An Analysis of the Progress in Automation of Manned Space-craft Test and Checkout

1975

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AN ANALYSIS OF THE PROGRESS IN AUTOMATION
OF MANNED SPACECRAFT TEST AND CHECKOUT

BY

JOHN E. MALONE
B.S., Tuskegee Institute, 1964

RESEARCH REPORT

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Graduate Studies Program of Florida Technological University

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ABSTRACT

Manned Spacecraft Programs are the largest research and development tasks ever undertaken by the government or by private industry in the United States. Under the direction of the National Aeronautic and Space Administration (NASA) these programs have advanced from Project Mercury in the early 1960's through Gemini, Apollo, including Moon Landing, and Skylab Programs to the present day Space Shuttle Program. With the development of each new program, there comes a growing awareness of the ever increasing complexity of tasks relating to integrated preflight test and checkout. Data rates have grown from one (1) pulse amplitude modulated/frequency modulated (PAM/FM) link with just over a hundred (100) measurements to multiple pulse code modulated (PCM) links with many thousands of measurements and bit rates up to fifty (50) megabits per second (MBPS).

A unique requirement of Manned Spacecraft Programs in the "Man Rating" concept. Man rating requires that every failure and test anomaly be analyzed, understood and/or corrected prior to flight. This further complicates an already complex test and checkout program. Exploitation of the potentials of automation was and is the only recourse for present day and future programs. Such automation should be as automatic as possible but must have a man-in-the-loop capability to assure that the test engineer has positive control at all times.

This paper analyzes the progress in automation in ground test and checkout from Project Mercury days with a simplified prototype technique for Space Shuttle.
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INTRODUCTION

In the early planning stages of Project Mercury it was learned that before spacecraft test and checkout can begin, very careful preparations must be made. Each step has to be formalized through configuration documents, check lists, and test procedures. Test complexes and ground support equipment (GSE) must be checked for readiness and compatibility with the particular spacecraft. The spacecraft can then be put into the test stand and after configuration conformance has been verified, test and checkout can begin.

Each functional spacecraft system must be tested to verify it operational and flight worthy. The functional systems include:

1. Environmental Control
2. Fuel Cell and Cryogenics
3. Power and Sequential
4. Guidance and Navigation
5. Stabilization and control
6. Propulsion and Reaction Control
7. Instrumentation and Telemetry
8. Communications

Data Measurements are generated within each system and processed and transmitted by the instrumentation and telemetry system. The measurements are the primary source of insight into the operation of the
system by the systems test engineers. The data is transmitted via hardline and/or radio frequency (RF) and is either PAM/FM or PCM.

The Mercury and Gemini Programs basically used conventional test and checkout methods. Manual operations using individual test equipment for each test and each spacecraft system were employed. Manual analysis of data measurements and test results was also used making the total operation very time consuming. A reduction in the reliability of the overall test effort was also an important factor due to the spacecraft cabin operators positioning switches and circuit breakers and technicians using meters, oscilloscopes, and other test equipment.

Ground Test and Checkout Computers were used sparingly until the Apollo Program, the first real attempt at automation. The primary drivers for automatic test and checkout were the number of tests to be done and the number of data measurements to be analyzed. The ground system used for Apollo and Skylab Programs was called Acceptance Checkout Equipment for Spacecraft (ACE-S/C) and provided centralized control of spacecraft test and checkout operations. ACE-S/C was used for independent as well as integrated test and checkout.

The requirements of Space Shuttle tests and checkout operations at Kennedy Space Center (KSC) will require the processing of spacecrafts in less time than for previous spacecraft. The Space Shuttle, being reusable and flying many missions per year,
places extreme demands on the ground test and checkout system for turn around time.

This research concerns the past, present, and future manned spacecraft ground operations where computer application play an ever increasing role.
A. DATA SYSTEMS

For the Mercury spacecraft a PAM/FM data system was chosen. It could provide the needed information and was a reasonably proven state-of-the-art type system which could be implemented on the ground test and checkout system with commercially available hardware.\(^1\)

The onboard instrumentation system consisted of transducer, ninety (90) segment PAM commutator, eight (8) redundant voltage controlled oscillators (VCO'S), and associated transmission equipment as shown in Figure 2-1.\(^2\)

The primary data system for Gemini was PCM. However, a PAM/FM system was also included on early flights for high frequency research and development data and was dispensed with as the program progressed. A Gemini PCM System is shown in Figure 2-2.

