MULTISTATION AUTOMATIC TESTING OF MINUTEMAN III INERTIAL GUIDANCE SYSTEMS

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INTRODUCTION

The Autonetics built Minuteman III Guidance System and subsystems are very complex inertial navigation systems. To verify that a newly manufactured unit functions properly and to isolate the cause of a "field failure" is a substantial task. Previously Autonetics utilized tape controlled test equipment to perform these functions on a single test station basis. This test equipment performed the task sufficiently, but there were shortcomings. First, the tests were not completely automatic and required the operator to observe measuring devices, interpret the data, perform certain test sequencing, and record the data. Also when a malfunction occurred, it was difficult to determine if it was in the test equipment or in the Unit Under Test (UUT).

The Minuteman (MM) III Test System was developed to replace this older method of testing. The purpose of the MM III Test System was to reduce test time and eliminate errors caused by operator techniques and interpretations. The new test system was to provide an effective automated method of performing both factory acceptance testing and maintenance testing of the MM III Missile Guidance System (MGS) and subsystems [Gyro Stabilized Platform (GSP) and Missile Guidance Set Control (MGSC)]. The Factory Acceptance Testing is performed in the course of equipment sell-off at the Autonetics facility in Anaheim, California. The Maintenance Testing is operated by the Air Force at their depot in Newark, Ohio.

SYSTEM OBJECTIVES

Autonetics made several time and economic tradeoff studies to review the various types of computer controlled systems which could be implemented for the MM III Test System. These studies indicated that, in addition to the software development, a very substantial hardware development was required. This hardware development involved the manufacturing of three unique types of interface consoles (MGS, GSP and MGSC) connecting the control computer and the various UUT's. The studies also showed that in addition to the three types of interface consoles, two support consoles would be required.

The two support consoles are the Self-Alignment Technique (SAT) console and the Central Power Console (CPC). The SAT console contains the electronics necessary to control special optical equipment which is required at the MGS and GSP test levels. The CPC contains special measurement equipment and power supplies to support the test activities at all test levels. The manufacturing and checkout of these interface and support consoles were, in themselves, an extensive task. Since each console is constructed from many Printed Circuit Boards (PCB's) (electronic modules), the checkout and validation of the modules, themselves, had to be considered. It was decided to incorporate into the MM III Test System the capability of testing the PCB's. To support the checkout of these Autonetics manufactured PCB's, a unique Printed Circuit Board Tester (PCBT) was required to provide the necessary interface between the control computer and the various to-be-tested PCB's.

SYSTEM OBJECTIVES (continued)

The conclusion of the studies was that the MM III Test System would involve some form of time-sharing with a central computer controlling the following four types of test stations:

(1) System Level - the Missile Guidance System (MGS)

(2) Gyro Stabilized Platform (GSP)

(3) Missile Guidance Set Control (MGSC)

(4) Printed Circuit Board Tester (PCBT)

Additional studies were made to determine the general requirements of the Test System such as the number of test stations to be controlled and the scheme for allocating computer resources. The finalized MM III Test System, reflecting these general requirements, has the following characteristics:

1. A test complex which concurrently controls six test stations.
2. The test station types (MGS, GSP, MGSC, and PCBT) are mixed.
3. Testing at each station is independent of and asynchronous to the testing of all other test stations.
4. Each station is insured of time allocation for real-time functions.
5. Computer resources are equally available and sharable among all test stations in operation.
6. A single copy of each test program is retained in relocatable format on the disk.
7. Programs in core are shared. (One copy is capable of servicing all six test stations at the same time).
8. Support test equipment is shared.

SYSTEM OBJECTIVES (continued)

The MM III Test System has the capability to verify that

(1) individual printed circuit boards function properly,

(2) the various interface consoles (constructed from the tested printed circuit boards) function properly, and

(3) the MM III Guidance System and subsystems (Aerospace Vehicle Equipment - AVE) function properly.

CENTRAL COMPUTER

The central computer, selected for the MM III Test System, is an IBM 1800 Processor-Controller (P-C) and is configured as follows:

Depot and Factory

IBM 1442 card read/punch

Two - IBM 1816 keyboard printers

Six - IBM 1053 printers

IBM 2310 disk storage unit - three drives

IBM 1627 plotter

Tally mylar tape punch

Digitronic mylar tape reader

Additional Equipment at Depot

IBM 1443 line printer

Western Electric 201B modem

Memory Size

Factory - 32K

Depot - 64K

TEST STATION COMMUNICATIONS

The P-C and a test station communicate through the use of the Terminal Boards (TB) contained in the IBM 1801 and the IBM 1826. The following types of points on the terminal boards were selected for use in MM III testing.

