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AUTOMATION IN SATURN I FIRST STAGE CHECKOUT

by B. J. Funderburk

George C. Marshall Space Flight Center
Huntsville, Ala.

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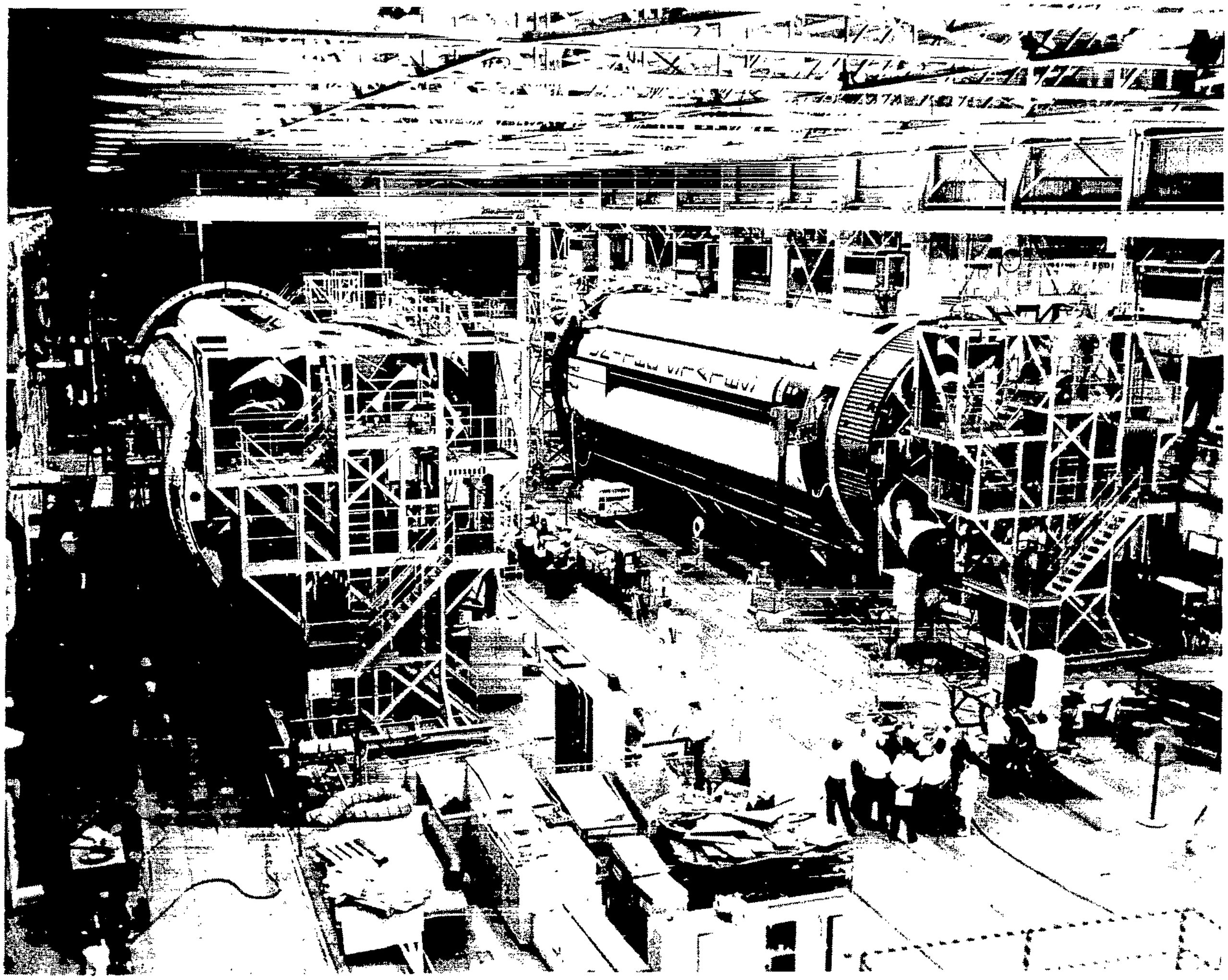

SATURN I FIRST STAGE CHECKOUT

AUTOMATION IN SATURN I FIRST STAGE CHECKOUT

SUMMARY

Automatic testing and checkout of space vehicles with digital computers began in the Quality and Reliability Assurance Laboratory in 1961 with the use of the Interim Instrumentation and Telemetry System developed by the Packard Bell Computer Corporation. It has since developed into a multimillion dollar effort with more than 200 digital computers and hundreds of specialized personnel being required for automation of the Apollo program.

The first section of the document after the introduction describes the hardware and software systems that have been used for or in support of automatic vehicle checkout at the Laboratory and at the Michoud Assembly Facility. The remaining sections summarize the test procedures and computer programs used in vehicle checkout and present some observations that have been made after a review of the automation effort.

The document includes information on the checkout of the Saturn I Block I stages SA-1 through SA-4, Saturn I Block II stages SA-5 through SA-10, and the upgraded Saturn I stages SA-201 through SA-206.

SECTION I. INTRODUCTION

Many problems and pitfalls were encountered during the implementation of the automated vehicle checkout effort at MSFC and at times, the effort appeared to be futile. The state-of-the-art at that time had been challenged by the introduction of the digital computer for the testing and checkout of hardware components and space vehicles.

An office was established to conduct training of laboratory personnel, integrate the ideas and requirements of the test engineers into a workable system, and to administer the technical aspects of the contract for the automatic test equipment.

One of the ground rules established for the automation effort required that the effort be developed parallel to the manual checkout operation and that the Saturn I first stage would not be modified solely for the purpose of automation. Although this was sound reasoning from the standpoint of maintaining schedules and avoiding the possibility of not being able to recover if automation failed, it necessarily complicated the progress of automation. The automatic checkout equipment had to be designed to receive and analyze the signals in the form that they were produced from the stage. In most cases, these were analog signals alien to the computer and elaborate switching and conversion equipment had to be fabricated to receive them. Likewise, stimuli going to the stage had to be converted on the ground into those signals which could be understood by the stage, which again required elaborate ground equipment. Today, this communication has changed considerably. With the introduction of the Digital Data Acquisition System (DDAS), Pulse Code Modulation (PCM), the Launch Vehicle Digital Computer (LVDC) for guidance, and others, a significant portion of the stage has been designed with automation in mind. These systems are digital in nature and allow for greater compatibility between the onboard stage systems and the ground computers.

SECTION II. SYSTEMS DESCRIPTION

A. Interim Instrumentation and Telemetry System

The Interim Instrumentation and Telemetry System was the first hardware utilized with Saturn vehicle testing which incorporated a digital computer as the controlling element of the system. This system was delivered in 1961 as a result of the contract with the Packard Bell Computer Corporation. The purpose of the early delivery of this system was to allow Quality Laboratory personnel to become familiar with the techniques and operations of automatic checkout prior to the delivery of the Packard Bell Saturn Automatic Checkout System as described in this section.

1. General Description. The Interim Instrumentation and Telemetry System consisted of the computer and peripheral equipment and the instrumentation and telemetry interface equipment. The system was delivered in specially designed equipment racks as a single unit. For reasons varying from organizational structure to operational feasibility, the system was later divided into two operational areas: computer and peripheral equipment and the remote test

station. The separation of the equipment was later to provide practical experience in operating a computer complex with remote test stations but was also to include problems with data transmission because of the original design as a single unit. Figure 1 pictures the computer and peripheral equipment and Figure 2 pictures the remote Interim Instrumentation and Telemetry Test Station.

2. System Theory, Hardware. A block diagram of the Interim Instrumentation and Telemetry System is shown in Figure 3. The system is shown functionally as two units, i. e., the computer with peripheral equipment and a remote test station. The computer utilized in the system was the Packard Bell PB-250 digital computer.* The PB-250 is a completely solid state, general purpose, binary, digital computer. The storage medium is a group of nickel-steel magnetostrictive delay lines. The basic memory of the computer contains 10 delay lines each capable of storing 256 words of information. However, additional delay lines were purchased and the total memory capacity was expanded to 10 000 storage locations. Each storage location consists of 22 bits which can represent either an instruction to the computer or a data word consisting of 21 bits plus sign. One word time in the computer is 12 microseconds. The time required to add two numbers together including the time of decoding the instruction and locating the number in the operand address can be as little as 24 microseconds. However, to obtain this speed the computer program must be optimized; i. e., data must be stored in the proper memory locations. Otherwise, an addition of two numbers may take as much as three milliseconds. Multiplication, division, and square root operations require approximately 250 microseconds for execution.

A modified Dynatronics photo-electric papertape reader was used for reading computer programs and data into the computer memory. The reading speed of the paper tape reader was 300 characters per second.

A modified Friden flexowriter was used as the input output controlling device by an operator. The flexowriter consisted of a standard typewriter keyboard plus a mechanical papertape reader and a mechanical papertape punch. The flexowriter was capable of reading papertape at the rate of 10

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*The Packard Bell Computer Corporation has since become part of the Raytheon Corporation and the computer is now known as the Raytheon-250. For purposes of this document the original nomenclature of PB-250 will be used.

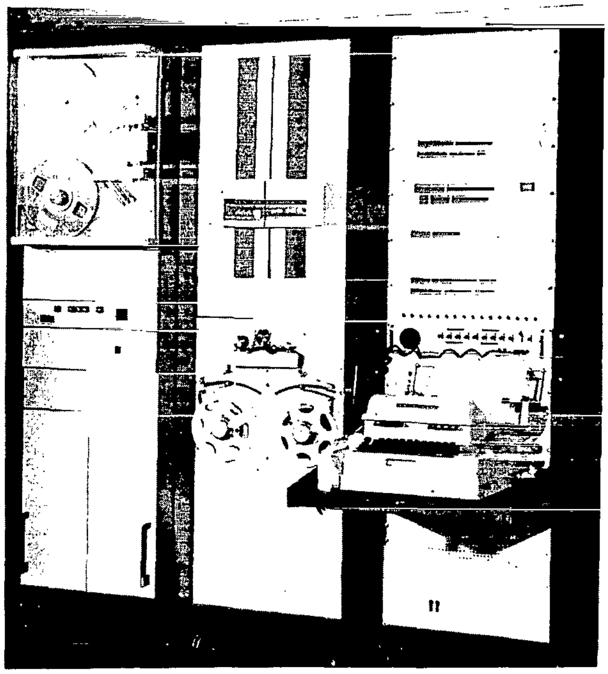

FIGURE 1. INTERIM COMPUTER

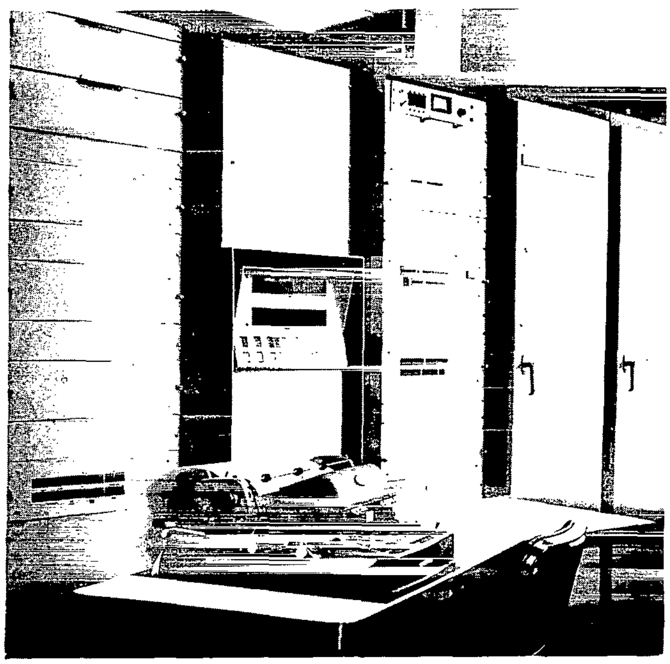

FIGURE 2. INTERIM INSTRUMENTATION AND TELEMETRY STATION

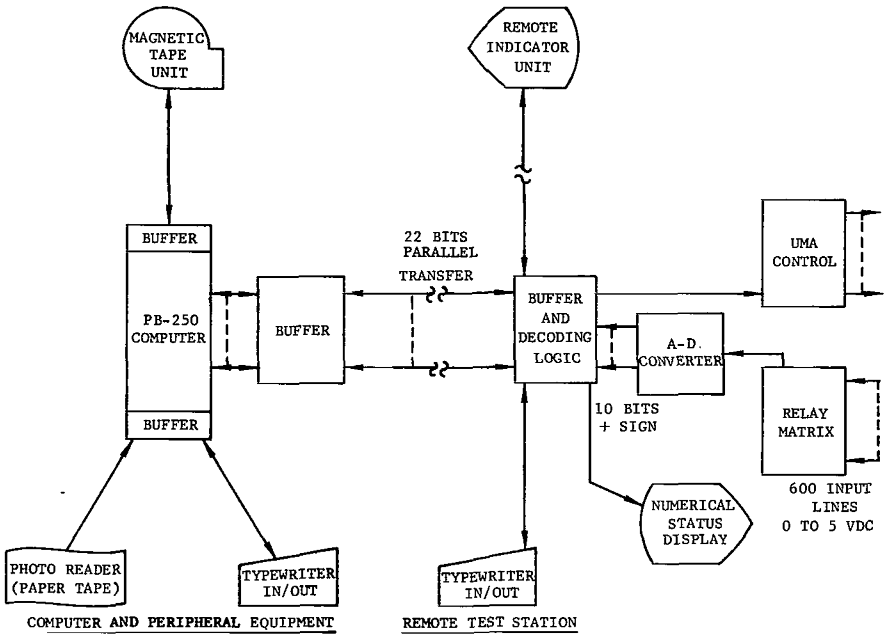

FIGURE 3. INTERIM INSTRUMENTATION AND TELEMETRY SYSTEM

characters per second and punching papertape at the rate of 15 characters per second under computer control. The computer was capable of interrogating the typewriter keyboard and the typewriter reader. The computer could therefore be programmed to interpret information being typed on the flexowriter keyboard by an operator. Responses to operator's instructions and the printing out of test data results could be accomplished on the typewriter.

A modified Potter magnetic tape unit was connected to the PB-250 computer. The magnetic tape unit was a low density 200 BPI unit.

Commands could be issued by the computer to the remote test station through a computer buffer. Commands would be formed in the computer memory and transferred 22 bits at a time to the buffer. Output of the computer buffer was transmitted over 22 parallel lines to the buffer and decoding logic in the remote test station. Decoding and execution of the 22 bits of information received in the test station was similar to the operation described in this section. Information collected in the remote test station could be transmitted back 22 bits at a time to the computer buffer over separate parallel lines.

The remote test station consisted of the buffer and decoding logic, a flexowriter input/output device, numerical status display, remote indicator unit, a-d converter, relay matrix, universal measuring adapter, etc., as shown in Figure 3. Various output controlling signals could be sent to the Saturn I first stage and responses being sent back from the stage could be sampled and read by the various measuring devices in the test station.

3. System Theory, Software. An executive routine as such was not utilized in the PB-250 computer. A utility package was utilized for certain control and program loading operations. In addition, a high speed photo-electric reader program was utilized in loading computer programs in the high speed memory. The octal utility package allowed the operator to perform certain transfer functions, printout locations of memory, store single words into memory, and begin the execution of programs that had been stored in memory. To perform a checkout operation, the computer operator would load the test program into computer memory either through the photo-electric papertape reader or via the flexowriter reader. Some of the test routines would contain several segments which would perform various operations in the remote test station. These segments were called up by a small executive included in the routine upon instruction received from the flexowriter. Test routines included the universal measuring adapter calibration program, telemetry discriminator test, telemetry subcarrier oscillator test, and telemetry identification test.

To illustrate the type of test performed by the system the universal measuring adapter calibration program will be discussed in some detail. Figure 4 illustrates a simplified block diagram of the onboard measuring and telemetry system. The measuring adapter (UMA) is simply a signal conditioning device which receives the output of a sensor and conditions the signal to a 0 to 5 volt level for input to the subcarrier oscillators. These UMA's are grouped in racks on the stage (Fig. 5).