The data is received in a signal distribution room (SDR) by wide-band transmission lines or from the common use RF checkout equipment (CURFCOE) antennae and receivers. The CURFCOE data is demodulated prior to being sent to the SDR. From the SDR the data is routed to the appropriate ground stations.

B. FM GROUND STATION

The FM Ground Station consisted of receivers and discriminators for acquiring and decommutating the data. The discriminators could be patched for single or multiple input configuration. Channel
COMMUTATOR (COMBINES 90 INPUTS INTO ONE OUTPUT)

SEVEN (7) CHANNELS OF BIOMEDICAL DATA, EKG'S, RESPIRATION, ETC.

FIGURE 2-1 MECURY PCM BLOCK DIAGRAM
Figure 2-2 Gemini PCM Block Diagram

- High Level/BI-LEVEL MULTIPLEXER
- LOW LEVEL MULTIPLEXER
- LOW LEVEL
- HIGH LEVEL

Signal Conditioner

Subsystems
selectors selected Inter-Range Instrumentation Group (IRIG) Proportional Bandwidth, American Institute of Aeronautics and Astronautics (AIAA) constant bandwidth, and/or other predetermined subcarrier frequencies. The discriminator outputs were recorded on magnetic oscillograph or direct write strip chart recorders as well as displayed on meters, lights, and other test equipment. The data was also recorded on magnetic tape prior to being decommutated.

C. PCM GROUND STATION

The PCM Ground Station provided for acquiring, synchronizing, decommutating, distributing, and recording the PCM data transmitted from the spacecraft systems. It consisted of redundant data acquisition and decommutation equipment (DADE). The incoming data consisted of 51.2 Kilobits per second (KBPS), eight (8) bits per serial data word. The DADE converts the serial data words into a parallel format and assigns an address for distribution. The serial data was also recorded on magnetic tape. Selected data measurements were converted from digital to analog and displayed on strip chart recorders and/or meters. One-bit-event data (eight (8) per data word) were displayed as "on" or "off" on event recorders and event lights. The DADE's were programmed by a patchboard.

D. OPERATIONAL TECHNIQUES

The status of the GSE was kept by technicians with the aid of gages, meters, and other measuring devices. The spacecraft responses to stimuli from the GSE was correlated by operational intercommunication system (OIS) conversation between the technician at the GSE and
the test engineer at some test control site.

The control site consisted of a room with system consoles to monitor certain operations and data measurements. Very few commands to the spacecraft were generated from the control room. System consoles had switches for emergency and critical functions such as spacecraft and/or GSE power down and control of hazardous operations such as propellant loading.

E. DATA REDUCTION

Data Reduction and correlation was a post test, manual task. Even though the data measurements numbered only in the few hundreds, there was not enough display capability to display all measurements in real time. Data recorded on magnetic tape had to be played back and recorded on strip chart analog and event recorders and displayed on data boards for the test engineers to review. There was a different spacecraft and GSE configuration for each test and test objective. Therefore reconfiguration time for each test was dependent on the time required for post test data analysis.

F. SUMMARY

This set-up worked very well for Mercury and Gemini with the relatively few data measurements and simple spacecraft systems. However, it was long recognized that this type of operation was not suitable for Apollo and future spacecraft. The increase in frequency of launches, complexity of systems, and amount of data measurements dictated a more automated test and checkout scheme.
PROJECT APOLLO/SKYLAB

A. DATA SYSTEMS

Project Apollo brought with it the most advanced integrated test and checkout equipment of its time, ACE-S/C. The ACE-S/C provides centralized, programmed control of both individual and integrated systems checkout. Large quantities of test data can be processed and displayed in real time as well as recorded for post test analysis.

