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APOLLO EXPERIENCE REPORT -
ACCEPTANCE CHECKOUT EQUIPMENT
FOR THE APOLLO SPACECRAFT

by I. J. Burtzlaff

Manned Spacecraft Center
Houston, Texas 77058

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| 16. Abstract Because of the increased complexity of the Apollo manned spacecraft, corresponding increases in the capability, and thus complexity, of the ground checkout equipment were required. In this report, the acceptance checkout equipment for the Apollo spacecraft is described, and the history of the major equipment modifications that were required to meet the Apollo Program check- out requirements is traced. Some major problem areas are outlined, and a discussion of future checkout methods is included. The concept of the future checkout methods presented in this re- port provides for an increase in test-equipment standardization among NASA programs and among all testing phases within a program. The capability for increased automation and reduc- tion in the test-equipment inventory is provided in the proposed concept. | | 13. Type of Report and Period Covered Technical Note | |
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APOLLO EXPERIENCE REPORT

ACCEPTANCE CHECKOUT EQUIPMENT FOR THE APOLLO SPACECRAFT

**By I. J. Burtzlaff
Manned Spacecraft Center**

SUMMARY

The acceptance checkout equipment for spacecraft (ACE-SC) system is a computerized checkout system which provides for centralized, programed control of spacecraft checkout operations in the Apollo Program. Most of the changes in the evolution of the ACE-SC system capability occurred in the computer programs. The initial design of the ACE-SC was based on a concept of simple, computer-controlled, command-and-response checkout of the Apollo spacecraft systems. Because of the developmental modifications to the Apollo spacecraft, changes were required in the ACE-SC system to keep pace with the Apollo Program test requirements.

The first major update was in the checkout-system software and was required to meet the test requirements for the guidance, navigation, and control system of the spacecraft. The second major change was implemented to optimize the use of ACE-SC memory. Because of the problems associated with accomplishing integrated testing of the Apollo spacecraft, approval was given in February 1968 for the addition of more memory capacity in the checkout system. Further system improvements included the capability for automatic data compression and automatic test sequencing during spacecraft checkout.

The ACE-SC system proved to be an effective tool; however, several undesirable conditions arose which should be corrected in the checkout systems and procedures used for future programs. These conditions can be summarized as follows.

1. Total ground operations were not integrated within the ground checkout system.
2. Different checkout systems were used for the booster and the spacecraft.
3. Extensive use of special test equipment increased program costs.

The unified-test-equipment concept, which has been proposed and is presently under development at the NASA Manned Spacecraft Center, significantly reduces these conditions in the following manner.

1. General-purpose test equipment, rather than costly special test equipment that cannot be reused in subsequent test phases, is to be used during the vendor testing and the subsystem buildup.
2. The test equipment is to be modular and expandable to meet the integrated-acceptance-test requirements during prelaunch operations.
3. The total test-equipment complex is to be designed to use significantly less ground-test equipment for an integrated test than was used in the Apollo Program.
4. Upon completion of factory testing and integrated acceptance testing, the test equipment is to be used for operational spacecraft testing and the costly development of new test equipment thus avoided.
5. The test equipment is to be designed to adapt easily to other NASA program checkout requirements.

The experience gained with the ACE-SC used for the Apollo spacecraft is expected to lead to the development of checkout systems which will reduce significantly the cost of testing and checkout activities in future programs.

INTRODUCTION

The effectiveness of the testing and checkout phases of the Apollo missions has played a significant role in the accomplishment of a successful lunar-landing mission. The acceptance checkout equipment for spacecraft (ACE-SC) system has supported all Apollo spacecraft factory-acceptance testing, environmental-simulation testing, and prelaunch testing at the NASA John F. Kennedy Space Center (KSC). No major delays have been attributed to a failure of the ACE-SC system. Changes in testing and checkout requirements were important in stimulating the evolution of the ACE-SC system. Significant problems were involved in implementing major system changes and test-philosophy changes in the middle of a program as dynamic as the Apollo Program has been. This report provides a basic description of the ACE-SC system, a statement of the original goals and requirements for the ACE-SC system, a discussion of the ACE-SC system evolution and the problem areas encountered, and a definition of proposed checkout-system concepts that will resolve some of the undesirable conditions encountered in the use of the ACE-SC system during the Apollo Program.