(1) Digital Output - Electronic Contact Operate (ECO).

(2) High-Speed Digital Input Voltage (DIV).

(3) Process Interrupt Voltage (PIV).

Each test station has two assigned ECO's and two DIV's. The two ECO's of a station are referred to as the Control Instruction (CI) and the Data Instruction (DI) of the station. The two DIV's of a station are referred to as Double Precision 1 (DP1) and Double Precision 2 (DP2) of the station. In addition, each test station is assigned three PI bits and their associated Process Interrupt Status Words (PISW). Analogously, communications between the support consoles (SAT and CPC) and the P-C are performed by utilization of assigned ECO's, DIV's, and PI's.

SOFTWARE DEVELOPMENT

The MM III test software, which was developed, consists of a set of programs which collectively insures the successful acceptance and maintenance testing of the Guidance Systems and subsystems. The operating system is the Executive program which manages and allocates the P-C resources in accordance with the requests of the various test stations. The actual testing of the Guidance Systems and subsystems is performed by the functional test programs (MGS, GSP, and MGSC). The functional test programs, in conjunction with the Executive, provide the means by which test generated data is displayed to the operator, stored on the disk, retrieved to output devices, transmitted via the Communications Adapter and/or plotted. To verify the integrity between the interface consoles and the "unit under test" a group of Malfunction Isolation programs was developed. In addition to the verification of the station consoles (MGS, GSP, MGSC, PCBT), the Malfunction Isolation (M/I) programs analyze the SAT and CPC consoles. The Printed Circuit Board Test program permits the analysis of individual electronic modules for errors. The electronic modules, which are tested, are those which are used in the fabrication of the four test station (interface) consoles and the two support consoles.

The Executive program is structured so that if a malfunction occurs while a Functional Test (F/T) program is being executed on a specific test station, the execution of the F/T program may be temporarily stopped by the operator and the appropriate M/I program executed on that station. If the problem is truly caused by the interface console, then it will be narrowed down to at most three modules. These modules would then be replaced in the interface console and the M/I program executed to verify that the console has no other problems. The M/I program would then be stopped and the F/T program would be restarted. That portion of the F/T program in which the malfunction was detected, would be re-executed and functional testing would continue if the malfunction was eliminated.

The defected modules would subsequently be analyzed by the PCB test station to determine the necessary rework, the modules would be tested again to verify that the rework was proper.

The Executive program is designed so that when the testing requirements for all test stations in a specific time interval have been satisfied, then control of execution will be given to the Nonprocess Functions. The Nonprocess Functions include the support software which is required for program development and checkout in the time-sharing environment. The Nonprocess Functions include two assemblers, disk management functions and utility programs. The Nonprocess Functions are structured to have minimal impact on the concurrent testing at the test stations.

HARDWARE DEVELOPMENT

The interface consoles were designed with the constraint that the P-C would be located a nominal 65 feet from the interface consoles. This induced the first major design limitation in that signals between the P-C and the interface consoles were limited to discretes or digital type signals. Therefore, the interface console provided the generation of all analog type signals required for testing of the Aerospace Vehicle Equipment (AVE) and the digitizing of all AVE analog signals before the P-C was capable of interpreting the data. In general, all of the interface consoles provide the following:

(1) 28 VDC primary power and monitoring circuits

(2) Coolant and power control and interlock circuits

(3) Digital multimeter for measurement of AVE and interface console signals.

(4) Test point selector for selecting any AVE or interface console signal.

(5) Limited signal conditioning for such items as peak detection.

(6) Central switching which provides loads for the AVE, stimuli application and interface console master reset.

(7) Process interrupts which are utilized by the interface console to notify the P-C of problems detrimental to the AVE, such as loss of coolant, or the completion of items such as digital multimeter measurements.

(8) Electrical isolation between the P-C and the interface consoles using input and output isolators.

In addition to the above common items, the interface consoles provide functions which are unique to each level of testing as described below.

MGS Interface Console

The testing of a MGS involves computer-to-computer communication between the P-C and the AVE computer of the MGS which is an Autonetics D37 computer. Since the AVE computer is a serial machine and the P-C is a parallel machine, the MGS interface console provides serial to parallel and parallel to serial converters for transfer of data between both computers. Since the AVE computer is continuously involved in the system test problem and the P-C is involved with six stations the two computers

MGS Interface Console (continued)

operate asynchronously. Data messages are transferred between the P-C and an AVE computer by utilization of interrupts and flags.