The spacecraft systems were largely the same ones as for Mercury and Gemini. However, the complexity of the systems were many times that of any previous spacecraft. The complexity of the spacecraft and its missions was such that testing was done in three (3) phases before the spacecraft was declared operational:

3. Verification and Man-Machine Compatibility of the Production Spacecraft.

The data system for Apollo was PCM with a research and development PAM/FM System. Data measurements had grown from one (1) or two (2) hundred to many hundred.
CENTRAL TIMING EQUIPMENT

TRANSMITTER

REMODULATION PROCESSOR

PCM UNIT

DATA DISTRIBUTION PANEL

SIGNAL CONDITIONER

SUBSYSTEM

FIGURE 3-1 APOLLO PCM BLOCK DIAGRAM
B. ACE-S/C FUNCTIONAL DESCRIPTION

The ACE-S/C System equipment is located in three physical areas at KSC: the Control Room, Computer Room, and Terminal Facility Room. The equipment performs the following functions:

1. Provides the operator with control and data processing facilities necessary to control spacecraft test stimuli equipment.

2. Receives, processes, displays, and records spacecraft tests derived from the spacecraft and GSE Instrumentation Systems.

3. Provides testing and calibration capability of itself and related equipment.

The Control Room contains the primary controls and displays and is arranged in a series of console groupings according to the spacecraft system being used. It provides a central location for stimulating and monitoring the performance of each spacecraft system.

The Computer Room contains the DADE's, the Command and Display Computer Complex, the Data Transmission and Verification Computer (DTVC) and Magnetic Tape Recorders. The Computer Complex consists of two (2) computers, a shared memory module, and associated peripheral equipment.

The Terminal Facility Room provides a flexible interface between remote spacecraft test areas and the ACE-S/C Station Equipment.

The ACE-S/C Equipment may be divided into two (2) functional groupings: the Command Equipment (Uplink) and the Data Recording and Display Equipment (Downlink). The Command Equipment comprises those
units that form the communication path over which all test commands and sequences are generated and transmitted to the spacecraft. Verification of receipt of these commands is transmitted from the spacecraft test area back through the command system to the applicable ACE-S/C Station Console. The Recording and Display Equipment comprises those units that form the communication path over which all S/C responses and test data are transmitted to the ACE-S/C Station and the equipment which records and displays it for evaluation.

C. COMMAND DESCRIPTION

Test Commands are initiated at the various systems consoles through three (3) types of control modules called START (Selections To Activate Random Testing) modules. The Computer (C-START), relay (R-START) and keyboard (K-START) START modules contains switches and indicators which the test engineers use to enter coded messages into the uplink, or command, computer where the desired preprogrammed routines are selected from memory.

The computer acts on these routines generating command words for transmission to the spacecraft test area. The commands are sent to the digital test command system (DTCS) which serves as an interface between the spacecraft and the servicing equipment. The DTCS decodes the uplink messages and routes them to the specified location in the spacecraft or test area.

C-START Modules provide manual selection of computer subroutines and the parameters required by the subroutines. R-START Modules provide manual closing and opening of relays. These modules are located
in varying numbers on the systems control consoles. A single K-START Module provides for manual or automatic data insertion into the spacecraft Guidance and Navigation Computer.

Each functional spacecraft system is controlled by a separate console equipment group. Each group operates simultaneously and independently with the other groups. In order that the command computer may systematically process each of the many inputs from the consoles, a unit called the communications unit executor (CUE) provides the interface between the START Modules and the Command Computer. The CUE sequentially interrogates the modules at a high scanning rate. When a data entry is detected by the CUE, the scanning momentarily stops and the CUE signals the computer that an input is forthcoming. The data is then transferred into the computer. The computer interprets and acts upon the command which may modify memory or cause some action to occur in the spacecraft test area. In the latter case, the computer formulates a command for transmission to the DTCS by the data transmission and verification converts (DTVC).

The DTVC performs a conversion of the test command from parallel to serial and verifies a correct command message transmission. Verification of correct transmission from the computer to the spacecraft test area is indicated to the test engineers by lamps on the START modules.

