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AUTOMATIC MEASUREMENT SYSTEMS
APPLICATIONS SERIES

Automated System Improves Spacecraft Testing

Synchronous Meteorological Satellite scheduled for launch early in 1974, will provide real-time weather information covering much of the western hemisphere.

A Solution to a Measurement Problem for PHILCO-FORD, WDL DIVISION, Palo Alto, Calif.

Automated System Improves Spacecraft Testing

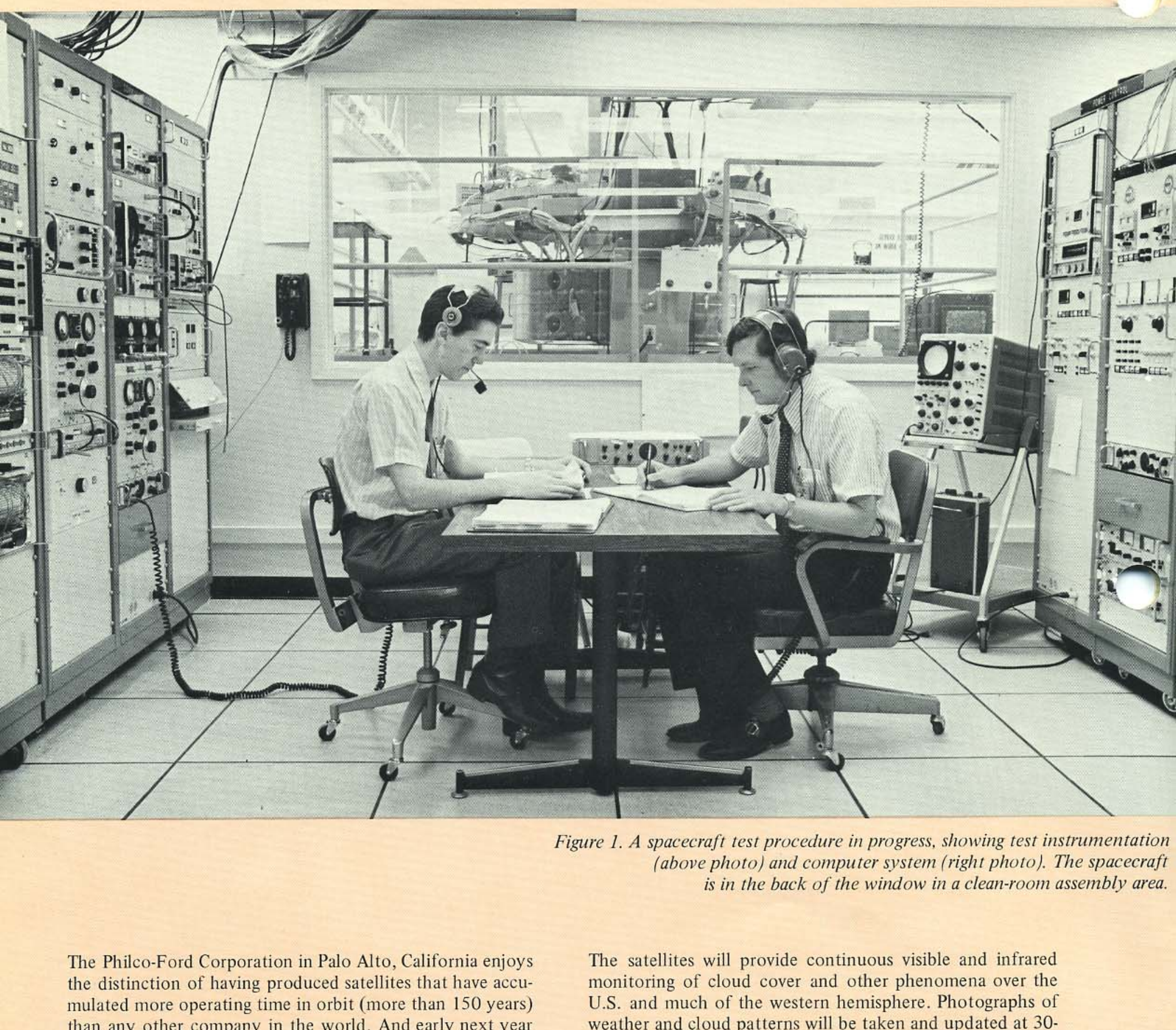


Figure 1. A spacecraft test procedure in progress, showing test instrumentation (above photo) and computer system (right photo). The spacecraft is in the back of the window in a clean-room assembly area.