Each of the universal measuring adapaters controlled by the UMA program could be adjusted manually by introducing a calibration voltage to the input of the amplifier in place of the sensor input. By adjusting the amplifier the output could be calibrated to a predicted value. The UMA calibration program would apply the calibration stimulus to the input of the UMA and would read the output level and signal the operator onboard the stage through the remote indicator unit (RIU, Fig. 6) as to the high or low condition of the output. Through repeated sampling of the output of the UMA and the adjusting of the calibration potentiometer on the amplifier the test engineer was able to

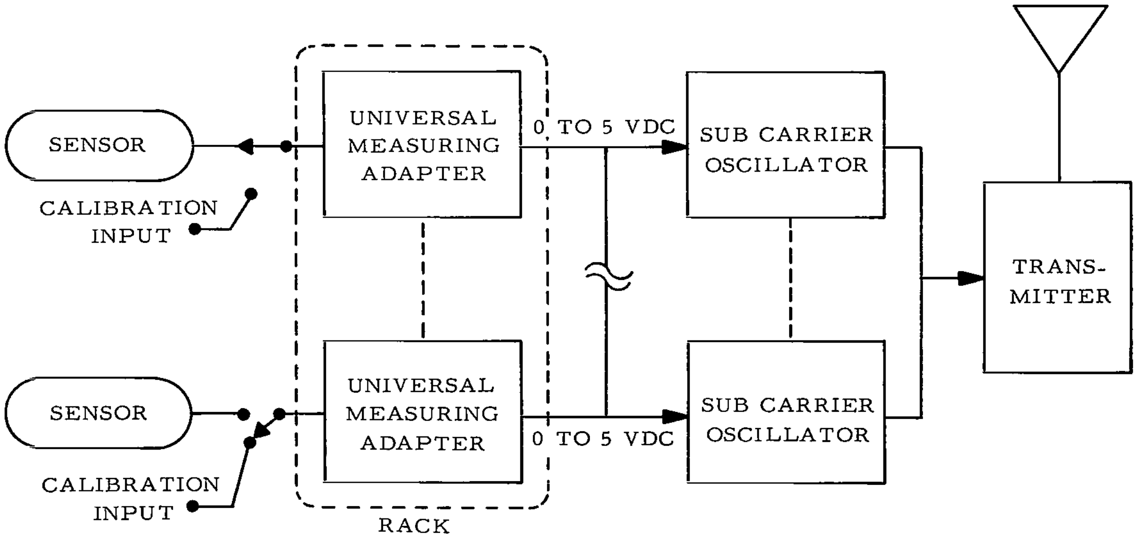

FIGURE 4. ONBOARD MEASURING SYSTEM

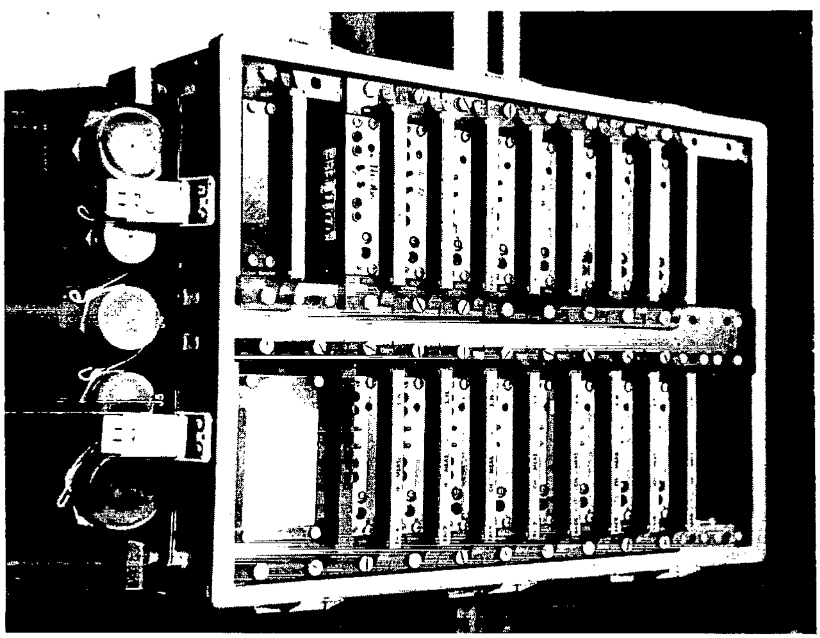

FIGURE 5. UNIVERSAL MEASURING ADAPTER (UMA)

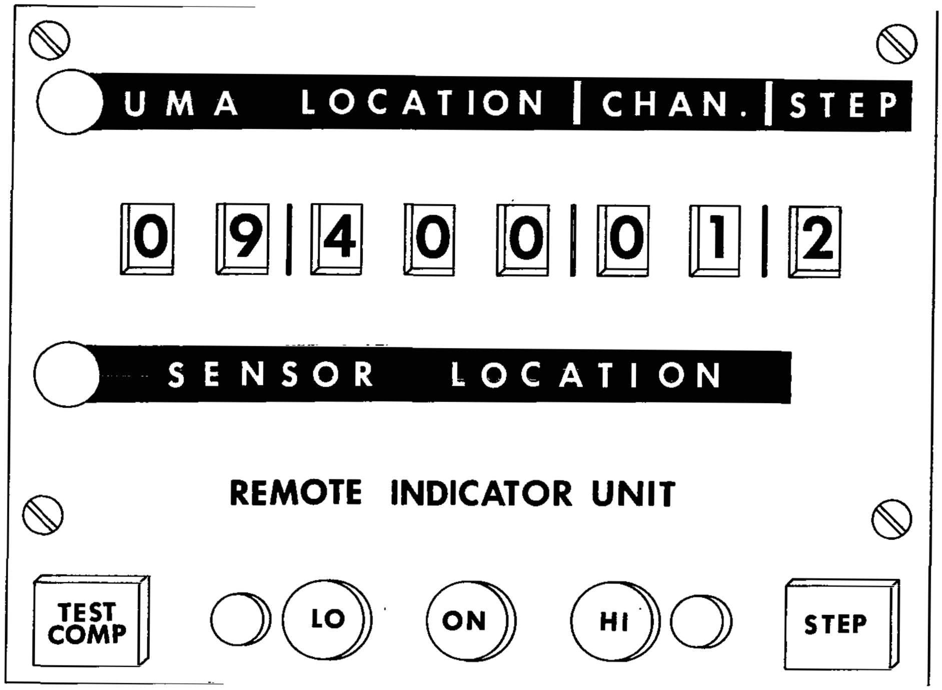

FIGURE 6. REMOTE INDICATOR UNIT (RIU)

calibrate the universal measuring adapter. Upon completing the calibration of one universal measuring adapter the test engineer would signal the computer by depressing a test complete button on the remote indicator unit. The computer program would then step to another universal measuring adapter and display to the test engineer the location of the next UMA to be calibrated. Each UMA was calibrated at two different points on its characteristic curve.

The test engineer had the capability of selecting the point at which he was going to calibrate and was able to alternate back and forth between the high and low calibrate points by depressing a step button onthe remote indicator unit. After the test engineer had attempted to calibrate each of the universal measuring adapters, the computer would print out on the flexowriter those measurements which were out of tolerance (no go conditions). Analysis of the malfunctioning universal measuring adapters could then be performed by the engineering personnel, and action could be taken to repair or replace the defective parts. The universal measuring adapters could then be recalibrated. The computer operator had the option of being able to look at the output of each universal measuring adapter prior to the calibration exercise. This procedure would provide the engineering personnel with a list of those measurements which were out of tolerance and would have to be calibrated.

The vehicle test station which was to be a part of the Saturn automatic checkout system was developed and completed early and as a result was delivered for use with the interim computer system. Communication with this test station was similar to that of the instrumentation test station with the exception of the information being transferred in serial rather than in parallel. Only one test station could be connected to the interim computer at one time. This required disconnecting the computer buffer for one test station and connecting the computer buffer for the other test station. The vehicle test station was to be an integral part of the Saturn automatic checkout system and will be discussed in detail with that system in Section III of this document.

B. Packard Bell Saturn I Automatic Checkout System

As launch operations increased and vehicles became more complex, a more sophisticated checkout system was required to handle the increasing number of tests, calibrations, and measurements. Automation was the best known solution to the problem and the digital computer proved the best means by which to control and evaluate the testing operations.

The basic philosophy leading to an automatic launch concept was increased confidence in system reliability and at the same time, a decrease in final vehicle checkout time at the launch site. In order to develop and implement a satisfactory checkout system, automated checkout concepts had to be integrated into the final verification tests performed on each stage at the manufacturer's plant. To establish guidelines for these operations, the Quality and Reliability Assurance Laboratory undertook an automated checkout program in July of 1960 which included design, development, and procurement of the operational hardware necessary to accomplish automated final tests on the first stage of the Saturn I, Block II, S-I vehicles. The goal was to achieve a checkout system with all practical steps carried out by automatic equipment. Packard Bell Electronics was selected to design and build the checkout hardware. Figure 7 illustrates the Central Computer Complex of the completed automatic checkout system.

1. General Description. The most attractive feature of the technical approach suggested by Packard Bell was the method of communicating with remote test stations via digital links. A multiple computer complex, centrally located, was proposed which would permit one slave computer to perform tests in one area, while a second slave computer performed tests in another area,

each completely independent of the other. However, the master-slave relation could be used where two or more test stations were to be operated in a composite test.

The hardware procured under this contract was operational during the poststatic checkout of the first stage of Saturn SA-5.

2. System Theory, Hardware. The automatic checkout system for the Saturn S-I stage basically consists of a Central Computer Complex and four remotely located test stations. Modular design allows expansion of the system to a total of ten computers in the central complex and 32 remote test stations. Figure 8 is a block diagram of the system function.

a. Central Computer Complex. The Central Computer Complex consists of three Packard Bell PB-250 computers with memory extension units, three magnetic tape handlers with a control unit, a high-speed paper tape reader and punch, and an operator's console. The operator's console is electrically connected as a remote station.

Each computer is a general purpose, fixed point, fractional, binary, digital computer. The memory consists of magnetostrictive delay lines 256 words long. The computers have a memory of 10 000 words each and can be expanded in increments of 256 words to a total of 15 888 words. Maximum access to any word in memory is 3.072 milliseconds and a word-time is 12 microseconds. Each word in the computer is 24 bits long. Only 22 of the bits are accessible to the programmer, the other two being parity and guard bits used by the computer.

b. Test station. Each test station can be considered as a computer which receives its instructions one at a time from the Central Computer Complex. The instructions are sent to the test stations as 22 bit words. Each word is interpreted as having an address, command, and data field as shown in Figure 9.

The test station interprets the address portion of the word to mean a particular unit within the station, i.e., analog to digital converter, stimuli generator, relay matrix, etc. The command portion designates an operation to be performed by the test station. The data portion is used to designate which relay is to be actuated in the relay matrix, what signal is to be applied by the stimuli generator, etc.

FIGURE 7. CENTRAL COMPUTER COMPLEX

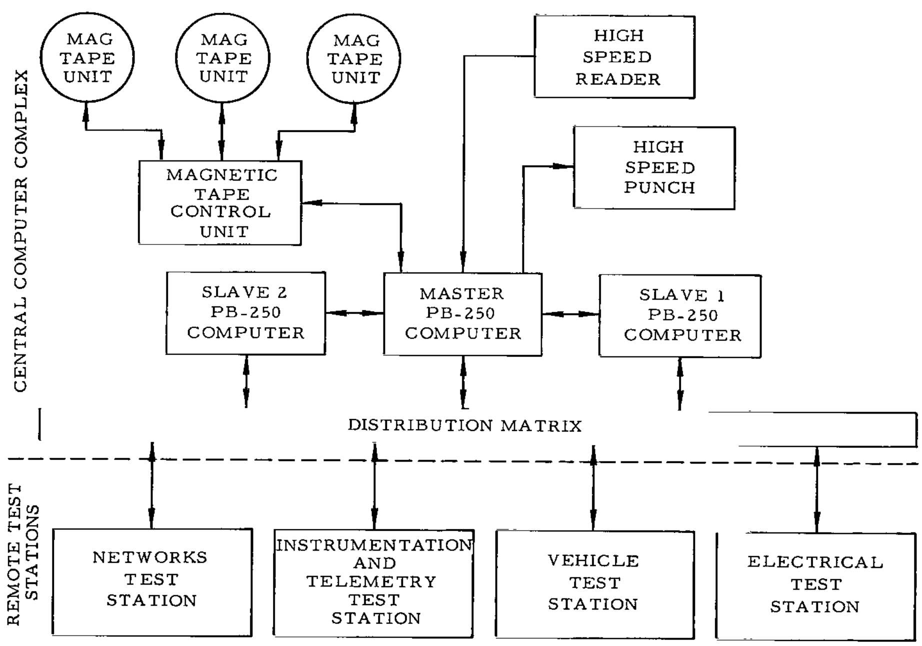

FIGURE 8. CENTRAL COMPUTER COMPLEX BLOCK DIAGRAM

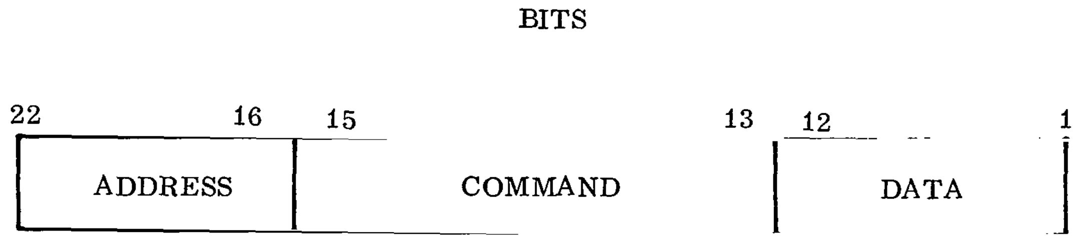

FIGURE 9. INSTRUCTION WORD FORMAT

Some instructions require that information be sent back to the Central Computer Complex after they are executed in the test stations. Such an instruction would be an analog to digital conversion. After the conversion has been made, the digital value would be read back to the Central Complex; up to 22 bits of information can be transferred back.

Each test station is designed to perform certain checkout operations on the S-I stage. The tests performed by the station are determined by the sequence and content of the instructions sent to the test station. In turn, the sequence and content of these instructions are determined by other instructions given to a computer in the Central Computer Complex.

The original design of the Saturn Automatic Checkout System included 11 test stations as follows:

1. Instrumentation and Telemetry System
2. Instrumentation and Telemetry Components
3. Guidance and Control System
4. Guidance and Control Components
5. RF System
6. Networks Test
7. Electrical Test Number 1
8. Electrical Test Number 2
9. Vehicle Test
10. Mechanical Assembly Test
11. Mechanical Components Test.

For reasons of economy, combination of functions, design techniques, etc., the number of test stations was reduced to the following four:

1. Instrumentation and Telemetry Test Station
2. Networks Test Station
3. Vehicle Test Station
4. Electrical Test Station.

A Guidance and Control Test Station was fabricated and installed for use with the RCA-110 Ground Computer System and development of an RF Systems Test Station was made inhouse. Neither of the stations was used in first stage checkout operations.

Because each of the four test stations used with the Saturn Automatic Checkout System are complex in themselves, each will be discussed in detail separately. However, portions of each test station are exactly the same. These common areas consist of the Test Station Operator's Console (Fig. 10), test station buffer, and flexowriter. The decoding logic for each station was different because of the varying functions to be performed in each test area.

The test station is operated either through the Central Computer Complex or manually by the operator. When the station is computer controlled, a choice of automatic or single-step operation is available. In manual mode, the station is programmed and controlled by the operator.

The automatic mode is under control of the computer program in the Central Computer Complex. The computer program specifies the necessary steps for the test to be performed. Manual intervention is necessary only when the system-under-test fails to respond to the program and the applicable check/troubleshooting subroutines.

The single-step mode is also under control of the computer program in the Central Computer Complex. During single-step operations, commands are transferred to the station from the computer one at a time (under control of the operator). This mode is used by the operator to check and/or troubleshoot an abnormal condition by single-cycling the computer program, and if an error is found, to either correct it or make note of location and proceed with automatic mode. This mode can also be used to check a new program. The station automatically performs the computer transferred command, and then waits until the operator manually signals the computer to transfer another command.

In manual mode, the station is electrically disconnected from the decision-making elements in the Central Computer Complex. The station will stop operating when a decision is required, and the operator must furnish the

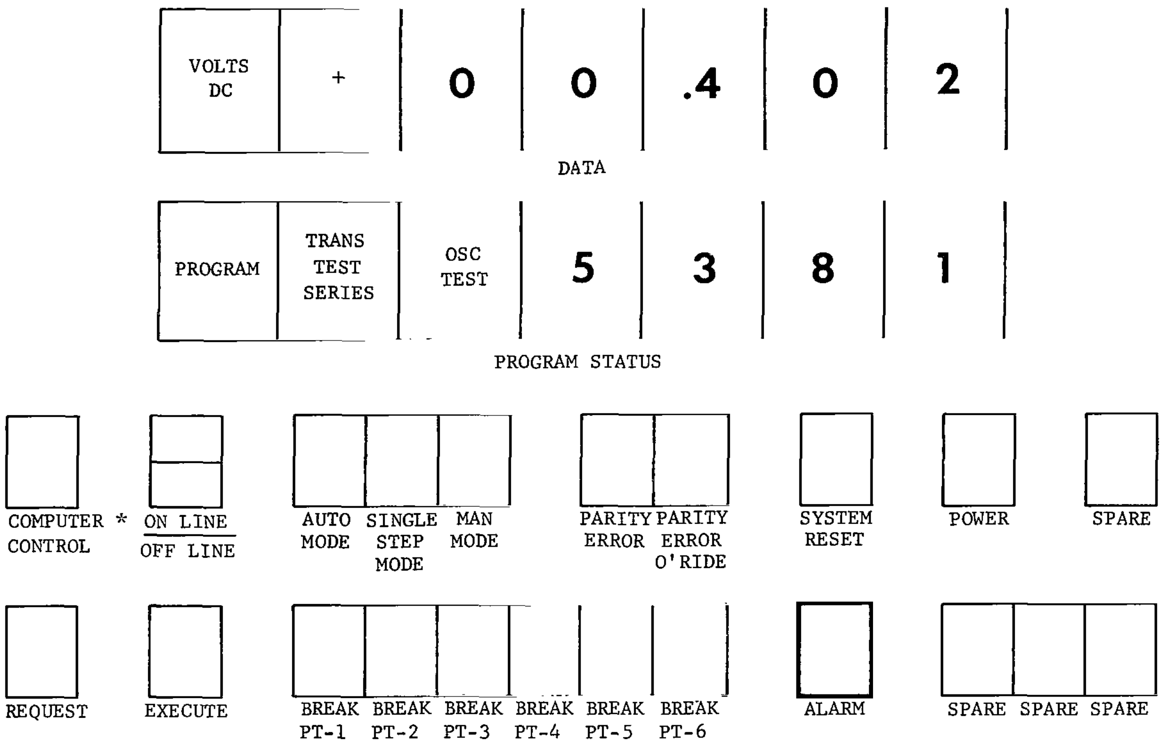

FIGURE 10. TEST STATION OPERATOR'S CONSOLE

decision before the operations can be resumed. The operator-furnished decision is in the form of a command loaded by the flexowriter. Commands may be loaded into the station using a prepunched paper tape and the flexowriter tape reader, or commands may be loaded using the flexowriter keyboard.