The information used in this report was accumulated through working experience with the ACE-SC system over a period of several years. The NASA and contractor personnel who have contributed to the success of the ACE-SC program (and hence to the information presented in this report) are acknowledged for the support and significant contributions they have provided.

DESCRIPTION OF THE ACE-SC SYSTEM

The ACE-SC system is a computerized system that provides for centralized, programmed control of spacecraft checkout operations. The ACE-SC system provides for manual, semiautomatic, and automatic operational modes to accommodate subsystem testing, integrated-system testing, and launch support. For the purpose of this discussion, the ACE-SC system (fig. 1) is considered in two parts, which are (1) the command subsystem and (2) the display-and-recording subsystem, also referred to as up-link and down-link subsystems, respectively.

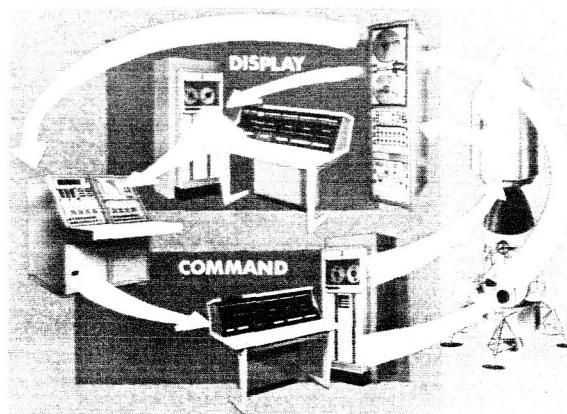


Figure 1. - Simplified data-flow diagram of the ACE-SC.

Up-Link Subsystem

The testing of spacecraft subsystems is controlled from selection-to-activate-random-testing (START) modules that are located in associated system consoles (fig. 2). Spacecraft subsystems that are tested by the various START modules include the environmental-control subsystem, the fuel-cell and cryogenics subsystem, the power and sequential subsystem, the guidance-and-navigation subsystem, the stabilization-and-control subsystem, the propulsion subsystem, the biomedical subsystem, the instrumentation subsystem, and the communications subsystem. The START modules facilitate the input of the appropriate command selections, computer-subroutine selections, or spacecraft-guidance-computer information to the spacecraft.

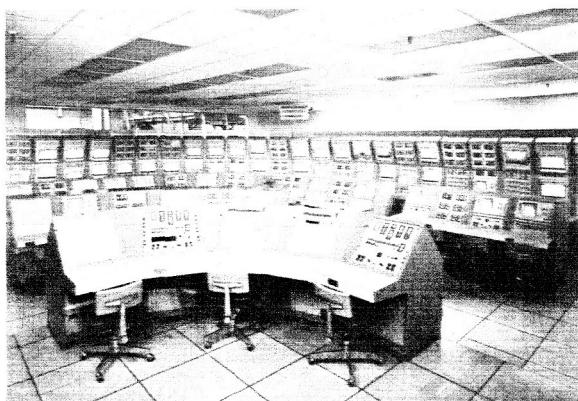


Figure 2. - Typical ACE-SC control room.

Checkout-subsystem consoles can operate simultaneously with and independently of other subsystem consoles. Each console has a variety of test-command capabilities which are necessary for the testing and checkout of a particular spacecraft subsystem. The up-link computer (fig. 3) interprets and reacts to the commands initiated from the subsystem console. A specific command may instruct the computer either to initiate an automatic test or to transmit a single command to the spacecraft. The signals generated by the ACE-SC ground station are transmitted by hardlines to the spacecraft vicinity, where the command signals are distributed by the digital test command system (DTCS). Redundant transmission checks and proper transmission verification tests are accomplished to ensure maximum confidence in proper command transmission.

