable improvement in overall accuracy.* These readings are added to a running total that has been accumulating in disc memory for that hour. At the end of each hour, the data are transferred to core memory where averages are calculated; the data are then transferred back to disc memory. Printouts of any previous segments of the data can be made available to further aid the laboratory supervisor and also to allow the programmers to check for proper operation. Because the disc memory is faster to access than magnetic tape, these data usually remain on disc for a short period of time to accommodate the need for recent hourly reports by engineers and others who may be interested. Data are periodically transferred to magnetic tape for permanent storage. Figure 5 is a composite illustration showing typical printouts. Figure 5(a) shows most of the measurement parameters for a typical engine – all are within limits. Figure 5(b) shows certain parameters measured on two engines which are out of limits. Note that only the measured values and limits for those values are printed out, thus saving much time searching through printouts for out-of-limit readings. Figure 5(c) is an hourly average report from information stored on magnetic tape. Although this covers a six-hour time frame, it could cover any length of time.

While the reduced data represent all the measurements in a very easy-to-read form, SwRI also plots the data by means of the computer-controlled X-Y plotter. *Prior to automating these functions, an evaluation which typically runs 480 hours required approximately three hours to manually calculate maximum-minimum-average figures and plot the results. Now, the computer system makes a plot in less than five minutes.*

SwRI early recognized that while new data are recorded every six minutes, there was no fast and accurate method of making this information available to the engine stand operators and supervisors. Here again, in-house ingenuity solved the problem. Figure 6 shows how a closed-circuit television system provides measurement data on-line to operators in the engine lab and to the shift supervisor in his office, as well as inside the computer lab. The CCTV system has proved to be quite valuable, particularly in the engine lab. For example, if the operator notices a problem, he can request, through the keyboard CRT display, that all current measurements for that particular engine be printed out and transmitted to the monitor in the engine lab. If out-of-limit conditions are shown, he can immediately adjust the engine for proper operation. A video camera, mounted on the ceiling, picks up the teleprinter printout and transmits it to the remote monitors. Presently, four remote monitors (actually black and white television receivers) are in use; this can be expanded by merely adding more channels to the distribution amplifier system.

Besides the measurement scans every six minutes, the computer scans all engine on-off switches every 60 seconds. This gives a running account of how long each engine has been on-line and also provides an accurate record of engine down time. A few minutes of engine down time is usually not important to the shift supervisor since it probably involved shutting down to make a simple adjustment. A shutdown period of several hours, however, usually means that the supervisor will check to determine whether or not the cause is serious, and possibly how to avoid future recurrences.

In another area, SwRI developed a relatively simple, but very accurate fuel rate measuring system. Fuel for an engine is taken from a beaker which rests on a balance-type scale. When the engine starts, a timing sequence begins in the HP 6940A Multiprogrammer. After one-half pound of fuel has been consumed, the timing sequence stops. This gives a weight/time fuel consumption rate which is then converted to any fuel rate units (BTU/hr, gal/hr, etc.) desired. Thus, by automating existing fuel rate measurement devices, SwRI retained the high accuracy inherent in the gravimetric measuring technique.

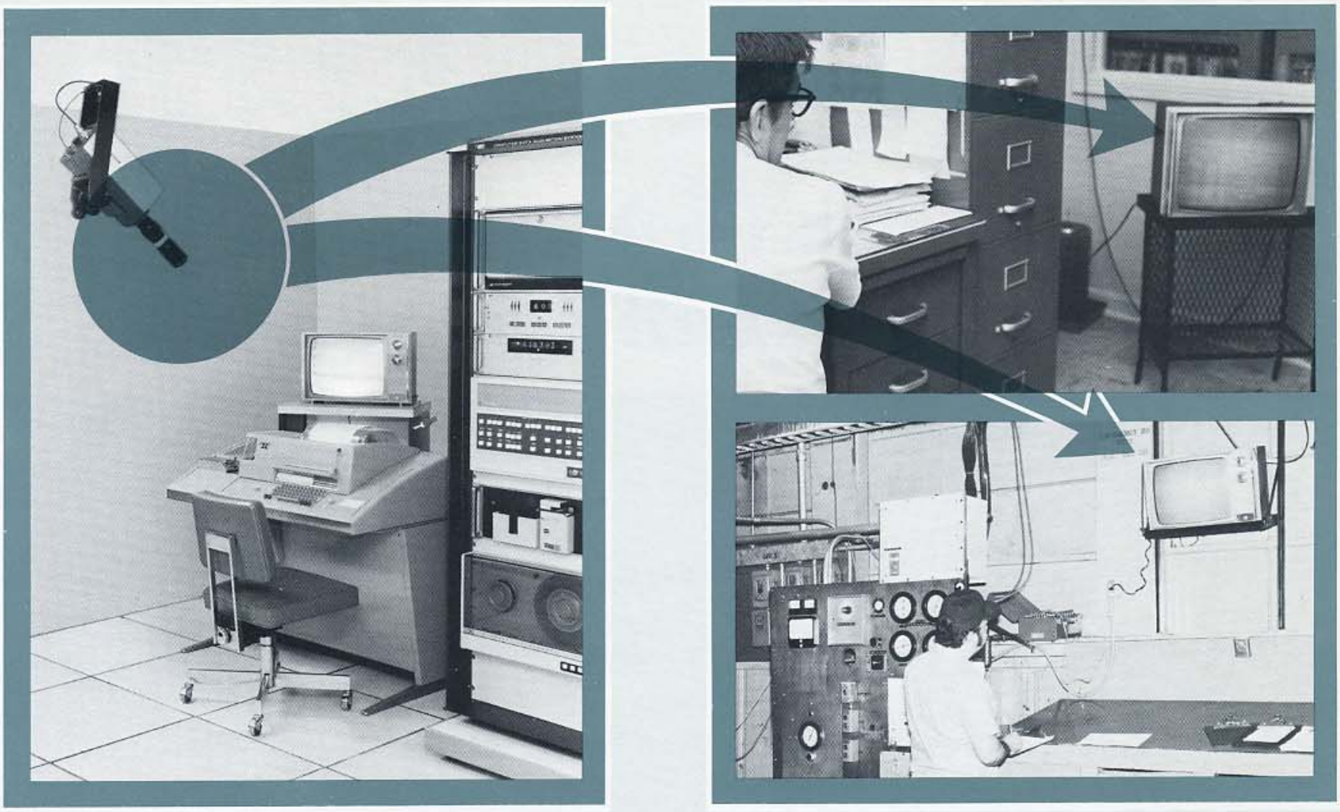
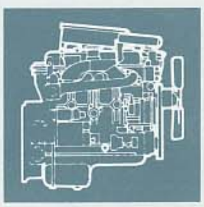


Figure 6. A novel closed-circuit television data transmission system. The ceiling mounted camera transmits the on-line teleprinter printout to video monitors in the engine lab and to the shift supervisor in his office.

Benefits of Automation

Southwest Research Institute considers its automated fuel and lubricant laboratory to be an important contribution to up-grading the technique of engine parameter measurement. With its demonstrated advantage in speed, the computerized system gathers ten times more data than before and with greater accuracy. Combining this significant contribution to lubricant research with SwRI's already well-deserved reputation for dependability adds up to better and more meaningful results for industry and government. Evaluation results now permanently stored on magnetic tape represent a valuable data base from which SwRI can perform larger in-depth analyses, as requested by sponsors whose products require comprehensive evaluation procedures. SwRI has successfully demonstrated that computerized evaluations are feasible and advantageous, benefitting the institute and its sponsors, and that a precedent has been established as a basis for automating other activities in the future.



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