3. Networks Test Station. The Networks Test Station, pictured in Figure 11 and illustrated in block diagram form in Figure 12, performs the two major functions of monitoring and control. The station monitors all signals passing between control panels, relay boxes, and the vehicle, so that stimuli and corresponding vehicle responses can be fully analyzed. The response may be ac or dc voltages or currents, resistances, contact closures, and on/off indications. Responses generated by either the vehicle system or its associated equipment are brought in through the patchboards and controlled by the response selector matrix. The Networks Test Station includes the following equipment:

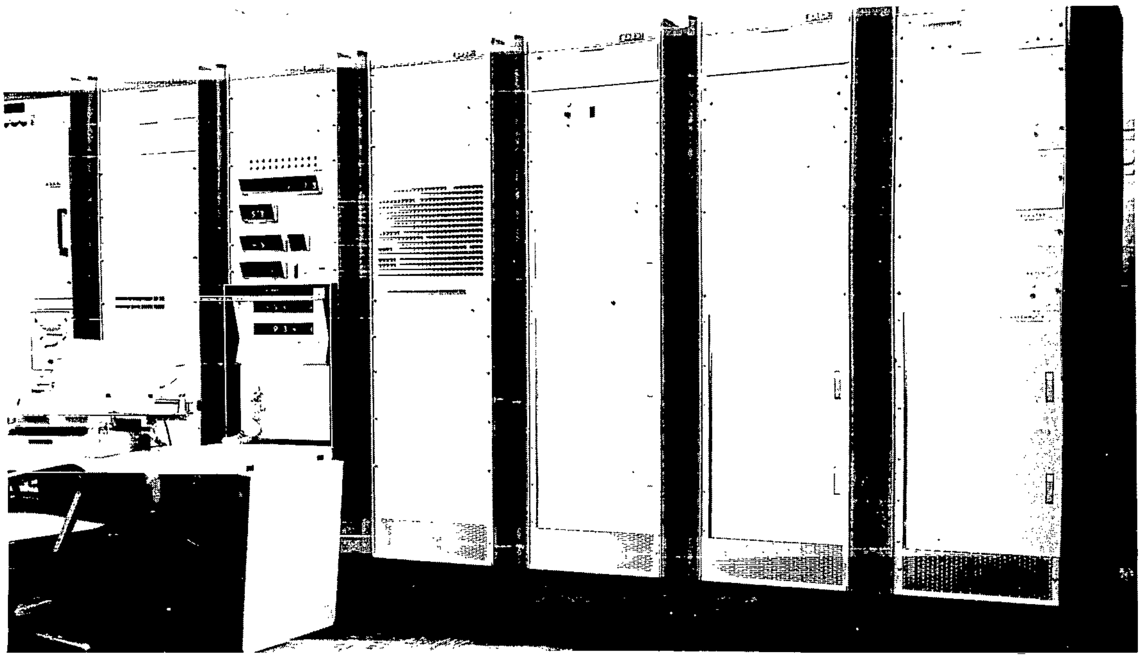

FIGURE 11. NETWORKS TEST STATION

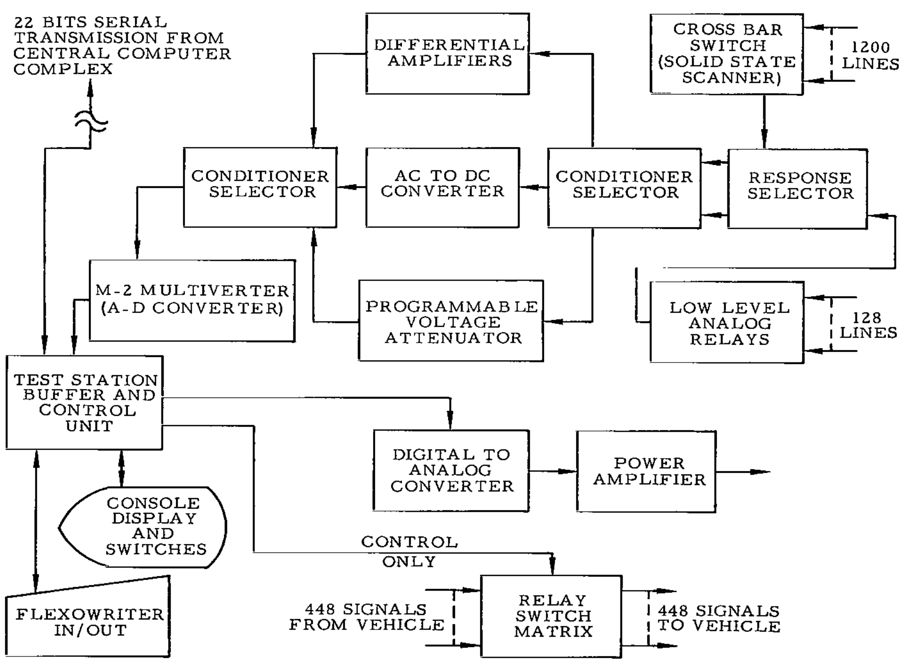

FIGURE 12. NETWORKS TEST STATION BLOCK DIAGRAM

a. Console. The area immediately in front of the operator, including the flexowriter and all numeric displays, is known as the common area. The common area is where the Networks Test Station operator monitors and controls all functions concerned with either automatic or manual operation of the station.

b. Auxiliary display panel. The auxiliary display panel contains three displays, the alarm indicator lights, the satellite station buffer, and the matrix selector display.

(1) The alarm indicators . The alarm indicators are connected to certain critical points around the vehicle and ground station where malfunction would require the immediate attention of the operator. The ground inverter phase, grounded indication, and the vehicle inverter phase, grounded indication, are connected to the alarm indicators.

(2) The satellite station buffer display. The satellite station buffer display is an eight position octal character display which is controlled by the output of the station buffer. It displays the last command executed from either the computer or the flexowriter by the station buffer until the station is reset or a new command is executed. The information displayed will be the address, command, and the data field. The first three characters are the address. The address denotes to what specified area the word is going. The fourth character is the command. The command denotes the type of operation to be performed by the area addressed. The last four characters are the data field. The data field is capable of subdividing an address into 4095 parts.

(3) The matrix display. The matrix display is located just below the satellite station buffer display. The matrix display indicates which, if any, select and hold coordinates of the response selector matrix are energized.

(4) The participating stations display. The participating stations display denotes which, if any, satellite stations are working with the Networks Test Station. This is a programmed function.

c. Actuator position display panel. The actuator position displays are unique in that they are not completely controlled through the buffer. The upper display is for the pitch position and the lower display is for the yaw position. The number of the engine being monitored is displayed to the right of the pitch position indicator. The engine number display can be controlled by a four position switch (one position for each engine) and two pushbuttons.

d. Satellite station buffer. The control unit in the satellite station buffer serves to interpret computer instruction and control functions in the station. Binary indicators are provided on the buffer (SSB-4) to permit observation of its contents.

e. Matrix display. The matrix display indicates which of 448 magnetic latching stimulus selection relays have been activated. The display contains 448 individual lights which are numbered to correspond to the relays selected.

f. Digital-to-analog converter. The digital-to-analog converter (DA-6) converts digital inputs to analog output voltages. Digital numbers are entered in parallel and are represented as binary input voltage levels. The analog output voltage is proportional to the digital input number. By knowing the range to which the DA-6 power amplifiers have been set, the operator, by utilizing the display, can determine the output voltage. The first bit is the sign bit, and the rest of the display is a binary representation of the voltage. Decimal conversion is required to evaluate the level of the signal.

g. Relay switch matrix. The relay switch matrix responds to stimuli by individually setting or resetting 448 latching relays. The relays are in seven groups of 64 relays each. Each group is enabled by a store command or an execute command and addresses 030 through 036 respectively. The relay switch matrix is used to route externally generated discrete stimuli to points on the vehicle.

h. ac to dc converter. This converter changes either 60 or 400 cycle ac voltages to dc signals for processing by the M-2 multiverter.

i. Time and frequency digitizer. The time and frequency digitizer provides the capability to count the number of cycles per controlled time period (frequency count) or the length of time to count a predetermined number of cycles (time count). It will also measure the time difference between two input signals. The gating, or starting, of the counting process can be on either the leading or trailing edge of one or two input signals, depending upon the application.

j. Response selector matrix. The response selector matrix is a crossbar switch with 12 "select" coils and 10 "hold" coils, which can be energized in all combinations of any one select or one hold. When a select and hold coil is energized, 10 contacts (levels) are closed. The crossbar switch has 1200 contacts (levels), 830 of which are used to discrete responses, routed straight to the buffer in groups of 10. The remaining 360 contacts are used for 180 analog responses; analog signals are switches in pairs. Although five analog responses (10 levels or contacts) are selected by the crossbar switch with each select hold combination, the response selector allows only one of these analog responses to be routed out of the chassis. The matrix display panel indicates the "select" and "hold" coils which have been energized.

l. M-2 multiverter (analog-to-digital converter). The M-2 multiverter receives dc voltage outputs from either a differential amplifier, the ac/dc converter, or the programmable voltage attenuator. The voltage is digitized and fed into the station buffer (SSB-4). Maximum input voltage to the M-2 is ± 5 volts dc. The low level selector chassis contains 128 nonlatching relays through which analog responses of low voltage amplitude are routed. Programming one of these relays and the conditioner selector will connect the analog signals to any programmed conditioning device. The programmable voltage attenuator (PVA) is a voltage divided network with 999 individual ranges of attenuation. It is used to attenuate large voltages and measure the potential difference from chassis ground.

m. Differential amplifiers. There are four differential amplifiers in the Network Test Station, each with a different input voltage range. Voltage ranges for these amplifiers are: 0-2 volts, 0-10 volts, and 0-60 volts. The maximum output voltage of each differential amplifier is ± 5 volts dc. The differential amplifiers are used for measuring low amplitude analog responses and/or floated-input responses.

n. Conditioner selector. The conditioner selector is used to switch one of the seven analog signal conditioners (four differential amplifiers, ac/dc converter, time and frequency digitizer and the programmable voltage attenuator) into the response channel. Both the input to, and the output from any conditioner are switched simultaneously. The same command that selects a conditioner can also start the M-2 conversion after a programmed delay for conditioner setting.

o. Response selector. The response selector chassis contains the logic that operates the response selector matrix (crossbar switch), which switches either the low level relay analog responses or crossbar switch analog responses into the proper conditioner selector channels.

4. <u>Instrumentation and Telemetry Test Station.</u> The Packard Bell Computer Instrumentation and Telemetry Test Station (Figs. 13 and 14) is computer-controlled with three major functions: to initiate, monitor, and interpret calibration and test results of three arbitrarily designated systems, the UMA Calibration System, Miscellaneous Sensor-Response System and Pneumatic Pressure Distribution System.

Hardwire output signals are brought out from the stage and latching relays select the individual wire for monitoring. In addition, high-level and low-level differential signals are brought out through the umbilicals of the stage and directed to the station for monitoring by means of relay multiplexers.

High-pressure and low-pressure digital-to-pressure generators are supplied for stimulating pressure transducers. Relay closures are provided to select the pressure switch manifold configurations for directing the proper pressure to the proper transducer under computer control. Stimulation of other transducer types is primarily manual or mechanical, but under computer control.

The telemetry substation is located remotely from the main satellite station. It is provided with contact closures for setting up the proper receiver-discriminator combination required by the various telemetry channels. It is also provided with circuitry for decoding and measuring decommutated PAM data trains. It also has the capability of driving calibration devices for calibrating the telemeter equipment itself. All operations are under computer control, and all measured data are returned to the test station for processing.

a. Functional Description. The test station proper consists of a telemetry interface, universal measuring adapter calibration interface, pneumatic pressure interface, pressure generating equipment, measuring devices, and a remotely located substation. The substation is used for the reduction of telemeter signals, and calibration and/or test signals from the vehicle.

b. UMA Calibration System. Near the tail section of the vehicle there are racks containing Universal Measuring Adapters (UMA), which consist of a relay and amplifier (see Section II). Each UMA accepts signals from sensors throughout the vehicle and converts them to 0 to 5 volts for subsequent application to telemetry equipment. Each UMA is calibrated at a high-level or low-level as required. The calibration cycle consists of energizing the appropriate calibration relay to provide the stimulus to the UMA.

There are approximately 600 measuring devices or sensors with hard-wire outputs to the test station, and approximately 125 sensors and control signals from the umbilical. These signals are compared with the same signals after transmission over telemetry links.

The computer through the UMA calibration register relay contact closures scans each UMA in the vehicle by supplying signals to the vehicle UMA digital calibrator. To select an individual calibration relay in a specific UMA module the stimulus selection matrix is energized by a programmed signal from the computer. The calibrate register by contact closure energizes the proper relays in the vehicle UMA digital calibrator. The calibrate register selects the UMA to be scanned. The computer automatically scans all UMA modules for the UMA programmed characteristic wave curve. If any curve is out of tolerance, the computer after scanning all the UMA's, will type in hard copy the locations of the UMA's not meeting specifications.

If a UMA requires adjustment, the operator in the vehicle follows a test procedure, and where necessary makes the proper adjustments. To aid in making the adjustments, the operator in the vehicle uses the indications on the portable remote display unit.

Calibration of the modules is done by the operator in the vehicle. The remote indicator unit shows the measurement or UMA canister, rack, channel, test step, and whether the readings are above or below tolerance. Wrong direction indicators light when adjustment is made in the wrong direction. When the calibration is within tolerance, a lamp lights. The computer proceeds to the next step in the test when the STEP pushbutton is depressed. When the test is complete, the operator depresses the TEST COMP pushbutton to allow the computer to proceed to the next test.

c. Miscellaneous Sensor Response System. The miscellaneous sensor response system requires either electrical, manual or mechanical stimulus for measurement purposes. The operator can apply the stimulus manually or with a mechanical device, or the stimulus can be supplied from another satellite station. The computer or the satellite station operator directs vehicle operators, by means of the portable remote indicator units to the proper sensor to be manually stimulated.

Various types of measurements are made: temperature, position indication, angle-of-attack, vibration, liquid flow rate, tachometer, liquid level, and other miscellaneous measurements. All manual operations

FIGURE 13. INSTRUMENTATION AND TELEMETRY TEST STATION

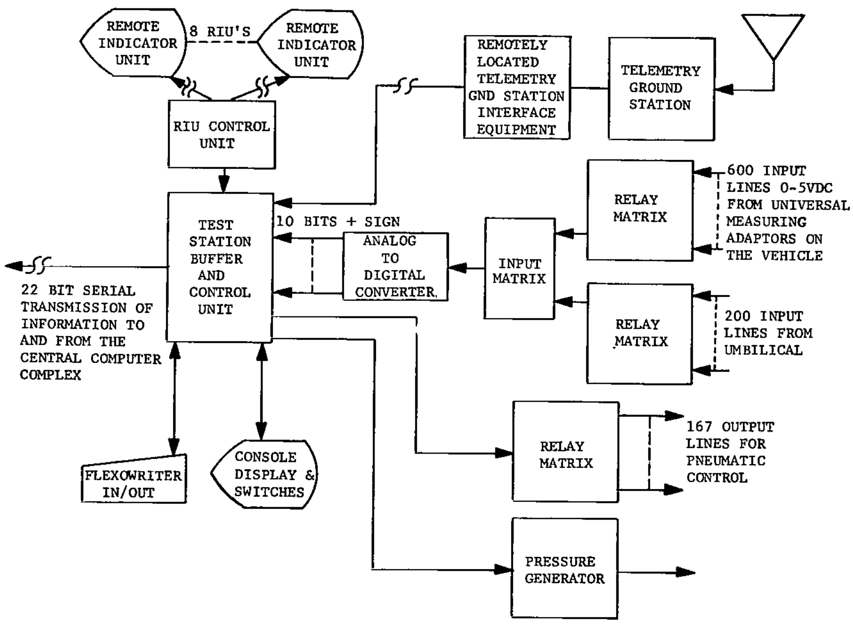

FIGURE 14. INSTRUMENTATION AND TELEMETRY TEST STATION DIAGRAM

and tests are commanded by the computer at the proper point in the test sequence. The results of the manual operation or test must be fed to the computer before the computer will permit the test sequence to continue. In this manner, complete data will be obtained and stored by the computer for future reference and analysis.

The connection between the sensor UMA output and telemetry equipment may be interrupted and the outputs may be brought out by hardwire connection. These signals are fed to the central computer for comparison with the signals received by the telemetry ground station.

d. Pneumatic Pressure Distribution System. The pneumatic measurement part of the test station provides different pressure ranges to individual pressure sensors. Both pressure range and stimulation are completely under computer control.

A pressure distribution relay matrix controls the operation of the vehicle manifolds to select the proper pressure transducer. The pressures used to stimulate the transducers are selected under computer control by means of relay contact closures.

A pressure generator is connected to the vehicle transducers through a system of manifolds. The generator is used for calibration of high and medium range pounds per square inch gage (psig), pounds per square inch differential (psid), and above atmosphere portions of the pounds per square inch absolute (psia) transducers. The computer system contains a relay-holding register which provides contact closures to activate the solenoid valves in the generator.

e. Satellite Substation. The substation is remote from the satellite station. All actions at the station are commanded and controlled by the computer.

Under the control of a computer program, the substation automatically connects the appropriate receivers, discriminators, or decommutators, so that selected telemeter data can be routed to an analog-to-digital converter. The digitized response signal is then transmitted back to the computer for analysis.

5. Vehicle Test Station. The Vehicle Test Station (Fig. 15) provides onboard tests of the electrical heaters, pressure systems, main Lox and fuel valves, and digital events in the performance of the vehicle. The VTS functionally consists of a satellite buffer, a stimuli section, and a response section. A block diagram of the test station is shown in Figure 16.

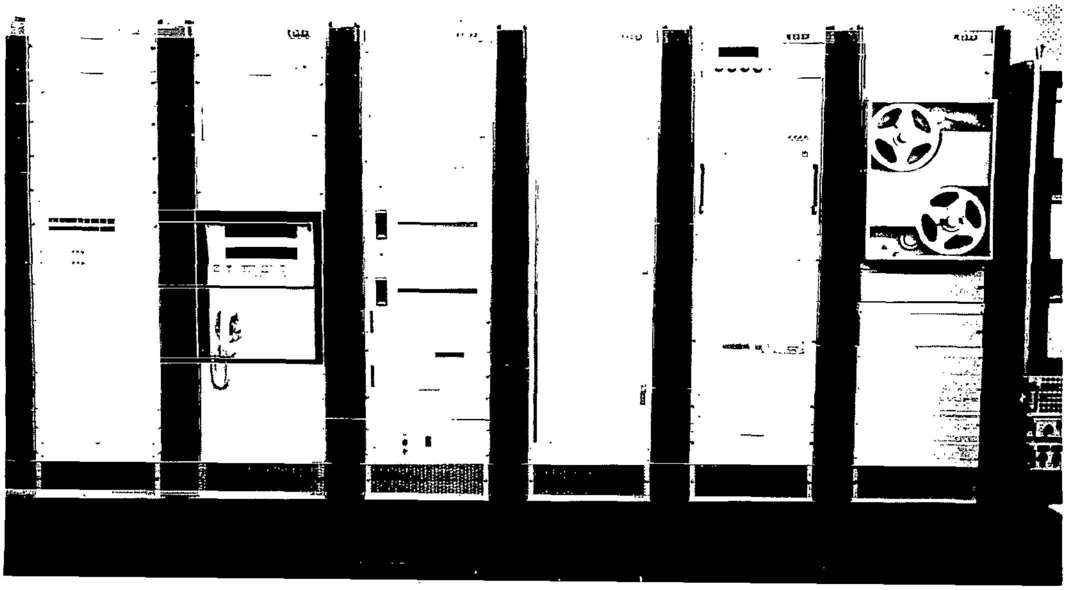

FIGURE 15. VEHICLE TEST STATION

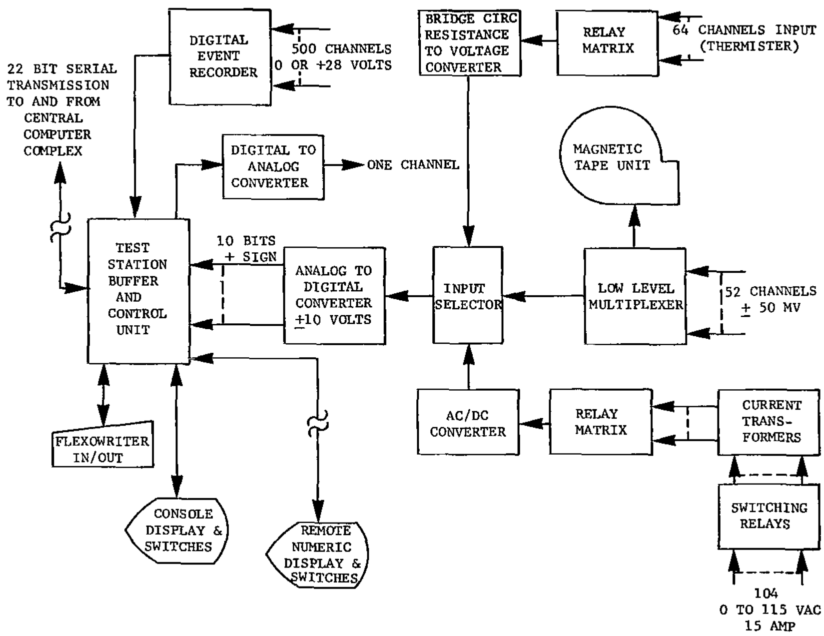

FIGURE 16. VEHICLE TEST STATION BLOCK DIAGRAM

The computer originates and stores digital test loop data and program information. The Vehicle Test Station checks out and tests the electrical heaters, pressurized systems, and fuel and Lox valves of the Saturn first stage by means of programmed test loops. The programmed test loops are serially transferred to the test station buffer from the computer. The test station buffer decodes the message from the computer into address, command, and data signals which activate addressed digital-to-analog conversion and stimuli circuits.