DOWN-LINK SUBSYSTEM

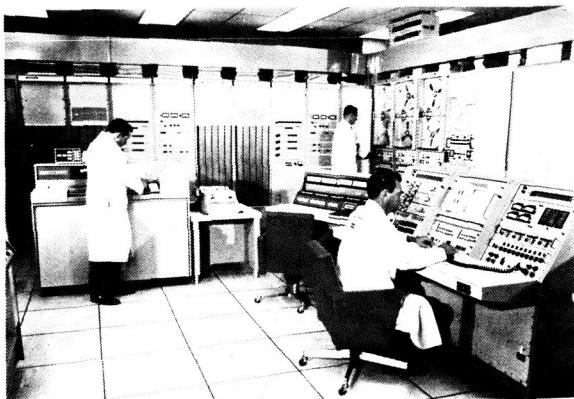


Figure 3. - Typical ACE-SC computer room.

Test data to be processed by the down-link equipment are obtained from sensors in the spacecraft, from the carryon equipment, and from the ground-support equipment (GSE). The test data are transmitted as serial pulse-code-modulation (PCM) data to the recording and display equipment which receives, records, and displays the spacecraft performance data, as required for the particular test procedure being conducted. The digital acquisition and decommutation equipment synchronizes on the incoming serial PCM bit stream, decommutes the data, and routes the data for appropriate processing or display (or both).

The down-link computer conducts the required processing, which includes such functions as predetermined limit checks, engineering unit conversions, data compression, and a variety of special processing for each spacecraft subsystem. Display information is transferred to a symbol generator and storage unit, which generates alphanumeric-character display signals for display on the appropriate subsystem console. The display can be specific parameters that will blink if the tolerance is exceeded, unique outputs based on special processing requirements, or status information for automatic test sequences.

INITIAL APOLLO PROGRAM REQUIREMENTS FOR THE ACE-SC SYSTEM

It was recognized early in the Apollo Program that the magnitude of the Apollo command and service module (CSM) and lunar module (LM) checkout requirements precluded the use of manual test equipment because of the excessive checkout time that would have been required. The ACE-SC system underwent a significant evolution from the initial Apollo Program requirements to the final capability that was used in the Apollo 11 lunar-landing mission. A major part of ACE-SC system evolution took place in the ACE-SC computer-programing system, which had to be modified to meet the evolving test requirements as the missions became more complex.

The initial requirements placed on the ACE-SC system for the early Apollo Program test phases were based on a concept of providing simple, computer-controlled

command-and-response checkout of the Apollo spacecraft. The capability to test several spacecraft subsystems simultaneously from one ACE-SC ground station also was included in the initial requirements. Basically, the requirements included the capability to perform the following functions.

1. To send a wide variety of test stimuli to the spacecraft from any ACE-SC subsystem console
2. To monitor and display several hundred spacecraft parameters in real time
3. To provide special processing and formatting of approximately 400 spacecraft parameters for real-time display
4. To provide complete documentation of the tests by recording all commands, recording digitally all out-of-limit parameters, recording raw PCM data, and recording selected parameters on strip-chart recorders

EVOLUTION OF THE ACE-SC SYSTEM

Because of the evolutionary development of the Apollo spacecraft, changes were required in the ACE-SC system to keep pace with Apollo Program test requirements. The number of spacecraft parameters to be processed increased substantially throughout the program. Special computer programs had to be written to accomplish Apollo guidance-and-navigation-subsystem testing, to achieve automatic control for static firing of the service-propulsion-subsystem engine, to control simulated altitude tests, to provide emergency detanking and spacecraft-system safing, and to meet many other requirements which caused the evolution of the ACE-SC hardware and software. The major advances which were accomplished during the ACE-SC system evolution are discussed in the following paragraphs.