The interrogation, command formatting, transmission and verification cycle normally occurs in microseconds so that to the test engineers there is no perceptible delay in their individual test procedures.
CONTROL ROOM

COMMAND & DISPLAY CONSOLE

TERMINAL FACILITIES ROOM

COMPUTER ROOM

S/C TEST AREA

FIGURE 3-2 ACE-5 C UPLINK BLOCK DIAGRAM

- AIR BORNE
- CARRY ON
- GSE

- DTCS
- DTV C
- CUE
- J BOX
D. DATA RECORDING AND DISPLAY DESCRIPTION

Spacecraft status and performance data is gathered by the Spacecraft Instrumentation System, carry-on checkout equipment, and service equipment. The data measurements are digitally encoded, commutated and transmitted in PCM form to the ground station DADE located in the computer room. Prior to processing by the ground station, the data is recorded on magnetic tape for permanent record. The data is decommutated, converted to a parallel format and addressed. The decommutator output is distributed to the display (downlink) computer and via the decommutator distribution/event storage and distribution unit (DD/ESDU) to analog and event displays and/or recording devices.

The display computer processing includes comparison of analog data with predetermined limits and the conversion of the data to engineering units. Binary words representing the values in engineering units are stored in storage registers in the computer input/output (I/O) unit.

The data is then transferred to the symbol generator and storage (SGS) unit where it is stored in memory and used to generate alphanumeric display symbol voltages. These voltages are gated to a cathode ray tube (CRT) display device upon command of the test engineers at the Control and Display Consoles. If the data does not fall within the predetermined values, the computer signals the SGS unit and that particular data display is caused to fluctuate in intensity (blink) on the CRT.

The DD/ESDU routes all digital test data words directly to the control room consoles. Decoding and conversion circuits in the
consoles select data words (by address) and convert them to analog voltages for display on meters and recording on strip chart recorders. The ESDU portion of the DD/ESDU selects event data words (by address) and stores them in registers. The event storage registers are connected to lamp drivers and/or strip chart recorders.

E. SUMMARY

The same ground test and checkout configuration was used for Skylab. ACE-S/C is still operational at KSC and is presently being used to check out the Apollo Command and Service Modules for the Apollo Soyuz Test Project (ASTP). A system similar to ACE-S/C can be adapted to the demands of Space Shuttle. Some of the unique requirements above and beyond those of Apollo are the greater number of data points to be processed and analyzed and the launch frequency. The next two (2) chapters take a look at some of these requirements and how ACE-S/C can be extended to accommodate these requirements.
A. INTRODUCTION

The Space Shuttle program is the most adventuresome endeavor ever undertaken by the NASA. The NASA and KSC in particular must approach this new frontier with an open mind for new ideas and concepts in operations and preflight test and checkout. For the past four years KSC has been actively participating in the development of the Space Shuttle program in many areas. One of KSC's most significant contributions has been in the development and definition of the preflight operational concepts and philosophies that will be required to achieve program objectives.

B. SYSTEMS REQUIREMENTS

The reusable nature of the Space Shuttle places unparalleled requirements on Systems Design. The systems must be such that they can be as easily maintained and refurbished as possible as well as durable. A uniquely important concept of System Design is the capability of passing from a research and development phase into an operational phase similar to commercial aircraft operations.

One of the program objectives of Space Shuttle is to put payloads into orbit at a cost less than ever before. If this is to be done, systems more complex than ever before must be maintained and checked out with a relative small number of test engineers and
support personnel. This places more and more of the burden of test and checkout on the Ground Checkout System.

The systems are basically the same as previous spacecraft but the complexity necessitates breaking some of the systems into sub-systems. For instance: the Propulsion System can be broken into the following subsystems:

1. Space Shuttle Main Engines (SSME)
2. External Tank (ET)
3. Solid Rocket Booster (SRB)
4. Reactional Control (RCS)
5. Orbital Maneuvering Subsystem (OMS)

The integration of these subsystems relies heavily upon the preflight ground test and checkout systems.

The requirements of the instrumentation systems are so intensive that new concepts had to be incorporated. Automatic fault detection and correction and self performance monitoring reduces the vast job of data analysis. Software programmable computers provides the flexibility needed to enhance the job of data processing for a particular mission. To facilitate preflight test and checkout of this system it is almost mandatory to have some type of software controlled ground checkout system.