The test station stimuli circuits actuate selected transducer elements in the stage. The transducer elements respond with analog output signals. The analog signals are applied to the test station response circuits andare converted to corresponding digital signals. The digitized data is transferred in parallel to the satellite buffer for temporary storage, and then serially transferred to the computer.

The test station automates the specified tests by accepting digitally coded instructions from the computer. These instructions select the point of measurement, the conversion and/or signal conditioning path, any local stimulus necessary, and display of printout of data. The test station contains all the necessary (addressable) measurement and conversion components required to perform the specified tests. Internal self check (addressable) measurement paths are incorporated into the test station as an aid to the operator when analyzing malfunctions or verifying measurements. To test for proper operation of the stage heaters, the Vehicle Test Station switches on and off, by program control, 43 heaters, through the activation of the switching relays. The current drawn by the heaters is measured with current transformers, an ac to dc converter, and an A to D converter. The temperature of each heater is then measured by thermisters located in proximity to the heaters and a bridge circuit and A to D converter. Upon the completion of three cycles of the thermostatically-controlled heaters, the computer turns off the heater. The computer prints out the peak and average temperatures and notifies the operator of abnormal temperatures or currents. The computer may or may not, as determined by the program, turn off the heaters if abnormal currents or temperatures are detected.

The test station includes provision for measuring and recording the electrical output of up to 52 pressure and pressure test related transducers mounted external to the station proper. These pressures are measured by a high speed relay matrix in the low-level multiplexers.

The Vehicle Test Station includes a magnetic tape transport and associated control and read/write equipment to continuously record on a twelve minute (minimum) automatically reversing tape the measurements from the 52 pressure and pressure test related transducers.

The station also provides a means for continuous dynamic monitoring of up to a maximum of 250 discrete digital event lines so as to record the time at which any of the lines changes state from on to off or vice versa. The equipment for this purpose (DER Digital Event Recorder) is capable of autonomous operation.

The test station includes all of the standard operator controls and displays except the flexowriter which is mounted on a mobile cart to permit remote operation of the VTS at a distance up to forty feet.

6. Electrical Test Station (Cable Analyzer). The purpose of the Electrical Test Station (Fig. 17) is to test and check out both the vehicle and GSE wiring and cabling systems. The checkout of the wiring system is made primarily to verify that interconductor or intercircuit resistor insulation is adequate and that point-to-point circuit resistances are less than the prescribed maximum. One test made with the test station cable analyzer is circuit continuity check, which verifies that the unit is wired as specified by determining that the point-to-point resistances of selected terminal pairs are below specified minimums. A second test made with the test station is a fault test, which determines if a short exists from one ordered wire to another wire of lower order. A fault (short) is found by checking that actual circuit resistance values are less than or equal to a programmed resistance value. If shorts in the circuit wiring exist, the test station scans all the connected terminals and locates the specific shorted terminal or terminals.

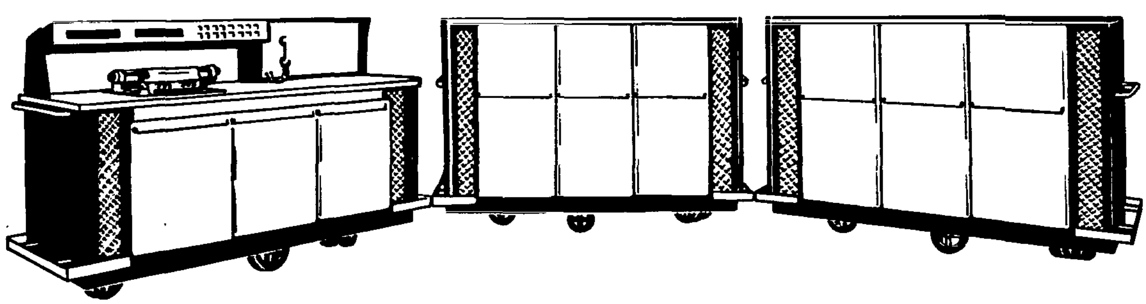

FIGURE 17. ELECTRICAL TEST STATION (CABLE ANALYZER)

The electrical test station operates in conjunction with a computer of the central computer complex and time shares computer space and information with the other test stations. The primary function of the test station cable analyzer is to check out wire and cable systems of up to 4000 test points (terminals) by testing for terminal-to-terminal current continuity and faults (leakage). The functional units of the test station are a cable analyzer and test station buffer.

The central computer complex originates and stores four ETS test loop and program words. These programmed words specify: the type of test being run, continuity or fault, the terminals and pin numbers used in the test and the specific parameters used to run the test. The four programmed words of the computer are serially transferred to the test station buffer which decodes the words directly into address, command, and data signals. The addressed signals activate the cable analyzer circuits to make the specified continuity or fault test.

The test station is an automatic cabling and wiring system analyzer, which functions with a minimum of information from the computer. The cable analyzer control cart controls the testing and logical analyses of the system under test. The system under test is initially connected to the switching cart input connectors, which are wired to numerically ordered switching module connector terminals. The selection of specific test terminals, type of test, and test parameters are provided by either the automatic computer programmed input to the control cart, or by the test station operator manually selecting these test parameters on the OVERRIDE panel of the control cart.

The test station cable analyzer control cart contains all of the equipment necessary to initiate and control the range of input parameters and type of test desired, and to analyze and determine the specific terminals within the switching cart connector matrix which contain the circuit fault or discontinuity. The control cart contains the indicators and indicator switches which display to the station operator the resultant condition of the switching cart system under test. The control cart logic section decodes and transmits the test results to the buffer cart satellite buffer, which, in turn, transmits information to the buffer cart display panel and to the computer.

The cable analyzer switching cart contains the patchboard inputs and cable input connectors used to check out a system. The switching cart uses four terminal-switching and bulk-shorting switching modules, each of which provides for an independent selection and use of input/output terminals. Each switching module provides: up to 1000 terminal connections; a partial selection of an output terminal (five terminals selected from 1000); the partial selection of an input terminal (50 terminals selected from 1000); and the means to short any portion of 1000 terminations in groups of 50 terminals to the system short line.

The selection of either input or output connector terminals is made through two 50-pole, 20-position stepping switches and twenty 50-pole bar relays within the switching module. These switches and relays obtain switching information from the control cart input lines.

The test station cable analyzer performs its continuity and fault test on three types of switching cart input points:

a. 66 Bendix connectors of 61 pins each.

b. A 3264 point AMP patch panel.

c. A 2560 point IBM patch panel.

Connectors and terminals are numbered in accordance with a fixed connector and pin assignment. The numbering of 80 connectors and 50 pins (4000 points) is made on an ordered arrangement, so that the lowest order terminal is designated as connector 00, pin 00, and the second lowest terminal point is designated as connector 00, pin 01. The terminals are wired consecutively up to highest order, designed as connector 79, pin 49.

The cable analyzer fault test checks the current flow condition between two selected terminals (insulated from each other) one of which is shorted (connected and used as a node terminal) to a number of other terminals. An address specifies the shorted terminal to which all terms of lower order are also connected and shorted.

A continuity test determines the resistance value between two specified test terminals. If the resistance value is more than the programmed value, a discontinuity or continuity error is determined and displayed on both the control cart indicator display and the buffer cart operator's control panel. For a more detailed functional description refer to the supplementary vendor cable analyzer manual, DIT-MCO, OM610A-1.

7. System Theory, Software. Under automatic checkout operation the computers are designated as Master, Slave 1, and Slave 2. The master computer is capable of communicating with the slave computers and vice versa through common memory lines. In this configuration, an executive routine called the Saturn Master Monitor is loaded into the master computer. Lesser executive routines called Slave Monitors are loaded into each slave computer.

a. Saturn Master Monitor. The Saturn Master Monitor program is the heart of the entire system. It is an elaborate routine offering control, monitoring, and input-output for the console and remote test stations.

The Saturn Master Monitor continuously monitors the remote stations for requests to perform checkout tests. To initiate a checkout test, the test station operator first consults a station program list for the identification number of the program to be run. The request switch is then depressed on the test station console. The Saturn Master Monitor senses the request. If a test is being performed in that test station, the program is automatically stopped by the monitor. The monitor begins communication with the test station operator by typing "BUSY, READY, or PROGRAM."

(1) BUSY. BUSY indicates that all slave computers are in use and it will not be possible to run the test. The Saturn Master Monitor continues its operation.

(2) READY. A slave computer has been connected to the test station and the operator may select one of five options.

(a) UTL. By typing UTL the operator causes control of the slave computer to be transferred to a utility program. The station operator may then communicate with the slave computer. This option is primarily for use by the programmer in debugging test routines.

(b) END. The Saturn Master Monitor will type out END, program number, time and date, and will release the slave computer for other tests.

(c) RST. The Saturn Master Monitor turns on the execute light on the test station console. By depressing the execute switch, the operator signals the Saturn Master Monitor to restart the test at an appropriate place.

(d) GO. By typing GO the operator causes the test program to resume operation.

(e) TEST. TEST indicated another test program is to be loaded into the slave and operation is continued as described under PROGRAM below.

(3) PROGRAM. The test station operator requests the test program by typing the program number (PP). The Monitor replys by typing out "START PROGRAM PP," the time, and date. The Monitor then searches the program magnetic tape for the requesting program. If the program is not on the tape the Monitor will type "NO PP" to the station operator. If the program is found, it is loaded into the slave computer and control is transferred to the slave to perform the checkout test.

b. Slave Monitor Program. The Slave Monitor is a small executive routine used for control of the slave computer and for transmission of information to and from the Master computer. During the operation of checkout programs the Slave Monitor is inoperative. The operation of the Slave Monitor is under control of the Saturn Master Monitor. The Slave Monitor contains utility subroutines which may be used by the checkout programs.

When a checkout program is to be loaded into the slave computer the Slave Monitor receives the program 256 words at a time from the Master computer and stores it in a designated location. Storage information is contained at the beginning of each line of information transferred to the slave.

C. Support Computer System

In August 1962 action was initiated in the form of a request to Computation Laboratories for a data processing type computer for the Laboratory. As the Packard Bell Central Computer Complex became more and more in use, the time available for the processing of these programs and data decreased. It soon became obvious that such an off-line computer system would be required. The GE-215 Support Computer System was subsequently purchased and installed in September 1963 for the purpose of preparing the data and programs required by the checkout computer and providing test results data after the completion of a test. The support computer is pictured in Figure 18 and illustrated in block diagram form in Figure 19.

One area in which the support computer was used to advantage was that of Instrumentation and Telemetry. Each of the test programs for this area required large tables of data (3000 to 5000 words) and when a new stage was tested, the data in these tables changed and required reprocessing.

Special circuitry had to be incorporated into the magnetic tape units to provide for the reading and recording of the PB-250 magnetic tapes. Likewise, special circuitry was incorporated into the paper tape equipment to allow for the handling of the random 8-channel paper tapes of the PB-250. However, the small additional charges were compensated for by the increased speeds of processing the bulk data for the testing operations. For example, to print out the results of a telemetry scan on the PB-250 flexowriters would require 45 minutes. It was a simple matter, however, to record this data on magnetic tape and print the information out on the GE-215 in 5 minutes. During this printout period, the test computer was released to continue checkout operations.

The GE-215 was not used solely for processing information for the PB-250. Support of the RCA-110 in the Saturn I Instrument Unit checkout was necessary.

1. System Theory, Hardware. The GE-215 computer was purchased with a 4096 word core memory, two magnetic tape units, a card punch, card reader, output typewriter and line printer. Statistics of the hardware are shown in Table I. The GE-215 computer was a medium size, solid state, general purpose computer with the capability of being expanded to meet future needs. This capability was proven when the machine was later expanded to the GE-235. The computer operates under both stored program and operator control. It is a buffered computer with an input-output priority system that permits simultaneous operations such as reading, writing, and processing.

2. System Theory, Software. The limited number of magnetic tape units necessarily resulted in the use of an unsophisticated method of operation. When a program had to be run on the GE-215, the program was loaded through the card reader. An executive, as such, was never used.

There were numerous programs written to run on the GE-215 in support of the Saturn I check-out. A partial list is included below:

(a) Electrical Test Station Sequence Data to PB-250 Binary Paper Tape.

(b) Astrionics Electrical Wiring Cards to Binary Paper Tape.

FIGURE 18. GE-215 SUPPORT COMPUTER

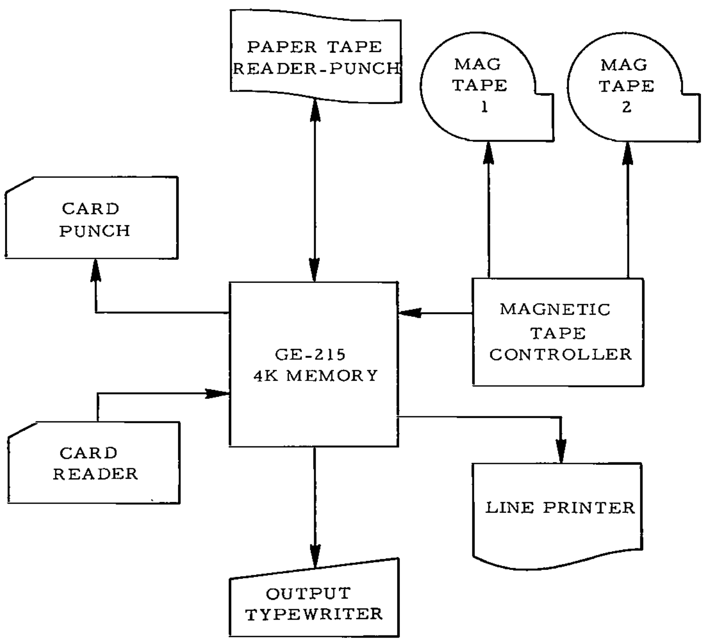

FIGURE 19. GE-215 SUPPORT COMPUTER DIAGRAM

TABLE I. GE-215 FEATURES

1.	Central Processor	General purpose, single address, binary, solid state, 36 m sec word time, 4096 word memory
2.	Magnetic Tapes	2 - 15 KC, 200 BPI AMPEX TM-4 type.
3.	Card Reader	400 CPM
4.	Card Punch	300 CPM
5.	Line Printer	450 LPM, 120 columns
6.	Output Typewriter	10 characters per second (IBM)
7.	Paper Tape Reader	300 characters per second
8.	Paper Tape Punch	110 characters per second

(c) Universal Measuring Adapter PB-250 Magnetic Tape to GE-215 Printer.

(d) Temperature Sensor PB-250 Magnetic Tape to Printer.

(e) Instrumentation and Telemetry Scan Magnetic Tape to Printer.

(f) UMA Test Data Cards to PB-250 Binary Tape.

(g) DDAS Test Data Cards to PB-250 Binary Paper Tape.

(h) Cards to PB-250 Paper Tape (Pressure Calibration Test).

(i) Temperature Sensor Data Cards to PB-250 Binary Paper Tape.

(j) DDAS/Hardwire Printout Program.

(k) Telemetry Data Cards to PB-250 Binary Paper Tape.

(l) Telemetry/Hardwire Data PB-250 Magnetic Tape to Line Printer.

(m) Digital Events Monitor Data Reduction.

(n) Digital Events Monitor Translation Print.

(o) Instrumentation and Telemetry Data Processing.

D. Digital Events Evaluator (DEE-3A)

The Digital Events Evaluator, Model DEE-3A (Fig. 20), is manufactured by Scientific Data Systems. This system became an integral part of the checkout equipment for the Saturn first stage when the need for high speed, high resolution monitoring of digital events became evident.

1. General Description. The Model DEE-3A Digital Events Evaluator is a special digital system which provides a convenient, self-controlling facility for detecting changes in the ON and OFF status of up to 768 input lines. Under the control of a computer program stored internally, the DEE-3A can continuously scan all 768 input lines at the rate of 4 milliseconds per scan and detect any change in the status of the lines that may occur. This is done by comparing the state of each input line being read with the stored copy of the state of the lines made during the previous cyclic scan. Each change in status is processed by the program and is output on a typewriter or punched paper tape. The processing of a status change results in the output of the identifying label of the input line, its present status, and the time at which the change occurred. Identifying labels for the various input lines are assigned by the test engineers.

The operation of the DEE-3 is closely directed by the equipment operator. During the initialization of a test procedure, a special program-preparation phase allows the equipment operator to specify various operating modes. During this phase, the operator names the input lines which will be used in the test. The number of input lines is also variable and is set at this time.

During the actual events evaluation run, the equipment operator has several control features available. These take the form of special functions that the operator may request by keying them into the DEE-3A via the input typewriter. Such controls are: the ability to change the mode of output from typewriter to paper tape punch during a test run, or the ability to request the output of all of those input lines which are in the ON state at the time of operator request. Operating modes such as calling for the previously mentioned sequence comparison feature are also available.

2. System Theory, Hardware. The system description of the DEE-3A hardware has best been made by considering first its characteristics and then its operation.

a. Characteristics. The DEE-3A is physically composed of an SDS-910 solid-state core memory digital computer and associated circuitry. This associated circuitry is used to implement the scanning capabilities of the DEE-3A system, giving it a capability of monitoring up to 768 input lines and evaluating "digital events" that occur on any of the input lines.