Software Design Changes

Increased requirements. - The first major changes to the ACE-SC system capability were accomplished by modification of the system software. These changes were necessary to meet the guidance-and-navigation-subsystem test requirements. The modifications facilitated the interpretation by the ACE-SC system of guidance-computer digital outputs, the loading of guidance-and-navigation tests from the ACE-SC system, and the recording of special guidance-computer data. In addition, the ACE-SC system software was expanded for additional spacecraft parameters and some special real-time data-processing functions.

Memory limitations. - The next major system software change was made because of the ACE-SC system memory limitations. The addition of numerous parameters on the spacecraft, the addition of special processing requirements, and the addition of new GSE and launch-support requirements at the KSC caused the ACE-SC system memory capacity to be exceeded in 1966. The memory capacity of the ACE-SC system could not be increased at the time; therefore, a major effort was initiated to rewrite the system software, with the emphasis on conserving memory space. The system software

was altered to provide the capability to call alternate test loads, which caused serialization of testing and constrained the amount of integrated testing that could be accomplished. Control programs and subroutines were integrated, and common subroutines were used where possible to conserve computer memory. This method of resolving the immediate problem caused the computer processing capability to be exceeded when new programs were added to meet increasing test requirements. The trade-offs between memory capacity and computer processing time must be considered carefully for each checkout requirement to ensure that the optimum system software efficiency is obtained. Checkout systems for future programs must be designed for modular adaptation (of both hardware and software) to different and increasing testing and checkout requirements.

Expansion of the ACE-SC System Memory

As the testing and checkout activities evolved, it became apparent that additional memory capacity for the ACE-SC system would be required to provide the type of integrated testing necessary for the Apollo Program. Serialization of testing at the LM prime-contractor facility and at the KSC, as a result of alternate computer-program loads, would have had an intolerable impact on the schedule if the additional memory capacity had not been provided. The addition of 24 000 words of memory capacity was approved in February 1968, and modifications to the system software were made to allow use of the additional memory capacity.

Data-Compression Techniques

The amount of testing and checkout data that had to be processed for the Apollo Program became such an overwhelming problem that a requirement was generated by the Apollo Spacecraft Program Office to provide the capability to reduce significantly the amount of test data. This capability was provided in the ACE-SC system by initiating a decommutator design change which enabled the decommutator to perform fixed-limit checks and dynamic-limit checks (on a change greater than 1.2 percent or on any data change) in conjunction with a computer program that filed only significant changes on digital tapes. In addition, this modification relieved the computer from some of its routine limit-checking functions and provided for the transmission of data to the computer in a direct-access mode. By providing for the transmission of data to the computer in a direct-access mode, a significant step was taken toward achieving the capability for automatic test sequencing during the testing and checkout of the Apollo spacecraft.

Automatic Test Sequences

One of the most significant steps in the evolution of the testing and checkout capability for the Apollo Program was the implementation of a computer program, which was referred to as the Adaptive Intercommunications Routine (ADAP). The ADAP provided the ACE-SC with the capability for closed-loop automatic test sequencing. "Adaptive" refers to the capability of the program to adapt to new test requirements and to add new test sequences without affecting other computer-program functions. The term

"Intercommunications" refers to the closed-loop aspects of the programs, which provide the capability to transmit up-link commands to the spacecraft, to receive the down-link response, and to initiate the appropriate action in a completely automatic mode. The status of the automatic operations is displayed in the ACE-SC control room, and appropriate override and restart-recycle capability is provided. Test sequences are called from digital tape, as required to meet the particular test-procedure requirements.

The next generation of the ADAP system is being designed and will be implemented for Apollo telescope mount testing at the NASA Marshall Space Flight Center (MSFC). Of major significance is the capability of the ADAP program to generate test sequences in a higher level, engineering-oriented language to help bridge the communications gap between engineering and programming personnel and to reduce the time required for definition of computer-programming requirements.