To facilitate in-orbit activities, five (5) general purpose computers are provided on the Space Shuttle as compared to one (1) for previous spacecraft. Three (3) computers are dedicated to Guidance and Navigation Operations and two (2) for performance monitoring, and automatic fault detection. This computer scheme is still
yet another reason for as much automated test and checkout as possible.

C. OPERATIONAL REQUIREMENTS

The objective of an Operational Space Shuttle is to recycle the flight vehicle to a launch configuration in two (2) weeks and still maintain a launch program that is cost effective. This is probably the most challenging aspect of the program. It was not uncommon for previous spacecraft to go through six (6) months or more of test and checkout at KSC. To achieve a Space Shuttle turnaround of two (2) weeks will indeed require new innovations for preflight test and checkout.

As with any new program, there will initially be little, if any, baseline data available on complex and intricate systems. It will therefore be necessary to go through rigorous and thorough test and checkout of the entire vehicle. Each system must be exercised repeatedly to gain sufficient data and information to give the test engineers confidence of successful mission operation. As experience and confidence are gained and system performance data accumulated, repetitive testing can be eliminated. By the time the Space Shuttle becomes operational data and information from previous flight and ground test can be used to facilitate turn-around.

To add to the complexity of ground operations, Space Shuttle will be checked out in four (4) different areas and integrated just prior to launch. Orbiter maintenance and refurbishment will be done in the Orbiter Processing Facility (OPF), a new facility at
KSC. At the conclusion of this maintenance and modification period, power-up testing will be done on all systems to verify them ready for the next mission. The external tank will be erected in one of four (4) vertical checkout facility test cells located in the vertical assembly building (VAB). After complete electrical, instrumentation and mechanical checks, the ET will be transferred to the mobile launch platform where it will later be attached to the solid rocket boosters (SRB) at the SRB Facility, the avionics system will be installed and checked out. Other build-up as necessary will be performed and the completed segments transferred to the VAB integration area. Presently, payloads processing is planned to be done in the Manned Spacecraft Operations Building (MSOB). Processed Payloads are installed in the Orbiter in the OPF and transferred to the VAB for mating with the ET and SRB's for a launch configuration.

D. SUMMARY

Ground Operations will include many firsts for KSC Test Engineers and Operation Crews. Post-flight safing, servicing, refurbishment, and maintenance of flight systems are some of the challenging new activities at KSC. The quantity of operations to be performed almost dictates the use of computers for such things as configuration management and logistics as well as for spacecraft test and checkout.
SIMPLIFIED PROTOTYPE CHECKOUT CONCEPT

A. INTRODUCTION

One of the most important objectives of Space Shuttle is its cost effective aspect of launching or retrieving payloads. To realize this objective the total launch, landing, maintenance, and refurbishment process must be cost effective. There are many factors affecting the cost of the total program of which the preflight test and checkout (maintenance and refurbishment) are considered here.

B. SOME DESIGN CONSIDERATIONS

To meet the requirements of Space Shuttle era launch maintenance and refurbishment, modern automation techniques must be employed. Many problems will be encountered in implementing a computer controlled test and checkout system. Many considerations and tradeoffs are involved in a system capable of handling the total ground operational requirement of Space Shuttle.

1. Computers. The heart of any automated system is the computer itself, and careful analysis must go into its selection. Some desirable features to look for are: a. high speed data transfer; b. as few I/O wires as possible; c. large number of device locations on the I/O bus; d. synchronization pulses to insure closed-loop operation; e. an efficient interrupt scheme; and f. good
internal structure. It is not likely that a computer can be found with all of these desirable features. It is then therefore, obvious that trade-offs are involved. Cost is also a factor along with the other features. Along with the purchase price and installation cost consideration must be given to programming, flexibility, maintenance, training, and other such operations.