The DEE-3A system is mounted in a three bay, RFI-proof relay rack occupying a floor area of 1738 square inches (112. 14 sq. m). An additional 900 square inches (58. 07 sq. m) of floor space is required for the table upon which the input/output typewriter is mounted. The main rack of the system measures 63. 2 inches (160. 53 cm) wide by 27. 5 inches (69. 85 cm) deep by 87. 6 inches (222. 5 cm) high and weighs approximately 2500 pounds (11 339. 81 kg).

Input/output capabilities are implemented by a Teletype typewriter, a Tally paper tape punch, and a Rheem paper tape reader. The paper tape punch is capable of outputting at the rate of 60 characters per second and is mounted in the main racks of the system. The Rheem paper tape reader, also mounted in the main racks, is capable of reading paper tape at the rate of 300 characters per second. The input/output typewriter, which is mounted on a table immediately adjacent to the main racks, is capable of accepting input or output information at the rate of 15 characters per second. The typewriter may be extended up to 30 feet (9. 14m) from the main racks without requiring additional drivers.

External connections for the system are required only for the input lines which are to be monitored and for the input operating power to the system. Input power requirements are 110 volts, single phase, 60 cycles per second. The input power is received through two receptacles which must be in series with circuit breakers of not less than 30 amperes each.

The input lines to the system are terminated at a bulkhead and distributed to the input filters by means of module terminated cables. Any of the input modules may be replaced by a special test module, which is connected to a test panel and allows any of the input lines to be checked manually.

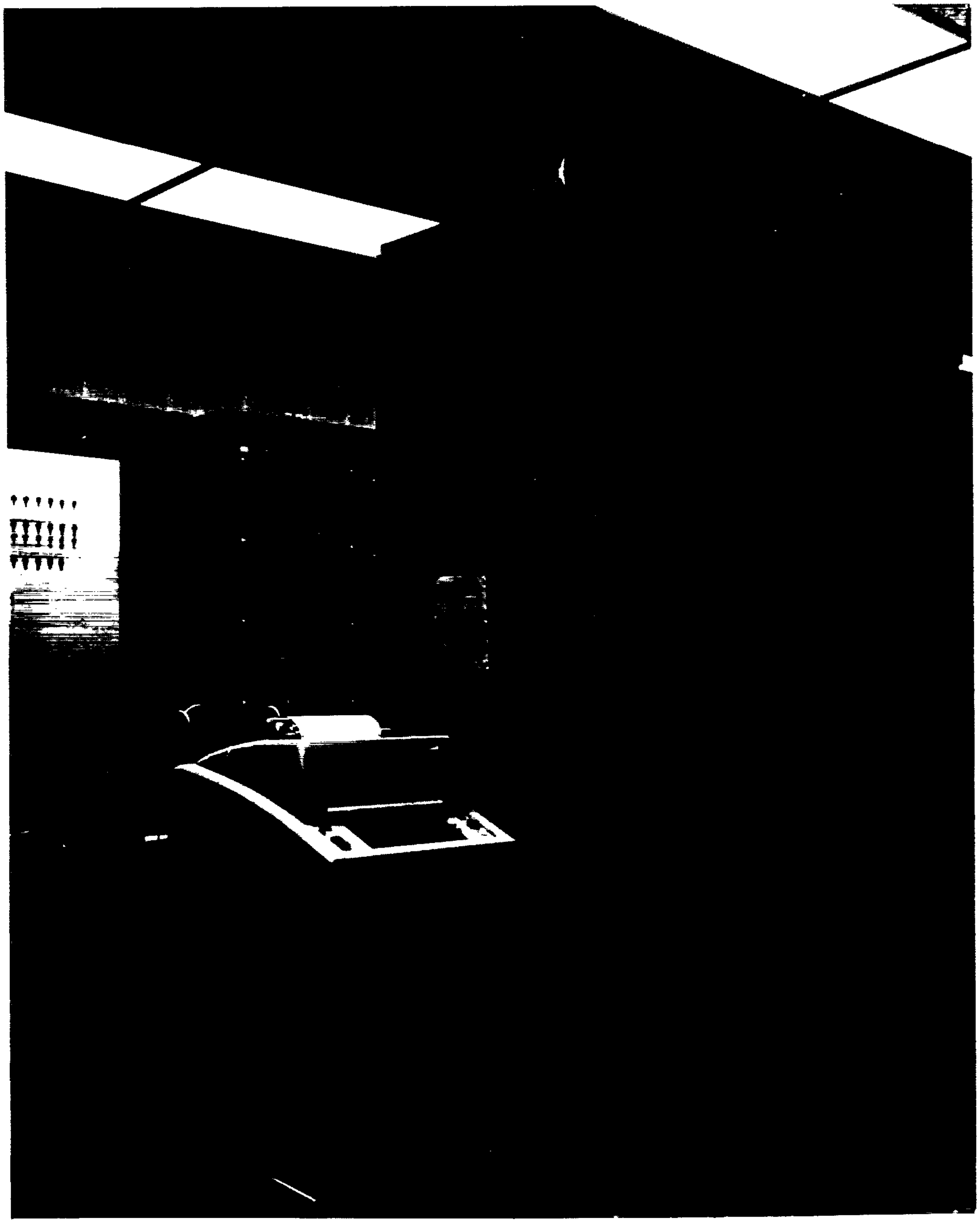

FIGURE 20. DIGITAL EVENTS EVALUATOR, MODEL DEE-3A

b. System Operation. A block diagram of the DEE-3A system is shown in Figure 21. It should be noted that the component blocks in this diagram are composed, in part, of actual hardwire circuits and portions of the core memory reserved for the DEE-3A program. The input circuitry, the comparator chassis, and the control chassis are all system electrical components. The previous Scan Cycle Memory and the Output Buffer are programmed tables set up in the core memory to facilitate processing of information concerning the digital inputs to the system.

3. System Theory, Software. The digital computer at the heart of the DEE-3A system is an SDS-910 Computer. A Binary Comparator functions with the computer to compare the status of input lines during successive scan cycles. Operation of the computer and comparator is controlled by the programming system as described in the following paragraphs and illustrated in Figure 22.

Controlling Programs. Primary functional control of the DEE-3A system is provided by the stored programming system which operates in the SDS-910 computer. The programs which make up this programming-control system are listed as follows:

Program	Control Function
Scan Program	Controls the system during the scan and comparison operations while status information is being placed on the input lines.
Processor Program	Controls the processing and formatting of all data to be output including the correlating of proper identification of input lines and the maintaining of proper sequence checks.
Output Program	Controls the output of status change information.
Control Program	Controls the system during the time that the operator is entering control and change directives.

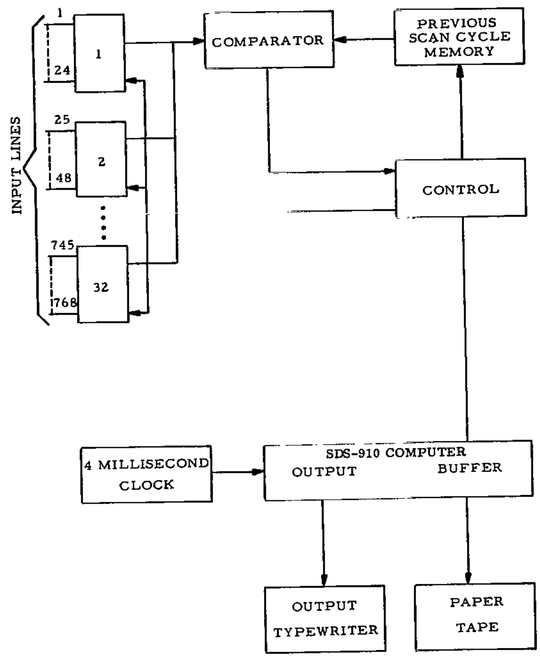

FIGURE 21. DEE-3A BLOCK DIAGRAM

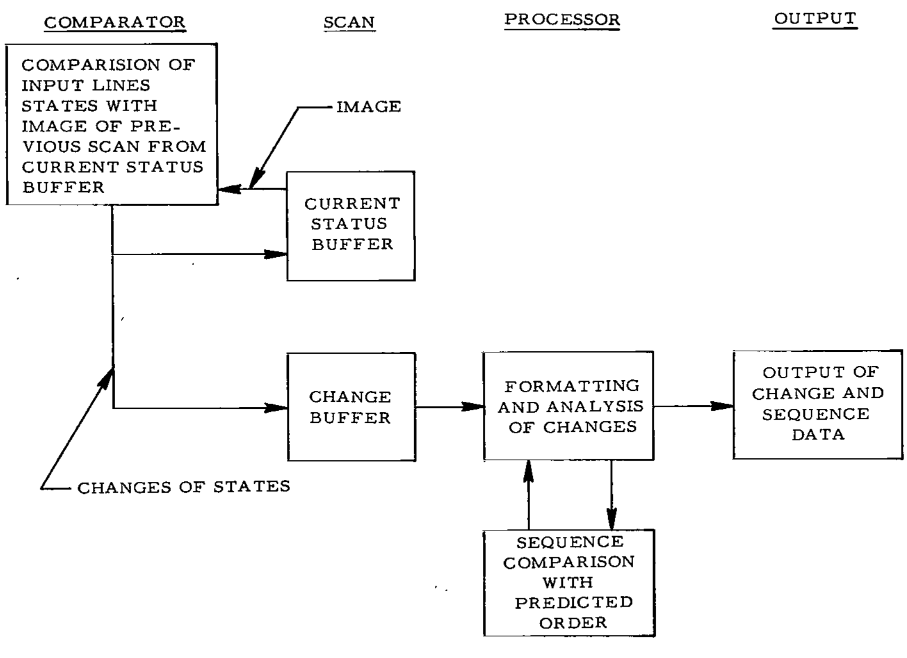

FIGURE 22. DEE-3A PROGRAMMING SYSTEM FUNCTIONAL BLOCK DIAGRAM

The contents of a relative time counter are stored by the Scan Program with each change of state or error condition. These relative times determine the order of occurrence and the time of occurrence, relative to the beginning of the test run. Under the operator control function, the operator can enter the "absolute" time that the test will begin. This time is held in the DEE-3A memory. When this absolute time has been entered and stored in the DEE-3A, the relative time count is added to this absolute time to determine the actual time of each change of condition or error. The DEE-3A will continuously update the relative time counter with each CLOCK interrupt.

At any time during the operation of the Object Program, the operator may interrupt to specify a change in the operating mode. This interrupt is analyzed by the Control Program.

The Control Program provides for operator control of the DEE-3A Object Program through typewriter inputs. The program is initiated when the CONTROL switch on the Interrupt Box is pressed. All functions of the Scan Program, except time incrementing, are inhibited while the Control Program is in operation. Each character transferred to the Control Program from the typewriter keyboard is checked for validity. Invalid characters are ignored and a new character is requested. All valid characters initiate various set and reset functions within the Object Program.

Figure 21 is a flow diagram showing control sequence from program to program during the operation of the DEE-3A system.

E. Michoud Automatic Test Equipment

The automated test equipment at the Chrysler Corporation Space Division at Michoud is categorized in four sections: Central Computer Complex, Support Computer, Program Verification Computer System, and Digital Event Evaluator (DEE)-3A.

1. Central Computer Complex. The Central Computer Complex at Michoud services two separate and complete checkout areas. Since the Packard Bell PB-250 computer complex was designed for expansion of the number of slave computers and satellite test stations, the Central Computer Complex at Michoud was expanded to contain a master computer, and five slave computers, and five remotely located test stations (see Figs. 23 and 24). This Central Computer Complex also includes four magnetic tape stations, a

papertape reader punch, flexowriter input/output, control console, and display unit. The remote test stations included two networks test stations, two instrumentation and telemetry test stations, and one vehicle test station. Theory of operation of the Central Computer Complex and the remotely located test stations are the same as described in Section II of this document.

2. Support Computer. The Support Computer selected for the Chrysler Corporation Space Division's Michoud Operation was the Scientific Data Systems SDS-920. The computer has a basic 16 000 words of memory, 4 magnetic tape units, teletype input/output, line printer, card reader, and papertape reader/punch. A block diagram of the support computer is shown in Figure 25 and the computer is illustrated in Figure 26. The purpose of the support computer is for use in preparation of data and computer programs for use in the Central Computer Complex and for the reduction of test results data and information.

3. Off-Line Program Verification System. The off-line program verification system is illustrated in Figure 27. This system is comprised of equipment that was used at the Quality and Reliability Assurance Laboratory in checkout of the Saturn I, S-I Stage. The system includes one master computer and one slave computer. Also included are two magnetic tape units, flexowriter input/output, papertape input/output, card reader, control console, Networks Test Station, and an Instrumentation and Telemetry Test Station. The functioning of each portion of the system is the same as that described in Section II of this document. The off-line program verification system is used for verifying computer programs that have been modified, rewritten, or newly developed prior to their operation in the Central Computer Complex. A majority of mistakes and problem areas can be removed from the programs through this type of operation before they are put on line and used for checkout of the stage.

4. Digital Event Evaluator (DEE-3A). There are two Digital Event Evaluators (DEE-3A's) at the Chrysler Corporation Space Division Checkout Facility. One DEE-3A is used for each checkout complex. The DEE-3A at Michoud is illustrated in Figure 28. The DEE-3A consists of an SDS-910 computer with a four thousand word memory, papertape input/output, teletype input/output, and 768 discrete input lines. The operation of the DEE-3A is described in Section II of this document.