Prior to the implementation of the ADAP program, there was no capability to provide special processing of checkout data without stopping the test or going to another available ACE-SC station. This problem has been reduced somewhat by using the ADAP test-sequence memory area and loading special data reduction programs to support "quick-look" requirements.

Present Checkout-System Problems

The ACE-SC system used on the Apollo missions does not adequately support all phases of ground testing that are desired in checkout systems for future programs. Vendor-acceptance and preinstallation testing are now delegated to special bench-test and acceptance-test equipment. The present ACE-SC system role begins after the subsystems are installed in the spacecraft. A complete ACE-SC station (control-room and computer-complex combination) is configured for a CSM or an LM, regardless of the magnitude of testing required (that is, subsystem testing or integrated testing). A complete ACE-SC station is required for each vehicle (CSM and LM) during combined CSM and LM testing; consequently, redundancy occurs in the system hardware elements. Station reconfiguration and site activation are lengthy processes that involve many test and operations personnel.

Lack of adequate control and monitoring capability in spacecraft systems and GSE prevents the automation of the entire checkout operation by using the present ACE-SC system. The entire subsystem diagnostic capability is vested in the ACE-SC computer system, with no provisions for a built-in self-test in the spacecraft subsystems. The lack of provisions for a built-in self-test is a major constraint on the simplification of ground checkout systems. Future spacecraft subsystems should have built-in test logic to ensure adequate and efficient checkout operations.

Digital-Test Command-System Problems

One of the most significant problems encountered with the ACE-SC system was in the spacecraft-to-ACE-SC interface equipment. This equipment, which is referred to as the DTCS, is the means by which commands are decoded and routed to the appropriate spacecraft test point.

On December 14, 1968, spacecraft 104 (the Apollo 11 command module) was inadvertently powered down as a result of the erroneous resetting of two latching relays within the DTCS located on Mobile Launcher no. 2. The cause of the problem was believed to have been a transient voltage generated by some external source. There were subsequently 15 additional occurrences of the DTCS problem.

A concentrated effort to solve the problem was initiated by the NASA Manned Spacecraft Center (MSC), the KSC, and all contractors that were associated with the use or manufacture of DTCS equipment. Because of the random nature of the problem, the source of the transients has never been definitely determined.

Several significant points should be made for the purpose of improving GSE and facilities for future space programs. Improvements that need to be made can be summarized as follows.

1. Susceptibility of critical GSE to transient voltage levels
2. Complexity of GSE cabling and patching arrangements
3. Adequacy of launch facility grounding systems, which require careful attention during facility design and subsequent configuration control procedures that are comparable to those used for spacecraft systems

An attempt to improve these areas in the early stages of future programs will not only reduce hazardous situations but should help reduce the time required to perform pre-launch operations.

Mechanical and Radio-Frequency System Interface Problem

One of the problems that impeded the advancement of automated checkout operations was the lack of digital interfacing of mechanical, hydraulic, and radio-frequency (rf) test-support equipment with computerized checkout systems. Much of the time involved in checkout operations is consumed because voice communications are required in order to coordinate the manual operation of valves, solenoids, and rf equipment. This equipment should be automated for future space programs. Automation will provide a reduction in the test time as well as in the number of personnel required to perform the more menial, repetitive operations. Automation of these areas will free technical personnel to apply their efforts to the analysis and evaluation of critical system areas and to the troubleshooting of system problem areas, which would provide for the more efficient use of manpower.

Facility Problems

Facility design and consideration of potential problems associated with power supply, equipment grounding, and equipment access can have considerable impact upon spacecraft testing if these areas are not given proper attention during the early stages

of system development. Examples of problems which were encountered on the ACE-SC system during the Apollo Program include the following.