The Philco-Ford Corporation in Palo Alto, California enjoys the distinction of having produced satellites that have accumulated more operating time in orbit (more than 150 years) than any other company in the world. And early next year an advanced design weather satellite – the first satellite to participate in the worldwide Global Atmospheric Research Program (GARP) – will be launched, followed by two more identical spacecraft at six-month intervals. All three are synchronous meteorological satellites (SMS), currently being built by Philco-Ford under contract from NASA/Goddard Space Flight Center, Greenbelt, Maryland. They will be operated by the National Oceanic and Atmospheric Administration (NOAA) as part of its geostationary operational environmental satellite (GOES) program.

The satellites will provide continuous visible and infrared monitoring of cloud cover and other phenomena over the U.S. and much of the western hemisphere. Photographs of weather and cloud patterns will be taken and updated at 30-minute intervals, enabling forecasters to rapidly determine the direction and speed of weather movements. By sending back the pictures and by regularly interrogating and relaying data from weather platforms at sea and other remote locations, the satellites will permit more accurate weather forecasting as well as real-time warnings of dangerous conditions, such as approaching hurricanes and typhoons.

Meticulous Testing

Keeping the public aware of anticipated achievements in space programs is quite often done by showing the easy-to-relate-to human aspect of astronauts performing selected experiments on simulated terrain, such as on the moon. Not so well publicized, but equally important, is the tremendous amount of testing done on the spacecraft and all its electrical and mechanical components.

At Philco-Ford, spacecraft testing is a specialty, quite aside from its demonstrated expertise in spacecraft design and production. Figure 1 shows the broad range of instrumentation (two groups of seven racks each) plus the computer equipment specifically dedicated to spacecraft testing, inside the test control room. With millions of dollars involved in design, manufacture, and launch, the need for testing is an established fact.

Only after meeting all specifications in a comprehensive testing sequence, can it be assumed, with a reasonable degree of confidence, that the spacecraft will perform satisfactorily in orbit. Constant attention to every detail assures that no questionable results will go unnoticed – all tests receive both Philco-Ford and NASA sign-off before proceeding to another phase of testing. All test procedures are fully documented – from computer system and instrumentation turn-on through detailed step-by-step test sequences.

Testing continues right up to launch. *In fact, Philco-Ford purchased a second system, identical to the first, to provide this capability.* After successful testing at Palo Alto, the spacecraft will be shipped, along with the second computer system, to the Eastern Test Range launch site. Here, the spacecraft will be fully retested to assure that no damage occurred in transit.

Configuring The Automated System

The very nature of spacecraft testing necessitates that many tests be performed and vast amounts of test data be acquired to verify compliance with specifications set forth in the contract. While Philco-Ford was motivated to provide a computer-controlled test system in order to realize the benefits offered by automation – better accuracy, better test repeatability, labor savings, and many others – it was difficult to justify a dedicated computerized system that would satisfy immediate needs only.

Faced with a requirement for thoroughly testing spacecraft, Philco-Ford chose a Hewlett-Packard computerized test system operating under control of the HP real-time executive (RTE) software operating system. The RTE system allows tests to be conducted in a real-time, priority-oriented, multiprogramming environment. With the RTE, the computer can control a number of functions in the real-time mode and at the same time low priority activities such as program compilation and debugging can take place. Now, Philco-Ford has a very flexible hardware/software combination. The system offers full capability for controlling all variable switches and other functions in the test equipment, or it can be programmed to exercise control over specified measurement parameters only. The computerized test system is shown in Figure 2.