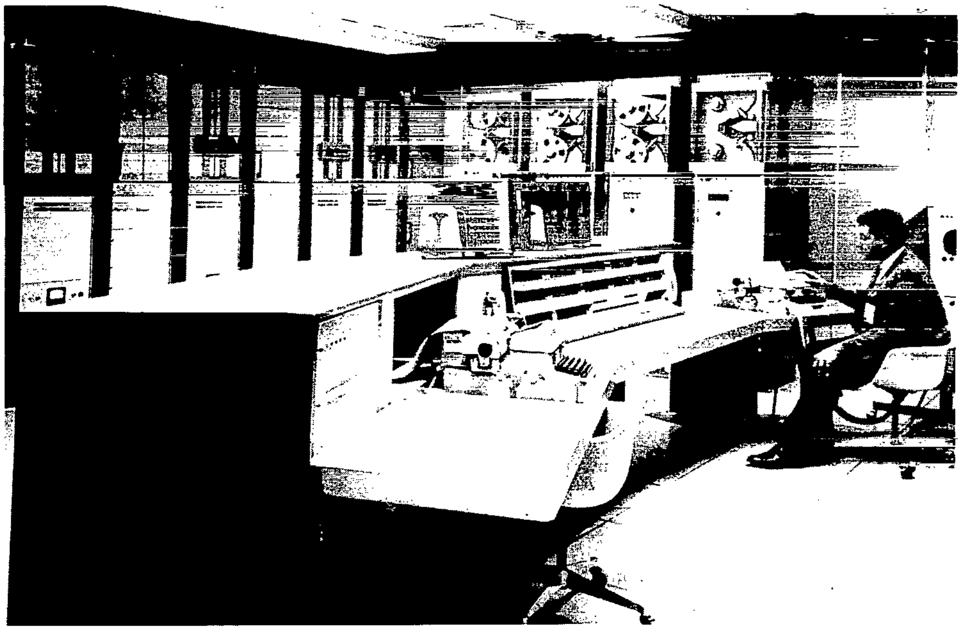

FIGURE 23. SATURN AUTOMATIC CHECKOUT SYSTEM AT MICHOUD

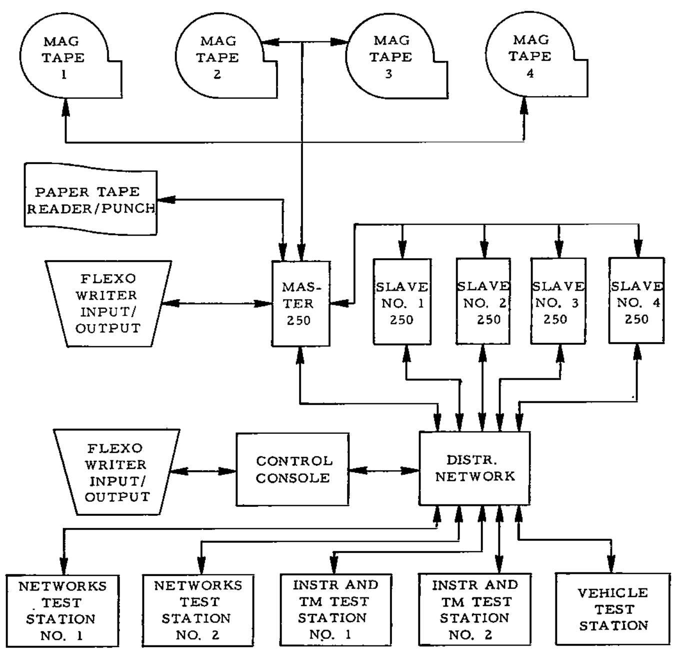

FIGURE 24. SATURN AUTOMATIC CHECKOUT SYSTEM BLOCK DIAGRAM

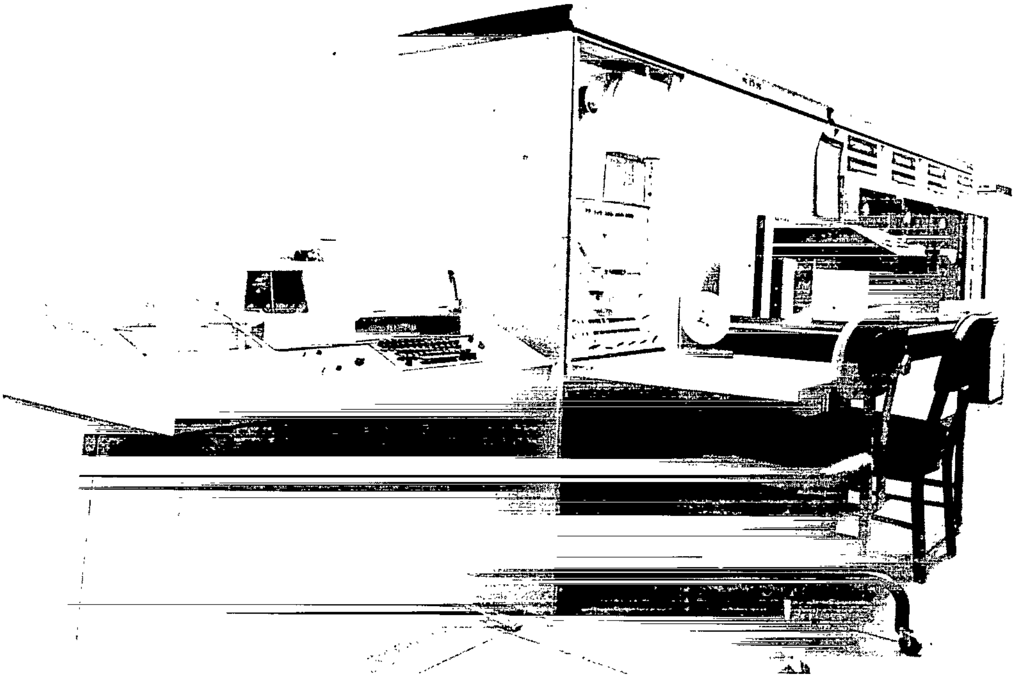

FIGURE 25. SUPPORT COMPUTER DIAGRAM

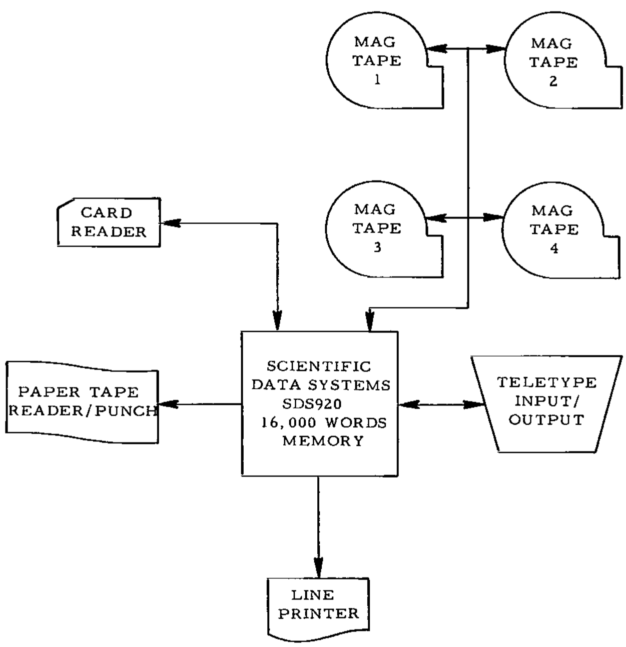

FIGURE 26. SCIENTIFIC DATA SYSTEMS SDS-920

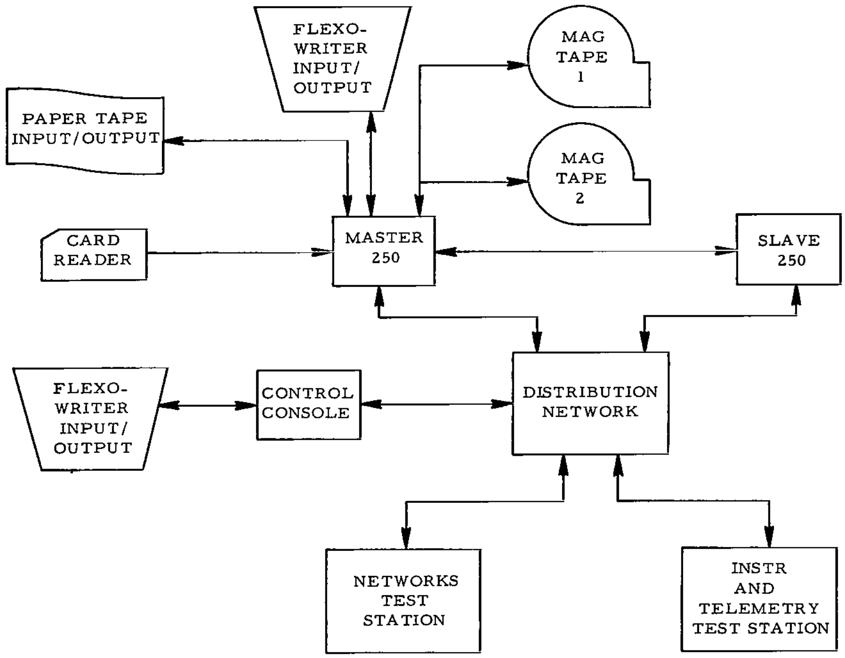

FIGURE 27. OFF-LINE PROGRAM VERIFICATION SYSTEM (CHRYSLER-MICHOUD)

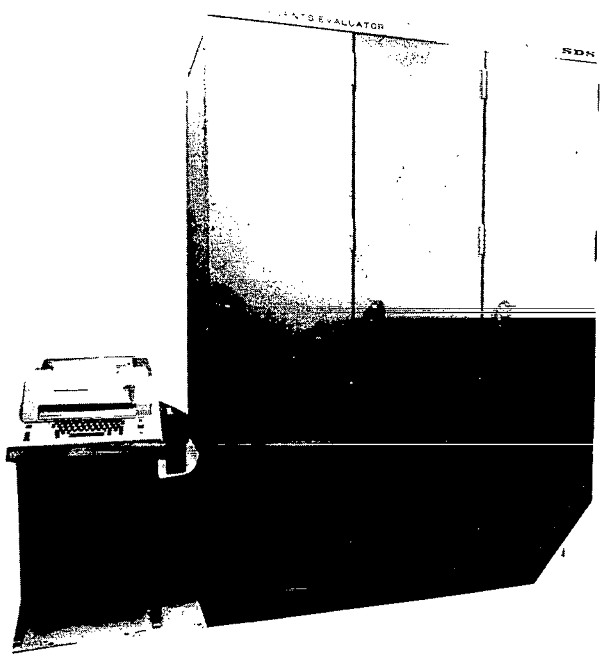

FIGURE 28. DIGITAL EVENTS EVALUATOR, MODEL DEE-3A (MICHOUD)

SECTION III. AUTOMATED TESTS

A. Introduction

There are many categories of tests involved with the complete testing and checkout of a Saturn vehicle. Receiving inspection, fabrication analysis, component and minor assembly analysis, major subassembly analysis, stage analysis, and assembled stage checkout are the more generally accepted categories.

Some component checkout (valves, distributors, accelerometers, etc.) and stage analysis (vehicle alignment, weight and center of gravity, etc.) functions were planned to be included in the first automation efforts. For various reasons these areas were almost entirely deleted from the automated movement and automatic checkout became almost completely directed to assembled stage checkout.

Assembled stage checkout is defined as a series of functional tests which determine that all systems of the vehicle will satisfy design and mission objectives and requirements when operating independently or compositely. For purposes of clarity in discussing the functional tests (systems tests), the terminology of the document "Space Vehicle Stage Analysis and Checkout Guidelines" SR-QUAL-64-13 will be used. To correlate the terminology for these tests at the Chrysler Corporation Space Division at Michoud and the Quality and Reliability Assurance Laboratory at MSFC with that of the document, Table II has been included. Because of changes in vehicle design from one stage to another in the Saturn I series, there is not a one to one correspondence between some tests.

All systems tests were not automated. Indeed, the majority were not completely automated; but, significant portions of some tests were automated.

Some computer programs were written to perform checkout of certain areas of the vehicle and became a part of a systems test. For example, the "Universal Measuring Adapter (UMA) Calibration" program and the "Temperature Sensor Identification" program formed a portion of the Measuring Systems Test. For clarification, a description of the systems tests will be given, followed by a description of the computer programs which formed a portion of those tests.

TABLE II. TERMINOLOGY CORRELATION

Stage Systems Tests (SR-QUAL-64-13)	Quality and Reliability Assurance Laboratory	Chrysler Corporation Space Division (Michoud)
1. Power Distribution	1. Power and Pneumatics (Also Power Distribution and Components)	1. Power Distribution (A 2.0) a. Power Up (A 2.1) b. Power Down (A 2.2) c. Power Up DDAS (A 2.3)
2. Airborne DDAS Calibration	2.	2. DDAS Calibration Verification (A10.8)
3. Pressure and Functional Tests a. A. C. Heaters b. Pressure Switches Test c. Others	3. a. A. C. Heaters b. Pressure Switches Test	3. a. Vehicle Heaters (A 4.8) b. T.O.P.S. Test (A 4.1)
4. General Networks and Malfunction	4. Cutoff Test, Also Overall Test No. 1	4. a. General Networks and Malfunction Cutoff Test No. 1 (A 5.0) b. Components (A 6.0) c. General Networks and Malfunction Cutoff Test No. 1 (A21.0)
5. Measuring System	5. Instrumentation and Telemetry Calibration	5. a. UMA Scan and Calibration (A 3.0) b. Pressure (A 4.4) c. Sensor I.D. (A 3.17) d. Instrumentation Compatibility Telemetry vs Hardwire (A10.0)
6. Telemetry Systems	6. Instrumentation and Telemetry Calibration	6. Discriminator-Subcarrier Oscillator Test (A10.2)
7. Instrumentation Compatibility	7. Instrumentation and Telemetry Calibration	7. Instrumentation Compatibility Telemetry vs Hardwire (A10.0)
8. Thrust Vector Control a. Engine Gimbaling b. Others	8. G and C Systems, Also Control Systems (Beta-Linearity and Actuator Linearity)	8. Actuator Linearity (A 9.4) a. Engine Gimbal (A 9.6)
9. Steering Over-All Test	9. Overall No. 2, Also Control Overall	
10. RF Compatibility Test	10. RF Systems C/O	10. RF Compatibility
11. Electromagnetic Compatibility Test (EMC)	11. Electromagnetic Compatibility (EMC)	11. Radiated Compatibility
12. R. F. Systems	12. R. F. System C/O	12. (Manual Tests)
13. Simulated Flight a. Simulated Plug Drop b. Plug Drop	13. a. Simulated Plug Drop, Also Overall No. 3 b. Simulated Flight	13. a. Simulated Plug Drop (A11.0) b. Simulated Flight (A20.0)

All systems tests are included whether manual or automatic. The systems tests include:

1. Power Distribution
2. Airborne DDAS Calibration
3. Pressure and Functional Tests
    a. A. C. Heaters
    b. Pressure Switches Test
    c. Control Pressure System
    d. Gas Generator Oxidizer and Fuel Control Valve Assemblies
    e. Gas Generator, Gas Turbine, Turbine Exhaust and Turbopump Gearcase Test
    f. Engine Control System Test
    g. Oxidizer Pressurization System
    h. Engine Purge System
    i. Propellant Utilization
    j. Oxidizer Tank and Combustion Chamber Test
    k. High-Pressure Spheres and Fuel Tanks
    l. Hydraulic Systems
    m. Instrument Canister and Cooling System
4. General Network and Malfunction
5. Measuring System
6. Telemetry Systems

7. Instrumentation Compatibility Test

8. Thrust Vector Control

   a. Engine Gimbaling

   b. Rate Gyro Assembly Tests

   c. Control Accelerometer Tests

   d. Auxiliary Control Systems Assemblies

9. Steering Overall Test

10. RF Compatibility Test

11. Electromagnetic Compatibility (EMC) Test

12. R. F. Systems

13. Simulated Flight Test

   a. Simulated Plug Drop Test

   b. Plug Drop (Simulated Flight Test)

B. Description of Tests

1. Power Distribution. Power distribution encompasses all power utilized on the stage to operate electrical networks and related electrical and electromechanical components. The purpose of this test is to assure compatibility of stage and support equipment, correct assembly, satisfactory power distribution, correct electrical and mechanical function, satisfactory design, and readiness for succeeding tests. This will include verification of the following.

a. Proper mating of the GSE and stage.

b. Proper distribution of power throughout the stage and ground system and the electrical operation of electromechanical components.

c. The energization of all buses from proper power supplies and in the proper sequence.

d. The control and monitoring circuitry associated with the stage having the proper supply bus, design intent, installation, continuity, and system compatibility.

e. Proper impedance on all buses.

f. Correct distribution of power so that no "shorts" or "sneak circuits" exist in the system.

2. Airborne DDAS Calibration. This calibration is to assure the airborne DDAS is accurately calibrated for its use as a checkout tool prior to the commencement of testing. Parameters of the airborne DDAS air measured as outputs of the DDAS ground station. The signal cables containing the analog measurements are disconnected from each commutator. A cable harness from a 0- to 5-volt precision power supply is connected to the input of each commutator in sequence so that a known voltage can be applied to all inputs of an individual commutator simultaneously.

3. Pressure and Functional Tests. The objective of performing pressure and functional tests on the mechanical systems of the stage is to assure the integrity and functional capability of the mechanical systems in the stage. The checkout shall not be a matter of merely making visual or functional type inspections in conformance with the design specifications, but rather it is an operational test.

a. General Requirements. The methods outlined in this paragraph shall be incorporated in the tests:

(1) All connections that are disconnected in order to perform a test must be retested for leakage.

(2) Leak test solution shall not be used on braiding of flexible lines, bellows, pneumatic bleed ports, or flared surfaces of AN fittings and tubings.

(3) All leak detection solution shall be completely removed from all fittings, lines, components, and assemblies, with an approved solvent, after testing. Care shall be exercised to prevent foreign matter from entering vents, bleeds, or pilot openings.

(4) All protective covers removed from the stage and test equipment shall be immediately replaced upon completion of test.

(5) At no time shall any line connections or fittings, flanges, or fixtures be disconnected while a system is pressurized.

(6) All systems being tested shall be pressurized slowly and shall not exceed the specified pressures of the system.

(7) If any audible leakage is detected within the specified pressure range, it shall be marked and recorded for correction.

(8) All test lines, connections, fittings, and fixtures shall be tested and free of external leakage prior to beginning any pressure "drop-off" test.

(9) Where it is not feasible to measure allowable component leakages by using downstream flowmeters or upstream flowmeters, the system shall be pressurized to a known volume and pressure/temperature will be monitored, and a decay or drop-off test shall then be performed.

(10) All high-pressure tests shall be conducted utilizing incremental pressure steps. Five-minute intervals are recommended between pressure steps.

(11) Audible leak detectors shall be utilized during high-pressure tests to inform the test conductor of system audible leaks.

(12) Structural system pressurization tests shall be conducted at test pressure, with the test cell evacuated of all personnel. Then systems will be checked at safe pressure with personnel in test cell to check for leaks using approved leak detection solution. Systems shall be vented and a trace gas leak check shall be conducted.

(13) Any faulty pressurized system must be depressurized before repairs are attempted.

(14) Tracer gas utilized for leak detection shall be handled in such a manner as to avoid contaminating areas where future leak tests will be conducted. Systems tested with tracer gas shall not indiscriminately be vented into these areas.

(15) In the event any system is "opened" after a leakage test has been performed, the system shall be retested for leakage.

(16) Using leak detection solution and tracer gas, check all fitting, tubing, connections, and flanges relevant to the stage systems. No external leakage is allowed.

(17) Flowmeter tests shall be utilized to check all valve seats, seals, etc.

(18) Care shall be exercised to insure that the pressure range of pressure transducers in any system shall not be exceeded during system pressurization tests.

(19) All pressure gages and pressure transducers must be calibrated within 30 days before use in testing a stage.

Records of all system actuation timing, pressure levels, etc., shall be obtained and evaluated. Testing time is minimized by performing instrument calibration tests in conjunction with instrumentation checkout personnel.

b. AC Heaters. Verification of proper heater operation - Temperature transducers are attached as close to the thermostat as possible without direct contact being established with the heater elements. Proper voltage is applied to assure validity of current readings received and all heater units are cycled three times. A comparison, display, and printout are made of the amperage drawn by each heater and temperature limits of the controlling thermostat for three cycles of each component.

c. Pressure Switches Test. The objectives of this test are to verify pressure switch operation, to leak test at system pressure, check for internal and external leakage, verify actuation and de-actuating pressure settings, and make and break repeatability of the switches.

(1) All pressurization cycles are performed three times in order to insure consistent results.

(2) All systems are pressurized at a reasonable rate to maintain adequate control. (High-pressure systems are limited to a maximum pressurization rate of one percent of maximum system pressure per minute near upper limits.)

(3) All pressurization system connections are leak checked at an intermediate level of operation.

(4) System pressure is applied slowly and vented to zero slowly for each cycle.

(5) All systems are checked for leaks on the first pressurization cycle. Actuation and de-actuation pressures are determined on the first and subsequent cycles. All switches are cycled three times by going to system pressure and then venting to zero for each cycle.

(6) The actuation and de-actuations are observed and recorded during increasing pressure and decreasing pressure, and they are checked to determine if they are within specified tolerances.

(7) All connections are leak checked.

d. Control Pressure Systems. The objectives of this test are to check system integrity, external and internal leakage of the system and components, minimum pressure required for component operation, and relief settings of high-pressure regulator and system relief valves. In addition, check response timing and repeatability of component operation, proof test system and components at normal system operating pressure, and check and assure that the GN_2 control system purges are within specification.

e. Gas Generator Oxidizer and Fuel Control Valve Assemblies. The objectives of this test are to determine external leakage of components and connections, internal leakage of poppet seats, pressure required to open poppets, and the repeatability of operation of the system components.

f. Gas Generator, Gas Turbine, Turbine Exhaust and Turbopump Gearcase Test. The objectives of this test are to check the gas generator system for external leakage, turbine seal leakage, turbopump torque, audible noise during turbopump torque test, and cracking pressure of lube oil drain check valve and its repeatability.

g. Engine Control System Tests. The objectives of this test are to check for external and internal leaks, for minimum pressure required to main oxidizer valve and main fuel valve operation, for "no actuation" and "actuation" of ignitor monitor valve, position potentiometer of main oxidizer valve and main fuel valve for closed position, open position and total valve position, functional operation of sequence valve, and system integrity. Also a check of response, timing, and repeatability of main oxidizer valve, main fuel valve, ignitor monitor valve, and proof test system for components at normal operating pressures of the system is conducted.

h. Oxidizer Pressurization System. The objectives of this test are to check for binding and bending of oxidizer lines and expansion joints, for external leakage, for seal leakages of valves, for system integrity, and proper functioning of the flow control valve. The system shall be pressurized to proof pressure.

i. Engine Purge System. The objectives of this test are to check for external leakage, system integrity, proof test at normal system operating pressures, component operation, and system flow rates.

j. Propellant Utilization. The objectives of this test are to check for external leakage, check regulators for pressure and flow regulation, and assure system integrity.

k. Oxidizer Tank and Combustion Chamber Test. The objectives of this test are to check for external leakage, internal leakage of vents and valves, system integrity, binding in all expansion joints and bellows on interconnects and feed lines, and functional operation of all components.

l. High-Pressure Spheres and Fuel Tanks. The objectives of this test are to determine external leakage, internal leakage of components, functional operation of components, binding in all expansion joints and bellows, and system integrity.

m. Hydraulic Systems. The objectives of this test are to check hydraulic systems for proper response, and system integrity. Each engine is gimbaled to verify structural clearance and proper travel.

n. Instrument Canister and Cooling System. The objectives of this test are to check structural integrity, external leakage, components for internal leakage, and operation of cooling system components.