1. The ACE-SC ground stations at the KSC underwent a significant number of power transients during spacecraft testing. In most cases, the ground-station computers required a program reinitialization or reload (or both) before the test activity could be continued. Power failures and transients also occurred at the contractor ACE-SC stations at Downey, California, and Bethpage, New York. After a total power failure at the prime-contractor site, a high incidence of ACE-SC hardware failures occurred. Normally, the failures were detected by the preoperational test programs and the diagnostic programs before spacecraft testing was continued.

2. Air-conditioning deficiencies and failures created various ACE-SC system problems. At the contractor facility, a broken water main to the air-conditioning system caused the shutdown of all ACE-SC stations. After the air-conditioning system had been repaired, the stations were powered up. Several ACE-SC system problems were detected and repaired before the spacecraft testing was continued. At the MSC, a deficiency in the air-conditioning system caused corrosion in the data-entry units in both ACE-SC control rooms. After several failures that were related to humidity and component corrosion had been identified, the affected elements were coated to reduce the effect of humidity on the system. The connections continued to corrode, however, and the problem was finally resolved by modifying the air-conditioning system to correct the temperature and humidity problems.

3. Isolated instances of poor equipment layout caused minor impact to spacecraft testing. The contractor recorded one incident in which two spacecraft being tested were interrupted as access to a unit in one control room had to be made through the control room of the other station. Another problem associated with poor equipment layout was the lack of isolated convenience outlets for the FR1400 recorders. Because the outlets were not isolated, there were instances of erroneous transients being recorded with the test data.

FUTURE CHECKOUT-SYSTEM OBJECTIVES

To overcome the problems discussed previously, the MSC checkout personnel have established the following objectives for the next generation of testing and checkout equipment (fig. 4), which is presently in the development stages.

1. To have a unified-test-equipment concept that will provide the standardization necessary to be capable of supporting subsystem, integrated, factory-acceptance, and launch-area testing (which would thus provide consistent test capability through all test phases and allow a complete data base to be established to support system operations)

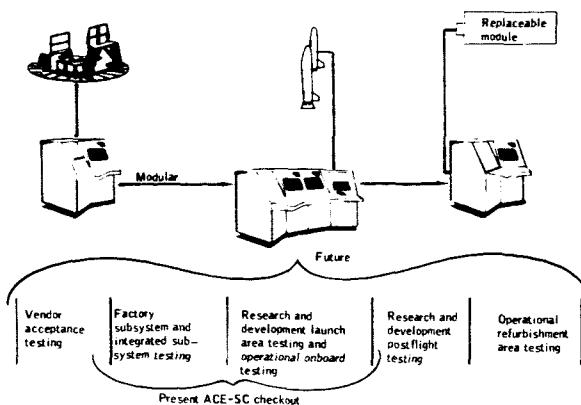


Figure 4. - Test and checkout phases.

2. To have a modular subset of the standard system that will be capable of supporting preinstallation and bench-maintenance testing to reduce the requirement for special-purpose test equipment
3. To have a built-in test capability both in subsystems and GSE to minimize ground diagnostic requirements
4. To have universal control and display consoles that are designed to allow maximum automation, thus reducing the number of required test personnel
5. To have a GSE control and monitor capability from the checkout station
6. To have a basic system that will be capable of modular adaptation to the checkout requirements throughout the program evolution
7. To have a central data facility for spacecraft system test history recording and data-processing support
8. To have a serial digital interface with the spacecraft and GSE

FUTURE CHECKOUT-SYSTEM CONCEPTS

The next-generation checkout-system concept is described in the following section under the two basic categories which encompass the more significant features of the system: equipment configuration and system interfaces. A basic diagram of the system is shown in figure 5.