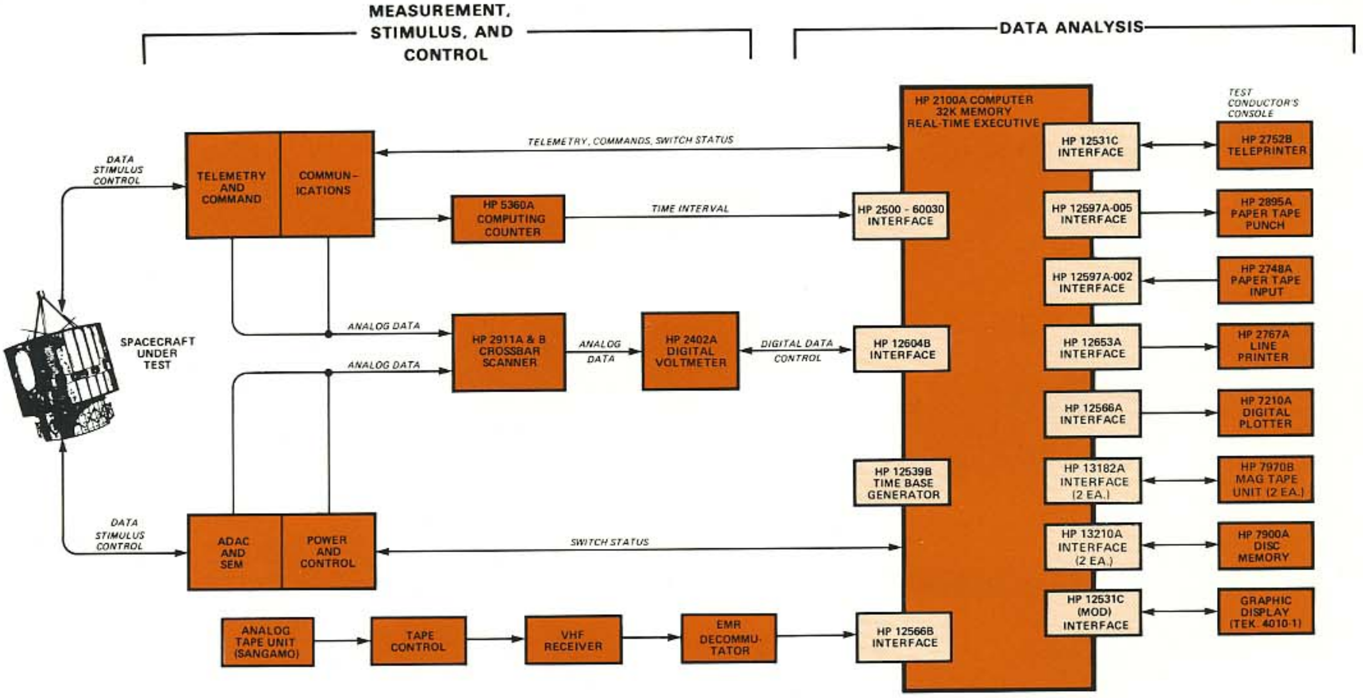


Figure 2. Computerized spacecraft test system at Philco-Ford.

At the heart of the system is an HP 2100A Computer with 32K 16-bit words of memory. The teleprinter serves as the test conductor's console for general purposes of communication with the system. The paper tape punch is used whenever a paper tape copy of an edited source program, binary program, etc. is desired. The paper tape input (reader) is used to read source and binary programs, data, long edit files, etc. into the system. The line printer provides printed readout of programs or test results as desired. The digital plotter is used for plotting the digitized video data from the onboard camera (VISSR) to detect interference patterns, bit errors (drop out), and aliasing degradation. The plotter is also particularly useful for following trends from test to test. One magnetic tape unit is used for storing pertinent telemetry, all commands, and measured data for current tests; the other tape unit plays this information back into the system as desired. The disc memory unit is used for temporary data storage and for storing test programs, libraries, and conversion tables. The graphic display/keyboard displays telemetry information as called for by the operator.

Analog data from the spacecraft under test is switched through the crossbar scanner to the digital voltmeter (analog-to-digital converter) for input to the computer. A broad range of instrumentation provides the necessary stimulus and control signals to the spacecraft under test. The analog tape unit continuously records telemetry data (voltage, temperature, etc.) from the spacecraft. The data can be played back through the computer to reproduce any unusual situation of interest to the design engineers.

In conformance with good engineering practices and contractual requirements, Philco-Ford has documented every test procedure required to thoroughly test the SMS. The complete spacecraft integration test procedure consists of more than 200 test procedure modules. In total, more than 150 spacecraft parameters are measured. Each module de-

Conducting Spacecraft Tests

Figure 3. The test conductor (right) is monitoring messages for discrepancies requiring his immediate attention. The test conductor communicates with test technicians over an intercom system.