4. General Network and Malfunction Tests. The objectives of this test are to verify overall design, function, and compatibility of the various cutoff sequences and verify proper operation and compatibility of the power transfer circuits, launch sequencer, and flight sequencer.

Requirements. All circuits required to obtain firing command are exercised. Power transfer is initiated from ground power to stage power and return. The stage flight sequencer is exercised to ascertain its proper operation. All methods of cutoff are exercised. This entails giving the firing command and introducing malfunctions to ascertain if the malfunctions can be detected and the proper action taken. After each cutoff, the system is recycled to prelaunch condition to prove that the system can be recycled to a safe condition. All elements of the CDR system are exercised and receipt of retro rockets, ullage rockets, and separation systems commands are verified. Conduct special tests if necessary to verify each redundant circuit.

The initial part of this test consists of verifying the network circuitry associated with vehicle engine cutoff in the following areas:

a. Command-destruct system with command receivers.

b. Flight sequencer.

c. Propellant depletion circuits.

d. Low thrust cutoff circuits.

The EBW subsystem in the retro rocket and destruct systems is verified.

The sequence of switching necessary for preparations completion is checked, followed by a check of various premature cutoff sequences by introducing malfunctions into the automatic sequence after firing command. A normal firing sequence is accomplished with umbilical retraction occurring automatically at the appropriate time. The umbilical retraction is simulated during the prestatic tests. The one-shot safety relays are test fired. Cutoff is given after liftoff by the ground command transmitter via the stage command receivers. Since no guidance and control equipment is connected during this test, position indicators are simulated.

5. Measuring System. The objectives of this test are as follows:

a. To verify the calibration of all transducers located on the stage where practical.

b. To verify the calibration of the signal conditioners associated with the transducers.

c. To assure subsystem conformance to proper channel assignments as determined by applicable documentation.

The parameters to be checked are dc voltages, ac voltages, and frequencies, representing measurements of the following:

a. Propulsion

b. Expulsion

c. Temperature

d. Pressure

e. Strain

f. Vibration

g. Flight Mechanics

h. Steering Control

i. Stabilized Platform

j. Guidance

k. RF and Telemetering

l. Signals

m. Voltages

n. Currents

o. Frequency, etc.

The outputs of the measurements and signal conditioners are returned to the checkout computer via the DDAS and/or the telemeter systems where they are compared against predicted values.

Those measurements originating from the operation of some system or component are monitored as the related system or component is operated through discrete steps.

Those measurements originating from the stage environment are monitored as they are stimulated by the proper environmental change. With some measurements, this consists of a gross stimuli applied just enough to obtain a significant output of the gage, with others, this consists of applying stimuli by means of special built-in aids, while others require the substitution or addition of some special networks just for checkout.

The rule is to actually stimulate or operate the system for every flight measurement. Stimulation is only accepted when degration of the stage would occur or the probe is inaccessible.

The computer program provides for a printout of all data, both acquired and stored, in various groupings to be utilized by the test conductor during checkout.

6. Telemetry Systems. The objective of this test is to determine that the telemetry system operates in compliance with applicable specifications while installed in and controlled via stage networks.

A functional checkout is made (including timing and calibration) of all TLM system components in a bench test setup. TLM antenna systems are tuned.

The following parameters are checked.

a. Transmitter power out and reflected power.

b. RF amplifier power output and reflected power.

c. All voltages on main and RF power amplifier chassis.

d. Calibration step amplitude.

e. Commutator rate and format.

f. Transmitter frequency and deviation.

g. Spurious signals of each transmitter.

h. Spurious signals of multicoupled transmitters.

i. Subcarrier oscillator frequency, deviation, stability linearity, and pre-emphasis.

j. Multicoupler efficiency.

All parameters, as a minimum, listed above are measured (either manually or automatically) while the TLM system is operating in the stage network in as near a flight configuration as possible. These measurements are compared with measurements obtained previously in the functional bench check to determine trends and for compliance with applicable specifications.

Calibration of subcarrier oscillators are checked and adjusted as necessary.

7. RF Systems. The objectives of the RF Systems test are to verify altitude measuring capability, verify proper antenna tuning and installation, validate proper response of safety RF systems, and verify that all tracking devices have the proper frequency.

The radar is interrogated with five known altitude simulation delays. The destruct and non-destruct commands are transmitted and all responses are monitored. AGC characteristics are determined at five signal input levels. VSWR and electrical phasing checks are made of the coaxial cables. Antennas with center frequency are stimulated and monitored for proper null. RF transponders are energized and measured frequency and power output are compared with bench test results.

The installation of all antennas are visually inspected for proper installation, sufficient electrical continuity, etc. Satisfactory antenna tuning is verified using the stage skin as a ground plane. Electrical phasing of all interconnecting coaxial cables is verified by actual test and proper cable installation is determined by visual inspection. The results of antenna tuning and cable phasing bench tests are used in determining satisfactory operation after stage installation.

Performance evaluation of the stage RF systems is variable as a function of the type of system being evaluated. All RF system evaluation is performed through an open-loop type coupling since this more nearly approximates flight conditions. RF receivers are interrogated from an appropriate ground station. This interrogation includes the transmittal of all command signals to which the receiver is to respond, and the careful evaluation of the receiver responses. Triggering of all stage RF transmitters is initiated from the appropriate ground station and the resulting transmitter response carefully evaluated. In general, the stage RF systems evaluation is not an absolute measurement of parameters previously measured during bench functional tests, but is an operational performance test. For example, absolute receiver sensitivity, bandwidth, etc., measurements are not attempted. Additionally, absolute transmitter power output levels are not measured during this evaluation, although frequency, pulse repetition rates, etc., are a part of the system evaluation.

8. Thrust Vector Control System.

a. Engine gimbaling system. The objectives of the engine gimbaling system test are to verify the linearity of each actuator position potentiometer, verify proper polarity of each actuator, verify that there is no interaction between actuator operations, and verify engine gimbaling system instrumentation.

b. Rate gyro assembly tests. The objectives of the tests of the rate gyro assembly are to verify proper functioning of the rate gyros and their associated electrical support equipment.

c. Control accelerometer tests. The objectives of the tests of the control accelerometers are to verify the proper functioning of the pitch and yaw control accelerometers and the associated electrical support equipment.

d. Auxiliary control system assemblies. The objectives of the auxiliary control system assemblies (i.e., reaction control devices) checkout tests are to verify that the initiation, actuation, duration, and decay of the flow through each reaction control device meets the designated performance specifications.

9. Steering Overall Test. The objectives of the steering overall test are to prove the compatibility of the thrust vector control system with the stage networks and to eject the umbilicals and prove the stage can function without the power and control cables connected to the GSE.

10. RF Compatibility Test. The objectives of the RF Compatibility test are to determine if any interaction exists between RF systems, determine if the RF systems are adversely affected by the operation of other electrical and electronic equipment, and determine if other electrical and electronic equipment is adversely affected by the operation of the RF systems.

11. Electromagnetic Compatibility (EMC) Test. The objectives of the Electromagnetic Compatibility (EMC) test are to determine if all vehicle and ground support equipment, electrical, electronic, and electromagnetic systems and subsystems will operate, both individually and simultaneously, without degraded performance due to EMC, and determine that the vehicle structure provides the low dc resistance and ac impedance necessary for a satisfactory vehicle ground plane.

12. Instrumentation Compatibility Test. The objective of this test is to verify the overall calibration polarity and operation of the flight instrumentation system, by making a complete end-to-end simultaneous check of each measurement channel.

The parameters to be measured and recorded are the outputs of the DDAS and telemeter systems. Built-in calibrations such as RACS and telemeter calibrations are checked at all points of operation. Pressure transducers with calibration ports are checked at three different pressure levels. Those measurements originating as functions of GSE or stage networks are monitored as these systems are cycled through significant operations. The telemetry and DDAS systems are active and operating with their ground stations. Each measurement channel is active and recorded by the computer and on magentic tape through the telemeter ground station as it is stimulated. The output of each telemetry channel is compared with the corresponding DDAS channel and a printout of this comparison is made by the computer. Those channels not returned to the computer by DDAS are compared to the calibration curve verified during the measuring system test. A complete set of oscillograph records of the telemetry systems operation during this test is made from the magnetic tape and made immediately available for a quick-look evaluation.

13. Simulated Flight Test. This test consists of both the simulated plug drop and the plug drop tests. The simulated plug drop test is run during manufacturing and poststatic operations, whereas the plug drop test is performed only during poststatic operations.

a. Simulated plug drop test. The objectives of this test are to verify that all of the stage systems can be brought to a state of readiness for firing command, to verify that power transfer can be accomplished without any adverse effects on any of the systems, to verify that exercising the thrust vector control system does not adversely affect any of the systems, and to verify that the stage can be programmed through the firing sequence, simulated liftoff, and that all inflight functions operate properly.

b. Plug drop (simulated flight test). The objectives of this test include the ones of the previous test plus the verification in detail that the measuring system operates properly and within the proper tolerances, that all of the systems will function properly after the umbilicals are disconnected, and verification that malfunction cutoff will shut down the stage.

C. Test Software

The computer programmers who developed programs for the Saturn Automatic Checkout System, coded the program in machine language. Because of the recirculating memory of the computer, the programs had to be optimized for time to reduce excessive delays in executing test programs. Since most of the data and other information which was required by a program had to be located in specific memory locations, an assembler could not be utilized by the programmers. After a test program had been coded and debugged, it was recorded on magnetic tape using the tape editor program. The tape editor program provided a method of preparing and updating a program library on magnetic tape. It was also used to reproduce a magnetic tape for backup purposes in the event the master program library became destroyed.

Following is a list of the test programs that were developed for the Saturn Automatic Checkout System:

1. A. C. Heaters

2. Actuator Linearity

3. Universal Measuring Adapter (UMA) Calibration

4. Temperature Sensor Identification

5. Telemetry versus Predicted, Telemetry versus Hardwire

6. Digital Data Acquisition System (DDAS) Calibration

7. Pressure Test

8. Thrust O. K. Pressure Switch (T. O. P. S.) Test

9. Frequency Modulated (FM) Telemetry (TM) Adjust

10. Cable Analyzer Program

11. Main Valves Program

12. Minimum Valve Pressure Program

13. Hydraulic Scan Program

The following is a description of the software programs used in testing of the Saturn I:

1. AC Heaters. The A.C. Heaters Program was first used in the Quality and Reliability Assurance Laboratory on the interim computer system and the Vehicle Test Station. The purpose of the program was to verify the proper operation of the onboard stage heaters. To perform this test, current was applied to a heater through the switching relays in the Vehicle Test Station. An ambient reading of the heater temperature was first made through readings made from thermisters placed on the stage with the appropriate heater. These thermister readings were made through the Vehicle Test Station with the bridge circuit and a resistance to voltage converter. The output of the bridge circuit was converted through an analog to digital converter to a digital value which could be read into the computer. The current through the heater was measured by current transformers in the Vehicle Test Station. A thermostat on the heater would turn the current off when the temperature reached a specified value. The A. C. Heaters program would look for the current to be turned off and would then read the temperature of the heater as indicated by the thermometer. The heater would remain off until the onboard thermostat sensed the low temperature setting. The computer program would monitor the current reading and look for the current to come on again. At this point, the low temperature reading of the heater would be measured by reading the value of the thermister. The computer programs would cycle each heater through three temperature cycles.

2. Actuator Linearity Program. The purpose of the Actuator Linearity Program was (1) to check the scale factor of the beta feedback potentiometer, (2) check the scale factor of the actuator position potentiometer, (3) check the linearity of the actuator position potentiometer, (4) make a check of the differential pressure transducer for correct operation and calibration, (5) monitor hydraulic pump oil level, hydraulic pump oil temperature, inlet pump pressure, and delta i voltage to insure safe operation of hydraulic system, (6) print tables containing beta potentiometer voltage, actuator position potentiometer voltage, inlet pump pressure, oil level, oil temperature, differential pressure, and delta i voltage which would obtain at 17 different measuring points while the engine was being gimbaled.

The program utilizes the Networks Test Station and the Instrumentation and Telemetry Test Station to perform the test. Voltage from transducers on the vehicle goes through a Universal Measuring Adapter (UMA) which changes it to a range of 0 to 5 volts. From the UMA the voltage comes to a crossbar point at the Instrumentation and Telemetry Test Station. When a measurement is desired, a point on the crossbar is selected and the voltage goes through the conditioning amplifiers to the M-3 multiverters. A command which causes the M-3 to convert the voltage to digital form is given and the measurement of the voltage is obtained by the computer from the test station. The program makes measurements of differential pressure, hydraulic oil level, hydraulic oil temperature, and actuator potentiometer voltage through the Instrumentation and Telemetry Test Station.

At the Networks Test Station voltages come from the transducers on the vehicle to the low level relays. To make a measurement, a relay is selected and the voltage at that point goes through the conditioner selector, which has been programmed to the desired range, to the M-2 multiverter. When a conversion signal is given to the M-2, the measured voltage is converted to digital form and can be obtained by the computer from the test station. The program makes measurements of delta i, inlet pump pressure, and beta voltage at the Networks Test Station.

A table for pitch and yaw containing measurements for beta voltage, actuator potentiometer voltage delta v, and linearity is printed at the Networks Test Station. After this table is completed, another table for pitch and yaw containing measurement of actuator position potentiometer voltage, inlet pump pressure, oil level, oil temperature, differential pressure extended, and differential pressure retracted is printed at the Instrumentation and Telemetry Test Station. The program evaluates measurements of the beta potentiometer voltage and the actuator position potentiometer voltage to determine the linearity of the actuator position potentiometer.

The running time for this program is about 10 minutes for each of four engines on the Saturn I/IB first stage.

3. Universal Measuring Adapter (UMA) Calibration Program. The purpose of this program was to allow for the calibration of the Universal Measuring Adapter Module on the stage to previously determined laboratory curves and to record the readings of the output of the Universal Measuring Adapter Modules. A small executive routine was contained within the UMA calibration program and allowed for the selection for several options within the routine. These options included:

a. The ability to interrupt the execution of any portion of the UMA calibration program.

b. Input UMA data from punched papertape by the way of the photo-electric reader.

c. Input UMA data from punched papertape by the way of the stations buffered flexowriter.

d. Input UMA data by the way of the keyboard of the buffered flexowriter.

e. Omit or include a UMA data entry.

f. Calibrate the UMA's by the way of eight remote indicator units.

g. Recycle the program to a particular UMA.

h. Check low level 400-cycle stimuli voltages.

i. Read the output of each UMA for the run, high, and low calibration mode and store the values in computer memory.

j. Calibrate the UMA modules found out of adjustment. Each of these modules will have its rack and channel numbers displayed on the remote indicator unit (RIU) together with the step number corresponding to the calibration relay selected. The program continuously scans the applicable module and indicates on the remote indicating unit whether the reading is high, low, or equal to the corresponding predicted value stored in computer memory. The equipment operator will manually adjust the UMA on the vehicle until an on indication is given signifying the module is calibrated with a specified tolerance. The equipment operator will then proceed to the next calibration step or to the next UMA module to be calibrated.

k. Print out all readings made and indicate a go or no-go condition, the measurement number, and the rack and channel number of the associated UMA.

l. Print out a listing of the UMA's having readings out of tolerance.

4. Temperature Sensor Identification. The purpose of this program is to verify that all temperature sensors on the stage are functioning and properly wired. The functioning of the temperature sensors is verified by the scan option of the program. While scanning the sensors, the program automatically measures and records the voltage output of each sensor at ambient temperature. The voltage at ambient temperature is checked to within a specified tolerance against the calibration value of the particular sensor at ambient temperature. Following the temperature sensor scan the program identifies each sensor and checks for correct wiring. This is accomplished by having the computer display the measurement number of the sensor on the remote indicating unit (RIU) on the stage. An equipment operator on the stage in turn acknowledges this and manually heats or places a simulator box on the displayed temperature sensor. Upon a signal from the equipment operator, the computer checks to see if a change in voltage has occurred from the selected sensor.

There are several options which are available in performing this program. They include:

a. Interrupt the program being executed.

b. Input test data from punched papertape by the way of the photoelectric reader.

c. Input test data from punched papertape by the way of the stations buffered flexowriter.

d. Input test data by the way of the keyboard of the buffered flexowriter.

e. Omit or include a data entry in the temperature sensors scan.

f. Read the ambient temperature of each sensor.

g. Identify each temperature sensor and check for correct wiring.

h. Print out all readings made with an indication of go or no-go and the measurement number for the temperature sensor.

i. Print out temperature sensor data with readings of out of tolerance only.

j. Record on magnetic tape all temperature data.

5. Telemetry (TM) versus Predicted. The purpose of the TM versus Predicted program is to read the output signals from the onboard telemetry systems and compare the values read with predicted values stored in the computer memory. Signals from the stage are telemetered to the ground station or are sent by hardline to the ground station. Under the control of the program, the ground station automatically connects the appropriate receivers, discriminators, or decommutators, so that selected telemetry data can be routed to the analog to digital converter. The digitized response signal is then transmitted back to the computer for comparison with the predicted values.

6. Digital Data Acquisition System (DDAS) Calibration Verification. This program was developed at Chrysler Corporation Space Division, Michoud. The program operates through the Vehicle Test Station and consists of three tests: Impedance test, Five Point Calibration, and Remote Digital Sub-Multiplexer (RDSM) discrete printout.

In the Impedance Test, a five volt dc signal is applied to each DDAS channel in series with a fixed resistance to check the input impedance of each DDAS channel.

In the Five Point Calibration test, six voltages of 0, 1.25, 2.50, 3.75, and 5.0 are applied to the DDAS channels under direction from the Vehicle Test Station. Responses from the DDAS system are measured through the Telemetry Ground Station and the Vehicle Test Station.

In the RDSM discrete printout, a test is made of all K measurements (all measurements of discrete signals). A 28-volt discrete signal is applied to one measurement at a time and all other measurements are checked to see that only the one measurement comes on. All measurements are then turned on and one measurement at a time is turned off with all other measurements being checked for a change in state.

7. Pressure Test. The purpose of the pressure test is to verify that the pressure transducers are connected to the pressure range and correctly positioned and operating as predicted. Also a hysteresis comparison is made between the two measured values of each pressure setting on a transducer with a no-go indication being made if the comparison is not within a specified tolerance. The hysteresis comparison is made by making readings from the pressure transducer while slowly applying an increasing pressure to the transducer. As pressure is being decreased from the transducer, measurements are again made at the same points. The difference in readings must fall within a predicted tolerance.