2. Interfacing Peripheral. For systems of the size anticipated for Space Shuttle there will be many pieces of peripheral devices and possibly many computers. The problem of integrating nonstandard peripheral devices (supplied by different manufacturers) looms big. If more than one computer is used, they may be capable of transferring data between them and/or linked manually. A vast and ever growing array of peripheral devices can be attached to buses for data transfer to the computers. The data may be transferred by human operator from typewriters or other keyboard machines or automatically, in the case of man-machine interface the peripheral device that is inconvenient or confusing to the operator will considerably impair the efficiency of the total system. Probably the most important aspect of automatic data transfer is the compatibility in speed of data transfer rates. Any incompatibilities can be taken care by use of buffers.

C. PROTOTYPE SYSTEM

1. Consoles/Computers. The amount of data processing for Space Shuttle is anticipated to be very, very large. For this reason it seems more feasible to equip each systems console with a
minicomputer for processing that system's data only. The console will also provide a complement of displays and controls which will be the primary man-machine interface. The test engineer can send commands to the spacecraft, service equipment, and carry on equipment through his console. The consoles will provide such things as:
a. automatic test and checkout procedures; b. display data processing; c. command functions; d. auto and manual control of hazardous and emergency operations; and e. retrieval of historical data and trend analysis. A keyboard will be provided for computer instruction and display requests.

Several test programs will reside on disc memory and read into main memory prior to program execution. Any test program can be called into main memory and executed from the console keyboard. This console configuration does the same operation, but on a larger scale, for a particular system as the ACE-S/C Test Console, Command Computer and Display Computer. A block diagram is shown in Figure 5-1.

Data Transmission to and from the spacecraft and associated GSE would have to be on several links to be compatible with the DADE System used for ACE-S/C.

The vast quantities of data to be processed would make the DADE so massive it would be cost prohibitive. It is therefore desirable to use the powers of minicomputers and a data bus system to handle these vast quantities of data transfers. Computers for Downlink Data and Uplink Command processing will interface the GSE and Space-
FIGURE 5-1 CONSOLE/COMPUTER BLOCK DIAGRAM

DATA BUFFER

CPU
MEMORY
ROM
I/O

DISPLAYS & CONTROLS
CRT GEN
CRT

MAG TAPE
DISC
KYBD

CONSOLE

DATA FILE

CONSOLE
craft System with the consoles and other data processing facilities.

Downlink processing includes conversion, formatting, and addressing of data. Processing depends on the test configuration data base loaded into memory. The data base contains information such as: a. measurements to be processed; b. limit checking; c. significant change criteria; and d. critical data criteria.

Compatibility of the Interface Computer with the Space Shuttle flight computer and software design will make it possible for direct ACE-S/C interface. However, an additional interface device will be necessary for interfacing the computer and the GSE.

Uplink Command are generated in the console computer by the operator keyboard or a test program. The interface computer reads the command and determines its destination or the subroutine to be initiated. The Interface Computer will also determine the validity of the command by checking it against a legality table. It further checks to see if there are any configuration prerequisites that must be done before the command can be executed.

The Interface Computer performs the applicable functions of the ACE-S/C DADE's, DTVC, and DTCS. The number required depends on the amount of uplink and downlink data to be processed, not the number of console computers. A block diagram is shown in Figure 5-2.

The Data Buses provide the communication between the Spacecraft and the Interface Computers. The data links between the Spacecraft and the Interface Computers consists of a synchronous bi-directional one megabit per second data, synchronous PCM downlink data and command uplink data, See Figure 5-3.
Figure 5-2: Interface Computer Block Diagram

- Data Buffer
- CPU
- Memory
- ROM
- I/O
- Data Buses to Spacecraft
FIGURE 5-3 SPACE SHUTTLE PCM SYSTEM BLOCK DIAGRAM
Data transfer is serial with the Interface Computer performing the necessary serial-to-parallel and parallel-to-serial conversion, coding, and decoding, and data decommutation and addressing.

A polling scheme is performed from a device and measurement scanning list in the interface computer memory for the synchronous bi-directional data link. Each device on the bus has a unique address and continuously monitors the transmission line for instructions. The Interface Computer will also have in memory the address and sample rate of each measurement it services. All timing and control signals necessary for initiation of a data request or command transmission are generated in the interface computer. The devices referred to in Figure 5-3 accepts, decodes, and executes instructions from the bus controller and codes and transmits data upon request.