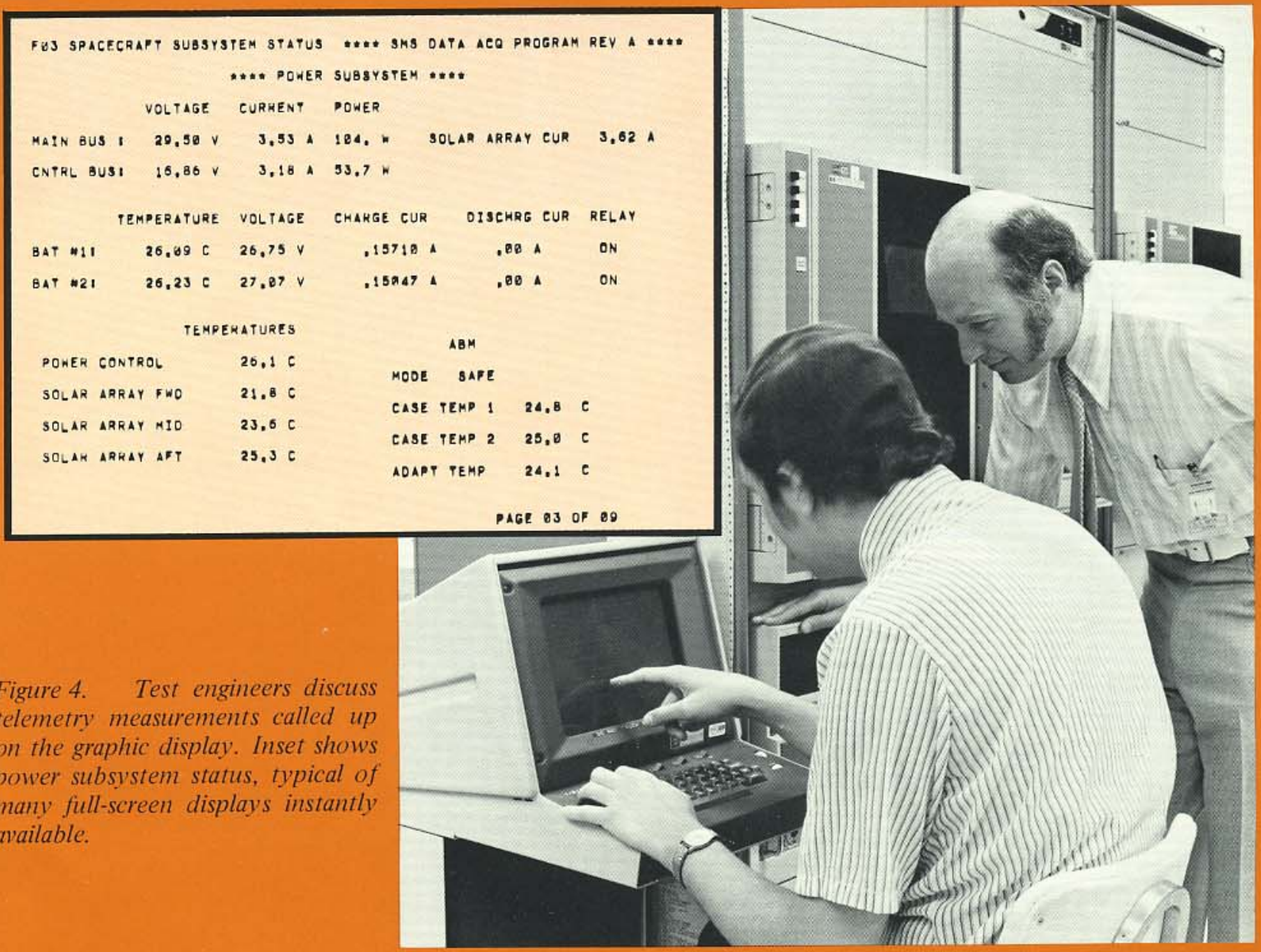
fines in detail a step-by-step comprehensive test procedure for a specific spacecraft function, such as primary power.

Construction of the spacecraft essentially consists of adding functional subsystems in a very specific order until the system is completed. Testing the spacecraft follows this same principle: a series of tests is conducted as subsystems are installed, ending in a final system integration test. In general, acceptance testing begins with the first functional test which is the base-line procedure. This involves overall testing of all electronic subsystems. Thus, a base line of data is acquired. The spacecraft is then subjected to various environmental conditions, after which all the tests are conducted again.

The interaction between subsystems in the complex structure of the spacecraft is not always known beforehand by designers, who are largely specialists in one specific area. For this reason Philco-Ford initially conducts all new tests manually, modifying the procedures as necessary until all bugs are worked out. Only then will the program be coded and entered into the computer system. An immediate benefit of this technique is that it is much easier and far less costly to change a typewritten test procedure than to change a fully-coded computer test program.