8. Thrust OK Pressure Switch (TOPS) Test Program. The purpose of this program is to verify the proper operation of the thrust OK pressure switches. This test is performed by the computer applying a ramp of pressure to the pressure manifolds. While the ramp is being applied, the thrust OK pressure switches are monitored to see at what point they operate. After the switches are operated, the pressure is ramped in the opposite direction and the switches are monitored again to see when they change state. This test is performed on each engine. The test is completely automatic and a printout of data results can be obtained after the test has been completed.

9. FM TM Adjust Program. The purpose of this program is to allow for the adjusting of the discriminators in the ground station and the subcarrier oscillators on the stage. The discriminators in the ground station are first adjusted. The subcarrier oscillators on the stage are then adjusted using the discriminators as a reference. The remote indicator unit is utilized in both the ground station and on the stage to indicate the high, low, and on status of the discriminators and subcarrier oscillators during adjustment.

10. Cable Analyzer Program. This program was utilized with the electrical test station to provide for the assembling of input data, monitoring of electrical test station operations, and providing printed output of test results from the DIT-M-CO model 610-A cable analyzer. The cable analyzer tests for inaccurate or faulty wiring on IBM patchboards, AMP patchboards, or cables terminated by Bendix connectors. With the use of adapters, any type patchboard or any type cable may be checked.

11. Main Valves Program. The purpose of this program was to measure the cracking pressure, resistance of a position potentiometer fully closed, the resistance of the potentiometer fully open, the differential position potentiometer value for the main lox and main fuel valves, the igniter valve cracking pressure, resistance, and position. This test was performed through the Vehicle Test Station.

12. Minimum Valve Pressure Program. The purpose of this program was to record the cracking pressure of certain pneumatic valves in the Saturn vehicle by sensing and interruption of the open or closed microswitch associated with the valve. This test was performed through the Vehicle Test Station.

13. Hydraulic Scan Program. The purpose of this program was to maintain a log as to reservoir level, accumulator pressure, reservoir pressure, pitch position, and yaw position of the four hydraulic systems of the outer engines. This test was performed through the Vehicle Test Station.

Table III illustrates the test software which was developed and its use at the Laboratory and at Michoud.

SECTION IV. FINDINGS AND CONCLUSIONS

The Packard Bell Saturn Automatic Checkout System has been a topic of conversation for many years and will be a topic of conversation for years to come. Although there is a great deal of controversy over the number of computers or the arrangement of computers for an automated checkout, it is commonly agreed among personnel of the Laboratory that the Packard Bell concept of the "master-slave" arrangement has been the most satisfactory and optimum type of arrangement of computers for an automatic checkout. Although the Packard Bell PB-250 computer is outmoded in terms of the speed and capability of computers being manufactured today, the Packard Bell System continues to be used effectively and to advantage in the automatic checkout of the uprated Saturn I stages at Michoud.

It is believed that the master slave arrangement utilized in the Packard Bell Central Computer Complex was the state-of-the-art design at the date of its conception and only recently has the concept been introduced into large multicomputer time sharing complexes of the third generation. The modularity of the design of the Central Computer Complex has been demonstrated by

TABLE III. TEST SOFTWARE DEVELOPMENT AND USE

Program	Used at		Remarks
	Q&RAL	Michoud	
1. A. C. Heater	yes	yes	Rewrite at Michoud
2. Actuator Linearity	yes	yes	Rewrite at Michoud
3. UMA Calibration	yes	yes	
4. Sensor Identification	yes	yes	
5. Telemetry versus Predicted versus Hardwire	yes	yes	Rewrite at Michoud
6. DDAS Calibration	yes	yes	Rewrite at Michoud
7. Pressure Test	yes	yes	Written at Q&RAL but not used, rewrite at Michoud
8. T. O. P. S. Test	yes	yes	Rewrite at Michoud
9. FM TM Adjust	yes	yes	
10. Cable Analyzer	yes	no	No electrical test station at Michoud
11. Main Valves	yes	no	
12. Minimum Valve Pressure	yes	no	
13. Hydraulic Scan	yes	no	

expanding the number of slave computers to four and the number of test stations to five. Total expansion capability of the system is nine slave computers and 32 satellite test stations with no additional software requirements.

An additional capability was incorporated into the checkout operation when the Central Computer Complex at the Quality and Reliability Assurance Laboratory was transferred to the Michoud checkout facility. The transferred equipment became the off-line program verification system. A link between the off-line program verification system and the central computer complex for checkout was established by Chrysler personnel. Now, in the event the master computer malfunctions during checkout operations in the Central Computer Complex, computer programs may be loaded into the Central Computer Complex from the master computer in the off-line program verification system. Under this arrangement, programs being loaded into the Central Computer Complex are loaded one memory line at a time and verified for accuracy in transmission between the off-line program verification system and the Central Computer Complex. This has increased the reliability and operational use of the Packard Bell systems.

A. Program Changes

When the Packard Bell Saturn Automatic Checkout System was first being implemented in the Quality and Reliability Assurance Laboratory, many changes in the design of the Saturn I stage were being made. This necessarily affected the implementation of automated systems in that many changes had to be made to both the ground support equipment and to the software involved. Many of the changes were minimized because of the design of the software. Since the computer programs were developed to allow for changes in tables of data, the requirement for making extensive and time consuming changes to the program instructions were minimized. However, many changes were made to the computer programs due to changes in stage systems and introduction of new stage systems.

As anticipated, however, by the end of the Block II Saturn I stages the stage design had become essentially fixed and the number of changes to software were held to a minimum.

With the transfer of the manufacture and testing of the Saturn stage to the Michoud facility, new problems were introduced. Although the computer software was operational in the Quality and Reliability Assurance Laboratory, the computer programs were unfamiliar to the personnel at the Chrysler Corporation who were to utilize the software. As a result, when changes were required to the programs, it was found to be very difficult to understand the coding that had been developed in Huntsville. It was therefore necessary for some of the programs to be rewritten by the Chrysler personnel. Four such programs were rewritten at Michoud. One of these programs (the pressure test program) was developed at Huntsville, but was never successfully implemented. However, Chrysler personnel rewrote the pressure test program and have successfully used the program at Michoud.

B. Personnel

As anticipated, the number of programming personnel has been significantly reduced. At the peak of the programming effort in the Quality and Reliability Assurance Laboratory, 18 computer programmers and system analysts and two computer operators were required. At Michoud, this number has been reduced to less than 10 computer programmers and analysts and three computer operators on a two-shift operation. The majority of the programmers develop software that operates off-line processing and support of checkout operations.

C. Checkout Time

Although reduction in checkout time was not considered a primary goal of automatic checkout, it was expected that some tests would experience a reduction in time. As anticipated, the time to perform some tests was reduced considerably by using automatic methods. For example, the engine gimbaling tests required four hours per engine using manual methods; using automatic methods this same test requires 10 minutes per engine. To perform the pressure switch test manually required eight hours; automatically only 45 minutes is required.

The overall savings in time for a complete postmanufacturing or post-static checkout is not significant. The first Saturn stages (SA-1, SA-2, etc.) required an average seven to eight weeks for checkout. The checkout being performed on the later Saturn stages (SA-205, SA-206, etc.) also requires about seven to eight weeks.

Several reasons can be given as to why automatic checkout has not reduced checkout time more. The actual performing or execution of steps in a test constitute only a portion of the activities required during checkout. First of all, the stage has to be "cabled up" to the ground support equipment - a function that has to be performed by operating personnel. In addition, during a testing sequence, encountering a no-go condition means that the automatic test is halted and an investigation into the cause of a malfunction is initiated— a manual and often time consuming task. Also, many design changes catch up with the vehicle while it is in checkout and the resulting engineering orders (EO's) must be incorporated into the stage. Cleanup of all upstanding discrepancies is also necessary prior to shipping the stage and requires additional delay in checkout operations. In addition to these, many functions are impractical to checkout automatically and would provide little or no improvement in testing over the so called manual method.

D. Vehicle Systems Conducive to Automation

It has been said that given enough time and money a computer can do anything. This may be true but certainly there are some things that should not be done by a computer. Nevertheless, there are some things that should be done with a computer. Some conclusions can be drawn as to the areas in which digital computers are most applicable as applied to checkout.

1. Repetitous Operations. Digital computers are best suited to solve those problems of a repetitive nature. A "noncheckout" example would be calculating the payroll of 10 000 employees, month after month. In this example, the same small program could be used for each employee and the only thing that would change would be the data, i. e., employees name, base pay, hours worked, deductions, etc. The same thing applies to checkout also; those checkout operations requiring repeated calculations, with only changes of data stage after stage, will normally lend themselves to automation.

One of the most obvious applications in the Saturn I series was in the Instrumentation and Telemetry Systems. Many areas even within this one category were applicable, such as the Universal Measuring Adapter Calibration. The Universal Measuring Adapter Calibration area contained more than 300 items to be verified and calibrated. Only one program was used in this example to verify one of the items and with only data changes, each item could be verified by the same program. Other examples in this category included the Telemetry versus Hardwire versus Predicted, DDAS Calibration, and Temperature Sensor

Identification (each area containing many similar items to be tested with only slight changes in data required to go from one item to another). In almost every case where the computer has been used for checkout, this has been true. Other examples are:

a. A. C. Heaters Test - 30 heaters to be cycled three times

b. Pressure Switches Test - Many switches to be tested

c. Engine Gimbaling - Four engines, each gimbaled several times in several directions

d. Pressure Test - Many pressure transducers to be tested

2. Application of Special Languages. As previously stated, the computer is best suited to solve those problems of a repetitive nature. To do otherwise is normally a waste of computer resources. The computer may be used, however, to advantage in areas where computer programs can be developed simply and changes to the programs can be made quickly. One area of checkout in which this technique can be applied is that of electrical networks. In this area, the functions to be performed on the various electrical systems can be grouped, i.e., closing and opening relays, reading voltages, sensing discrete status, etc. In addition, these grouped functions occur in sequential order, i.e., the execution of one function depends upon the satisfactory completion of the previous function.

A language was developed that would allow computer programs for the electrical networks tests to be developed quickly, as compared to developing the UMA Calibration program. And, since the computer program that was developed for one stage was essentially a table of data, changes could be incorporated easily and the program could be used for succeeding Saturn stages.

The electrical networks area was conducive to automation not because it contained repetitious operations for the computer to perform but because programs using a simplified language could be developed in a relatively short time. Changes could be incorporated in the program with minimum effort.

E. Interim Computer Evaluation

The interim instrumentation and telemetry system provided valuable training and experience for test personnel and programming personnel in advance of the delivery of the Saturn automatic checkout systems. There were many problems involved in getting the equipment into an operational status as it was the first application of computer controlled automatic checkout and because of the new and complex electronic designs involved. The magnetic tape unit in the computer complex was unreliable and the complexity required in programming and operation of the tape unit made it impractical to use. The fact that only one tape unit existed added to the inefficiency of the computer operation. The computer system itself was input/output bound, and it was very difficult to get programs and data into the computer and get test results data printed out.

Most of the programs executed in the computer complex of the interim station contained large tables of data. These tables of data were changed in value up to the last minute prior to the running of a test. Considerable difficulty was encountered in updating this data as it was contained on punch paper-tape. The programs, however, were designed to accept last minute changes entered on the keyboard of the Flexowriter and this relieved the situation to some extent.

Printout of test results was a long and tedious operation. Many of the factors that have been mentioned were later to lead to a partial justification for the purchase of an off-line support computer system. With the delivery of the Saturn automatic checkout system, the interim computer complex was converted into a programming support operation and an off-line data and program debugging system.

Another problem encountered with the interim system was the lack of sufficient displays of information and data being processed by the computer.

Because of the recirculating type of memory in the computer, programming was necessarily more difficult. In order to obtain the speeds required for fast sampling rates and various other timing requirements, the computer programs had to be optimized for data access in the computer memory. This was a tedious operation and required more time for program development than normally would be required for a random access memory type computer.

Changes being made to the computer program would often upset the optimized portions of the program and would increase the difficulty even more.

With the separation of the test station from the computer complex in the interim system, a communications problem existed between the operating personnel. However, this was somewhat alleviated by the installation of special voice communications equipment. Much of a computer program could be debugged in the computer complex. However, when the portion of the program involved with testing had to be debugged, the programmer had to perform these operations in the test station area. This generated the requirements of having a utility program developed which would operate from the flexowriter located in the remote test station area and provide the programmer with a means of communicating with the computer directly. Here again, the lack of displays in the test station area hindered program debugging operations.

F. Program Verification

It is essential that as many mistakes and design discrepancies as possible be removed from computer programs before they are executed in a checkout procedure. The method by which these "bugs" are removed from programs vary from one programmer to another, but basically they follow the same pattern.

To insure the operational accuracy of the computer program, three types of errors must be investigated: logic, coding, and operating.

1. Logic Errors. Experience has shown that 50 to 70 percent of the logic in a computer program can be debugged on an off-line basis, i.e., on a separate computer or on the checkout computer if it is not connected into the stage or item under test. A certain amount of the logic can be verified at the programmer's desk. However, one obvious and important difference between the debugging operations in checkout programming and those of large scientific or data processing operations is that the individual who writes the program personally loads it into the machine and debugs it. This necessarily requires a more detailed knowledge of the test and computer equipment. A procedure for debugging the logic of the program could be as follows:

a. The program is divided into small logical segments each generally representing one block of information on the flow chart.

b. After these small segments are verified, the critical loops of the program are checked for logic errors.

c. Each loop includes several small segments of the program which are then integrated into functional segments and verified.

d. These larger segments are integrated into subroutines and verified.

e. The complete operational system is then verified.

About 20 to 45 percent of the logic can be verified through the use of hardwire type simulators. This verification and the off-line verification account for about 95 percent of the logic errors in the program indicating that possibly one out of twenty logic functions may be in error at run time. It is evident that this percentage does not reflect sufficient reliability in testing critical items.

Another approach to program verification is to substitute the test item with a second computer which is programmed to simulate the test item. Although this method is generally adequate and satisfactory, there are conditions which cannot be substituted for by a simulation computer. For these conditions, the test item is used in the debugging exercise and once the program is verified, the program is then used to check out the test item. Of course this latter technique is most undesirable and is only used when absolutely necessary. This technique would never be used under circumstances which might result in personnel injury or damage to the equipment.

If, when using the test item during program verification, a malfunction occurs, the test is stopped and the trouble corrected. If the computer program is at fault, the coding and logic are corrected. On successive items under test, however, the computer program has already been completely verified and the risk of running into malfunctions in a second test due to program logic errors is extremely small if not completely nonexistent. (This is assuming, of course, that the requirements for the program have not changed and the item under test is the same.)

2. Coding Errors. Experience has shown that 99.9 percent of the coding errors can also be detected through off-line debugging techniques. This indicates that about one instruction out of a thousand in the computer program is probably in error at the time the program is put on-line for test purposes. Many of the coding errors can be discovered through error searching techniques that are designed into translator and assembler programs. Also, manual review of the program by the coder reveals many of the coding errors. Experience is an important factor in detecting coding errors. An experienced programmer will necessarily make fewer mistakes in his coding than an inexperienced programmer.

3. Operating Errors. Operating errors can be reduced through good documentation of the computer program and test procedure, training of test personnel, and through experience.

It is difficult, if not impossible, to determine the operational accuracy of a computer program before it is actually used in testing, even though error reduction has been performed as previously described. However, the programmer can have a high degree of confidence as the result of error reduction methods that the program is operational and error free.

In order to determine the extent a computer program should be verified before it is actually used in testing, it is necessary to determine the criticality of the computer program. There are some computer programs which, if they were in error, could endanger the equipment and personnel involved in testing. Conversely, there are computer programs which have no adverse effect on the test item or personnel even if the program was a complete failure. An example of a critical program would be one used in the pressurization testing of Lox and fuel tanks. Should the program in this case be in error at a critical point in the test, a malfunction could possibly result in injury to both equipment and personnel. Noncritical programs would be programs not involving hazardous testing and that are being tested far enough ahead of schedule to allow fault isolation and maintenance in the event of malfunction without delaying the checkout schedule. Other noncritical programs would be those which have manual backup. If manual backup is not available, the program may become critical due to delaying the checkout schedule. An example of less critical programs would be one which would record the value of a telemetered signal during the calibration of a noncritical temperature circuit.

G. Percentage of Automation

It is very difficult to determine the amount of checkout that was performed by the computer. The ground rules by which this determination can be made is likewise difficult. Past estimates have ranged from 10 percent automation on the SA-2 to 60 percent automation on the SA-9 and subsequent stages. These estimates are considered to be high.

If receiving inspection, fabrication analysis, component analysis, etc., are considered in the estimation, then automation constituted only a very small portion of the total effort. On the other hand, if only assembled stage checkout is considered, the percentage is higher.

Table IV provides a more realistic representation of automation in the Saturn I program by indicating those systems tests which were manual, partially automated, and automated. Since the assembled stage checkout operations were the ones most affected by automation, the comparison of manual to automation will be limited to this area.

Although the figure indicates partial automation on the SA-2, very little if any of the tests performed on the stage were "bought off" by using automation. It was not until SA-5 and subsequent stages that any significant tests were run automatically for record. This fact is not significant in itself, however, considering that automation was, as intended, a parallel to the manual checkout operation. Experience was being gained in its use, and the confidence level in automation was being raised.

No attempt has been made to convert the figures in Table IV to percentage values since the results would be meaningless.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama, October 27, 1967
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TABLE IV. MANUAL - AUTOMATED SYSTEMS TESTS

Test Name Stage SA-	1	2	3	4	5	6	7	8	9	10	201	202	203	204	205	206	Remarks
1. Power Distribution	X	X	X	X	A	A	A	A	A	A	A	A	A	A	A	A	
2. Airborne DDAS Calibration																	
3. Pressure and Functional																	
A. C. Heaters	X	X	X	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	
Pressure Switches	X	X	X	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	
4. General Networks and Malfunction	X	X	X	X	A	A	A	A	A	A	A	A	A	A	A	A	
5. Measuring System	X	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	
6. Telemetry System	X	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	
7. Instrumentation Compatibility	X	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	
8. Thrust Vector Control	X	X	X	X	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	XA	
9. Steering Overall Test	X	X	X	X	A	A											Discontinued After SA-6
10. RF Compatibility Test	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
11. Electromagnetic Compatibility							X	X	X	X	X	X	X	X	X	X	Covering All Systems
12. RF Systems	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
13. Simulated Flight																	
Simulated Plug Drop	X	X	X	X	A	A	A	A	A	A	A	A	A	A	A	A	
Plug Drop	X	X	X	X	A	A	A	A	A	A	A	A	A	A	A	A	

X = Non Automated Test
XA = Partially Automated Test
A = Automated Test

NOTE: SA-8, SA-10, and SA-201 - SA-206 were checked out at the Michoud Facility.

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