They serve as the interface between the subsystems and one megabit per second serial bus. Analog and discrete data are converted to a digital PCM format, given an address, and transmitted out on request.

Analog data words are encoded in eight bits and discrete events (1 bit) are placed into groups of eight. The data is available to the interface computer as addressed PCM words, on request from the computer or as time division multiplexed PCM words.

The data is then transferred to a specific location in the Data Buffer.

2. Data Buffer. In addition to the many computers operating simultaneously, other peripheral devices will also be operating in
the total system. The amount of data processing and temporary storage required makes it more economical to use mostly external buffering. The buffer will provide inter-communication between console computer, interface computers and other peripheral devices. The various communication paths are controlled by I/O Modules. Each device connected to the buffer will be allowed to write in a particular block of memory only. This "write protect" capability prevents a computer from issuing another computer's commands.

The I/O interface will scan the many computers until it recognizes a request for buffer access. The scanning stops until this transaction is completed then continues until it receives another request for entry to the buffer. To prevent any one device from tying up the buffer with massive data transfers, communication will be by a one-word transfer at a time, per device.

When a device signals that it has data ready for buffer entry, the I/O recognizes the request from the console computer and allows it to write a message into a specified allocated memory block. If the designated device is busy, it so notifies the console computer. If it is not busy, the device reads the message from the buffer and proceeds to execute the message.

The buffer, an extension of the ACE-S/C CUE, services many devices with cycle times in the order on one (1) micro-second. It is therefore required to be much faster than the rest. A cycle time of approximately one hundred (100) nanosecond is desired. Present day technology provides metal oxide semiconductor (MOS) memories with cycle times approaching this requirement. Other devices,
such as silicon-on sapphire (SOS), offer faster cycle times but at a much higher cost. Economic reasons and advancements in memory technology makes MOS memories the prime choice for the buffer.

3. Data File. The data processing system will be required to store large amounts of data as well as many software programs. The quantity is sufficient to warrant a central storage system.

The system will be capable of a. real time data storage and retrieval, b. program compilation and storage, c. unprocessed and processed data storage, d. simulation for software validation, and other data handling functions as required. It will also provide for an automated information management system for dissemination of task and pertinent management data. Management provisions will include: a. configuration management; b. failure reporting; c. logistics; and d. work authorization control.

The major components of the system will be magnetic tape recording devices, a computer, and direct access storage devices. The storage devices will contain: a. operating system programs, b. compilers, c. a library of console computer test programs, d. a library of simulation models, e. data for historical recall and trend analysis, and f. data tables.

Access to the central storage system for input and retrieval from the console will be by keyboard and test programs.

A complete simplified system block diagram is shown in Figure 5-4.

4. Software. The variety of task to be performed leads naturally to a modular software architecture. The flexibility
Figure 5-4 Overall Block Diagram
provided leads itself to ease of operation in all configurations and will require a full up system with consoles for all systems plus launch pad, mobile launcher and other data link interfaces. A single console configuration will suffice for test and checkout in some dedicated areas such as in the ET vertical checkout facility.

Each systems console will contain identical disc operating system for executive control, program loading from disc, test program interpreter and data display and entry service. The operating system will be designed to be capable of real time operations thereby requiring extensive support from compilers. In addition to the systems consoles a master console will provide the control for console interactions.

From a test and checkout standpoint, the most important programs are the test programs. They will be used by test engineers that are not necessarily familiar with programming and computers. These programs will use a higher order language oriented toward the spacecraft rather than to the test system itself. The test engineer then never addresses a device in the system but describes the test or function to be performed on the spacecraft in a language that utilizes English-like statements.