GSP Interface Console

At GSP testing, there is no AVE computer to control the testing of the platform, thus the GSP interface console, in conjunction with the P-C, must perform the normal control functions of the AVE computer. This is accomplished by providing counters which measure the output pulses of inertial instruments, such as gyros, for fixed periods of time (i.e., 60 msec). The contents of these counters provide the P-C with position information of the platform. The position control of the platform requires application of analog and/or binary signals. The analog signals are generated by use of Digital-to-Analog Converters (DAC) and the binary signals are generated by parallel to serial converters. The binary signals are timed out by the Real-Time Interrupt which occurs every ten milliseconds. Therefore, the P-C can control such items as the slewing rate of the platform or holding the platform to a given position by knowing the change of position of the platform during any 60 millisecond period.

MGSC Interface Console

The MGSC interface console provides special stimuli such as modulated signals, discrete signals for control of certain MGSC functions, simulated D37 and GSP loads, and analog stimuli signals simulating inputs from the D37 computer and the GSP.

HARDWARE DEVELOPMENT (continued)

Support Consoles (CPC and SATCC)

Two support consoles are used in conjunction with the above interface consoles to test MM III Guidance Systems. The two consoles, the Central Power Console (CPC) and the Self Alignment Technique Control Console (SATCC) provide those unique functions which were considered cost effective to combine, or have low usage and the capability could not be justified on an individual station basis.

The SATCC is the console which allows the P-C to control the unique optics utilized for an azimuth reference during testing of MM III systems. The SATCC controls the movement of optics when directed by software in the P-C and informs the P-C when the optics are driving or have reached a prescribed position. In addition, the optics are calibrated prior to each use by programs stored in the P-C. This calibration data is used during the azimuth capability determination testing of MM III systems.

The CPC provides those functions which can be time-shared by up to six stations with a minimum of interface. These include the following:

(1) Gyro Start Voltage - a power supply that provides the high gyro start voltage required to start gyros.

(2) Frequency Counter - a Beckman frequency counter which is utilized to provide the following measurements:

(a) Frequency

(b) Period

(c) Time interval

(d) Frequency ratio

HARDWARE DEVELOPMENT (continued)

Support Consoles (CPC and SATCC) (continued)

The P-C controls the type of measurements to be made, the signal to be measured, and the analysis of the output of the frequency counter data.

(3) Frequency Analyzer - a Weston frequency response analyzer is used to determine the frequency and gain responses of MM III servo loops during dynamic testing. The P-C controls the voltage level, frequency, servo loop to be tested, and whether the signal is applied continuously or pulsed. The P-C analyzes the results of those measurements to determine if the servo loops are operating correctly.

(4) Timing Signals - the CPC provides the timing signals for the program loading of the airborne computer (D37), the Real Time Interrupt for the P-C, and those timing signals required to operate the different interface consoles.

TEST PHILOSOPHY

Each test program (both functional test and M/I) is divided into a set of test sequences which must be performed to satisfy total test requirements (e.g., the GSP has a Pre-Vibration Sequence and Post-Vibration Sequence). Each sequence is further divided into modes. Each mode consists of sub-tests which must be performed to satisfy that mode. Each sub-test is programmed at the subroutine level. Programming at the subroutine level permits one to easily make corrections, to incorporate

TEST PHILOSOPHY (continued)

diagnostics and to respond to hardware design changes with a new or revised program.

Each test program has a test program sequencer which is loaded into core and controls the sequencing of the test according to operator command inputs. The sequencer cycles through requested sub-tests or modes as follows: the first sub-test or mode is loaded into core, executed, and then released upon successful completion; the second sub-test or mode is loaded into core, executed, and then released upon successful completion; all subsequent sub-tests or modes are handled similarly.

The operator actually may request the sequencer to automatically execute an entire sequence, a specific mode, or a stack of eight modes to be executed as a group. The sequencer will verify that all initial requirements for each selected mode have been executed. If all requirements have not been met, then the program sequencer will cause the execution of those modes which will satisfy these initial requirements and then execute the selected mode.

EXECUTIVE PROGRAM

The Executive Program is the operating system of each test complex. It controls and allocates the computer resources and the support consoles in accordance with the requests of the different test stations. In April, 1969, Autonetics presented a paper on the Executive Program when it was still in the design and development phase. The following discussion reflects the finalized Executive Program and its operational status.

EXECUTIVE PROGRAM (continued)

Features of the Executive Program include the following:

(1) Scheduling algorithm with both real-time and time-sharing attributes.