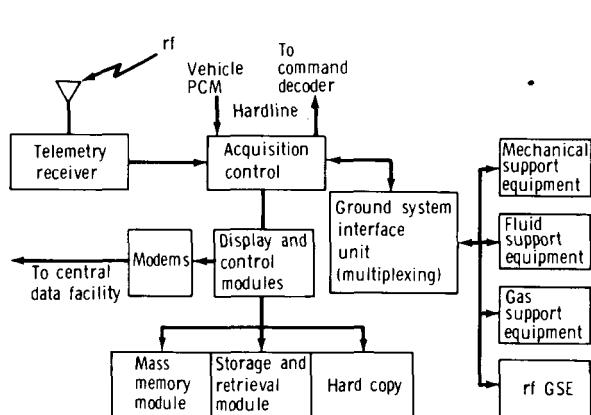


Figure 5. - Space-station and shuttle-vehicle ground checkout station.

Equipment Organization and Configuration

The basic elements of the new system are the control and display console (fig. 6), the ground system interface units, the acquisition and control module, and a central computer facility. Multiple elements or portions of these elements will be used in the performance of all phases and levels of the testing and checkout activity, including unit, subsystem, and integrated-system tests.

During checkout or prelaunch operations, commands would be initiated from the control and display consoles and transmitted