Each step in a test, whether it be a computer-controlled or a manually-controlled parameter, is first checked by the computer before proceeding. For example, the computer will check for proper switch position; if correct the parameter will be measured; if not, testing will stop until the switch is manually set correctly. Certain switches are under computer control and others must be set manually, as specified in the test procedure. Measurements are made by the system test equipment and the results recorded in computer memory. The computer compares the measurement with a set of limits which are part of the test program. If out-of-limits, a message will appear at the test conductor's console. At this point, the test conductor must make a decision to stop the testing or continue. If he elects to continue, he must type in his name on the console. This transaction becomes part of the permanent test record. Figure 3 shows the test conductor examining a printout informing him of an out-of-limits condition. The permanent test record consists of two printed records: (1) a test data sheet and (2) a test flow sheet. The test data sheet, as printed out on the line printer, lists measurement parameters, limits, units, and the actual measured value of each parameter which result from the execution of a specific test program. The test flow sheet, as printed out on the test conductor's console, lists, as they occur, all commands sent to the spacecraft under test, out-of-limits telemetry words along with the limits, out-of-limits test parameter values, telemetry status incompatible with the command just sent, and the condition of the spacecraft test batteries. Thus, the two records are complementary and make up a complete record of the entire test. Any questionable values, for example, can subsequently be compared against the test flow sheet to help determine the cause of the poor performance. During the course of a day's testing, the measured data and other pertinent test information are stored on disc. At the end of the day (usually), information on disc is transferred to magnetic tape. The tape includes all the information contained in both the data sheets and the test flow sheets.

The all-important "health" (voltages, temperatures, etc.) of the spacecraft is continuously monitored and sent to the telemetry and command instrumentation in a continuous stream of 1s and 0s. This telemetry information is decommutated into a 156-word pattern in computer memory. A basic 64-word frame plus 64-word and 32-word subcommutated frames handle all telemetry data. Certain critical parameters are supercommutated to provide timely detection of serious malfunction. The telemetry is stored in common in the computer memory. Various test and display programs access this common data. A generalized display, print, and plot software system makes the telemetry data available to the test engineer in formats of his choosing. This scheme gives wide flexibility for the present SMS program and also greatly reduces new programming efforts for future spacecraft testing programs. Figure 4 shows telemetry information displayed on the graphic display console being examined by computer systems test engineers.



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F03 SPACECRAFT SUBSYSTEM STATUS  **** SMS DATA ACQ PROGRAM REV A ****

                    **** POWER SUBSYSTEM ****

            VOLTAGE   CURRENT   POWER

MAIN BUS :   29,50 V    3,53 A  104, W    SOLAR ARRAY CUR   3,62 A

CNTRL BUS:   16,86 V    3,18 A  53.7 W

          TEMPERATURE  VOLTAGE   CHARGE CUR    DISCHRG CUR  RELAY

BAT #1:     26.09 C   26.75 V      ,15710 A      ,00 A       ON

BAT #2:     26,23 C   27,07 V      ,15047 A      ,00 A       ON

               TEMPERATURES
                                         ABM
 POWER CONTROL          26,1 C
                                    MODE   SAFE
 SOLAR ARRAY FWD        21,8 C
                                    CASE TEMP 1   24,8  C
 SOLAR ARRAY MID        23,6 C
                                    CASE TEMP 2   25,0  C
 SOLAR ARRAY AFT        25,3 C
                                    ADAPT TEMP    24,1  C

                                              PAGE 03 OF 09
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Figure 4. Test engineers discuss telemetry measurements called up on the graphic display. Inset shows power subsystem status, typical of many full-screen displays instantly available.

Benefits of Automated Testing

The Hewlett-Packard automated test system is giving Philco-Ford a broader vision of satellite performance characteristics. Gone are the human errors inherent in manual data recording, manual verification of calculations, manual data analysis, and all other manual functions. Instead, the automated system is providing this information at a higher degree of confidence and accuracy.

Moreover, computer power allows much more data to be collected over a given period, thereby increasing the quality of measurement results and overall testing reliability. The flexibility of the computer hardware/software combination has given Philco-Ford a generalized data acquisition and control system, rather than a system dedicated to one type of spacecraft only. This means that not only can the present SMS series spacecraft be tested, but all future spacecraft as well. The computer has completely eliminated the time-consuming chores of manually recording meter readings, setting critical switches, sending and verifying commands, and other frequently repeated functions. Since a spacecraft test cycle runs for a period of months, a few minutes saved per test quickly adds up to a very significant factor in both efficiency and manpower utilization.

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