5. Data Flow

a. Downlink Data. Electrical signals are generated in the subsystem by the transducers and are proportional to the quantity of a particular measurand. A typical example is a resistive diaphragm pressure transducer. As the pressure changes flex the
diaphragm its resistance changes. This causes a corresponding change in the output voltage across the diaphragm. Since the change in resistance is very small the output voltage change is small. An amplifier is used to condition the output signal to a level compatible with the bus and devices. The analog signal is converted to an eight bit digital PCM signal in the device and placed on the bus by pre-programmed sequence or upon special request. The data is then transferred through the bus controller on the 1 MBPS bus to the GSE or through the computer to the PCM unit for downlinking. Data is also routed directly to the PCM unit from the Device.

The data reaches the interface computer on the 1 MBPS bus or the 64/128 KBPS lines and is transferred to its special location (2) in the data buffer. Here it remains for use by the data file and console computer until updated with new information.

b. Uplink Data. Uplink commands are pre-programmed or special instructions from the Console Computer. Both commands are generated in the console computer and sent to a special location(s) in the data buffer. Once in the data buffer it can be used by the interface computer or by the Data File.

The test engineer may have written his test program such that in a sequence of operations a spacecraft valve is manipulated. At that place in the sequence the command is sent from its location in computer console memory to the data buffer. When the interface computer polls the data buffer for data bus access, it recognizes the presence of the command and accepts it. The commands are decoded
CONCLUSION

Ground test and checkout of the reusable Space Shuttle featuring commercial airline operational concepts to achieve rapid turnaround is the foremost challenge facing the aerospace industry today. The design and development and operational cost to realize program goals. Automation offers several advantages in the area of testing and economy. Automated test sequences can be repeated exactly, thereby reducing possibility of operator error and increasing reliability. All programs contain several options or branches planned in advance. This preplanning reduces the amount of real time decisions the test engineers have to make. The test engineers should not have to perform the function that can be accomplished more efficiently by machines, leaving him more time for his observation and decision-making role.

An automated test and checkout system will reduce the number of personnel required in the control room for any given test. It will also reduce the time required for data analysis and to complete testing. The results are more detailed testing in a shorter period of time and more historical test records. This does not imply that every test can be automated. Some mechanical tests can still be performed more efficiently using manual techniques.
A good example of this would be servicing a gaseous oxygen tank where temperature changes are critical.

One problem area of concern is software. It is highly unlikely that many of our test engineers have more than a basic knowledge of programming and programmers of the hardware. Therefore, it is almost imperative that a higher order language comprised of English-like statements be used. Still, a great amount of training and cross-training has to be done. While this may be somewhat of a disadvantage it serves as a stepping stone for future automatic test and checkout systems for manned spacecraft.
LIST OF DEFINITIONS

DOWNLINK
That link from the spacecraft to the data recording and display equipment including both RF transmission and hardline.

REAL TIME COMMAND
RF Transmitted commands to the spacecraft, both on the ground and in orbit, at the discretion of ground personnel. No preprogramming or sequencing is involved in command transmission.

UPLINK
That link from the ground command and control equipment to the spacecraft including both RF transmission and hardline.
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tr>
<td>ACE-S/C</td>
<td>Acceptance Checkout Equipment-Spacecraft</td>
</tr>
<tr>
<td>DADE</td>
<td>Data Acquisition and Decommutation Equipment</td>
</tr>
<tr>
<td>DTCS</td>
<td>Digital Test Command System</td>
</tr>
<tr>
<td>DTVS</td>
<td>Data transmission and Verification Convertor</td>
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<tr>
<td>GSE</td>
<td>Ground Support Equipment</td>
</tr>
<tr>
<td>KBPS</td>
<td>Kilo-Bits Per Second</td>
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<tr>
<td>KSC</td>
<td>Kennedy Space Center</td>
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<tr>
<td>MBPS</td>
<td>Mega-Bits Per Second</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics And Space Administration</td>
</tr>
<tr>
<td>PAM/FM</td>
<td>Pulse Amplitude Modulation/Frequency Modulation</td>
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<tr>
<td>PCM</td>
<td>Pulse Code Modulation</td>
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<tr>
<td>RF</td>
<td>Radio Frequency</td>
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<td>SDR</td>
<td>Signal Distribution Room</td>
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FOOTNOTES


9 Ibid.

10 Ibid.

BIBLIOGRAPHY

Books


Article


Proceedings


Governments