(2) Dynamic memory allocation with a paging technique.

(3) Nonprocess Functions.

(4) Special message processing and data handling.

(5) Input/Output processing.

(6) Operator communication.

(7) Interrupt processing.

(8) Error processing.

Scheduling Algorithm

The scheduling algorithm of the Test System includes both real-time and time-sharing attributes. The most constringent time-critical element exists in the testing of the MM III Guidance System. The Guidance System requires a 60 msec servo control servicing rate. This servicing, however, may be performed in 6 msec or less. It was determined that an additional 4 msec would be sufficient to handle the non-time-critical functions of a test system, such as Special Data Handling, Operator Communication, Executive Bookkeeping, etc. The Schedular was thus designed to operate with 10 msec intervals and to allocate time among the six test stations.

A 10 msec Real-Time Interrupt (RTI) generated by the CPC is used to control the allocation of time in a cyclic manner among the programs of the six stations. The time-critical portion of a test station program is

MAGNITUDE OF DEVELOPED PROGRAMS AND HARDWARE

The amount of programming maintained for the present MM III Test System is extensive. The amount of programming for the MGS functional test include both P-C and D37 coding.

The following software is listed as separate complete programs.

	WORD COUNT
MM III EXECUTIVE PROGRAM	81,000
MM III MGS FUNCTIONAL TEST PROGRAM	85,000
MM III GSP FUNCTIONAL TEST PROGRAM	48,000
MM III MGSC FUNCTIONAL TEST PROGRAM	20,000
MM III MALFUNCTION ISOLATION PROGRAM	92,000
MM III PRINTED CIRCUIT BOARD TEST PROGRAM	60,000
MM III NONPROCESS FUNCTIONS	34,000
TOTAL	420,000

The following table indicates the amount of hardware developed and maintained to support the MM III Test System.

MGS Interface Consoles (including holding fixtures)	20
GSP Interface Consoles (including holding fixtures)	14
MGSC Interface Consoles	2
PCBT Consoles	2
SAT Consoles	5
CP Consoles	9
TOTAL	52

MAGNITUDE OF DEVELOPED PROGRAMS AND HARDWARE (continued)

The MM III Test System (operational since July, 1970) is presently being used at the following locations:

(1) Autonetics Manufacturing Facilities - Anaheim, California
Three Six-Station Complexes for MM III Functional Testing.

(2) Newark Air Force Station (DEPOT) - Newark, Ohio
Four Six-Station Complexes for MM III Malfunction Isolation and Checkout.

(3) Autonetics Laboratory Facilities - Anaheim, California
(for hardware and program development)
Four Complexes with various multistation capabilites.

NOTE: A test complex is configured to handle six stations with the software; however, not all test complexes contain the necessary hardware for all six stations.

CONCLUSION

The utilization of an automated real-time multistation test system for acceptance and maintenance testing of complex electronic systems has been highly effective and very well received. The system is structured such that with minor modifications it may be utilized for similar test environment applications. The system could be expanded to accommodate more test stations where the time constraints of the UUT's permit such an expansion. The system (software and hardware) has proven to be highly effective in determining the source of a detected malfunction, whether it is in the unit under test or in the test equipment consoles. Also, the system has been very successful in reducing the overall test time and the errors which are caused by operator interface.

CONCLUSION (continued)

The utilization of a paging scheme is extremely useful for programming in a multistation environment and eliminates the constraint that programs must be designed to execute from fixed areas. The Nonprocess Functions, which support software development in the time-sharing environment, have contributed significantly in reducing the time involved in program development and checkout.

GLOSSARY

AVE - Aerospace Vehicle Equipment
CDAAS - Central Data Acquisition and Analysis System
CPC - Central Power Console
DAC - Digital to Analog Converter
DIV - Digital Input Voltage
ECO - Electronic Contact Operate
F/T - Functional Test
GSP - Gyro Stabilized Platform
IBT - Interrupt Branch Table
IPROT - Programmed Interrupt Branch Table
I/O - Input/Output
MGS - Missile Guidance System
MGSC - Missile Guidance Set Control
M/I - Malfunction Isolation
MM - Minuteman
NTC - Non-Time-Critical
P-C - Processor-Controller
PCBT - Printed Circuit Board Tester
PIBT - Process Interrupt Branch Table
PISW - Process Interrupt Status Word
PIV - Process Interrupt Voltage
RTI - Real Time Interrupt
SAT - Self-Alignment Technique
SSA - Station Save Area
TCB - Task Control Block
UUT - Unit Under Test