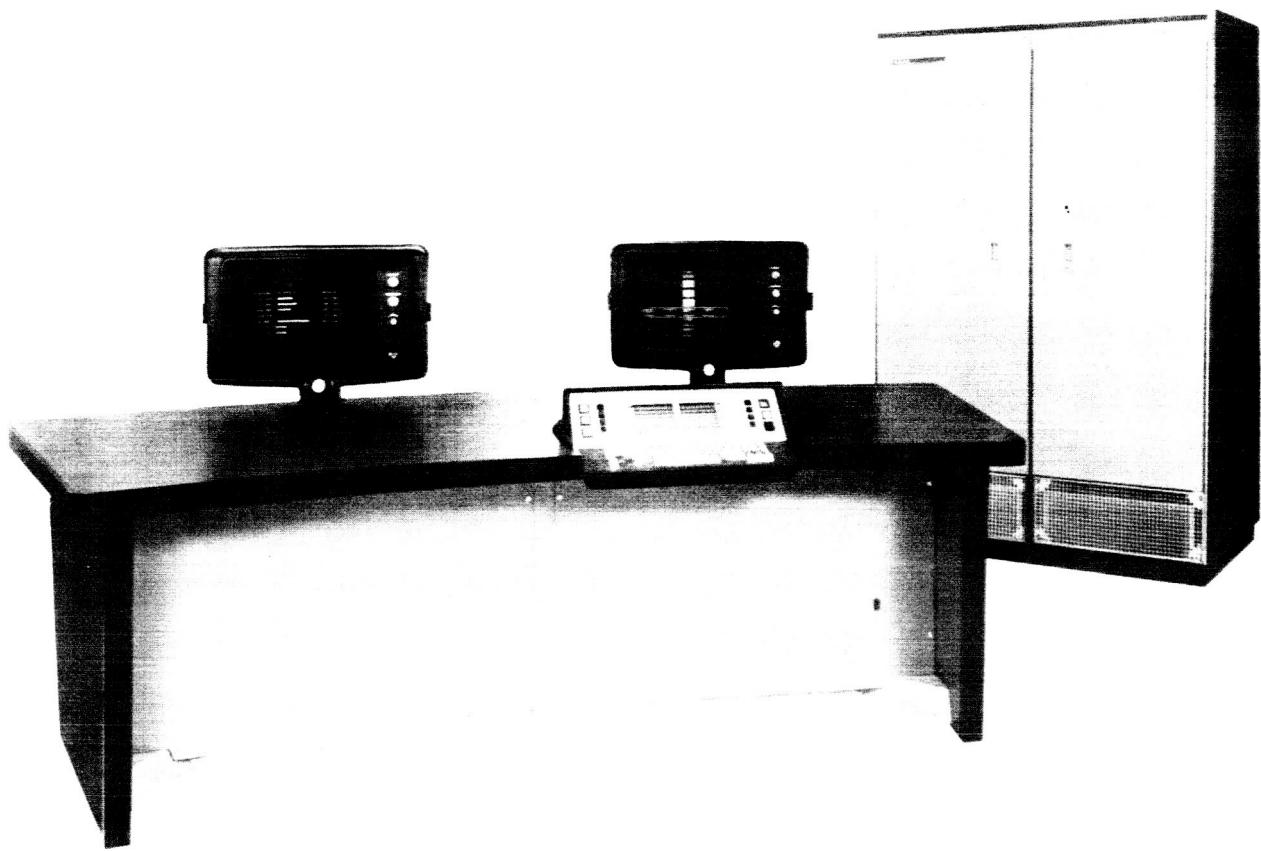


Figure 6. - Control and display console.

to the spacecraft or the GSE. Responses would be received by the acquisition module and routed to the control and display modules for processing, display, and recording. Test history data would be recorded on the storage and retrieval module for subsequent use. The test history data would be transmitted to the central data facility on a non-interference basis. One console would be required for subsystem preinstallation tests.

System Interfacing

The system functional interfaces have three basic elements: (1) the space-station and space-shuttle hardware and the GSE, (2) the centralized computer facility, and (3) the operator interface. Each of these functional interfaces must be connected by a serial digital interface to provide the required information or data-acquisition capability.

The complexity of the ground-system cabling presently used for the Apollo spacecraft checkout will not satisfy future space-program requirements for simplicity, reliability, and fast turnaround time. The system under consideration would use serial digital up-link commands to control the spacecraft and PCM data for response monitoring. The interface between the checkout station and the GSE would be in the form of a

coaxial cable that carries information and data at a frequency of 1 to 5 megahertz. Because the central data facility would be performing a non-real-time function, standard remote-terminal computer techniques would be used for test-area-to-central-facility communications.

One of the major goals of the new system is to minimize the number of personnel involved in the on-line, real-time conduct of spacecraft tests, which would thereby minimize the complexity of the man and machine interface. This goal can be accomplished by using the standard test console, by integrating the GSE with the checkout system, by providing specialist backup to the test conductors through standard television links, and by modular sizing of the control and display system to meet program phases.

CONCLUSIONS AND RECOMMENDATIONS

The ACE-SC system has performed all test and support functions in an outstanding manner. Major advances have been made in the automation of selected test sequences, and confidence has been established in computerized systems for real-time checkout and evaluation of manned-spacecraft systems. However, major areas for improvement still remain that will contribute significantly to the efficiency of future testing and checkout programs. Areas for future improvements include the following.

1. In the past, spacecraft systems and ground-support equipment have not always been designed with testing and checkout in mind. Future spacecraft and ground-support-equipment systems must have the designed-in capability for automatic checkout.
2. The present checkout system does not provide the capability to support pre-delivery and preinstallation testing of spacecraft subsystems. Future checkout systems must be capable of modular adaptability to all phases of test activity as well as to changing test requirements. This will reduce the amount of special-purpose test equipment which has been required in the past as well as the modifications to the checkout equipment.
3. The present ACE-SC system does not adequately provide for "quick-look" data processing with hard-copy data. Future checkout systems should be interfaced with a central computer facility to provide this capability as well as data-recording and trend-analysis capabilities.
4. The communication of test requirements from engineers to the computer programmer is a problem that can be reduced by the implementation of engineering-test-language compilers. Therefore, a test engineer with a minimum of training is allowed to submit requirements for test programs in engineering terms with which he is familiar. This procedure has been implemented with the Adaptive Intercommunication Routine, which is presently being used on the ACE-SC system; however, this computer program is highly oriented toward the ACE-SC system. A higher level test-language compiler is presently in development and will be made available for future testing and checkout activities.

The experience gained in the use of the ACE-SC system has been invaluable. It is anticipated that the benefit of this experience will contribute to the design of even more efficient and successful checkout systems for future programs.

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